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**PROOF** RESEARCH PAPER

# Benthic Disturbance-Recovery Dynamics after Construction Impact in Mountain River Mzymta (Sochi, Black Sea Basin)

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**Abstract**

Changes of zoobenthos structure in the main channel, upper reaches and tributaries of the River Mzymta (Sochi region) during four-year Olympic construction activity were analyzed. It was showed that river stretches in the upper reaches and minor tributaries, which were not affected by the construction, were inhabited by typical lithorheophilic fauna, and zoobenthos was characterized by high diversity and biomass. The natural state of the ecosystem in the main river channel was disturbed and the slopes of the flood plain and the channel itself were damaged. The pebble-boulder ground was covered by clay sediments and finely dispersed mineral particles. As a result, in the section of the river from the construction zone until the sea, a distance of about 40 km, the biomass of zoobenthos decreased. Small chironomid larvae began to predominate and the food supply of juvenile Black Sea salmon (*Salmo trutta labrax* Pallas, 1814) has considerably decreased.

*Keywords*: river, stream, environmental impact assessment, hydroecology, invertebrates.

## Introduction

The River Mzymta is a relatively small river on the Black Sea coast. It flows from the glaciers of the Main Caucasian Ridge at an altitude of 2472 m above sea level. The river is 89 km long, and its mean annual discharge is 46.5 $m^3/s$ (Surface water resources, 1964). The subsurface water basin covers an area of 885 $km^2$ and displays a mountain relief and considerable altitude variations. The river channel is 6–30 m wide in the upper reaches and up to 100 m at the river mouth. Extensive rapids and crossings alternate with short, moderately deep slow portions of the river. The bottom of the rapids and crossings consists of pebble-boulder ground. There are many blocks in the upper reaches of the river channel. The current velocity at the rapids varies from 0.5–2.3 to 2.9 m/s. The subtropical climate of the area is responsible for strong showers and frequent floods.

The upper River Mzymta flows along mountain gorges in a natural landscape. The main river channel and the mouths of many tributaries were considerably affected by the Olympic construction in 2010–2014. The Mzymta River portions, extending upstream from Pslykh tributaries, retain their natural state. Down the river, over a distance of about 5 km, the channel was mainly canalized and deepened. Natural hydraulic barriers, such as large blocks and boulders, were removed from the channel. They controlled flow structure and turbulence and the direction of local water filaments, which are vital for rheophilic aquatic organisms. Local impacts have disturbed the geomorphology of the slopes, flood plain and channel. The natural landscape was most heavily damaged near bridges, railways and highways under construction. Some portions of the river channel were transformed. The depth, current velocity, fractional ground composition and subchannel flow structure have changed. Down the river, over a distance of 40 km from the construction site, between Roza-Khutor Town and the area where the river flows into the sea, the pebble-boulder river bed is overlain by clay sediments, finely dispersed mineral particles and less common detritus. The impact of the construction was intensified by mudflows brought about by the destruction of the vegetation-free river slopes.

The reaches and crossings of the River Mzymta are the reproduction sites of Black Sea salmon (*Salmo trutta labrax* Pallas 1814) and the habitat of its juveniles. The diadromous form of this species feeds and grows in the Black Sea and is listed in the Red Data Book of the Russian Federation (2001). The zoobenthic organisms of the river reaches are the basic food of juvenile freshwater and diadromous salmon.

The zoobenthos fauna of mountain Caucasian rivers is diverse and endemic. The species composition and quantitative characteristics of Mzymta River zoobenthos have not been studied thoroughly, and species identification, based on dominant larvae in the bottom communities of the rivers, is hard to perform (Kornoukhova, 1991; Gorelov, Babiy, & Yankovskaya, 2001; Chertoprud, & Peskov, 2003; Zubarev, 2009; Reshetnikov, & Pashkov, 2009; Denisenko, 2014).

The goal of the project is to study the composition, abundance and biomass of the zoobenthos in the main channel and tributaries of the River Mzymta during and after the construction.

