O.A. TIMOSHKIN, V.V. MALNIK, M.V. SAKIRKO, C. BOEDEKER

ECOLOGICAL CRISIS ON LAKE BAIKAL: Diagnosed by Scientists

In some areas of North Baikal, a crust of rotten *Spirogyra* up to 10 m wide covers the once cozy beaches. *October 2013. Photo by V. Korotkoruchko*

Huge stinking piles of rotting algae that stretch for hundreds of meters on the beaches; the shoreline studded with thousands of shells of dead snails; the bottom under a dense coat of green algal wisps; sponge bodies, ulcerated and covered with red spots; and finally, water that one cannot drink and where one cannot swim... A few years ago, it was impossible to even imagine that these lines would ever be written about Lake Baikal, the deepest and cleanest freshwater lake in the world and a home for rare animals and plants that are found nowhere else on our planet. According to limnology scientists, the cause of this ecological disaster is not global warming or other planetary-scale phenomena, but pollution with wastewater that contains excess nutrients. So far these effects have been confined to the lake's coastal zone and have not affected its deep part and, thus, the hydrochemical indicators of the Baikal water. However, the process does not stop, and untreated and poorly treated wastewater and fecal sewage continue to flow, slowly but surely, into the sacred Baikal...

Will Baikal repeat the tragic fate of another marvel of nature—the Great Barrier Reef, whose coral cover has decreased over the last century by more than two-thirds due to long-term latent contamination? Are these negative environmental phenomena reversible? What must we do to let the future generations as well as us know the taste of pure Baikal water?

Key words: Baikal, eutrophication, Spirogyra, algae, algal bloom, coastal zone, gastropods, sponges, sponge disease, ecological crisis, wastewater, wastewater treatment facilities

Oleg A. TIMOSHKIN, Doctor of Biology; Head of the Laboratory for the Biology of Aquatic Invertebrates, Limnological Institute SB RAS (Irkutsk). Author and coauthor of more than 250 scientific publications, including 5 collective monographs. Scientific director of the 2013—2014 expeditions to the coastal zone of Lake Baikal

Valery V. MALNIK, Candidate of Biology; Senior Researcher at the Laboratory of Biogeochemistry, Limnological Institute SB RAS (Irkutsk). Author and coauthor of 9 scientific publications

Maria V. SAKIRKO, Candidate of Geography; Researcher at the Laboratory of Hydrochemistry and Atmospheric Chemistry, Limnological Institute SB RAS (Irkutsk). Author and coauthor of 23 scientific publications

Christian BOEDEKER, PhD (Biology), Victoria University of Wellington (New Zealand). Author and coauthor of 25 scientific publications. Professional diver

The events of recent decades show that unfortunately, people are not prudent hosts on this planet: anthropogenic pollution increases and environmental disasters are no longer a rarity. All this fully applies to lakes. During the last century, many of the world's great lakes were severely polluted, including with heavy metals or nutrients, which cause the infamous "bloom" of water (rapid development of algae and cyanobacteria).

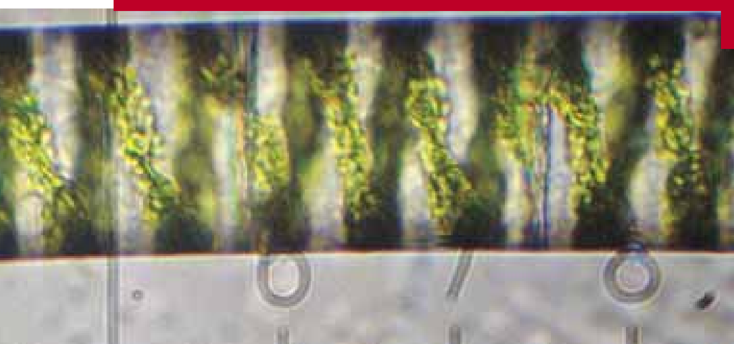
The "textbook" cases include such lakes as Geneva, Ladoga, Biwa, the Great Lakes of America, etc. Not long ago, there was an environmental disaster at Lake Kotokel in Buryatia, where fatal cases of Haff disease were reported (Ozero Kotokel'skoe..., 2013). This hazardous trend is observed worldwide: people continue to pollute lakes until it becomes dangerous the use of the water or fish from the lakes.

Until recently, Baikal was believed to be one of the cleanest lakes in the world and was recognized as a UNESCO World Heritage Site. There was a good reason to think that: the Russian government spends several billions of rubles every year on the protection of Lake Baikal. However, the question remains—is the state monitoring of Baikal ecosystem effective in diagnosing the "diseases" of this unique body of water?

