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STUDY OF SUSTAINABILITY AND CONFORMITY OF FUNCTIONING OF LOTIC ECOSYSTEMS ON THE EXAMPLE OF THE DZKNAGET RIVER (ARMENIA)

V. L. ASATRYAN [1*], M. R. DALLAKYAN [1**], I. V. SHOKHIN [2], R. M. AROUTIOUNIAN [3], G. G. MATISHOV [4]

[1] *Institute of Hydroecology and Ichthyology of SCZHE of NAS of the RA*
[2] *Institute of Arid Zones of SSC of RAS*
[3] *Chair of Genetics and Cytology of YSU, Armenia*
[4] *Chair of the Presidium of SSC of RAS*

Hydroecological studies in different parts of the Dzknaget River were carried out in 2015–2017. Based on data of benthic macroinvertebrates spatial and temporal patterns of functioning of different ecotopes through river course have been revealed as well as the differences in sustainability have been discussed. The results of water quality assessment by different bioindication methods have shown that at all seasons water quality in the middlestream part was higher than in the downstream part. Also it's been proved that the R. Dzknaget has low negative impact on Lake Sevan water quality.

***Keywords*:** Lake Sevan, water quality, benthic macroinvertebrates, bioindication.

Introduction. One of the most complicated issues for water governance regimes is the establishment of freshwater resources use without harming the sustainability of hydroecosystems [1]. The problem is especially urgent in Lake Sevan basin due to its significant strategic importance as the biggest reservoir of freshwater in South Caucasus region and unique ecosystem providing different environmental services. Object of the study the River Dzknaget, is the second largest river in the basin of the Small Sevan (northern part of Lake Sevan). Its length is 22 *km* and the drainage basin area is 90.5 km^2. River valley is changing from V-shape, the upperstream to U-shape in the downstream part. Mean annual discharge is 1.11 m^3/s, and fluctuating significantly among the seasons due to feeding by melting and rain waters. Mean discharge reaches 13.6 m^3/s during the high water period. Such fluctuations are playing a crucial role on sustainability and functionality of hydroecosystem in different seasons. Water abstracted from the river mainly goes for irrigation purposes [2]. Currently about 4500 dwellers live in the basin of the Dzknaget River [3] and leaving their ecological footprint by using and consuming different provisioning and regulative ecosystem services such as agricultural and domestic water use, water quality, which forms due to filtration, decomposition of organic wastes and pollutants in water and the assimilation and detoxification of compounds [4]. The last is one of the most important outputs for all rivers of Lake Sevan basin.

[*] E-mail: vardanasatryan@yahoo.com [**] E-mail: dallakyan.marine@gmail.com

According to EU WFD (2000/60/EC), different types of water monitoring for surface water bodies have to include not only periodical hydrochemical measurements, but also hydrobiological studies [5]. Bioindication methods are providing structural measurements (like water quality or taxonomic composition of aquatic organisms) of water health [6], which is more informative in the aspect of sustainability and functionality of ecosystems than just measurements of different pollutants. Moreover, the process of accumulation of organic matter in the rivers depends on structural features of river bed such as the width, gradient, velocity etc., and in the mountainous rivers of Armenia is quite low, but the situation changes significantly in river mouth parts. Even though different hydrobiological studies in the Dzknaget River basin have been carried out by different authors for different purposes in the past [7–11], the problem of differences in sustainability of ecosystem and their functionality has not been accented yet. Thus, the aim of the current study was to reveal the spatial and temporal differences in sustainability and functionality of studied parts based on structural measurements. For that, the attempt to differentiate the studied parts of the rivers into different ecotopes has been done based on statistical analyzes of gathered data. The most current study of rivers comparative impact on Lake Sevan's water quality by hydrochemical parameters has shown that the Dzknaget River is in the subgroup of rivers with low negative impact [12], thereby, one of the objectives of current study is to check that result by bioindication methods.

