Assessment of seasonal differences of ecological state of lotic ecosystems and applicability of some biotic indices in the basin of Lake Sevan (Armenia): case study of Masrik River
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ABSTRACT
Complex studies of seasonal differences of the ecological state of Masrik River (Armenia) were realized in 2017. Water quality was assessed by BMWP, ASPT and FBI indices based on studies of qualitative and quantitative structures of benthic macro-invertebrates. Potential reference sites in the basin were revealed using the %EPT taxa index in addition to water quality assessment by bioindication methods as well as hydro-chemical, -physical and -morphological measurements. The applicability of the used biotic indices for the different parts of Masrik River was discussed.

Key words | benthic macro-invertebrates, bioindication, Lake Sevan, Masrik River, reference site, water quality

INTRODUCTION
One of the most complicated issues for water governance regimes is the establishment of freshwater resources use without harming the sustainability of hydroecosystems (Wiek & Larson 2012). This issue is urgent in Lake Sevan basin as a result of its significant strategic importance as the biggest reservoir of freshwater in the South Caucasus region and a unique ecosystem providing different environmental services (Yu et al. 2015). Lotic ecosystems play a crucial role in the formation of the water quality of Lake Sevan as a result of the small ratio between the drainage basin area and lake surface area. According to EU WFD (2000/60/EC), different types of water quality monitoring for surface water bodies have to include not only periodical hydro-chemical and -physical measurements, but also hydro-biological studies (European Commission 2000). As is known, bioindication methods provide structural measurements (water quality or taxonomic composition of aquatic organisms etc.) of water health (Young et al. 2008), which is more informative than just the measurement of pollutant concentrations. Considering that benthic macro-invertebrates are sensitive to different consequences of anthropogenic impact like eutrophication, worsening of habitat conditions, toxicity, contamination by heavy metals etc., many authors have concluded that for mountainous rivers they are becoming the most valuable and broadly used indicators of water health when long-term influences are obvious (De Pauw & Hawkes 1993; Johnson et al. 2006; Springe et al. 2006). Thereby, studies of seasonal changes of the ecological state of lotic ecosystems by bioindication methods using benthic macro-invertebrates are providing more sustainable and reliable results for decision-making in integrated water resources management. These kinds of studies are also contributing to the establishment of a hydro-biological monitoring system in Armenia.

Masrik River is one of the main spawning areas for the endemic fish species of Armenian ichthyofauna – Sevan trout (Salmo ischchan Kessler, 1877) (Asatryan et al. 2018), which used to be an object of commercial and sport fisheries.
As a result of mismanagement of the water and bio-resources of Lake Sevan it is registered in the Red Book of Animals of the Republic of Armenia (Government 2010) as a ‘Critically Endangered’ species (corresponding to IUCN category: CR A2cd). Water resources of the river mainly serve for irrigation and hydroelectric power generation. The river is exposed to various anthropogenic pressures like gold mining, sewage and agricultural wastewater discharge etc. Therefore, the aim of the study is to reveal the seasonal fluctuations in water quality of Masrik River and its tributaries based on complex studies as well as to discuss the applicability of some widely used biotic indices for the assessment of its water health. No less important, the presented results can serve as a good platform for the establishment of reference conditions in the basin of Lake Sevan. Even though some studies of the benthic community, carried out by different specialists during the last 20 years, have also included some parts of Masrik River (Ecology 2010; Hakobyan 2013; Zinchenko et al. 2013), such a broad spatial network of sampling sites in one of the rivers of Lake Sevan basin has never been used before.

**STUDY AREA**

The study area is located in the south-east part of Lake Sevan (40°00’–40°15’N, 45°3’–45°59’E). The sampling site network involved the whole course of Masrik River and the main tributaries (Figure 1). As is known, Masrik River has the biggest drainage basin area (685 km²) among the 28 tributaries of Lake Sevan. The source is at 2,880 m.a.s.l. and the mouth is at 1,901 m.a.s.l. It flows 45 km through the territories of three altitudinal climate zones: (1) cold mountainous, (2) moderate, with short, cool summers and cold winters, (3) moderate, with relatively dry, warm summers and cold winters. The river gradient is 27‰, mean discharge is 3.42 m³s⁻¹, but flow is relatively stable during the year in the lower part of the course as a result of the 78% proportion of groundwater flow in the river discharge.
The valley shape changes from a V-shape to a U-shape, then to a flat-floor valley as the river moves from its upper to its lower course. The part of the lower course has been channelized for agricultural purposes.