According to the recent data obtained by the Limnological Institute (LIN) SB RAS (Irkutsk), the answer

The *Spirogyra* expeditions traveled by ships of the Limnological Institute SB RAS, *e.g.*, *G. Titov (above)*. The expedition participants collected hundreds of microbiological and hydrobiological samples as well as lake and river water samples and algae specimens.
Bottom left: E.P. Chebykin, Cand. Sci. (Chem.) is taking samples of coastal water for elemental analysis; right: Valery Malnik, Cand. Sci. (Bio.) is plating microbiological samples onboard the ship.
October 2013.
Photo V. Korotkoruchko

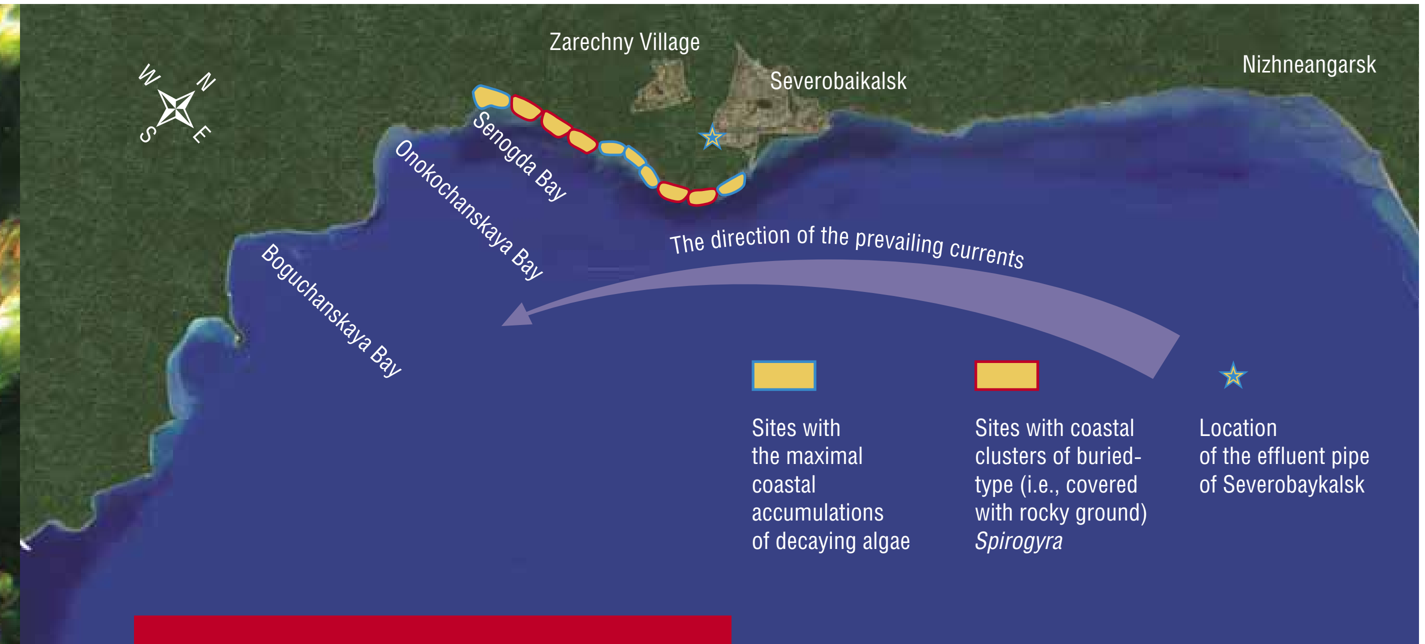
Oleg Timoshkin is examining *Spirogyra* samples on board the research ship *G. Titov*. *Photo by V. Korotkoruchko*



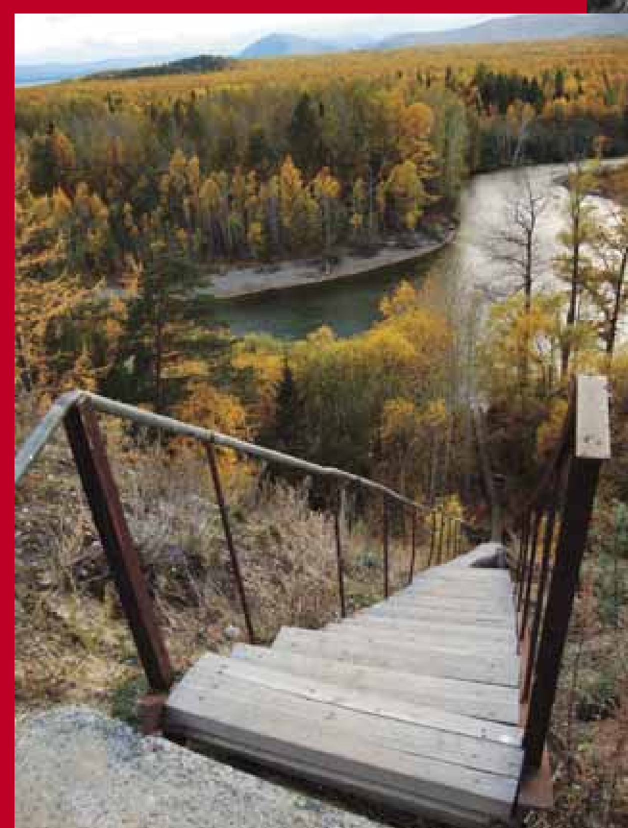
An important classification criterion for determining *Spirogyra* species are features of the formation of conjugation bridges in the sexual reproduction of the algae, whereby there is association of cells of two (more seldom, three) algal filaments *(left)*. At the same time, conjugation is a rare phenomenon for many of the *Spirogyra* species. *Photo by O. Timoshkin*

