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Characteristics of zebra mussel (Dreissena polymorpha) populations in infested reservoirs, northwest Bulgaria

Teodora A. Trichkova a*, Dimitar St. Kozuharov b, Zdravko K. Hubenov a, Ivan Sl. Botev a, Mladen T. Zivkov a and Svetoslav D. Cheshmedjiev c

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The zebra mussel populations in the Reservoirs Ogosta and Rabisha (northwest Bulgaria, Danube River basin) were studied with respect to distribution, shell morphometry, abundance and biomass. In the reservoirs, the zebra mussels occurred at depths between 3.5 and 10.0 m and only on hard and mixed substratum. Based on principal component analysis, the majority of total variance of morphometric data was explained by the shell size and only a small proportion by the shell shape of the zebra mussels. In the Rabisha Reservoir, shell plasticity in respect to site location was observed. The absolute abundance and total biomass of zebra mussels differed among the sites within both reservoirs. The mean values in the Rabisha population were much higher than in the Ogosta population. The relations of shell morphometry, abundance and biomass of zebra mussels to the physicochemical conditions in the reservoirs were discussed.

Keywords: Dreissena polymorpha; shell morphology; abundance; biomass; reservoirs

Introduction

The zebra mussel Dreissena polymorpha (Pallas, 1771) is a typical invasive species with great potential to cause severe ecological and economic problems (Ludyanskiy et al. 1993; Nalepa and Schloesser 1993). When present in abundance, zebra mussels can dramatically change the ecology of infested water bodies by adversely impacting plankton populations (MacIsaac 1996; Bastviken et al. 1998; Pace et al. 1998; Maguire and Grey 2006), benthic invertebrate communities (Ricciardi et al. 1996; Nalepa et al. 1996; Burlakova et al. 2000), and fish populations (Strayer et al. 2004). At the same time they can interfere with vital water supply intakes and navigation structures and thus affect thermoelectric and nuclear power plants, drinking water treatment plants and various industries (Clarke 1952; Erben et al. 2000).

The zebra mussel is a Ponto-Caspian relict species native to the drainage basins of the Black, Azov, Caspian and Aral Seas (Starobogatov 1970; Marinov 1990). In Bulgaria, the zebra mussel was first reported for the River Danube by Kreglinger (1870). Later, its occurrence was recorded in the Danube and its tributaries, as well as in the Black Sea coastal lakes and rivers (Wohlberedt 1911; Drensky 1947; Valkanov 1957; Russev et al. 1994; Angelov 2000). Recently, a rapid spread of zebra mussel in Bulgarian inland water bodies has been observed. It was reported from the Ovcharitsa, Zhrebchevo and Sopot reservoirs (central and southeast Bulgaria), as
well as from Lake Chepintsi (west Bulgaria) (Hubenov 2005). Most recent records were from the Pyassachnik, Ticha and Malko Sharkovo reservoirs (central and east Bulgaria) (Black Sea and East-Aegean Sea Basin Directorates). As a result of infestation of the Ovcharitsa cooling-reservoir, the Maritsa-East 2 Thermoelectric Power Plant has suffered continuous problems, such as clogging of cooling system pipes, screens, pumps and other facilities, as well as enormous increase in corrosion of metal surfaces (Hubenov 2002).

The reservoirs in the northwest Bulgaria are considered to be of great vulnerability to infestation by zebra mussel because of their proximity to the River Danube. Two of them, Rabisha and Ogosta reservoirs, have already been reported as infested (Hubenov 2002, 2005). The present goal was to study the zebra mussel populations in these reservoirs, in respect to distribution, shell morphometry, abundance and biomass.

Study area
The two reservoirs are located in the northwest Bulgaria and belong to the River Danube drainage basin (Figure 1).

The Rabisha reservoir is located within the catchment of the Archar River at an altitude of 278 m above sea level. It was built as a part of the irrigation system “Rabisha” at the place of the former Lake Rabisha in 1963. Lake Rabisha was of tectonic origin and was a completely closed water basin – without surface inflows or outflows (Valkanov 1938). Now the reservoir is filled with water from the River Oshane and a smaller Reservoir Oshane through an artificial derivative channel. The Rabisha reservoir has a maximum surface area of 324.6 ha and maximum volume of $45 \times 10^6$ m$^3$ (Irrigation System Company – Vidin). The maximum depth is 22 m. The dam is an earthfilled embankment type, reinforced with gravel and stones. The bottom is sand, gravel, stones and mud, overgrown with submerged macrophytes, such as *Typha* sp., *Potamogeton cf. densatum*, etc., in the littoral zone.