## Materials and Methods

Samples of zoobenthos were collected from Mzymta River rapids in late August–early September, 2011 – 2014, when the water level was minimum. 27 sampling sites were studied and 81 quantitative and 20 qualitative zoobenthos samples were collected and analyzed. The sampling sites were located in the main channel and tributaries (Figure 1).

The sampling sites were divided into four groups. Group 1 included rapids in the upper Mzymta River reaches (upstream from Pslukh tributary) and all the tributaries studied (14 sites). The sites were unaffected by the construction, the channel is typically narrow (less than 20 m), the natural landscape in the flood plain is preserved, and the slope vegetation is abundant. Group 2 (five sites) included the main channel rapids unaffected by the removal and handling of the ground. However, the pebble-boulder ground was found to be overlain by clay sediments. Group 3 (three sites in the main channel) comprises rapids at which construction with ground handling was carried out less than a year ago. Group 4 (five sites in the main channel) comprises the rapids at which ground handling operations were conducted 1-3 years ago.

One qualitative and three quantitative samples were collected from each site using a rectangular frame (Surber sampler) 0.04 $m^2$ in area (Surber, 1937; Komulainen, Kruglova, Khrennikov, & Shirokov, 1989). The sampler can be used to study compact rocky ground. It is similar in design to the benthometer used successfully for collecting zoobenthos samples from the rivers in Far Eastern Russia (Tiunova, 2003). The samples collected were fixed in 70% ethanol solution (Hauer, & Resh 2006). Two to three months later the samples were divided into systematic groups, counted and weighed. Shannon's index was calculated for both abundance and biomass (Gilyarov, 1969; Magurran, 2004). The saprobity index was estimated using Pantle-Buck's method modified by Sladecek (Zelinka, & Marvan, 1961, 1966; Sladecek, 1973; Makrushin, 1974; Deutsche Norm…, 1990; Moog…, 1995). The mean values of functional characteristics are presented with a standard deviation value. The abundance and biomass values of zoobenthos displayed a lognormal distribution which differs markedly from the normal one. Therefore, their mean values are presented together with minimum and maximum values. To compare pairs of samples using Student's t-criterion, they were transformed to normal distribution by logarithming (Shitikov, Rozenberg, & Zinchenko, 2003; Sokal, & Rohlf, 1995). Species were identified using modern manuals (Tsalolikhin, 1997, 1999, 2001; Lillehammer, 1988; Malicky, 2004).

## Results

Organisms of 59 species and taxa ranking as superspecies was found (Table 1). Chironomid (Chironomidae) larvae, revealed in 89% of the

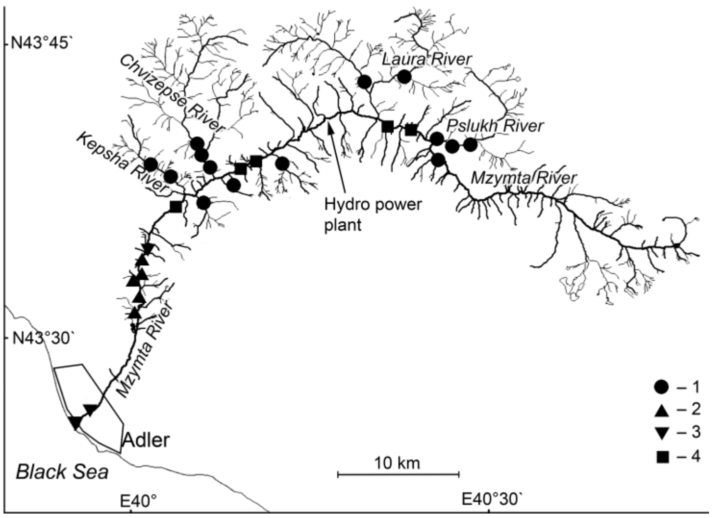


**Figure 1.** Scheme showing the location of sampling sites in the River Mzymta: 1 – in the tributaries and upper reaches unaffected by construction; 2 – in the main channel affected by clay sediments; 3 – in the main channel during the construction; 4 – in the main channel 1–3 years after the construction.