Taking into consideration that benthic macroinvertebrates are sensitive to different consequences of anthropogenic impact like eutrophication, worsening of habitat conditions due to sedimentation and growing of toxicity, raising of contamination level by heavy metals, many authors concluded that for mountainous rivers they become the most valuable and broadly used indicators of water quality when long time-scale influences are obvious [13–15].

Materials and Methods. Sampling of benthic macroinvertebrates aiming to investigate qualitative and quantitative structures of the assemblage, as well as to assess water quality, have been carried out in the middle and downstream parts of the Dzknaget River (Fig. 1), because those parts are more exposed to anthropogenic influence due to domestic and agricultural wastewater discharge as well as more extensive farming. Parallelly, some core hydrophysical (temperature, flow velocity, ground types) and hydrochemical parameters (pH, DO) have been measured by Hanna HI9813-5N Waterproof pH/EC/TDS and Hanna HI9147-10 DO meters. Material of macrozoobenthos has been collected during the following seasons: autumn of 2015, spring, summer and autumn of 2016 as well as spring of 2017. Sampling has been done by surber sampler with the catch area of 0.09 m^3 (cell size was 500 μ) on 5 replications by standard hydrobiological methods [16, 17]. Collected material has been placed in containers clearly labeled with the sampling sites' geographical coordinates, determined by Garmin eTrex 20 GPS receiver and fixed by 70% ethanol solution. Further processing has been done in the laboratory. Mapping of sampling sites location has been done by ArcMap 10.1 software. Taxonomic composition has been identified up to family level (besides *Oligochaeta* order) using the keys [18–22]. Then the number of individuals from each taxon in the sample has been calculated and their biomass measured.

After that, the data from different reaches of the same part of the river collected at the same time have been combined and arithmetical means has been calculated for further statistical analysis, if comparisons did not reveal significant differences in the qualitative and quantitative structures of benthic macroinvertebrates. This allowed revealing possible structural and functional differences among studied parts of the river.

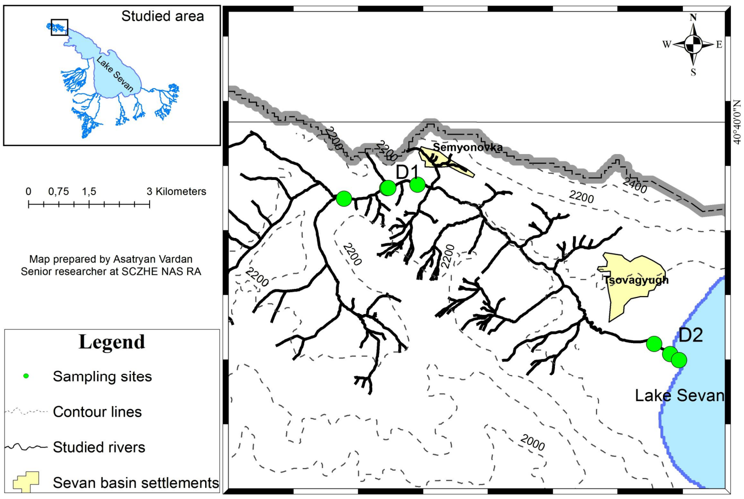

Fig. 1. Map of sampling sites distribution in the basin of the R. Dzknaget (D1 – middlestream part; D2 – downstream part).

Water quality has been assessed by BMWP (Biological monitoring Working Party) index, in combination with ASPT (Average score per taxon) index. The BMWP score equals the sum of the tolerance scores of all macroinvertebrate families in the sample (Tab. 1). The ASPT equals the average of the tolerance scores of all macroinvertebrate taxons represented in the reach [23]. Unlike to BMWP, ASPT index has 7 ranks of water quality (Tab. 2).

