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Introduction into biology of the coastal zone of Lake Baikal. 1. Splash zone: first results of interdisciplinary investigations and its role for the lake ecosystem monitoring

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Abstract. Splash zone of the most Eurasian lakes**,** as an above-water part of the littoral zone, remains “terra incognita”. Meanwhile, it became conventionally accepted that this zone provides most accurate evidence of immediate ecosystem’s response to the current anthropogenic changes. The term “splash zone” is commonly used by marine biologists in intertidal zonation, denoting a part of the littoral zone subject to water splashes. A similar zone with a variety of environmental gradients, defined by abiotic factors also exists on Baikal extending from the water’s edge to the slope foot. It is 1800-2000 km long, the lower margin of the splash zone extending 10 or more meters landwards as a result of the water level rise. Investigation of the splash zone as a significant constituent of the lake ecosystem sets a new trend for limnological studies on Baikal. The splash zone has been found out to be rich in feeding resources: high concentrations of detritus and domestic waste providing a favourable biotope for specific communities and affecting hydrochemistry and microbiology of interstitial and coastal waters. At least, four invertebrate faunistic complexes of different origin were encountered in this zone: palaearctic, cosmopolitan and other species (immigrants from Eurasian or Siberian water bodies) (1); common or endemic Baikal hydrobionts (2); as well as soil infauna (3) and terrestrial epifauna (4). Recent observations showed that this zone is subject to most heavy anthropogenic load: its grounds serve a special buffer filtering waters discharged from the neighbouring settlements; maximal concentration of domestic waste is registered in the splash zone. Hence, the anthropogenic load on the lake can be easily recorded in the splash zone, a sensitive “indicator” of the changes in Baikal ecosystem. The present paper initiates a series of reports on interdisciplinary research in the splash zone of Lake Baikal. It introduces a term, “splash zone” of Baikal, provides brief characteristics, principal effects on the community productivity, as well as our proposals on establishing an effective monitoring system in this area.

Key words: Splash and coastal zone, macrophyte and invertebrate communities, fluctuations of the lake level, Baikal monitoring.

Paradoxical as it may seem, surface (land) part of many Asian lake shores, such as Khubsugul, Kotokel, Ivano-Arakhleysky lakes, is most easily accessible for researchers, yet it remains actually unknown. Lake Baikal, a world known water body, is not an exclusion, there are only several works on infaunal taxonomy of detrital mats (ciliates [46]), sand (cyclops [1; 42], rotifers [5; 6]), oligochaetes [37] or biology of macrozoobenthos of beach, including splash zone [9; 10]. Recent observations (Baltic Sea, Lake Leman and Ohrid in Europe, Lake Biwa in Japan and others) show that splash zone is the most sensitive indicator of the anthropogenic changes in the ecosystem. Geomorphological examination of the Baikal shores carried out within the last decades by T. G.

Potemkina [32–34] provided evidence of some problems related to the work of Irkutsk Hydro Power Station and regulation of the lake, construction of Baikal–Amur Railway, tourism and health-spa services, construction of many piers and berths, etc. All these factors effect the relief and soil formation, ecological characteristics of the near-shore area.

Analysis of relevant publications revealed that no data are available on the chemical composition of interstitial waters within the splash zone of most Russian lakes. Geochemical composition of water and microbial communities of the splash zone was studied in the 80s on Lake Baikal, and the results have not been published yet. Natural and human-induced processes on the near-shore coastal environments are subject to extensive and thorough examination worldwide [44; 50].