Currently about 32,000 dwellers inhabit the drainage basin of Masrik River (National Statistical Service 2016) and leave their ecological footprint by using and consuming different provisioning and regulative ecosystem services such as agricultural and domestic water use, fish, water quality etc. The last is one of the most important outputs for all the tributaries of Lake Sevan.

**MATERIALS AND METHODS**

In order to assess the water quality of Masrik River and its main tributaries, the benthic macro-invertebrate community was investigated during spring, summer and autumn in 2017. Considering physical and environmental barriers for the sampling works like the drying up of some parts of the river or mass emergence of biting flies, the number of sampling sites varied among the seasons from 11 to 13. The sampling sites’ coordinates and altitudes were registered by a Garmin eTrex20 GPS receiver in situ. Measurements of temperature, pH level and dissolved oxygen (DO) were made by Hanna HI9813-5N pH/EC/TDS and Hanna HI9147-10 DO meters, respectively. Hydro-morphological measurements were made in typical transects across the width of each sampling site. Widths were measured by marked rope, and depths for the interval of 50 cm by metre stick. Velocity measurements were made by float in 10 m transects along river course by three replications. Two measurements were made near the right and left banks accordingly and one measurement at the central part. The average velocity was calculated as an arithmetic mean. A ruler was used to measure the substrate components. Substrate compositions were determined according to the Wentworth classification (Neuendorf et al. 2011). Sampling of benthic macro-invertebrates, further processing and determination were done according to AQEM methodology (AQEM Consortium 2002) using the keys (Bestimmungshilfen 2010; Waringer & Graf 2011). Water quality was assessed by the family-based biotic index (FBI) widely used in the USA (Hilsenhoff 1987), as well as by biological monitoring working party (BMWP) and average score per taxon (ASPT) biotic indices widely used in EU countries (AQEM Consortium 2002). The formulas are:

$$BMWP = \sum_{i=1}^{n} T_i,$$

$$ASPT = \frac{BMWP}{N_{taxa}},$$

where $T_i$ is a tolerance score and $N_{taxa}$ is the number of macrozoobenthos taxa in the sample,

$$FBI = \frac{\sum (X_i T_i)}{n},$$

where $X_i$ is the number of individuals in each taxon; $T_i$ is a tolerance score; $n$ is the total number of macrozoobenthos individuals in the sample.

In order to reveal potential reference sites for Lake Sevan basin, the percentages of Ephemeroptera, Plecoptera and Trichoptera taxa in the composition of benthic macro-invertebrates were calculated and seasonal variations were discussed. As is known, representatives of these orders of freshwater insects are susceptible to a broad variety of stressors (Piggott et al. 2012). Use of different principles for water quality assessment increase the reliability of the results. Mapping of the results was done by ArcGIS 10.1 software.

**RESULTS AND DISCUSSION**

As a result of the vast variety of factors influencing the benthic community and water quality of Masrik River, initial clustering of sampling sites by geographical and hydrological principles was realized. The sampling sites were split into two categories and four subcategories. Category 1 involves sampling sites on Masrik River and is split into subcategory 1 (M5–M8) – potential reference sites and subcategory 2 (M1, M9, M11–M13) – potential impacted sites. Category 2 involves sampling sites on the main tributaries and is split into subcategory 3 (M2–M4) – right-bank tributaries (mainly Sotq River) as well as subcategory 4 (M10) – left-bank tributary – Akunq River. As sampling site M2 is located on a seasonal stream, the assessment of water quality there was realized only in spring.
Hydro-chemical, -physical and -morphological studies