Rotting mass of *Spirogyra* thrown on the shore of Lake Baikal near the Zarechny village. *October 2013. Photo by V. Korotkoruchko*

Spirogyra **is a genus of green filamentous algae, which is common in fresh stagnant and slow flowing waters (not to be confused with blue-green algae, which belong to prokaryotic organisms, more accurately called cyanobacteria). The** ***Spirogyra*** **genus includes 275—400 species. The mass development of these algae is often observed in waters prone to eutrophication, i.e., oversaturation with nutrients. Previously, these algae were only very rarely reported in some Baikal bays and gulfs.** ***Spirogyra*** **spends most of its life in a vegetative state, in the form of simple strands with spiral chloroplasts. Conjugation (sexual reproduction) leads to zygospores, which are round or oval bodies covered with a protective sheath. The key to identifying the algal species is the microstructure of the sheath layers and the shape and size of the zygospores, and only then—the size and number of the chloroplasts and the structure of the connective portions of vegetative cells. An exact identification of the** ***Spirogyra*** **species, which have proved to be capable of rapid reproduction in the cold waters of Lake Baikal, and its ecological preferences will allow a deeper understanding of the causes of this phenomenon**



Visual inspection of the coast of the lake's northern basin in September and October 2013 showed that the giant clusters of dying algae are confined to the estuary of the Tyya River and to a 10-km coastal zone stretching to the west of the estuary. The portions of the coast from the city of Nizhneangarsk to Severobaykalsk was found to be free of any accumulations of coastal Spirogyra *algae.*
Chart by O. Timoshkin and E. Zaitseva



This famous ladder with many steps leads straight to a sewer pipe of a treatment facility in Severobaikalsk; the pipe is located near the confluence of the channels of the mountain river Tyya, which flows into Lake Baikal. The right, clear channel is very different from the left one, into which the wastewater goes. In the shallow area of Lake Baikal, where the Tyya River flows into the lake, the bottom is almost completely covered with a bright green *Spirogyra* thicket *(above). September 2014.*
Photo by O. Timoshkin

to these questions is likely to be negative. The current federal monitoring system for Lake Baikal is able to track only a limited range of hydrophysical, hydrochemical, and hydrobiological parameters of lake water; i.e., the system is focused almost exclusively on the lake's water body and cannot ensure rapid diagnostics of environmental emergencies at the bottom of Lake Baikal, especially in its coastal zone. However, the latter concentrates a half of the biodiversity of unique animals and plants that live nowhere else in the world (Annotirovannyi spisok..., 2011).

Indeed, to observe at least a slight change in the hydrochemical indices of water in and around the giant water body of Lake Baikal, it is necessary to discharge in it a huge amount of pollutants at once, which is a purely hypothetical situation (Grachev, 2012). However, what will happen if pollutants come gradually and slowly and primarily affect the coastal zone, which is most populated and sensitive to contamination?

Spirogyra expeditions

Since 2007, researchers of the Laboratory for the Biology of Aquatic Invertebrates, LIN SB RAS have been carrying out a comprehensive interdisciplinary study of the coastal zone of Lake Baikal with an emphasis on the splash zone (surprisingly, this project had been the first study of this zone of Lake Baikal and other lakes in Asia). The researchers showed that these zones are the fastest to respond to anthropogenic pollution (Timoshkin *et al.*, 2012).

Thus, already in 2010, the limnologists discovered the mass bloom of the filamentous macroalgae *Spirogyra* (which is unusual for Baikal) in the Bolshie Koty Bay, South Baikal (Timoshkin *et al.*, 2014). A year later, they found nutrient contamination and excessive development of algae that are alien to the open Baikal (including *Spirogyra*) in the Listvennichny Gulf (Kravtsova *et al.*, 2012). There were several reports on the unusual mass development of algae in different parts of the lake both in print periodicals and electronic media.

In September 2013, the Director's office of the LIN SB RAS received an official letter from Russia's Federal Supervisory Natural Resources Management Service (Rosprirodnadzor), which informed them about "... the detection of extensive pollution of Lake Baikal's coasts and coastal waters in the area of the Severobaikalsk city." Immediately, in September and October of the same year, the institute organized three expeditions to North Baikal using the institute's research ships.

What researchers saw after the disembarkation on the shores of Baikal surpassed their worst expectations.

The rolling waves were bringing viscous black-green organic matter, which formed foul-smelling swells stretching hundreds of meters on the lake's shore. A microscopic analysis of these clusters showed that they consisted mainly of strands of that very *Spirogyra* that was found previously in South Baikal.