**Table 1.** Abundance and biomass (ind./m$^2$ / mg/m$^2$) of the species in the River Mzymta

| Taxon | Tributaries (Group 1) | Main river channel (Groups 2 and 4) | Rapids during construction (Group 3) |
|---|---|---|---|
| Bryozoa sp. | + | – | – |
| *Planaria torva* (Müller, 1774) | 5.8 / 9.7 | – | – |
| Lumbriculidae sp. | 5.1 / 304.0 | – | – |
| *Ancylus* sp. | 2.6 / 14.3 | – | – |
| *Gammarus* sp. | 0.6 / 0.5 | – | – |
| Hydracarina sp. | 0.6 / 0.3 | 0.8 / 0.4 | 5.5 / 2.8 |
| *Serratella ignita* (Poda, 1761) | 6.4 / 29.5 | 3.0 / 9.8 | 5.6 / 48.3 |
| *Baetis* gr. *lapponicus* | 3.2 / 3.0 | 9.1 / 13.8 | 25.0 / 16.1 |
| *Baetis* gr. *rhodani* | 163.0 / 125.8 | 131.2 / 168.0 | 39.4 / 62.5 |
| *Baetis muticus* (Linnaeus, 1758) | 11.5 / 13.8 | – | – |
| *Heptagenia samochai* (Demoulin, 1973) | 0.6 / 0.3 | – | 8.3 / 68.9 |
| *Rhithrogena* sp. | 9.6 / 54.6 | 19.7 / 54.9 | 5.5 / 27.2 |
| *Epeorus (Caucasiron)* sp. | 23.7 / 216.0 | 2.3 / 28.6 | – |
| *Habroleptoides caucasicus* Tshernova, 1930 | 1.3 / 1.3 | – | – |
| *Ecdyonurus*s. str. sp. | 19.2 / 197.0 | 6.8 / 135.0 | 11.1 / 206.0 |
| *Psychomyia pusilla* (Fabricius, 1781) | 1.9 / 2.6 | 0.8 / 0.4 | – |
| **Rhyacophila fasciata aliena* Martynov, 1916 | 4.5 / 36.5 | 6.1 / 18.9 | – |
| *Rhyacophila abchasica* Martynov, 1934 | 1.2 / 17.2 | – | – |
| *Hydropsyche pellucidula* (Curtis, 1834) | 69.2 / 741.0 | 56.1 / 1068.0 | 52.8 / 246.0 |
| *Hydropsyche* gr. *instabilis* sp. | 0.6 / 14.6 | – | 11.1 / 83.6 |
| *Hydropsyche* sp. | 3.8 / 19.0 | – | – |
| *Diplectrona robusta* Martynov, 1934 | 3.2 / 32.7 | – | – |
| *Diplectrona juliarum* Grigorenko & Ivanov, 1991 | 0.6 / 5.7 | – | – |
| *Philopotamus tenuis* Martynov, 1913 | 0.6 / 1.3 | – | – |
| *Polycentropus auriculatus* Martynov, 1926 | 0.6 / 1.3 | – | – |
| *Tinodes curvatus* Martynov, 1934 | 2.6 / 4.6 | – | – |
| *Agapetus* sp. | – | 0.8 / 0.4 | – |
| **Glossosoma capitatum* Martynov, 1913 | 78.8 / 138.0 | 17.4 / 17.9 | – |
| *Sericostoma grusiense* Martynov, 1913 | 5.1 / 10.6 | – | – |
| *Lepidostoma* sp. | 4.5 / 6.7 | 2.3 / 1.5 | – |
| *Hydroptila* sp. | 0.6 / 0.3 | – | – |
| *Ceraclea* sp. | 3.8 / 0.9 | – | – |
| *Perla* sp. | 68.6 / 921.1 | 9.1 / 133.3 | 2.8 / 145.3 |
| *Perlodes dispar* (Rambur, 1842) | – | 0.8 / 2.3 | 2.8 / 16.7 |
| *Leuctra* sp. | 44.9 / 44.8 | 4.5 / 8.4 | – |
| *Isoperla difformis* (Klapalek, 1909) | – | 1.5 / 3.8 | – |
| *Xanthoperla apicalis* (Newman, 1836) | – | 3.8 / 2.6 | – |
| *Taeniopteryx nebulosa* (Linnaeus, 1758) | – | 2.3 / 1.9 | – |
| *Nemoura dubitans* Morton, 1894 | 0.6 / 3.8 | | |
| *Protonemura* sp. | 12.2 / 27.4 | 2.3 / 1.5 | – |
| *Osmylus* sp. | 0.6 / 3.6 | – | – |
| **Limnius volckmari* (Panzer, 1793) | 5.1 / 8.4 | – | – |
| *Elmis* sp. | 11.5 / 11.8 | 0.8 / 0.38 | 2.8 / 2.2 |
| *Hydraena* sp. | 2.6 / 2.1 | 0.8 / 0.4 | – |
| Ceratopogonidae sp. | 1.9 / 2.2 | 0.8 / 0.8 | – |
| *Orthocladius* sp. | 191.0 / 71.6 | 13.6 / 7.4 | 19.4 / 9.7 |
| Tanypodinae sp. | 12.2 / 13.8 | 3.7 / 3.4 | 2.7 / 8.3 |
| *Polypedilum* sp. | 43.0 / 12.3 | 9.0 / 3.1 | – |
| *Rheotanytarsus* sp. | 65.0 / 20.5 | 17.0 / 8.2 | – |
| Chironomidae spp. | 111.0 / 41.7 | 453.0 / 190.7 | 2263.9 / 980.0 |
| *Simulium* sp. | 53.2 / 40.5 | 72.7 / 40.9 | 2.8 / 1.4 |
| *Dioptopsis* sp. | 35.2 / 41.9 | 75.0 / 97.9 | 5.6 / 6.9 |
| *Hexatoma* sp. | 7.0 / 102.8 | 4.5 / 31.6 | – |
| *Antocha* sp. | 14.7 / 27.2 | 0.8 / 0.8 | – |
| *Atherix ibis* (Fabricus, 1798) | 5.8 / 41.8 | 0.8 / 6.7 | – |
| *Tabanus cordiger* Meigen, 1820 | 1.2 / 19.2 | – | – |
| *Dixa* sp. | – | 0.8 / 0.8 | – |
| *Dicranota* sp. | – | 3.0 / 6.4 | – |
| *Hemerodromia* sp. | – | – | 2.8 / 5.5 |
| *Chelifera* sp. | 3.2 / 3.8 | – | – |
| *Prionocera turcica* (Fabricius, 1787) | 5.1 / 541.2 | 0.8 / 65.7 | – |
| Number of species | **53** | **36** | **18** |
| N Number of samples | 42 | 30 | 9 |
| Number of sampling sites | 14 | 10 | 3 |