Table 1

BMWP scores and water quality

Water quality	Excellent	Very good	Good	Not high	Poor
Score	>150	101–150	51–100	26–50	<25

Table 2

ASPT scores and water quality

Water quality	Excellent	Very good	Good	Moderate	Rather poor	Poor	Very poor
Score	5+	4.5–4.9	4.1–4.4	3.6–4.0	3.1–3.5	2.1–3.0	0–2
Rating	7	6	5	4	3	2	1

Pinder & Farr, analyzing the sensitivity of BMWP and ASPT indices, concluded, that this combination is the best system of bioindication [24]. Fluctuations of water quality scores among the seasons as well as structural changes of macrozoobenthos have been considered for the assessment of sustainability of studied ecotopes. Some statistical analyses (correlation, Paired samples T-test) aimed to reveal spatial and temporal patterns of structural changes in benthic macroinvertebrate community have been done using IBM SPSS Statistics 22 software.

Results and Discussion. In the middlestream part of the R. Dzknaget ground mainly consists of boulders (*R*>256 *mm* (40%)) and cobble (*R*=64–256 *mm* (30%)). Average gradient in studied stretch varies from 10 to 14‰, and flow velocity varies from 0.6 to 0.8 *m*/*s*, which ensure good aeration (oxygen saturation varies from 89 to 95%) and high self-purification potential. pH values (7.62–7.87) are also fluctuating in a range of pure water norm. By nature this is typical upland lotic ecosystem.

Table 3

Qualitative and quantitative composition of benthic macroivertebrates from studied parts of the R. Dzknaget in 2015–2017

Registered taxa / Schedule of studies		2015		2016						2017	
		Autumn		Spring		Summer		Autumn		Spring	
Order	Family	D1/*	D2/*	D1/*	D2/*	D1/*	D2/*	D1/*	D2/*	D1/*	D2/*
Amphipoda	*Gammaridae*	17/230	1/6	22/180	2/42	36/744	12/14	24/170	6/36	56/617	2/3
Coleoptera	*Elmidae*	8/6	1/2	28/37	1/1	3/3	–	7/4	4/2	23/36	6/6
	Dytiscidae	2/3	–	–	–	–	–	2/2	7/104	–	–
	Dryopidae lv.	–	–	–	–	–	2/2	–	–	–	–
	Gyrinidae	–	–	–	–	–	–	–	4/9	–	–
	Haliplidae	–	–	–	–	–	–	–	2/6	–	1/1
Heteroptera	*Corixidae*	–	–	–	–	–	39/220	–	–	–	–
Arachnida	*Hydrachnidae*	–	–	–	–	–	–	6/29	–	–	1/2
Diptera	*Chironomidae*	135/125	29/16	46/62	330/439	3/1	99/70	31/25	207/712	80/272	153/296
	Simuliidae	–	1/3	–	4/9	2/1	3/1	–	18/24	–	7/14
	Tipulidae	–	1/20	1/44	–	–	–	1/4	1/3	–	1/2
	Limoniidae	–	–	–	–	5/39	1/10	–	–	–	–
	Ceratopogonidae	–	–	–	–	–	42/38	–	10/2	–	4/4
	Tabanidae	–	–	–	–	–	2/16	–	1/9	–	–
	Psychodidae	–	–	–	–	–	–	–	–	2/2	2/2
	Blephariceridae	–	–	14/101	8/30	–	–	–	–	–	–
Oligochaeta		2/2	1/1	3/140	6/7	1/1	3/1	–	17/17	–	5/8
Ephemeroptera	*Caenidae*	1/3	9/17	–	4/6	1/1	96/214	–	–	–	1/2
	Heptageniidae	17/247	2/5	26/106	63/324	66/764	4/54	22/79	9/10	31/109	5/95
	Baetidae	5/10	3/9	474/1500	137/269	32/114	58/192	85/57	9/19	192/377	21/66
	Ephemerellidae	–	–	–	–	–	4/24	–	–	–	–
Arhynchobdellida	*Erpobdellidae*	–	–	–	2/405	2/398	1/174	–	3/22	–	–
Tricladida	*Dugesiidae*	2/2	–	10/62	–	–	–	6/29	–	3/9	–
Gastropoda	*Planorbidae*	51/648	–	24/279	–	31/700	–	53/542	3/41	20/195	1/3
	Lymnaeidae	–	5/10000	–	–	–	–	–	1/2	–	1/14
Bivalvia	*Dreissenidae*	–	–	–	–	–	2/22	–	–	–	–
Plecoptera	*Capniidae*	–	–	–	–	–	–	6/18	15/24	–	–
	Perlidae	–	–	2/457	–	–	–	–	–	–	–
	Perlodidae	–	–	–	–	–	–	–	–	1/6	–
Odonata	*Coenagrionidae*	–	–	–	–	–	2/100	–	–	–	–
Trichoptera	*Rhyacophilidae*	1/2	1/12	1/22	–	–	–	9/37	–	3/28	–
	Hydropsychidae	7/464	2/4	12/45	–	8/414	–	55/676	55/2749	20/680	1/52
	Limnephilidae	–	–	6/36	1/6	4/558	–	–	5/1212	–	4/62
	Leptoceridae	2/2	–	–	–	–	–	–	–	–	–
	Glossosomatidae	–	–	–	–	–	1/2	–	–	–	–
	Sericostomatidae	–	–	–	–	–	16/640	–	–	–	–
	Psychomyiidae	–	–	–	1/2	–	–	–	–	–	1/4
	Goeridae	–	–	1/8	–	–	–	–	–	–	–