According to local residents, the process began roughly in 2010. Naturally, it had an adverse effect on the attractiveness of the local tourist centers, children's camps, and hotels—who would want to swim in water that looks like a dark seaweed "soup"? Moreover, even cows and horses refused to drink this water. The population had to use water from the surrounding coastal lakes or drill wells to obtain artesian water. All this happened on the shores of the world's largest freshwater reservoir...

A visual inspection of the coast of the lake's northern basin showed that the giant clusters of dying algae were confined to the estuary of the Tyya River and to a 10-km coastal zone stretching to the west of the estuary. The total mass of the rotting seaweed thrown out on the shore was no less than 1,400 tons. The location of the clusters was well consistent with the direction of the currents prevailing in this part of the lake.

Wastewater is to blame

All the evidence showed that the excessive growth of algae on the northern side of the lake and in the river estuary was in some way connected with the functioning of wastewater treatment plants in Severobaikalsk. In October 2013, a group of LIN SB RAS scientists together with the representatives of Rosprirodnadzor and the Baikal Transport Prosecution Office conducted an official audit of the municipal wastewater treatment plants: they took samples of treated and untreated wastewater coming from the city and those from the train depot. (Importantly, the audit revealed that the domestic and industrial wastewater got to one and the same treatment facility.) To understand the problem, the commission also took samples of artesian water from the wells that supply the city and those of the detergents used for cleaning railway cars.

The documents obtained by the transport prosecution office and surveys of the treatment plants' staff showed that since about 2009, the train depot had been using, instead of the usual detergents, new synthetic substances containing strong antibacterial agents.

Over the next three months, LIN SB RAS scientists were working very hard. The work involved several dozens of researchers from the laboratories for the biology of aquatic invertebrates, biogeochemistry, and hydrochemistry and the group for the chemistry of siliceous nanostructures as well as the entire range of the institute's analytical instruments.

The analysis of samples that was carried out under the direction of V. I. Smirnov, Cand.Sci.(Chem.) (Favorsky Institute of Chemistry SB RAS, Irkutsk) showed an increased phosphorus content of the *Spirogyra* samples from the wastewater discharge area of the Tyya River in comparison with those taken in a relatively clean area of Lake Baikal. Algae are known to accumulate inorganic phosphorus in a medium enriched with this element. Indeed, the hydrochemical analysis revealed almost equally high contents of nutrients (primarily, mineral phosphorus, 5–7 mg/l, and nitrate nitrogen, 33–39 mg/l) in untreated wastewater and the water coming from the treatment plants. It turned out that these substances, which cause a rapid growth of algae, were "transiting" through the treatment facilities, and a part of them got into Lake Baikal via the river. Moreover, the analysis revealed a multifold excess of the federal norms for other wastewater quality indicators.

Next to the operating wastewater treatment facilities of Severobaikalsk, there are ruins of the old ones—dilapidated, with holes filled with a foul-smelling liquid. According to local residents, for many years sewage trucks drove up here almost every day and poured the city's wastewater into these holes; free of charge, of course. This discovery was the key to understanding the "strange" phenomenon—the abundant bloom of filamentous algae, including *Spirogyra*, in the left sleeve of the Tyya River about 700 m upstream from the location of the currently working sewer. *May 2014*. *Photo by O. Timoshkin*

The hydrochemical analysis conducted by Maria Sakirko, Cand.Sci.(Geogr.) showed almost no difference between the treated and untreated wastewater from Severobaikalsk in terms of nutrients and some other pollutants. *Photo by V. Korotkoruchko*

These colonies of thermotolerant coliform bacteria in a Petri dish are the result of a microbiological analysis of a pore water sample taken from a hole on the lake shore near rotting algae to the opposite of the Zarechny village (near Severobaikalsk). The number of colonies reached record levels in 1950 colony-forming units per 100 ml, indicating substantial fecal contamination. *September 2013*. *Photo by V. Malnik*

How could this happen? Why did the treatment facilities of Severobaikalsk fail to clean the wastewater? These plants were built in the early 1980s. During the past 25 years, different organizations were in charge of these plants, but over the past few years, until the summer of 2014, they were under the jurisdiction of the Russian Railways. In their days, these treatment facilities were quite effective, but in recent years, the staff repeatedly raised alarms about the sharp deterioration in the quality of wastewater treatment, although these signals remained unanswered. The quality deterioration was caused, they believed, by the frequent emergency discharges of industrial wastewater from the train depot.

The reason is that the depot began to use detergents with a strong antimicrobial agent to clean railway cars. These antiseptics either weakened or almost completely suppressed the activity of the so-called activated sludge, a community of diverse bacteria and protozoa that is a compulsory "live" component of biological treatment facilities (this assumption was later confirmed by experiments conducted by Dr. V. Malnik at the LIN SB RAS). Like any biological system, the activated sludge of treatment facilities needs substantial time to restore its efficiency; the sludge just did not have enough time to recover between the industrial wastewater discharges.

Is there a way out?