The Ogosta reservoir is located at an altitude of 185 m above sea level. It was constructed in 1985 by damming the River Ogosta and flooding abandoned settlements, agricultural land, meadows, fruit orchards and vineyards close to the town of Montana. The reservoir is also filled by the Rivers Barziya and Zlatitsa. It has a maximum surface area of 2360 ha and maximum water volume of $505 \times 10^6$ m$^3$ (Irrigation System Company – Montana). The maximum depth is 56 m. The embankment dam is earthfilled and reinforced with gravel and stones from the upstream side. The bottom substratum is mixed, from mud and clay to stones and concrete. At present, the two reservoirs are used mainly for irrigation and recreational fishing.

Material and methods
The reservoirs were visited in April 2006. Fifteen sites were sampled in the Ogosta reservoir and seven sites in the Rabisha reservoir. Quantitative samples of adult zebra mussels were collected with a Petersen bottom sampler of medium size (17.0 × 16.5 cm) and fixed in 4% formalin. Transparency was measured with a Secchi disk. Water temperature, dissolved oxygen, oxygen saturation and pH were measured using portable oxygen and pH meters Schott GMBH. One-litre water samples were taken in plastic bottles and transported to the laboratory in a cooler.
with ice for determining calcium and bicarbonate concentrations as well as total hardness.

In the laboratory, calcium concentration was determined using volumetric method, with Na<sub>2</sub>EDTA solution with murexide indicator. The same method but with eriochrome black T indicator was used for determining hardness. Bicarbonate concentration was determined by titration with HCl solution and methylorange as the end point indicator (Golterman and Clymo 1970; Höll et al. 1970). The zebra mussels were sorted and the following morphometric parameters were measured: shell length (SL) – the maximum anteroposterior dimension of the shell; shell height

Figure 1. Study region and sampling sites in the Ogosta and Rabisha reservoirs.
(SH) – the maximum dorsal-ventral dimension of the shell; shell width (SW) – the maximum lateral dimension with valves closed; and individual weight – fresh dry weight including shells. Measurements were made with a calliper and electronic balance to the nearest 0.1 mm and 0.1 g, respectively. A total of 141 specimens from the Ogosta reservoir and 122 specimens from the Rabisha reservoir were analysed. Absolute abundance and total biomass were calculated per square metre.

Ordination technique based on principal component analysis (PCA) was used to summarize the major patterns of variation within the environmental data. Ordination was implemented by the computer program CANOCO 4.0 (Ter Braak & Šmilauer 1998). PCA based on correlation matrix of the morphometric variables (SL, SH and SW) was carried out to determine their loadings on the principal components. Analysis of variance (ANOVA) and Duncan’s multiple comparison post hoc test were applied on the resulting principal components to test the differences in component scores among the eight sites. ANOVA was also applied directly on the morphometric parameters. Duncan’s post hoc test was used to determine which of the eight sites was significantly different from the others with respect to the ratios SH/SL, SW/SL and SW/SH. These statistical analyses were carried out using the program STATISTICA (StatSoft Inc. 2001).

Results
Live zebra mussels were found at five sites (out of 15 sampled) in the Ogosta reservoir, and at three sites (of seven sampled) in the Rabisha reservoir. The characteristics and water chemistry of the sampling sites are shown in Table 1.

The results of PCA performed are presented as a correlation biplot (Figure 2). The first two principal components ($\lambda_1=0.574$, $\lambda_2=0.283$) explained cumulatively 85.7% of total variance of data. The first axis was related to transparency as well as to calcium concentration and correlated parameters – bicarbonate concentration and total hardness. The latter three parameters had strong positive Pearson product-moment correlation coefficients between them (1.00, 1.00, 0.99, P<0.05) and negative Pearson product-moment correlation coefficients with transparency ($-1.00$, $-1.00$, $-0.99$, P<0.05, respectively). The first axis contrasted the Rabisha reservoir sites with higher Secchi disk transparency and lower concentrations of calcium, bicarbonates and total hardness (plotted top and bottom on the right of the diagram) with the Ogosta reservoir sites with lower values of Secchi disk transparency and higher calcium, bicarbonate concentrations and total hardness (plotted top and bottom on the left of the diagram) (Figure 2). Axis 2 reflected the dissolved oxygen gradient and separated sites Rab1, Og1 and Og2 with higher oxygen concentrations and saturation above 100% (plotted top right and left of the diagram) from all the other sites with lower values of dissolved oxygen and saturation below 100% (Figure 2).