As a result of the analyses, some seasonal fluctuations in hydro-chemical, -physical and -morphological parameters (Table 1) at different parts of Masrik River were revealed. In particular, the most significant seasonal fluctuations in pH level were revealed in the area of Sotq River (M3, M4) and the nearest downstream part (M9). Such fluctuations could be the result of mining activity in the upper course part of Sotq River during the October/November period. Proportionate fluctuations in temperature were registered everywhere but in the territory of subcategory 4 (M10), where groundwater discharge into the Akunq River plays a crucial role. This part of Masrik River had the most stable physical–chemical parameters during the year.

Ranges of average velocity and dissolved oxygen (DO) values were higher at the part of the middle course, comprising sampling sites of both subcategories 1 and 2. The highest seasonal fluctuations were registered for the discharge parameter. Amongst all factors, serious problems in water governance lead to up to a ten-fold reduction in river discharge during the summer season. Such fluctuations seriously harm water quality. The results of physical–chemical analyses showed that potential reference sites located in the middle and upper course parts of the river were also impacted by economic activities upstream. Particularly, the main effects come from water abstraction for hydroelectric power generation and irrigation purposes as well as from seasonal grazing of livestock.

### Hydro-biological studies and applicability of biotic indices for the assessment of water quality

As a result of both the complexity of factors influencing the benthic macro-invertebrate community and features of the used biotic indices’ applicability, the results of seasonal fluctuations in water quality for the same parts as well as for the territories of different subcategories of Masrik River were quite different for each of the used indices.

The BMWP index adopted a five-rank classification of water quality unlike the seven-rank classifications developed for the ASPT and FBI indices. Moreover, BMWP reflects the diversity of taxa composition at the site, and ASPT the average tolerance of determined taxa despite their diversity, while FBI is focused on both the diversity/abundance parameters and the tolerance scores. No less important, the tolerance scores for the BMWP/ASPT and FBI indices are

<table>
<thead>
<tr>
<th>Sampling sites</th>
<th>Main substratum</th>
<th>Altitude (m.a.s.l.)</th>
<th>pH</th>
<th>t (°C)</th>
<th>DO (mg/l)</th>
<th>Average velocity (m/sec)</th>
<th>Discharge (m³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Cobble, Boulder</td>
<td>1,984</td>
<td>8</td>
<td>6.8–8.3</td>
<td>8.6–10.5</td>
<td>0.6–1.2</td>
<td>0.3–3.6</td>
</tr>
<tr>
<td>M2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Pebble, Cobble</td>
<td>1,989</td>
<td>7.7</td>
<td>10.8</td>
<td>9.3</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>M3</td>
<td>Pebble, Cobble</td>
<td>2,028</td>
<td>8.3–8.9</td>
<td>6.5–18.5</td>
<td>8.1–10.2</td>
<td>0.4–1.2</td>
<td>0.1–1.6</td>
</tr>
<tr>
<td>M4</td>
<td>Cobble, Pebble</td>
<td>2,133</td>
<td>8.2–9</td>
<td>6.6–18.1</td>
<td>8.5–12.6</td>
<td>0.6–1.2</td>
<td>1.6–1.0</td>
</tr>
<tr>
<td>M5</td>
<td>Pebble, Cobble</td>
<td>2,351</td>
<td>8.1–8.2</td>
<td>6.4–17.6</td>
<td>8.3–8.6</td>
<td>0.4–1.3</td>
<td>0.08–1.0</td>
</tr>
<tr>
<td>M6</td>
<td>Boulder, Cobble</td>
<td>2,326</td>
<td>8–8.7</td>
<td>6.5–18</td>
<td>8.1–9.1</td>
<td>0.4–1</td>
<td>0.08–1.2</td>
</tr>
<tr>
<td>M7</td>
<td>Cobble, Pebble</td>
<td>2,222</td>
<td>8.1–8.6</td>
<td>6.2–17.9</td>
<td>8.7–9.4</td>
<td>0.7–1.2</td>
<td>0.3–2.2</td>
</tr>
<tr>
<td>M8</td>
<td>Cobble, Boulder</td>
<td>2,059</td>
<td>8.1–8.5</td>
<td>6.8–18.3</td>
<td>8.9–11.1</td>
<td>0.5–1.6</td>
<td>0.35–3.8</td>
</tr>
<tr>
<td>M9</td>
<td>Pebble, Gravel</td>
<td>1,947</td>
<td>8.1–8.8</td>
<td>7.1–18.5</td>
<td>9–9.6</td>
<td>0.3–1.5</td>
<td>0.15–4.7</td>
</tr>
<tr>
<td>M10</td>
<td>Sand, Pebble</td>
<td>1,924</td>
<td>8–8.2</td>
<td>7.5–13.9</td>
<td>8.4–8.7</td>
<td>0.7–0.9</td>
<td>1.8–2.1</td>
</tr>
<tr>
<td>M11</td>
<td>Pebble, Cobble</td>
<td>1,914</td>
<td>7.9–8.4</td>
<td>7.3–16.1</td>
<td>8.2–9.8</td>
<td>0.9–1.4</td>
<td>2.6–4.4</td>
</tr>
<tr>
<td>M12</td>
<td>Pebble, Cobble</td>
<td>1,903</td>
<td>8–8.3</td>
<td>7.3–16.1</td>
<td>8.2–9.7</td>
<td>0.9–1.6</td>
<td>2.5–3.6</td>
</tr>
<tr>
<td>M13</td>
<td>Sand, Pebble</td>
<td>1,945</td>
<td>8.2–8.7</td>
<td>7.1–18.5</td>
<td>7.2–9.1</td>
<td>0.6–1.4</td>
<td>1.2–4.6</td>
</tr>
</tbody>
</table>