In May and June 2014, there was a court trial as a result of which the train depot got a closed water treatment system, which is also used for cleaning railway cars. The treatment facilities of Severobaikalsk have been transferred to the city authorities, but the situation with the hydrochemical indicators of the city's wastewater, including with the high concentrations of nitrogen and phosphorus, has not changed.

The most pressing question for today is what to do next. Of course, it would be best not to wash railway cars at all in the immediate vicinity of the legendary lake; however, the depot was built when people did not even think about such things. In addition, it provides stable jobs for many of the local residents.

This story leads to obvious conclusions: first, industrial water must not be directed to a facility designed for treating domestic sewage, and substances with toxic agents must not be used for cleaning railway cars. As is clear from the hygiene certificates, one had not even tested the toxicity of these detergents with respect to endemic invertebrates and fish as well as activated sludge.

Today we cannot yet assess the environmental impact of the harsh detergents that have already been discharged into the ecosystem of the North Baikal on the life of the unique Baikal animals and plants. One of the most illustrative examples is the disorders in the behavior and reproductive cycle (up to the change of sex!) of fish that are observed in some of the European lakes. Unbelievably, the reason is the synthetic hormones contained... in birth control pills (!), which get in small concentrations into the water bodies with domestic wastewater.

Second, the cause-and-effect relationships in an environmental situation can only be determined by specialists and specialized institutes of the Russian Academy of Sciences. By the way, according to the oral reports of local residents, there was a government commission in Severobaikalsk in 2012, which classified the observed abnormal growth of algae as a "natural phenomenon." Finally, any new chemicals applied on a large scale by companies located in the lake's central ecological zone, as well as any new buildings, must pass a qualified environmental audit.

It may take decades to resolve the most urgent problems of Severobaikalsk. Further stabilization calls for such emergency measures as the termination of the use of synthetic detergents with a toxic effect, reorganization of the city's wastewater treatment system, recovery of the activated sludge, and modernization of the treatment plants.

However, the first step was to prevent the discharge of toxic wastewater into the lake. To this end, it was necessary to immediately stop the dumping of toxic industrial wastewater into the municipal sewage system. A solution was found: the industrial wastewater could be moved outside the central ecological zone to settlements such as Ust'-Kut, or even to Irkutsk, where there are special treatment facilities. This is quite feasible: according to the latest official information from the senior staff of the Severobaikalsk train depot, they have already reached an agreement with one of the Irkutsk firms, and the condensate of their industrial wastwater is regularly transported to a station adapted for cleaning this waste.

Does the story repeat itself?

The fifth and final *Spirogyra* expedition was organized by the LIN SB RAS in September 2014 on two research ships. Forty-two people participated in the expedition—professional hydrobiologists, hydrochemists, microbiologists, and scuba divers, including algae experts from New Zealand and the Netherlands. The expedition managed to explore almost the entire perimeter of the Baikal coast. Having made 37 dives, the divers explored many parts of the bottom; the team was able to collect more than a thousand samples of soil, water, and aquatic plants and animals and take dozens of videos and thousands of photos... This huge amount of material has yet to be thoroughly analyzed, but the first conclusions can already be made.

A cemetery of thousands of gastropods in the Senogda Bay in North Baikal.
May 2014
Photo by V. Korotkoruchko

The situation in Severobaikalsk and Tyya's estuary has not improved: huge masses of algae continue to rot in large areas on the northern coast of the lake. Moreover, it is clear that *Spirogyra* continues to occupy the coastal zone of Baikal, and its range is expanding rapidly. Like a dense carpet covering the coastal cliffs and rocks, *Spirogyra* successfully displaces the unique local algal species.

A substantial mass of *Spirogyra* was discovered at Berezovy Cape, a LIN SB RAS environmental test site near the village of Listvyanka, where scientists are carrying out an interdisciplinary study of shallow-zone ecology. There are mass developments

The affected areas on the body of this branching sponge were found to contain cyanobacteria of the *Phormidium* genus, clearly visible under the microscope (*below*), and a huge amount of small nematodes, crustaceans, and *Vorticella* ciliates. *South Baikal, 2014. Underwater photos by S. Ihnken; light microscopy by O. Timoshkin*

The endemic Baikal sponges Lubomirskiidae are unusual multicellular creatures; their green color is due to microalgae living in their cells. The Lubomirskiidae thickets not only make the underwater scenery of Lake Baikal look so unique but also contribute to cleaning the lake water

of these algae along almost the entire eastern coast of the lake and almost half of the western coast. A very similar situation, whereby large amounts of aquatic plants, including *Spirogyra*, are thrown ashore to decay, is observed, albeit on a smaller scale, in several bays of the Barguzin Bay and Maloe More and on the southernmost tip of Lake Baikal (near the village of Kultuk).

Christian Boedeker, an algologist and diver from New Zealand, who came to Baikal for the second time to study Cladophoraceae, a family of green algae with endemic species in Lake Baikal, noted with surprise and sadness that in many places the lake's bottom looked very different compared to 2011. In many cases, he could barely detect the endemic algae, whose tufts he literally had to "dig out" from under the dense *Spirogyra* carpet. As a rule, those were weakened or diseased plants. In some parts of the coast, *Spirogyra* had won complete domination.