Investigations of the last decades proved the importance of long-term continuous observations, regular sampling and collecting hydrobiological material to understand long-term trends in limnological characteristics of Baikal ecosystem. For instance, joint Japanese and Russian studies on nitrogen and carbon stable isotope ratios in the scales of Baikal omul (collections of V.V. and N.S. Smirnov, 1947–1995) elucidated an interesting fact that the rate of changes of stable isotope ratios in omul scales is in surprisingly good approximation with that in the Earth's atmosphere [43]. Observations of the quantitative and qualitative fluctuations in zooplankton, temperature and plant pigments carried out by Prof. M. M. Kozhov and his followers for last 60 years enabled the researchers to discover a phenomenon of chlorophyll "a" concentration increase (the pigments have been studied within 30 years), as well as growth of cladoceran abundance in zooplankton at the Station № 1 in Southern Baikal [49]. It seems that these are records of the global climatic changes[1] suggesting a key role of Lake Baikal as a natural laboratory to study these processes. Small-scale and local changes might have already taken place in the surface part of the coastal lake zone that remains actually unknown so far[2]. That is presumably the reason why there is no agreement among researchers regarding anthropogenic impacts on Baikal ecosystem as a whole [2]. In 2009, we started interdisciplinary investigations of hydrochemical, hydrophysical, microbiological and biogeochemical processes in the splash zone, as well as seasonal dynamics of algae, micro-, meio- and macrozoobenthos in the interstitial waters, worked out procedures, suggested a monitoring system of the above-water part of Baikal coastal zone. The first stage of this work, including development of research strategy, investigation of the water level fluctuations and changes in the zonality of macrophytes, and biology of dominant species they induced, was in a relatively clean area of Bol'shye Koty Bay (Southern Baikal). In this paper we provide a definition of the splash zone of Baikal[3], complex procedures and approaches in brief, focus on urgent research problems of this poorly investigated biotope and give some recommendations on monitoring the ecological situation.

General research and sampling patterns

The idea of extensive research on the splash zone of Lake Baikal was brought up in 2006–2007 during comparative meiozoobenthos investigations in the under-water and above-water parts of sandy beaches in Bol'shye Koty Bay. Somewhat later preliminary results of studying coastal aggregates of detritus (detrital belts consisting of dead grasshoppers, caddisfly imagines, algae etc.) and their infauna were obtained by O. A. Timoshkin. Most complex and extensive investigations of the splash zone as a constituent of the coastal zone were carried out by our research team in 2009–2011 on the State Project of Limnological Institute (LIN SB RAS) (see Acknowledgments). Generally, the observations were performed monthly, from May until November at the Station of LIN in Bol'shye Koty Settlement. Samples were also sporadically collected in Listvyanichny Bay, Maloe More Strait, Olkhon and Bol'shoy Ushkany Islands, Chivyrkuy Bay and on the eastern coast of Southern Baikal. Firstly, we divided the splash area in Bol'shye Koty Bay into morphological zones with accent on geology and mineralogy, outlined the location of transects for interdisciplinary observations. Hydrobiological (including microbiological), hydrochemical and biogeochemical sampling was done simultaneously at 4 standard sections:

[1] In the view of the first author, assumption on the long-term abundance dynamics of cladocerans based solely on the data obtained from a single site in Southern Baikal could be hardly valid for such a huge water body, as Lake Baikal. Great numbers of cladocerans were observed in Chivyrkuy and Barguzin Bays during an open water period, as well as in Maloe More Strait, in the northern basin of the lake. According to the author's observations, the ground samples collected by a dredge or grab sampler at the depth of 50–250 m in the northern basin of Baikal, often contain significant amounts of *Bosmina* ephippia and their empty valves, a convincing indirect evidence of these crustacean abundance in plankton.

[2] Importance of this study has already been foreshadowed [3; 4].

[3] Late Prof. Dr. E. B. Karabanov was the first researcher, who has mentioned the splash zone on Baikal without paying special attention on its ecology [31].