<sup>a</sup>Data for spring and autumn seasons.
<sup>b</sup>Data only for spring season.
also quite different. Thus, their responses to the seasonal changes of abiotic factors also vary.

The highest diversity of benthic macro-invertebrates (from representatives of 16 families at M5 in the summer season to 25 families at M8 during the spring season) was registered in the area of subcategory 1. This fact is obviously expressed in the results of the water quality evaluation (Figure 2). Particularly, the BMWP score varied from 79 (good quality) for M5 in the summer season to 137 (very good quality) for M8 in the spring season. Water quality at all parts of subcategory 1 was excellent during all seasons according to the ASPT index, while FBI scores fluctuated from good quality at M5 in the spring season to excellent quality at M5–M7 in autumn and at M6–M8 in the spring season. The presence of a vast variety of oxyphil and least tolerant to the organic pollution species of caddisflies (Trichoptera), mayflies (Ephemeroptera) and stoneflies (Plecoptera) also proves the high results of the water quality assessment there. Juxtaposing the results of all studies carried out, it can be stated that the FBI index reflects more accurately the changes of ecological state in the territory of subcategory 1. Thus, this index is better suited for further use in the hydro-biological monitoring of these and similar parts of the Lake Sevan tributaries. The ASPT index reflects more weakly and thus, is hardly suited for the monitoring of the parts with reference or near-reference conditions. The results of water quality assessment for the areas of subcategories 2 and 4 (besides the M13 sampling site showed the weakest seasonal fluctuations. All these parts are located within the lower course part of Masrik River and exposed to relatively stable anthropogenic impact. Sampling site M13 is located in the territory of Mets Masrik village and, amongst other threats, exposed to direct and regular morphological alterations as well as wastewater discharge. Thereby, seasonal patterns of water quality change are hardly visible there. According to the BMWP index results, the water quality of Akunq River (M10) was lower by one rank in all seasons (the BMWP score varies from 29 to 38) compared with the other parts of subcategory 2. Akunq River is isolated from the effects of anthropogenic pressure in the upstream parts of Masrik River, and such low scores of water quality could be the result of not only contamination coming from the territory of Akunq village, where the source of this tributary is located, but also of the physical-chemical and hydro-morphological features of this river. Unlike the BMWP index, the FBI index shows that the water quality of Akunq River fluctuates from fair in the autumn season to excellent in spring. The ASPT index shows for this part the fluctuation from poor in the autumn to moderate in both summer and spring seasons. The analysis of qualitative structure of benthic macro-invertebrates from this area shows that the representatives of the Chironomidae, Simuliidae, Gammaridae and Baetidae families were the dominant species in all seasons. Only one individual of the oxyphil species of Caenidae mayflies was registered there during seasonal studies. Thus, the water quality in Akunq River is quite low, which means that the FBI index has serious restrictions in applicability for this tributary. At the same time, joint use of the BMWP and ASPT indices for this part provides results quite reliable enough to propose them for use in further hydro-biological monitoring activities. The most reliable results for the other parts of subcategories 2 and 4 were also obtained by the BMWP index. Thus, it is proposed for further hydro-biological monitoring activities in the tributaries of Lake Sevan which are under stable anthropogenic pressure.