However, scientists found even more alarming environmental phenomena—real cemeteries of gastropods that were confined to the areas of mass *Spirogyra* vegetation and those of the Severobaikalsk wastewater discharge and the mass disease and death of endemic Baikal sponges (depending on the dive area, the degree of damage to branching sponges was 30 to 100%).

In all the three basins of the lake, researchers found sponge specimens whose soft parts were half destroyed or covered with black-crimson spots. A microscopic analysis of these spots showed that they were clumps of filamentous organisms belonging to cyanobacteria (blue-green "algae") of the *Phormidium* genus. It is known that *Phormidium* can develop massively on weakened coral specimens and thus affect coral reefs, with many of the benthic species of this genus producing toxins (NOAA Coral Reef Conservation Program). Therefore, these bacteria are unlikely to be the primary cause of the mass death of the sponges. They are more likely to dwell on sponges that are already diseased for the yet unknown reason. The question whether the species of *Phormidium* found in Baikal produce toxins, is to be answered in the near future.

The situation with Baikal reminds of the fate of the Great Barrier Reef, a unique ecosystem, which is also on the list

A huge number tiny invertebrate animals—hydras—are sticking to the surface of these dead brown "branches" of an *L. baikalensis* sponge (*left*). Apparently, the decaying bodies of the sponges attract zooplankton, the main source of food for hydras. The death of the sponges may entail mass death of their symbionts—sideswimmers (*right*). *South Baikal, 2014 Photo by S. Ihnken and O. Timoshkin*

of World Heritage Objects (Australia's World Heritage, 1996). Over the past hundred years, the solid cover of the coral reef has decreased by more than 70% (Bell *et al.*, 2014). The reason was the massive skeletal disease of the corals and the intense reproduction of pests and algae that oppressed the corals' vital functions. These events were due to the chronic latent eutrophication of the ecosystem as a result of wastewater discharge. By analyzing the cases of other coral ecosystems, scientists found out that such a change in ecosystems and development of macroalgae does need thousands of truckloads of pollutants, but a small yet permanent excess over the normal level of nutrient concentration—only 14 micrograms of inorganic nitrogen per one liter of water, which is often below the sensitivity of the measurements (Yamamuro *et al.*, 2003).

For highly productive eutrophic water bodies, where organisms are used to living in the conditions of an excess of organic substances, such a small difference in the nutrient concentrations will not matter. However, for low-productive oligotrophic ecosystems, such as Lake Baikal and the Great Barrier Reef, whose inhabitants had been adapting to nutrient deficiency for thousands of years, such a change can destroy the natural balance of the communities.

In the case of Baikal, as well as the Great Barrier Reef, there are visible changes in the shallow water communities, including massive algal blooms and damage to colonial sessile invertebrates, which are often accompanied by profuse development of cyanobacteria of one and the same genus. All this comes amid the "minor" changes in the hydrochemical characteristics of the water column. Aren't there too many sad analogies for a coincidence?

In the case of the Great Barrier Reef, the "smart" scientists and government officials ignored the warnings of their more cautious colleagues and were late with their diagnosis at least for half a century...

The environmental situation on Lake Baikal, which is due to the excessive reproduction of *Spirogyra* and other processes, is rightly recognized by the LIN SB RAS experts as an emergency. It is obvious that the currently observed adverse processes affect the coastal zone ecosystems across the entire lake.

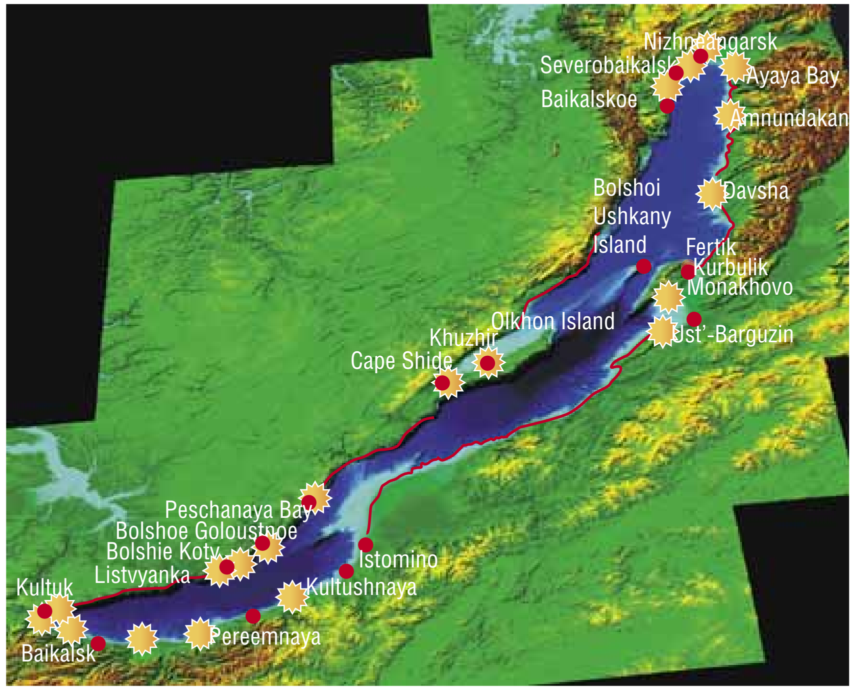
The mass bloom of *Spirogyra*, as well as the hydrochemical analysis of the wastewater entering the tributaries of Lake Baikal from the treatment plants located in the lake's central ecological zone, is evidence of the large-scale long-term latent eutrophication of the lake's shallow areas, which is attributed not to natural causes such as aging of the reservoir, but to the excessive intake of nutrients.