opposite Varnachka Valley (sometimes samples were collected in Sennaya Bay), Zhilishche and Chernaya Valley and a small bay ca. 200 m southern of Zhilishche. At each site we took interstitial water from sample holes 1 m above the water edge (1); lake water 1 m (2) and 100 m below the water edge (3). Each sampling site was sampled thrice. Abiotic parameters, such as air, water and ground temperature, pH, electric conductivity as well as granulometric composition of bottom sediments were simultaneously measured at all sites. In the shallow and splash zones temperature measurements were taken in: 1) lake water 100 m, 1 m from and at the water's edge; 2) ground and interstitial water, 0,5 or 1 m above the water edge. Temperature of the wet ground was measured as well with 0,5–1 cm intervals from the surface 20–25 cm inside (Checktemp thermometer with a stainless steel tip). Diurnal temperature fluctuations were registered at the ground surface within the splash zone (0,5 m above the water's edge), at the water edge, near the bottom 1 and 20 m from the water edge (at the depth of 0,1 and 3,0 m, respectively) using TidBit Loggers [15; 40]. Biogeochemical analysis of the water, ground and hydrobionts of the coastal zone (including splash zone) was a special part of our study. In order to understand the role of dominant macrophyte species for abiotic processes in the environment, we found approaches to identification of the daily oxygen consumption and pH variations induced by habitat-specific *Ulothrix zonata* Kuetz. alga in mesocosms. Changes in the area of the splash zone were photographed opposite the Station of LIN SB RAS during 2006–2011. Moreover, monthly measurements of the distance between the water's edge and a steel stick fixed at the foot of the slope were done monthly, in calm, windless days. At the same time, we studied the composition, quantitative characteristics and seasonal dynamics of the coastal detrital mats, as well as their infauna. Microbiological comparison of the interstitial water from the holes on the beach and water sampled 1 m and 100 m in the near offshore provided evidence on the seasonal fluctuations of the total bacterial abundance (TBA), number of colony-forming units per 5 selective media[4], as well as the sanitary-microbiological situation. Phyto- and zooplankton from the interstitial water of the splash zone was compared to that from the water 1 and 100 m lakewards from the water's edge. We also sampled micro- meio- and macrozoobenthos to understand seasonal dynamics of these assemblages. Since some species serve adequate indicators of pollution, autecological studies of abundant macrophyte and macrozoobenthos species, i.e. ecology, morphology and life cycles of green *Ulothrix zonata*; ecology, morphology, life cycles and diet of *Mesenchythreus bungei* oligochaetes dominating splash zone communities; ecology, life cycles and feeding of amphipods and planarians living immediately below the water's edge and in the splash zone were carried out as well. When analyzing the detrital composition on the splash zone, we focused on life cycles, seasonal dynamics of the flora, zonation, physiology of the macrophyte thallomes in the bay area and its major tributaries. Besides, the following aspects were examined during this investigation: composition and quantitative characteristics of the "transitional communities" from the land–water ecotone, as well as the effect of such natural events as showers and landslides on the ecology of the splash zone, including input of terrigenous matter in the microbial communites before and after heavy rains.

All photographs were provided by O. A. Timoshkin (for color illustrations, see the original paper [8]).

"Splash zone" of Lake Baikal and its role in environmental studies

The term "splash zone" was originally used in coastal marine zonation. At present, it is in common use in oceanography, marine and freshwater biology [41; 51]. It is defined by the Cambridge University Dictionary of ecology, evolution and systematics as follows: "splash zone – the region of the shore immediately above the highest water level that is subject to wetting by splash from breaking waves" [41]. It should be emphasized that the previous researchers (besides Prof E. B. Karabanov, see the footnote No 3) did not define the splash zone as a separate part of Baikal shore hence it fell out of consideration when dividing the lake ecosystem into subregions [21; 31; 39]. To avoid any disputes on the pros and cons of the term "littoral zone" concerning lake ecosystems, we suggest some supporting arguments of the term "splash zone" in the Lake Baikal zonation scheme. There actually exists a special zone that is, first, subject to high-energy wind and wave activity. Second, this zone is the place of the largest levels of detritus accumulation being a biotope for specific communities, affecting the hydrochemical and microbiological composition of the interstitial

[4] Plain agar (to check presence of saprophytes), inorganic phosphate medium (microorganisms consuming inorganic phosphorus), Waksman medium with nitrates (fungi and actynomycetes), starch agar (microorganisms destroying polysaccharids), milk agar (microorganisms destroying proteins).

waters. Third, this zone is a biotope for Baikal endemics that are either present in the shore biocenoses or are specialized to inhabit the interstitial waters above the water line of the beach, and, therefore, should be regarded a constituent part of Baikal ecosystem. Our observations within the splash zone revealed "transitional" communities including, as least, four different faunistic complexes of invertebrates: Palearctic, cosmopolitan and other species (invaders from Eurasian or Siberian water bodies) (1), common or endemic species inhabiting Lake Baikal (2), terrestrial infauna (3) and representatives of land biocenoses (4) (Figs. 1–9). The species representing the Lake Baikal fauna in these communities are few in number. As a rule, taxocenoses of the splash zone are dominated by a 1 or 2–3 species, therefore, actually all species may be chosen as indicator species of the anthropogenic load on the zone. Hence, it seems reasonable to investigate their life cycles in detail as well as the seasonal and interannual dynamics of their quantitative characteristics before compiling lists of indicator species. For instance, macrozoobenthos of these communities includes 1–2 planaria species abundant near the water edge, where they lay cocoons (Fig. 1) [16; 26]; 2–3 Oligochaeta species dominated by *Mesenchytraeus bungei* Michaelsen, 1901 and the same number of amphipods (Fig. 2) [9; 10]. A similar situation exists with other meiozoobenthic organisms in the splash zone: microturbellarians, tardigrades, crustaceans (Figs. 4–6)[5]. Our data on the abundance and biomass of all these animals that attain very high values during summer will subsequently be published. Surprising as it may seem, forest and terrestrial animals got adapted to challenging splash zone environment of Baikal. Numerous mites, spiders, Coleoptera (especially Carabidae, Fig. 7), Myriapoda, Collembola, Diptera larvae constantly inhabit this area and are awaiting their researchers. Terrestrial species, regularly or sporadically encountered in the splash zone, have not been even preliminarily classified. Quantitative and qualitative studies of the inhabitants of the shore detritus accumulations, i.e. the infauna, have also been just initiated.