Shell morphometric characteristics of zebra mussels in the two reservoirs are presented in Table 2. In the Ogosta reservoir, the greatest individual mean sizes were detected at site Og3 and the smallest at site Og4. In the Rabisha reservoir, the highest mean individual sizes were measured at site Rab2. The sizes of individuals at site Rab3 were close to them, while these at Rab1 were the smallest.

The principal component analysis of SL, SH and SW variables showed that the first component explained the majority (97.8%) of total variance of the data
(Table 3). All of the first component loadings were strongly positive and almost equal with respect to the three morphometric variables. This indicated that the first component was a measure of the overall size of the shell. A small proportion of total variance (1.5%) was explained by the second principal component. The loadings on PC2 were positive with respect to shell height, slightly positive with respect to shell length and negative with respect to shell width (Table 3). The different signs of the

<table>
<thead>
<tr>
<th>Site</th>
<th>DS</th>
<th>Substrate</th>
<th>SDT</th>
<th>T</th>
<th>pH</th>
<th>DO</th>
<th>OS</th>
<th>HCO$_3^-$ (mg/l)</th>
<th>Ca$^{2+}$ (mg/l)</th>
<th>TH</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Og1</td>
<td>8</td>
<td>mud, stones</td>
<td>115</td>
<td>9.4</td>
<td>7.1</td>
<td>11.59</td>
<td>122</td>
<td>103.7</td>
<td>32.06</td>
<td>5.61</td>
<td>3</td>
</tr>
<tr>
<td>Og2</td>
<td>6</td>
<td>stones, mud</td>
<td>115</td>
<td>9.4</td>
<td>7.1</td>
<td>11.59</td>
<td>122</td>
<td>103.7</td>
<td>32.06</td>
<td>5.61</td>
<td>28</td>
</tr>
<tr>
<td>Og3</td>
<td>9</td>
<td>clay, stones</td>
<td>125</td>
<td>9.2</td>
<td>7.4</td>
<td>8.75</td>
<td>82</td>
<td>103.7</td>
<td>32.06</td>
<td>5.61</td>
<td>35</td>
</tr>
<tr>
<td>Og4</td>
<td>8</td>
<td>stones</td>
<td>115</td>
<td>8.6</td>
<td>7.3</td>
<td>9.93</td>
<td>97</td>
<td>105.2</td>
<td>32.07</td>
<td>5.75</td>
<td>35</td>
</tr>
<tr>
<td>Og5</td>
<td>6.5</td>
<td>stones</td>
<td>100</td>
<td>10.0</td>
<td>8.0</td>
<td>7.80</td>
<td>81</td>
<td>103.7</td>
<td>32.06</td>
<td>5.61</td>
<td>40</td>
</tr>
<tr>
<td>Rab1</td>
<td>3.5</td>
<td>gravel, mud,</td>
<td>&gt;350</td>
<td>13.5</td>
<td>7.8</td>
<td>11.09</td>
<td>109</td>
<td>82.4</td>
<td>23.05</td>
<td>4.91</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>submerged</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>macrophytes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rab2</td>
<td>10</td>
<td>sand, gravel</td>
<td>380</td>
<td>10.5</td>
<td>8.2</td>
<td>9.95</td>
<td>91</td>
<td>82.4</td>
<td>23.05</td>
<td>4.91</td>
<td>39</td>
</tr>
<tr>
<td>Rab3</td>
<td>8.5</td>
<td>mud, stones</td>
<td>360</td>
<td>10.2</td>
<td>8.8</td>
<td>9.28</td>
<td>96</td>
<td>82.4</td>
<td>23.05</td>
<td>4.91</td>
<td>41</td>
</tr>
</tbody>
</table>

Note: DS, depth of sampling (m); SDT, Secchi disk transparency (cm); T, water temperature (°C); DO, dissolved oxygen (mg/l); OS, oxygen saturation (%); TH, total hardness (°d); N, number of individuals.