The most likely reason for this phenomenon is the long-term discharge of insufficiently treated or untreated wastewater, including sewage, into the lake. According to the expedition's report, the old treatment facilities in Severobaikalsk, Baikalsk, and Kichera, which were built during the Soviet period, are far past their prime, and those in Ust'-Barguzin are completely ruined. Even the new wastewater treatment facilities in the towns of Babushkin and Slyudyanka virtually do not clean the wastewater that they discharge.

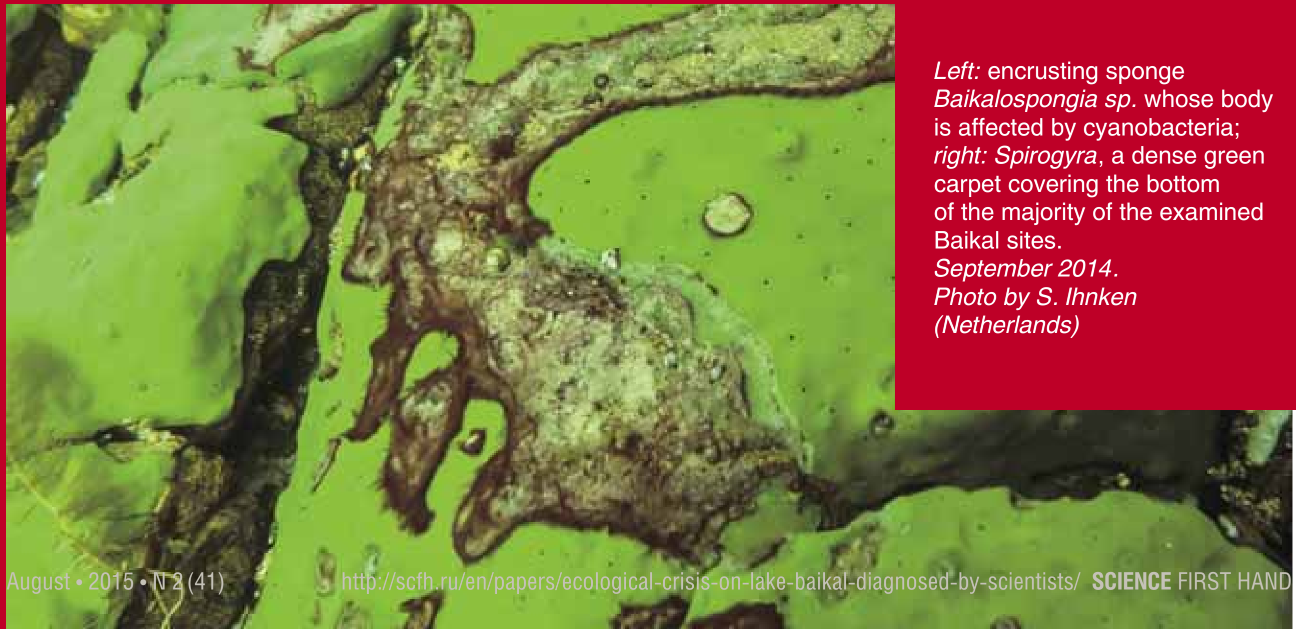
Furthermore, there is mass discharge of untreated sewage and bilge water, which contains petroleum products, from the numerous vessels. In addition, the majority of coastal settlements with mass construction of tourism infrastructure have no wastewater treatment facilities at all.

All these adverse phenomena, which have been observed in the lake for the past four years, were not documented and not reflected in the government reports on the state of Lake Baikal's ecosystem in 2011 and 2012. This situation clearly shows the inefficiency of the government monitoring system for Lake Baikal because it is fundamentally incapable of diagnosing the possible damage to the lake bottom ecosystem due to the hidden eutrophication. Figuratively speaking, it can only "diagnose cancer in the terminal stage."