Great numbers of red forest ants concentrate in the splash zone during massive flights and death of endemic caddisfly imagines. Actually along most of Baikal shoreline and its islands one could see shoals of worker ants carrying caddisfly imagines to the formicary located several dozen or even hundred meters from the water's edge (Fig. 8). After that the ants carry away and feed on other insects thrown from the water onto the splash zone (bugs, butterflies, etc.), but they are much fewer in number. In zones of protein depletion on Bol'shoy Ushkany Island isolated from the mainland of Svyatoy Nos Peninsula, massive flights of caddisfly imagines in spring–summer, as well as infrequent forest fires and lack of predators that feed on ants, their eggs and destroy their hills, apparently provide favourable conditions for ants to build many hills there [14].

Most interesting constituent of the terrestrial fauna that adapted to the splash zone environment are earthworms from Lumbricidae family (Fig. 9.1; 9.2) constantly found in "stone-unit" samples[6] collected from Bol'shye Koty Bay. They were occasionally encountered even at the lake water's edge and the intestines of these worms were filled with substantial amounts of filaments of dead and semi-digested green alga, *U. zonata.* The regularity of such findings as well as feeding on shore detritus, including filaments of *Ulothrix* dominating the area at the water edge (Figs. 9.3; 9.4) suggest that earthworms adapted to the splash zone. The external features and sizes of mature earthworms (judging by the pronounced clitellium) sometimes varied indicating that they were different species. It seems likely that their food specialization would lead to taxonomic isolation and might be the first step towards formation of *Lumbricus* species that adapted to Baikal splash zone. Regular occurrence of earthworms in the splash zone is presumably caused by the following: active migration of individual specimens searching for food (semi-decayed plants within the shore detritus being an ideal source of organic matter for detritophagous *Lumbricus* species) and heavy rains washing the worms onto this zone. It remains unclear whether the worms overwinter in this part of the lake shore or active/passive immigration of other worms from the neighbouring forest soils enables these animals to sustain their number. Besides terrestrial fauna, flora and microscopic fungi (first results will be published later), mud flows accumulated along the lake shore line (especially on the western shore) supply great amounts of organic and inorganic matter that is a large contribution to the substance turnover on the splash zone

[5] According to the data of our laboratory obtained during investigations in 2000–2011 [13; 17; 23; 35; 36], analogous situation is typical for the communities inhabiting the shallow-water stony littoral. Dominant macrozoobenthic species are very few in number or even single.

[6] In hydrobiology, a routine method of quantitative benthos sampling: specimens are collected from a stone in the lake and from the stone underside in the splash zone; counting their projective cover [3].

and lake shores. Our observations at the standard transect located opposite the Station of the Limnological Institute SB RAS in Bol'shye Koty Bay showed that alongside with rapid storage of the shore detrital accumulations and transfer of eroded forest soils onto the splash zone, muddy flows deliver allochthonous material into the lake as far as dozens of meters from the water's edge (Fig. 10). Further research aims to quantitatively assess these processes and their impact on the biota of the splash and shore zone.

Finally, one more distinctive and critical feature of the splash zone should be pointed out, i.e. maximal anthropogenic load on this region. The ground of the shore and splash zones serve a buffer filtering the sewage discharged from the nearby settlements and thus protecting the lake water; accumulation of the domestic waste was found to be maximal in this zone as a result of intensive recreational activities (Fig. 11.1). In addition we observed traces of oil left by boats and ships, and drivers washing their cars there (Fig. 11.2). Thus, as evidenced by the global environmental monitoring (Lake Biwa, Ohrid, etc.), anthropogenic pollution of the lake ecosystem generally starts at the shore zone, and consequently, it may be easily documented there. From this point of view, processes on the splash zone may be regarded most indicative of the current ecosystem's changes, providing cost-effective opportunities for environmental monitoring of Baikal.