Note: the symbol «*» indicates the species identified by imaginal features (in caddis flies, male genitals were prepared for species identification from pupae).

samples, dominate in frequency of occurrence. Representatives of the family Ortocladeinae and the larvae of the mayfly *Baetis* gr. *rhodani*, whose frequency of occurrence is 73%, are abundant. Stoneflies of the genus *Perla* (47%) and the caddis flies *Hydropsyche pellucidula* (42%) are widespread. The larvae of black flies (Simuliidae), *Dioptopsis* sp. (Diptera) and caddis flies *Glossosoma capitatum* were found in 30-40% of the samples. Chironomids form the largest group and make up 43% of zoobenthos. The mayflies *Baetis* gr. *rhodani* (14%), the caddis flies *Hydropsyche pellucidula* (6%) and black fly larvae (6%) are also abundant. The biomass of bottom communities is basically formed of the large species *Hydropsyche pellucidula* (27%), the larvae of the stoneflies of the genus *Perla* (17%), the larvae of the cranefly *Prionocera turcica* (9%), the larvae of the mayfly *Ecdyonurus* s.str. sp. (6%) and small but abundant chironomid larvae (8%). The poorest zoobenthos (scarce individuals of *Baetis* gr. *rhodani* and *Hydropsyche pellucidula*) was revealed in Laura tributary in 2012 (the channel is 14 m wide, no impact of human activities). It is probably because the temperature of the water flowing from the glacier was 7–9°C lower in the tributary than in the main channel. In other tributaries such a difference in temperature was not more than 2–3°C. Besides, Laura tributary has milky-green water due to landslide. As this site clearly differed from others, it was disregarded in calculations.