Figure 2. Principal component analysis (PCA) correlation biplot of the environmental variables. ▲ – Ogosta reservoir sites; ■ – Rabisha reservoir sites.
loadings showed that the second component was a measure of the shell shape. The third principal component explained a very small proportion of total variance (0.7%). The loadings on the third principal component were positive with respect to shell length and slightly negative with respect to shell height and shell width (Table 3), indicating that this component was also a measure of zebra mussel shape.

The scores of the first principal component (PC1) differed significantly between site Og2 and all the other sites in both reservoirs ($P < 0.05$), between site Og3 and all the other sites in the Ogosta reservoir ($P < 0.001$), and between sites Rab2 and Rab3 and all the other sites, except Og3 ($P < 0.001$). There was no significant difference between sites Rab2 and Rab3. The scores of the second principal component (PC2) differed significantly only between site Og3 and all the other sites ($P < 0.001$), as well as between site Rab2 and all the other sites ($P < 0.05$). The scores of the third principal component (PC3) did not differ significantly among the sites.

The analysis of the morphometric ratios showed that the ratio SH/SL did not differ significantly among the sites. The ratio SW/SL differed significantly only between Rab2 and all the other sites, except Rab3 ($P < 0.05$). The ratio SW/SH differed significantly between site Rab2 and all the other sites, except Rab3 ($P < 0.01$), and between Rab3 and all the other sites, except Rab2 ($P < 0.05$). There was no significant difference between sites Rab2 and Rab3 with regard to morphometric ratios.

The absolute abundance and total biomass of zebra mussels in the Ogosta reservoir were the highest at site Og3 (Figure 3). The abundance and biomass at

### Table 2. Morphometric characteristics of zebra mussels at different sampling sites in the Ogosta and Rabisha reservoirs.

<table>
<thead>
<tr>
<th>Site</th>
<th>SL Mean</th>
<th>SD</th>
<th>SH Mean</th>
<th>SD</th>
<th>SW Mean</th>
<th>SD</th>
<th>SH/SL Mean</th>
<th>SD</th>
<th>SW/SL Mean</th>
<th>SD</th>
<th>SW/SH Mean</th>
<th>SD</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Og1</td>
<td>7.40</td>
<td>2.41</td>
<td>3.77</td>
<td>1.25</td>
<td>2.70</td>
<td>1.30</td>
<td>0.51</td>
<td>0.04</td>
<td>0.36</td>
<td>0.04</td>
<td>0.71</td>
<td>0.09</td>
<td>3</td>
</tr>
<tr>
<td>Og2</td>
<td>10.90</td>
<td>0.79</td>
<td>5.74</td>
<td>0.41</td>
<td>4.68</td>
<td>0.42</td>
<td>0.53</td>
<td>0.01</td>
<td>0.43</td>
<td>0.01</td>
<td>0.81</td>
<td>0.03</td>
<td>28</td>
</tr>
<tr>
<td>Og3</td>
<td>19.82</td>
<td>0.70</td>
<td>10.94</td>
<td>0.37</td>
<td>8.43</td>
<td>0.38</td>
<td>0.55</td>
<td>0.01</td>
<td>0.42</td>
<td>0.01</td>
<td>0.75</td>
<td>0.02</td>
<td>35</td>
</tr>
<tr>
<td>Og4</td>
<td>6.33</td>
<td>0.70</td>
<td>3.61</td>
<td>0.37</td>
<td>2.81</td>
<td>0.38</td>
<td>0.54</td>
<td>0.01</td>
<td>0.44</td>
<td>0.01</td>
<td>0.83</td>
<td>0.02</td>
<td>35</td>
</tr>
<tr>
<td>Og5</td>
<td>7.03</td>
<td>0.66</td>
<td>3.82</td>
<td>0.34</td>
<td>2.82</td>
<td>0.35</td>
<td>0.55</td>
<td>0.01</td>
<td>0.40</td>
<td>0.01</td>
<td>0.73</td>
<td>0.02</td>
<td>40</td>
</tr>
<tr>
<td>Rab1</td>
<td>7.56</td>
<td>0.64</td>
<td>3.83</td>
<td>0.33</td>
<td>2.99</td>
<td>0.35</td>
<td>0.51</td>
<td>0.01</td>
<td>0.39</td>
<td>0.01</td>
<td>0.77</td>
<td>0.02</td>
<td>42</td>
</tr>
<tr>
<td>Rab2</td>
<td>18.66</td>
<td>0.67</td>
<td>9.38</td>
<td>0.35</td>
<td>9.30</td>
<td>0.36</td>
<td>0.51</td>
<td>0.01</td>
<td>0.50</td>
<td>0.01</td>
<td>0.98</td>
<td>0.02</td>
<td>39</td>
</tr>
<tr>
<td>Rab3</td>
<td>17.57</td>
<td>0.65</td>
<td>8.86</td>
<td>0.34</td>
<td>8.47</td>
<td>0.35</td>
<td>0.51</td>
<td>0.01</td>
<td>0.48</td>
<td>0.01</td>
<td>0.94</td>
<td>0.02</td>
<td>41</td>
</tr>
</tbody>
</table>