Splash zone stretches from the water's edge to the base of slope (cliff) or constructions on the shore like parapets, wooden or concrete embankment walls, etc. In case of a gently sloping shore (for instance, the eastern shore of Baikal), the upper margin of the zone is the edge of the region of maximal wind-wave activity. On Baikal the length of the zone coincides with the shoreline and is approximately 1800 km [7]. M. M. Kozhov [21] wrote that the shoreline was approximately 2000 km, and the shoreline of the islands – 139.2 km. As a result of annual rise of the lake level, the splash zone migrates 10 m (western shore) or more than 10 m (eastern shore, bays) [7] landward during the summer time (Figs. 12, 13), and in winter-spring period it moves backward. The water level varies within 1 m. Average width of the splash zone is approximately 10 m along the western shore (Bol'shye Koty Bay).

[7] Measurements were taken from a steel stick (repère) fixed at the base of the slope opposite a standard transect near the Station of LIN SB RAS in Bolshye Koty Settlement.

Integrated approaches and main reasons for monitoring environmental impacts in the shore zone of Lake Baikal

First of all, study sites and/or transects are ecological tools that allow us to carry out environmental monitoring within aquatic ecosystems [46]. Our team accumulated extensive experience in ecological research on Lake Baikal [18; 21; 31]. The following factors supported our choice of transect and study site location as well as the periods and frequency of observations: a) intensity of anthropogenic stress that is indirectly related to the number of permanent population of the nearby settlements and/or recreational activities; b) periodical natural phenomena and processes, biological characteristics of the dominant species (including climatic features, ice cover formation and destruction, life cycles of hydrobionts, their reproduction periods, etc.); c) geological features of terrestrial and underwater landscapes; d) any available past data. Moreover, levels of organization of living organisms that might be subject to anthropogenic load should be taken into account as well. Let us consider these factors in more detail.

Anthropogenic load. Assessment of the intensity of anthropogenic effects on the splash zone in the vicinity of large settlements (towns) and natural objects visited by many tourists should be carried out annually and some parameters are to be registered several times a year (see below). The areas with highest rates of recreational activity include: Listvyanka, Bol'shye Koty, Bol'shoe Goloustnoe, Buguldeika, Goryachinsk settlements, Aya Bay, mainland and island part of Maloe More shore (Malye Olkhonskie Vorota Strait, Mukhor Bay, Khuzhir Settlement), Khakusy Bay, Monakhovo Settlement, Zmeinaya Bay and Chivyrkuy Bay, Turka Settlement; town-like settlements with 10–12 thousand residents and small industrial towns, such as Baikalsk (14 thousand), Slyudyanka (19 thousand), Severobaikalsk (25,5 thousand) and Nizhneangarsk (5,5 thousand).

Periodicity in some natural phenomena, biological characteristics of dominant species, etc. Climate changes and hydrodynamic processes have significant impact on the shore zone. Great amounts of sponges and even cottoid fish are annually left on some capes protruding into the open lake after strong storms (Fig. 14). Showers cause large mudflows delivering enormous amounts of soil (biogenes) and representatives of terrestrial communities (microflora, terrestrial saprophytic fungi in particular, invertebrates, etc.) onto the splash zone (Fig. 11). Seasonal periodicity of biota and biological characteristics of dominant species of Lake Baikal and surrounding areas affect the processes in the splash zone, such as regular annual massive flight of endemic caddifly and chironomid imagines, egg laying near the water's edge (Fig. 15) and subsequent death of insects; abundant vegetation and death of aquatic and terrestrial macrophytes; massive molting events of invertebrates inhabiting the shore (Fig. 16), etc. All of these processes, including extensive accumulation of domestic waste washed onto the splash zone after tourist season and ice cover breaking, entail hydrochemical and microbiological changes in the near-shore and interstitial waters and should be considered in determining optimal location and number of sample transects, as well as sampling regularity. Most of these issues will be considered in detail in separate publications, since the data obtained are quite new, interesting and important for further limnological research on Lake Baikal.