Comparison of the zoobenthos structure in the tributaries and rapids of the main channel, except for sites with traces of construction, has shown that the bottom communities of small streams exhibit the highest biological diversity and biomass (Table 2).

The mean zoobenthos abundance values are relatively small. Our study has shown considerable variations in the abundance and especially biomass of bottom communities: they increase locally to 7.5 thousand ind./m$^2$ and 20.0 g/m$^2$ and decrease practically to zero values. The abundance of zoobenthos in the main river channel and tributaries did not differ considerably, but biomass in the tributaries was much higher (see Table 2). The high abundance of zoobenthos (in spite of its low biomass) in the main channel is formed dominantly of small chironomid larvae. Species diversity in the tributaries was also higher. The mean saprobity values for both the main channel and the tributaries are in β-mesosaprobic zone, suggesting moderate pollution. The saprobity values for the tributaries were found to be higher than those for the main channel.

The impact of construction was estimated by comparing the zoobenthos structure of the main channel rapids: a) with no traces of construction, b) with traces of recent construction and c) with indications of post-construction recovery (construction was terminated 1–3 years ago) (Table 3).

Valid differences between the quantitative characteristics of zoobenthos (Student's t-criterion, $p = 0.05$) were revealed only for Shannon's index calculated from the abundances of zoobenthic organisms for rapids affected by clay sediments and construction and for rapids during construction and 1–3 years after construction. Other differences were found to be statistically unreliable.

Some rapids affected by construction display a considerable increase in the abundance and biomass of chironomids – up to 7.5 thousand ind./m$^2$ and 3.8 g/m$^2$, respectively. The percentage of chironomids in bottom communities in the channel during construction increases to 90% in abundance and 50% in biomass (commonly 40–45% in abundance and 6–10% in biomass). No valid differences in the saprobity index between the above three types of rapids have been revealed. A decline in biological diversity (Shannon's index for abundance), caused by the damage of the channel by the construction, is due to a high percentage of chironomid larvae (no species identification was performed).

**Table 2.** Characteristics of zoobenthos in the tributaries and rapids of the main river channel (except for sites with traces of recent construction)

| Characteristics | Tributaries (Group 1) | Main river channel (Groups 2 and 4) | Validity of differences* |
|---|---|---|---|
| Width, m | Less than 20 | Over 20 | |
| Shannon's index for abundance | 1.8±0.35 | 1.2±0.57 | P<0.05 |
| Shannon's index for biomass | 1.4±0.37 | 1.0±0.49 | P<0.05 |
| Number of species (groups) in a sample | 9.5±3.00 | 5.8±2.47 | P<0.05 |
| Saprobity | 2.5±0.71 | 1.9±0.49 | P<0.05 |
| Abundance, ind./m$^2$ | 1250 (125–3950) | 950 (125–3925) | P>0.05 |
| Biomass, g/m$^2$ | 4.4 (130–20010) | 2.1 (178–14193) | P<0.05 |
| N number of samples | 39 | 30 | |
| Number of sampling sites | 13 | 10 | |

* – in accordance with Student's criterion

**Table 3.** Characteristics of the bottom communities at the main channel rapids of the River Mzymta

| Characteristics | Rapids affected by clay sediments (Group 2) | Rapids during construction (Group 3) | Rapids 1–3 years after construction (Group 4) |
|---|---|---|---|
| Shannon's index for abundance | 1.3±0.51 | 0.8±0.47 | 1.3±0.49 |
| Shannon's index for biomass | 1.0±0.45 | 1.0±0.53 | 1.1±0.49 |
| Number of species (groups) in a sample | 5.6±1.92 | 4.7±1.89 | 6.5±2.83 |
| Saprobity | 1.8±0.45 | 1.8±0.29 | 2.0±0.53 |
| Abundance, ind./m$^2$ | 966 (150–3925) | 2550 (200–7575) | 793 (75–1925) |
| Biomass, g/m$^2$ | 2.4 (0.18–7.63) | 2.0 (0.15–3.77) | 2.3 (0.20–14.19) |
| N Number of samples | 15 | 9 | 15 |
| Number of sampling sites | 5 | 3 | 5 |

## Discussion

There is a high percentage of Caucasian endemic species in Mzymta River zoobenthos. As many of them occur as larvae, the insect species are hard to identify completely. The most complete list of zoobenthos species from Mzymta River rapids and crossings is presented in this paper. The presence of some species, indicated by imaginal features, is supported. Diptera make up a high percentage of zoobenthos. Species identification requires special methods and is sometimes impossible in the absence of imago. Therefore, further study is needed.