D1 – middlestream part, D2 – downstream part;
* – number of animals in the sample in numerator (ind.), biomass – in denominator (*mg*).

Totally, the representatives of 11 orders of benthic macroinvertebrates have been registered in the middlestream part. At family level the larvae of mayfly and caddisfly insects had the highest diversity (3 to 4 families) at all seasons, which also state the near pure conditions of this lotic ecosystem. At all seasons litorheophilic and phyto-rheophilic individuals of mayflies of Heptageniidae and Baetidae families dominated by quantity besides the autumn of 2015, when 54% of the total number of individuals were larvae of flies of *Chironomidae* family (Tab. 3). Due to higher individual mass, the representatives of *Planorbidae* (order Gastropoda), larvae of *Hydropsychidae* (order Trichoptera) and *Heptageniidae* (order Ephemeroptera) families have been dominant by biomass.

Higher variety of physicochemical parameters has been registered in the downstream part of the river, where cobble and sand with some mud near the banks have strong dominancy in different stretches of studied parts. Quantitative and qualitative analyze of the data from the stretches with dominancy of cobble and other structure reveal significant differences (differences in number of families in the samples reaching 9 against 16 in spring seasons) in the structure of macrozoobenthos, which is allowed to differentiate those stretches as local ecotopes. But taking into consideration the aim and objectives of the current study as well as the fact that stretches with the dominancy of sand and other ground types involving almost all diversity of families from the stretch with dominancy of cobble, the decision to summarize the overlapped data and hereafter represent the mean values for ecosystem level discussions has been made. Flow velocity at different parts varies from 0.4 to 0.1 *m*/*s*, pH values from 7.78 to 7.91 and oxygen saturation values from 85 to 102%. Due to water stagnation in near the river mouth parts, organic matter is accumulating and FPOM increasing as well as structural changes in biocenosis occur. Registered families of macrozoobenthos at this part is close to both lotic and lentic ecosystems.

Totally, the representatives of 13 orders have been registered in the downstream part of the course. At family level the larvae of flies had the highest diversity at all seasons proving the differences in functionality of studied ecotopes. The share of flies in quantitative structure varied from 55% in spring of 2015 to 77% in spring of 2017, and only in the summer of 2016 larvae of *Baetidae* family (Ephemeroptera) has dominancy in the sample (41% of all individuals). At all seasons chironomids were dominant or subdominant family both by number and biomass. By the biomass gastropods (*Lymnaeidae* and *Planorbidae* families), mayflies, caddisflies (order Trichoptera) and flies have been dominant in different seasons (Tab. 3), which is the result of features of both their life cycles and water level fluctuations.

As a result of qualitative and quantitative studies of macrozoobenthos community, assessment of water quality has been done, which shows some peculiarities and patterns.