Underwater and terrestrial landscapes: geological aspects. Mineral composition of the shoreline bedrock alongside with the available detrital material has a significant influence on the hydrochemical properties of interstitial water in the splash zone. Hence, these factors should be taken into account in selecting locations of transect. Baikal shoreline was previously divided into 9 landscape-ecological zones [31]. In accordance with this pattern, 8 transects were established on the western shore in 2000 by our research team: test site at Berezovy Cape (I); Bol'shye Koty Bay (II); opposite Birkhin Cape (III); western and eastern shores at the northern termination of Olkhon Island (IV and V, respectively); Bol'shoy Ushkany Island (VI and VII); Elokhin Cape (VIII). Two of them were located on carbonated rocks (VI and VII), one – on gabbroid rocks (III), the rest – on granite and mixed rocks. Long-term regular observations of the abiotic factors and all the trophic levels in the ecosystem of the shore were carried out at Berezovy test site. Recent results of these investigations were briefly overviewed in a number of papers and short communications [13; 28–30], a series of chapters in a multi-author monograph [4; 27]. A separate chapter presents justification of Baikal ecosystem monitoring and results of hydrobiological research [18]. Some of the above-mentioned transects should be included into a shore-based network of stationary monitoring points on Lake Baikal.

Previous observations of macro-, meio- and microzoobenthos. In contrast to pelagial ecosystem and its inhabitants that attracted the attention of researchers for many years, bottom hydrobionts in the littoral zone remained insufficiently studied. A lake-wide quantitative investigation of Baikal macrozoobenthos has been carried out once [24] alongside with a single brief report [25]. Only fragmentary data on quantitative and qualitative characteristics of macrozoobenthos from the following lake regions were published: Utulik–Murino, Bol'shye Koty Bay, Selenga shallows, Berezovy Cape, Bol'shoy Ushkany Island [19; 20; 22; 36]. No information on seasonal and interannual dynamics of micro- and meiozoobenthic communities in the splash zone of Baikal is available from the literature (except preliminary data from Bol'shye Koty and Berezovy test site (see [11; 17; 38]).

Levels of biotic organization. It seems that anthropogenic stresses affect the Baikal biota at all levels of its structural organization (communities [I] → populations [II] → organisms [III] → cells [IV] → molecules [V]). Following this suggestion, we assume that an ideal monitoring scheme includes observations of all biotic levels. Such observations will be focused on the structure of communities and population (levels I and II, common practice), dynamics of quantitative characteristics of dominant species, invader or habitat-specific species (levels I–III). Such characteristics, as percentage of specimens showing morphological deviations (teratism; level III) (or percentage of clutches, embryos), abnormal clutches and embryos (levels III–IV) as well as percentage of specimens with chromosomal aberrations should be given special concern. However, only few species may be regarded as model objects for biomonitoring. Appropriate research approaches and procedures were discussed earlier [18].

Selection of indicators of current ecological changes in the lake splash zone

It is a well-known fact that anthropogenic stress in the splash zone is most rapidly and directly reflected in hydrochemical (presence of oil products, changes in the concentration of organic matter, heavy metals, biogenes, oxygen, etc.), microbiological (change of the total bacterial abundance, TBA, amount of organotrophs, *Escherichia coli* and enterococci) and hydrobiological (changes in the species composition, number of short-living micro- and meiobenthic protists, rotifers, crustaceans) parameters. Moreover, registration of the accumulation rate of anthropogenically impacted onshore detrital material allows easy and quick monitoring. Observation of these particular variations would facilitate annual monitoring of the ecological processes on the splash zone within the studied areas.

Thus, we offer some recommendations for annual monitoring (two times a year during minimal and maximal lake level rise) of hydrochemical, microbiological indicators, meiozoobenthos (at the level of taxonomic groups), as well as the level of anthropogenic pollution of the splash zone in each of the studied Baikal areas.

The data obtained during our investigations [23; 48 and others] showed that maturation process of many indicator (dominant) macrozoobenthic species from the shallow-water regions and their average life span were 2–4 years long. Therefore, with the aim to register all possible variations of the quantitative and qualitative characteristics in macrozoobenthic communities, we suggest to conduct complex hydrobiological survey work and analysis (at the level of taxonomic groups) once in 4 years at some of our study areas. These might include Berezovy Cape (relatively clean part of the lake bottom, availability of reference data on many parameters collected during 2000–2005, presently a place of intensive recreational load; granitoid basement rocks), Bol'shye Koty Bay (a limnological research station, currently a place of intensive recreational load, granitoid basement rocks), Birkhin Cape (relatively clean part of lake bottom, reference data on macrozoobenthos obtained in 2004, gabbroid basement rocks), Bol'shoy Ushkany Island (absolutely clean bottom part, reference data on macrozoobenthos obtained during 2002–2004, carbonated basement rocks).