Note: SL, shell length (mm); SH, shell height (mm); SW, shell width (mm); SD, standard deviation; N, number of individuals.

### Table 3. Loading of zebra mussel shell morphometric variables on the first three principal components.

<table>
<thead>
<tr>
<th></th>
<th>PC1</th>
<th>PC2</th>
<th>PC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell length (SL)</td>
<td>0.993</td>
<td>0.025</td>
<td>0.117</td>
</tr>
<tr>
<td>Shell height (SH)</td>
<td>0.988</td>
<td>0.136</td>
<td>-0.074</td>
</tr>
<tr>
<td>Shell width (SW)</td>
<td>0.986</td>
<td>-0.161</td>
<td>-0.044</td>
</tr>
<tr>
<td>% of total variance</td>
<td>97.8</td>
<td>1.5</td>
<td>0.7</td>
</tr>
</tbody>
</table>
other sites were comparatively low. The individuals at sites Og4 and Og5, regardless of their low biomass, showed higher abundance than sites Og1 and Og2. In the Rabisha reservoir, the highest abundance and biomass were registered at site Rab3 (Figure 3). The zebra mussels at site Rab1 also had a high abundance though their biomass was low.

**Discussion**

The two reservoirs are located within the catchment and in the proximity to the River Danube, which is the native distribution range of the zebra mussel. The upstream and overland dispersal of zebra mussel, in most cases, is associated with human activities (Johnson and Carlton 1996; Minchin et al. 2003; Frischer et al. 2005). It is assumed that larger water bodies are colonized more easily, presumably due to a greater number of access points and a larger number of human users (Kraft and Johnson 2000; Frischer et al. 2005). The Rabisha and Ogosta reservoirs are the largest in terms of surface area and depth in the region. The Ogosta reservoir is located close to the town of Montana. It is very easily accessible and is frequently visited by local people for recreation, motor boating and sports fishing. According to official data it was stocked with fish on eight occasions during the period 2001–2005. The Rabisha reservoir is situated in the vicinity of the Magurata Cave which is a popular tourist attraction. It was stocked with fish on 12 occasions in the same period. The higher situated Oshane reservoir whose water flows into the Rabisha reservoir was not infested by zebra mussel (our data). So, the most probable cause of introduction of the zebra mussel to these two reservoirs were the transport of larvae or adult individuals with fishing equipment, boats and fish-stocking material from the Danube.

Some of the most important physicochemical parameters for the survival and growth of zebra mussel are water temperature, pH, dissolved oxygen, calcium
concentration and substratum size (Hincks and Mackie 1997; Cohen 2005; Frischer et al. 2005; Jones and Ricciardi 2005). The water temperature during sampling ranged between 8.6 and 13.5°C (Table 1). It was higher in the Rabisha reservoir, probably because of its smaller surface area and shallow depth. Maximum water temperature reported for the Rabisha reservoir in the past was 32°C (Valkanov 1938). In the Ogosta reservoir, mean monthly temperatures measured for the period 1998–2006 were 6°C for February and 24°C for August (Bulgarian Ministry of Environment and Water, BMEW). The values of pH measured during sampling ranged between 7.1 and 8.8 (Table 1). The mean pH value in the Ogosta reservoir for the period 2002–2006 was 8.3 (BMEW).