Significant fluctuations of hydro-chemical, -physical and -morphological parameters registered in the parts of subcategory 3 was weakly reflected by the used biotic indices. The problem is that the used indices are more effective in revealing organic pollution, rather than contamination from the mining activities expressed here by the change in water hardness, oxygen regimen, transparency etc. The diversity of benthic macro-invertebrates at the studied parts of Sotq River (M3, M4) increased from the spring to autumn seasons. Also, the rise of the portion of individuals of mayflies of the Baetidae family and different flies (Diptera) was registered in the summer season. Even these qualitative changes were reflected only by the FBI index, but its use in hydro-biological monitoring activities for Sotq River requires further studies and specific analyses.

As the water quality at the M2 sampling site was assessed only for the spring season, further analyses of applicability of the used indices for this tributary were not realized.

In order to reveal the possible reference or near-reference sites in the basin of Masrik River, the portions of mayflies, stoneflies and caddisflies were calculated and summarized in the %EPT taxa index (Table 2). The results show that most of the parts of the middle and upper courses can act as potential reference sites (%EPT > 50%) in the spring season, but only the M3, M4 and M9 parts can in the autumn season.
Figure 2 | Seasonal changes of Masrik River water quality.
Such significant changes are mainly the result of increasing anthropogenic pressure in the summer season as a result of uncontrolled water abstraction. The M9 part was excluded from the initially chosen reference or near-reference sites based on further analyses of the structure of benthic macro-invertebrates, as the main component of EPT taxa there is mayflies of the Baetidae family known by their relatively high tolerance of organic pollution. In addition to the M3 and M4 sampling sites the M8 part also had a good potential to act as a reference site because of the stable high diversity of oxyphil and less tolerant to pollution species of benthic macro-invertebrates. According to this criterion the M6 and M7 parts can act as near-reference sites.

**CONCLUSION**

Worsening of water quality during the summer season followed by significant improvement during the autumn season at almost all studied parts of Masrik River was revealed. This is probably the result of seasonal changes in agriculture-related activities in the drainage basin. The main exception was Sotq River, where mining is the main anthropogenic activity affecting water quality. Seasonal changes of water quality in the lower course part were the weakest. Particularly, the most stable situation was discovered at the M10 sampling site (Akunq River) as this tributary is isolated from the effects of anthropogenic pressure in the upstream parts of Masrik River. All other parts of the lower course are exposed to relatively stable anthropogenic impact within the year. It has been revealed that the ASPT index, on average, reflected more weakly the changes in hydro-chemical, -physical and hydro-morphological parameters. Thus, this index is not well suited for monitoring activities in the basin of Masrik River. The BMWP index is the most appropriate one for revealing seasonal changes in water quality of the parts where anthropogenic pressure is obvious and stable, whereas the FBI index is well suited for the parts of reference or near-reference conditions. Even though some seasonal fluctuations of water quality were revealed at the M3, M4 and M6–M8 sampling sites, the values of the used indices remained high during the year. Thus, these parts can act as reference or near-reference for hydro-biological monitoring purposes.

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