A detailed list of research activities on the splash zone of Baikal shores (from the water line up to the limit of the lake level fluctuations, i.e. approximately 1 m depth) and schedule of future observations are provided below.

Stages and periods of data collection

1. Monthly (open water period) and seasonal (winter-spring period) measurements of the water level at monitoring sites (repères located on the shore at the slope-splash zone, water edge boundary[8]).

2. Monthly (May–October) monitoring of shore detritus accumulations at the study sites; their types, plant and animal species composition of major groups from the detritus, as well as identification of their quantities and dimensions (% of wet weight, approximate size and location of shore detritus accumulations). Holes for collecting microbiological, hydrochemical and other samples should be located taking into account presence of detritus accumulations.

3. Special attention should be given to the anthropogenic-impacted shore areas, detritus accumulations (including domestic waste) in particular, their composition and mass per unit area using macro photography.

4. Quantitative and qualitative assessment of protists and algae inhabiting the interstitial water parts within the splash zone. Sampling procedure: collecting samples three times from each of 0,3–0,5 m deep holes (until the interstitial water is reached) into 0,6–1,0 l plastic vessels. The holes should be bored 0,5 m above the water line, sample collection during windless days. Some samples are fixed with Lugol's[9] (algae, flagellates and others), others are examined and counted alive (ciliates and other protists). In both cases, a species list is provided, as well as the number of individuals per unit volume or/and area.

5. Monthly (May–October) observations of macrophyte species as indicators of the lake shore: a) three *U. zonata* subzones, b) *Didymosphenia*, c) *Tetraspora*, d) *Cladophora*, e) *Nostoc* and *Stratonostoc*, f) *Draparnaldioides* (including, subzones of regression and inhibition of *U. zonata,* thallome condition, relative abundance of epiphytic blue-green algae, diatoms, etc.); macro-level monitoring (underwater photography) and use of light optical microscopy (microphotographs). Study of vegetative pigment content (chlorophylls) will be carried out in subzones of regression and inhibition within the macrophyte belts dominated by *U. zonata, Draparnaldioides baicalensis* and in the regions where epiphytic algae, blue-green and diatoms are abundant.

6. Biannual collection of meiozoobenthos during its growth peaks (May–June, August–September) at the splash zone sites (of the whole shore zone if possible) for subsequent quantitative assessment. Species composition, ratio of the groups, as well as availability of abundance maxima of these short living animals may be used as indicators to assess the state of these communities.

7. Monthly (May–October) observations of macroinvertebrate species as indicators of the shore zone: *Baikalobia* planarians (1 species), *Mesenchytraeus* oligochaetes (1 species, *M. bungei*), *Eulimnogammarus* (1–2 species),

[8] Due to annual rise of the lake level, the water line (bordering the splash zone) migrates inland, and the dynamics of these migrations could be measured by means of repères.

[9] Samples fixed in Lugol's or Utermehl's solution have limited storage time (3–4 months in darkness and stable conditions) and should be counted during this period. After expiration, samples become useless for quantitative analyses of nonloricate flagellates and other protists.

Micruropus amphipods (1–2 species), *Baicalina, Baicalinella* and *Thamastes* imagines (3–4 species). Collection of these animals for the assessment of the total abundance and biomass per unit area during minimal, average and maximal water level rise, paying special attention to the number of planarian cocoons and egg masses of caddisflies per unit area at or above the water line.

8. In summer every 5 years, monitoring of teratism in dominant invertebrate groups as well as the chromosomal aberrations in indicator gastropod species of the genus *Benedictia* W. Dybowski in the shallow-water area neighboring large towns and settlements (in the places of most heavy anthropogenic load and recreational activity) [12].

A scheme of monitoring shallow parts of the lake (splash zone included) involves several stages and preliminary data:

– Selection of monitoring sites (experimental sites, transects, stations) focusing on: a) degree of anthropogenic loads; b) unique landscape features; c) geological framework of the region.

– Pre-monitoring preparations in the shore zone: setting survey markers (repères) on the lake bottom, numbered concrete blocks, etc.

– Brief overview of preliminary investigations in the study areas.

– GPS coordinates at all stations, transects and experimental sites.

– Periodicity of data collection and hydrobiont sampling procedures at each of the study sites.