Comparison of the zoobenthos structure at Mzymta River rapids has shown that the bottom communities of the main channel are suppressed. On the contrary, the zoobenthos of small tributaries displays a high abundance and biomass. Similar damages to the bottom communities of the rivers on the Black Sea coast in the Caucasus have been reported earlier. For example, Kornoukhova (1991) has found that the bottom biocenoses in upper river reaches upstream from residential areas retain their natural structure. Chertoprud and Peskov (2003) have noted that the natural habitats of aquatic organisms in the mountain and piedmont portions of Caucasian streams remain unchanged.

The abundance and biomass of Mzymta River zoobenthos are as low as 0.9–1.3 thousand ind./m$^2$ and 2.1–4.4 g/m$^2$, respectively. However, density varies considerably between the sampling sites, increasing locally to 7.5 thousand ind./m$^2$ and 20.0 g/m$^2$. Comparison of the zoobenthos abundances in the main river channel and tributaries has shown that the biomass of bottom communities is higher in minor tributaries that remain in a natural state. However, the difference in abundance is not considerable, because small chironomid larvae are more common in the clay-covered substrates of the main channel. Zoobenthos is considered as food for juvenile Black Sea salmon. In accordance with Y.A. Shustov's classification, zoobenthos is at "the medium food level" in the tributaries and at the "medium-low level" boundary in the main channel (Shustov, 1983).

Saprobity in the tributaries is much higher than that in the main river channel. Examples from some rivers in Northern and Central European Russia, presented earlier, show that as the size of a stream increases, saprobity tends to grow (Baryshev, 2011; Chertoprud, 2005). We have revealed a reverse relationship: the saprobity index in minor streams is higher (see Table 2). This is probably due to some characteristics of mountain subtropical rivers. As the saprobity index shows the organic pollution level, the authors assume that the relative scarcity of river communities in the main channel is due to the intense washing-out of forest litterand other organic substances by frequent (up to 12 times a year) intense floods. One of the reasons for that is that pebble-boulder ground is protected by a clay cover, which prevents the persistence of organic detritus in it.

## Conclusions

Thus, the zoobenthos in the upper reaches and minor tributaries of the River Mzymta was in natural state during and after the construction. The bottom communities are dominated by chironomid larvae in abundance and by caddis flies in biomass. The structure of the bottom communities at the construction sites was damaged by the removal and handling of ground in the river channel. The diversity and biomass of zoobenthos have decreased, pellophilic chironomid larvae began to grow, while rheophilic species, typical for clean pebble-boulder grounds, which are used as basic food by juvenile Salmonidae, have disappeared. The food supply of juvenile Black Sea salmon has been considerably impoverished. After one to three years the structure of the bottom communities at these sites has recovered: both diversity and biomass increased and the species, which disappeared earlier, came back. However, the main channel rapids, where the ground remained undisturbed during the construction, were affected by clay sediments which covered the pebble-boulder ground and resulted in the impoverishment of zoobenthos and, consequently, in the poorer food supply for salmon juveniles.

After the completion of the construction, intense frequent floods began to wash out the ground. The removal of clay from the vegetation-covered slopes, including those supported by a special net, has decreased. Large quantities of pebble-boulder ground and blocks rolled down the slopes into the river channel and were gradually displaced by the flow and transported downstream. As a result, after one year the cross-section of the altered portions of the river channel was no longer canal-like. The relief was subdued by vigorous floods characteristic of a mountain river. The natural state of the river and the species composition and biomass of benthos as food for Black Sea salmon are gradually being recovered.

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