Particularly, water quality within studied period fluctuated in almost the same range in both parts (Fig. 2). The amplitude of BMWP score in the middlestream part was 23 (max 80 in spring 2016, min 57 in spring of 2017) and in the downstream part was 28 (max 86 in summer 2016, min 58 in spring 2016). Implemented nonparametric correlation analysis (Spearman *r*) was revealed statistically significant links between qualitative data of macrozoobenthos among two studied parts in almost all seasons (min correlation coefficient is 0.6 at sig (2-tailed) 0.02), besides the summer season of 2016 (sig (2-tailed) 0.084). Juxtaposing this results with the changes in water quality asessed by BMWP in different seasons confirm that at low-water period the differences in functionality of the studied ecotopes are higher and the ecotope of middlestream part is more vulnerable to anthropogenic impact.

During all period of investigations water quality in both studied parts assessed by BMWP index remains in the frame of “good quality”, and implementation of

ASPT not only confirms that result, but also shows that water quality in the middlestream part was higher at all seasons and even can be assessed as excellent besides summer season (Fig. 2).

Qualitative data for the same parts show the presence of strong positive correlation (min Spearmen correlation coefficient is 0.76 at sig (2-tailed) <0.01) between the same seasons of different years, which stated high sustainability of studied ecotopes. The results of Paired samples T-test analysis also did not reveal any significant differences in quantitative data of macrozoobenthos of different parts neither between studied parts in the same seasons (sig (2-tailed) > 0.06) nor between the same parts in the same seasons of different years (sig (2-tailed) > 0.14). This results show that both ecotopes are fairly sustainable and their functionality didn't change significantly in temporal or spatial scales.

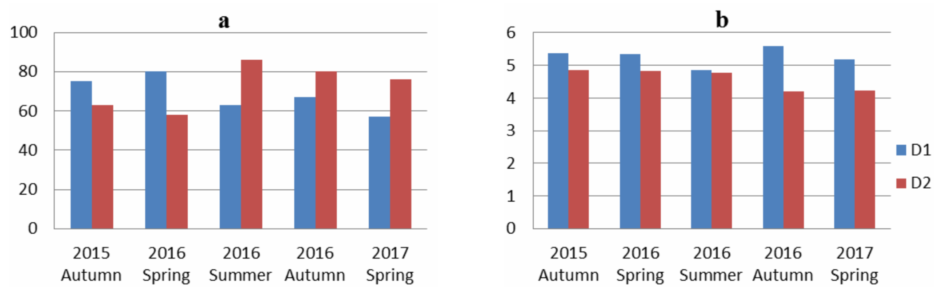

Fig. 2. Water quality of middlestream (D1) and downstream (D2) parts of the River Dzknaget by BMWP (a) and ASPT (b) indices.

Due to absence of dams and fragmentations in the river the processes taking place along the rivercourse are corresponding to river continuum concept (RCC) statements, which also is proved by some structural changes in benthic community (dominancy of shredders vs grazers in the middlestream course and vise versa in the downstream course). According to the RCC [25], ecotope of the middlestream part of the R. Dzknaget is less sustainable and allochthonous inputs of CPOM are a necessary resource for consumers. Thus, human-based interruptions can lead more serious changes in it functionality. However in case of more sofisticated water resources management in the middlestream part in low-water periods the anthropogenic impact could be reduced to minimum.

Conclusion. The results of studies obviously show that two studied parts of the river course can be distinguished as different ecotopes with some differences in patterns of functioning as well as persistance to antropogenic impact. Even though the anthropogenic pressure is higher on the part of downstream, but due to hydrological features the middlestream part of the river is more vulnerable. As a result of higher diversity of biotopes as well as functional groups of benthic macroinvertebrates the sustainability of downstream part ecotope can be assessed higher and its ecological functions more broad, thus, in case of more sofisticated water resources management it can provide more environmental services than the studied part of middle course. Also the use of bioindication methods proves that the R. Dzknaget really can be placed to the subgroup of the rivers with low negative impact on water quality of Lake Sevan.

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