What monitoring includes:

a) Temperature profiles monitored by TidBit or HOBO temperature data loggers during the whole period of observations. Loggers are to be placed as follows: 1) shady side of the study site (air temperature measurements), 2) ground surface 0,5 m above the water line (near 3 sampling holes), 3) water line area, 4) ground surface 0,5 m below water line, 5) ground surface at the 3–4 m depth (average depth for the shallow water zone with most abundant flora and fauna). Temperature dynamics in the ground is an important indicator of the processes at the depth of 5, 10 and 20 cm from its surface.

b) Granulometric composition of the ground collected from the sampling holes.

c) Hydrophysical (temperature, electric conductivity), hydrochemical (pH, O_2 concentration, basic nutrients, biochemical oxygen demand (BOD), total organic matter (TOM), etc.) and microbiological indicators (identification of types of microorganisms on selective media, estimation of total bacterial number of *Colibacillus* and *Enterococcus*).

d) Photo- and video documentation of onshore detrital accumulations, records of water level changes, well-developed macrophyte belts (special accent put on *U. zonata*), macro- and light miscroscopic analyses; registration of teratic organisms.

Summing up, we presented a definition and first data on the splash zone of Lake Baikal. Almost total lack of articles dealing with the limnology of the splash zone enables us to regard this research as a significant contribution opening new perspectives in the study of Baikal. Research methods and approaches developed by the authors to study the environment of Lake Baikal may be applied to analogous study areas on other Siberian lakes. It is strongly suggested to introduce a science-based environmental monitoring of the splash zone of Lake Baikal into the national monitoring system that would allow us to manage the shoreline ecosystem already responding to current changes. Since the splash zone is particularly sensible to external factors and its role in the shoreline ecosystem is important, the new data on limnology of the splash zone might provide convincing evidence of anthropogenic impacts on Baikal ecosystem. The scheme for environmental monitoring of the splash zone suggested is preliminary and may be partially modified as a result of extreme situations, weather conditions, and other factors.

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Биология прибрежной зоны озера Байкал
Сообщение 1. Заплесковая зона: первые результаты междисциплинарных исследований, важность для мониторинга экосистемы

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Аннотация. Заплесковая зона (как надводная часть зоны прибрежной) большинства озёр Евразии практически не исследована. Как показывает мировой опыт, именно она является наиболее индикаторной, «быстро и чутко» реагирующей на антропогенные изменения экосистем. Термин «заплесковая зона» широко используется в литературе по морскому зонированию побережья и обозначает часть литорали, подверженной влиянию брызг. Аналогичная зона с наиболее контрастными градиентами абиотических факторов постоянно существует и в Байкале, распространяясь от уреза воды до подножия склона. Её длина составляет 1800–2000 км, а нижняя граница заплесковой зоны, вследствие поднятия уровня перемещается вверх, к береговому склону, в пределах 10 и более метров. Исследование заплесковой зоны – совершенно новая область лимнологии Байкала. Поэтому изучение этой части экосистемы как важной составляющей прибрежной зоны озера весьма перспективно с научной и практической точек зрения. Выяснено, что заплесковая зона весьма богата пищевыми ресурсами: здесь происходит концентрация скоплений детрита и бытовых отходов, которые являются благодатным биотопом для развития особых сообществ и оказывают существенное влияние на гидрохимический и микробиологический режимы интерстициальных и прибрежных вод. В этой зоне обнаружены представители как минимум четырёх разнородных по происхождению фаунистических комплексов беспозвоночных: палеарктические, космополитные и др. виды (вселенцы из евразиатских или сибирских водоёмов), широко распространенные или эндемичные байкальские гидробионты, инфауна почв и представители наземных биоценозов. Выявлено, что именно заплесковая зона подвержена наиболее активному влиянию антропогенной деятельности: грунты прибрежной и заплесковой зоны являются своеобразным буфером, фильтром, защищающим чистоту озера от сточных вод прибрежных посёлков; именно в заплесковой зоне наблюдается максимальные скопления бытового мусора. Следовательно, антропогенное воздействие на озеро наиболее легко диагностировать в заплесковой зоне; это – своеобразный «градусник» экосистемы Байкала. Настоящая серия статей посвящена первым результатам междисциплинарных исследований заплесковой зоны Байкала. В первом сообщении приведено определение заплесковой зоны Байкала, её краткая характеристика, перечень основных факторов, влияющих на продуктивность сообществ заплесковой зоны, а также – конкретные предложения по организации системы слежения за состоянием этой зоны.

Ключевые слова: заплесковая зона, методы исследования, сообщества, макрофиты, беспозвоночные, мониторинг, прибрежная зона, колебания уровня, Байкал.

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