An important physicochemical variable in the analysis was dissolved oxygen. It separated the sites Rab1, Og1 and Og2, which had higher oxygen concentrations and oxygen saturation above 100%, from the rest of the sites (Table 1, Figure 2). Site Rab1 was shallow and a comparatively high abundance of zebra mussels was recorded (Table 1, Figure 3). They were represented by young individuals with small sizes and low biomass (Table 2, Figure 3). All of them were found attached to the stems of the submerged macrophyte Potamogeton cf. densum which occurred widely in the littoral zone of the Rabisha reservoir. Lutzkanov (1975) also reported dominance of young individuals in the shallow parts of Lake Shabla, related to their requirements for high oxygen content and suitable substratum. Sites Og1 and Og2 were located closer to the River Ogosta inflow than other sites (Figure 1). These sites were characterized by a comparatively low abundance and biomass of zebra mussels (Figure 3). For the period 1998–2005, the values of dissolved oxygen and oxygen saturation in the Ogosta reservoir were in the range of 6.2–13.8 mg/l and 57.5–125.0%, with mean values of 9.3 mg/l and 88%, respectively (BMEW). The optimal oxygen saturation for the species reported in literature was 80–85% (Cohen 2005).

The analysis of the physicochemical parameters showed that during the sampling period the Ogosta sites had higher calcium concentration, bicarbonate concentration and total hardness, and lower Secchi disk transparency than the Rabisha sites (Table 1, Figure 2). The calcium concentration in the water is very important for shell production, growth and survival of zebra mussels (Jones and Ricciardi 2005). In the Ogosta reservoir, it had values of 32.06 mg/l and did not differ among the sites (Table 1). In the period 2005–2006, the concentration measured in the reservoir was in the range of 22.0–38.1 mg/l with a mean value of 30.1 mg/l (BMEW). In the Rabisha reservoir, calcium concentration was 23.05 mg/l at all sites. According to some authors, zebra mussels had the highest biomass when calcium content was between 23 and 25 mg/l (Hincks and Mackie 1997; Jones and Ricciardi 2005).

As efficient filter feeders, zebra mussels are responsible for the considerable increase in Secchi disk transparency in the infested water basins (Fahnenstiel et al. 1995; MacIsaac 1996). Much higher Secchi disc values were recorded in the Rabisha reservoir where the infestation seems to be higher (Table 1, Figure 3).

The zebra mussel did not have an even distribution in the study reservoirs. It was recorded at depths between 3.5 and 10 m (Table 1); in the Rabisha reservoir four other sites with depths between 13 and 16.5 m were sampled but no live zebra mussels, only shells, were found at these sites. According to Stanczykowska (1977) the abundance of zebra mussel populations was highest in the littoral and sublittoral zones between 2 and 12 m. In the Black Sea coastal lakes Shabla and Ezerets, zebra mussels were found at depths between 0.3–8.0 m, and were most abundant at about
3.5–4.5 m (Kaneva-Abadjieva and Marinov 1967; Lutzkanov 1983). In the Danube, zebra mussels occurred at depths between 0.2 and 15.0 m and had the highest biomass in the range of 4–7 m (Russev 1966). The highest abundance and biomass were recorded at depths of 8.5 m in the Rabisha reservoir and at 9 m in the Ogosta reservoir. In the shallowest parts of the littoral zones only young individuals (site Rab1) or shells of dead zebra mussels were found. This was probably due to fluctuations in the reservoir water level. During the period of sampling the water level in the reservoirs was high; in summer, the level decreases and these parts usually become dry.

Another factor which seems to limit the distribution of zebra mussels in the Rabisha and Ogosta reservoirs was the type of substratum. Results showed that the species attached preferably to hard substratum, mainly stones, as well as to tree branches (site Og2), stems of *Potamogeton cf. densum* (site Rab1), and shells of *Viviparus viviparus* (L., 1758) (sites Rab2 and Rab3). The zebra mussels were not found on purely clay and muddy substratum. Some authors reported that in the early stages of invasion zebra mussel required hard substratum for settlement and survival (Stanczykowska 1977). Over time, adult zebra mussels also started to use soft sediments, but again preferably colonized hard substrata and their density was determined by substratum size (Karatayev et al. 1998; Jones and Ricciardi 2005). Other molluscs and macrophytes are also common substrata for zebra mussel colonization (Ricciardi et al. 1996; Diggins et al. 2004).

Several authors used shell morphological characteristics of zebra mussel to compare differences between populations related to environment (Lutzkanov 1975; Pathy and Mackie 1993; Lajtner et al. 2004). Based on the study of recent and fossil zebra mussels from several Black Sea lakes and rivers and the River Danube, Lutzkanov (1975) found a relation between shell morphology and depth, salinity and water velocity. Lajtner et al. (2004) separated the river and lake populations of zebra mussel into two morphological groupings. Considerable plasticity in shell morphology of zebra mussel from different lakes and rivers has been reported by other authors as well (Pathy and Mackie 1993; Rosenberg and Ludyansky 1994).

The principal component analysis of SL, SH and SW variables indicated that the majority of total variance of data was explained by the shell size of zebra mussels (Table 3). Individuals of different sizes were found in both reservoirs: SL was in the range from 2 to 28.9 mm, SH from 0.8 to 15.4 mm, and SW from 0.8 to 15.2 mm. The sites Og3, Rab2 and Rab3 differed significantly from the other sites with respect to shell size, while there was no significant difference between them. These sites had the greatest depths (8.5–10 m), and were inhabited by the largest individuals (Tables 1, 2). The smaller individuals were found in the shallower parts of the reservoirs (3.5–8 m) (sites Og1, Og4, Og5, Rab1) (Tables 1, 2). The site Og2 differed significantly from all the other sites concerning the shell size, individuals with intermediate sizes were recorded there (Table 2).

Only a small proportion of total variance of the morphometric data was explained by the shape of the zebra mussels (Table 3). The scores of the second principal component (PC2) differed significantly between site Og3 and all other sites, as well as between site Rab2 and all other sites. Further analysis of the morphometric ratios showed that the ratio SH/SL did not differ significantly among the sites. A significant difference between both sites Rab2 and Rab3 and the rest of the sites, with respect to the SW/SL and SW/SH ratios, was observed (Table 2). The individuals at these sites had the highest values of the SW/SL and SW/SH ratios.
which suggested a faster increase of shell width than increase of shell length and height. According to other authors, zebra mussels with a similar type of shape were found at shallow sites with higher water velocity and at low densities (Lutzkanov 1975; Lajtner et al. 2004). This did not correspond with the present results. The site Rab2 was located near the water intake tower (Figure 1), it had a depth of 10 m and sandy and gravel bottom substratum (Table 1). Individuals of large size, of intermediate abundance and biomass, and attached to shells of *V. viviparus* were found there (Table 2, Figure 3). The site Rab3 was located on the opposite side of the reservoir, had a depth of 8.5 m with mud and stones at the bottom (Figure 1, Table 1). The zebra mussels recorded were large, with comparatively high abundance and biomass, and were attached to stones and shells of *V. viviparus* (Table 2, Figure 3). The two sites did not differ between each other but they both differed significantly from site Rab1 in regard to morphometric parameters. The site Rab1 was located near the dam, at depth of 3.5 m with gravel and muddy substratum overgrown with *Potamogeton cf. densum* (Table 1). The zebra mussels recorded were represented by young individuals of small size, comparatively high abundance and low biomass (Table 2, Figure 3). All of them were found attached to the stems of the submerged macrophyte. The shell plasticity demonstrated by the adult zebra mussels at sites Rab2 and Rab3 was probably a result of an adaptation to a combination of habitat characteristics including depth, substratum type, and water physical and chemical parameters.

Although the sites in the Ogosta reservoir were different in terms of location, depth and substratum, no significant differences with regard to zebra mussel shell morphometric ratios were observed (Tables 1, 2).

Absolute abundance and total biomass of zebra mussels differed among the sites in both reservoirs (Figure 3). In the Ogosta reservoir the highest values were recorded at site Og3 and in the Rabisha reservoir, at site Rab3. The mean values of the Rabisha population (3712 ind./m² and 1516.8 g/m²) were much higher than the Ogosta population (885 ind./m² and 443.6 g/m²).

The results of the present study showed that the Ogosta and Rabisha reservoirs in northwest Bulgaria support abundant zebra mussel populations which have adapted successfully to local conditions. The degree of infestation in the Rabisha reservoir was higher. Further studies including risk assessment are necessary in order to assist in taking preventive measures against zebra mussel dispersal to other reservoirs in the region.

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