How reversible are all these phenomena? It is still difficult to give a definite answer about *Spirogyra*. The reason is that, firstly, it is impossible to stop the discharge of wastewater into the lake from all the existing ships and settlements, build new treatment facilities and fix the old



The LIN SB RAS expedition of September 2014 showed that *Spirogyra* had spread in the coastal zone almost across the entire lake (*asterisks indicate the locations of mass development of Spirogyra*). It is easier to name the areas where this algae has not yet been detected: the Ushkany Islands, the best part of the Olkhon Island (except the Khuzhir village and the Perevoznaya bay), and a part of the west coast of the Cape Elokhin up to the Maloe More (*the red line indictaes the yet unexplored parts of the coast*)



Left: encrusting sponge *Baikalospongia sp.* whose body is affected by cyanobacteria; *right: Spirogyra*, a dense green carpet covering the bottom of the majority of the examined Baikal sites. *September 2014. Photo by S. Ihnken (Netherlands)*

According to the population of the Maksimikha village (one of the places where large masses of the algae are thrown ashore), the local wastewater is delivered by sewage trucks to this "treatment facility" in the Ust'-Barguzin village, which is actually in ruins (*above*). The service is, of course, not free of charge. The question where the wastewater actually goes remains open.
Photo by V. Malnik

ones, and, finally, change the environmental thinking of the population in the Baikal region and the tourists. All this will take years, if not decades. As for the sponges, the average growth rate of these amazing creatures is only about 1 cm per year (Gombrayh, 1987, 1988; Semiturkina *et al.*, 2009). Therefore, the age of individual 100-cm sponges, which are quite normal for Baikal, can be as old as one hundred years. Therefore, in the case of mass illness and death of the sponges, their population can only restore when decades have passed after the disappearance of the causes of the disease.

Today, researchers' task is to understand, as quickly as possible, all the cause-and-effect relationships underlying the adverse environmental events observed in Lake Baikal. One can only hope that professional scientists will be given an opportunity to really understand this situation, and their advice on adjusting the existing monitoring system will be respectfully heard and followed.

It is imperative to adopt in the near future a single valid and objective position on this issue as the future of Lake Baikal hinges on it. International experience shows that positive changes in the rehabilitation of ecosystems begin with a clear ecological diagnosis of environmental events and elaboration of a consensus among scientists, community, and government officials responsible for monitoring the lakes... The irony of fate—after returning from the last expedition to Lake Baikal, we happened to read the recently published volume of the government report "On the State of Lake Baikal and Measures for Its Protection" (Moscow, 2014), which clearly states in the Conclusions section: "The state of Lake Baikal in 2013 did not undergo any significant changes ..." (p. 362).

This work was supported in part by the SB RAS, project VI.51.1.10 "The current state of biodiversity and ecology of the coastal zone of Lake Baikal" (No. 01201353447), RFBR project No. 13-04-01270, and Marsden FastStart grant (No. E2516-3416) of the Royal Society of New Zealand

WHAT IS TO BE DONE?

The following action must be taken as quickly as possible:

• Make a science based assessment of the environmental situation at Lake Baikal at the level of federal agencies. Find a common language between all the stakeholders—scientists, state agencies, and population.

• Reduce the biogenic (mineral nitrogen and phosphorus) load on the lake's coastal zone. Introduce strict control over the functioning of treatment facilities and the discharge of bilge water from ships and begin the construction of new treatment facilities. Launch a propaganda campaign against the use of phosphate-containing detergents among the population of the lake's central ecological zone. The best option is to follow the suggestion of Academician M. A. Grachev, *i. e.*, ban the production of these synthetic detergents across Russia, as is done in other countries.

• Assess the impact of the mass development of *Spirogyra* on the coastal communities. Resume the studies of the food spectra of Baikal omul and examine the populations of demersal-pelagic species of endemic sculpins, which are an important food source for omuls.

• Upgrade the existing state monitoring system and "allowable discharge standards" in Lake Baikal. To introduce monitoring in the coastal zone, including in the splash zone, near-bottom waters, and bottom biocenoses. A detailed scheme of the works, approved by the World Limnological Congress (Lahti, 2004), is already available (Timoshkin *et al.*, 2011; Timoshkin *et al.*, 2005).

• Establish a nondepartmental Federal Institute for Monitoring of Lake Baikal with a single-site storage of environmental information collected according to the upgarded scheme; eradicate the departmental monopolies on information storage and all restrictions on the use and analysis of the original information on the state of the lake's ecosystem

Selected References

Annotirovannyi spisok fauny ozera Baikal i ego vodosbornogo basseina (An Annotated List of the Fauna of Lake Baikal and Its Catchment Basin) / Ed. by O. A. Timoshkin. Novosibirsk: Nauka, 2011. Vol. 2, Book 2. 1668 pp. [in Russian].

Grachev M. A. O sovremennom sostoyanii ekologicheskoy sistemy ozera Baikal (On the Current State of the Ecological System of Lake Baikal). Novosibirsk: Sib. Otd. Ross. Akad. Nauk, 2002. 156 pp. [in Russian]

Kravtsova L. S. et al. Disturbances of the vertical zoning of green algae in the coastal part of the Listvennichnyi gulf of Lake Baikal // Doklady Biological Sciences. 2012. Vol. 447 (1), pp. 350–352.

Timoshkin O. A. et al. Massive development of green filamentous algae of the genera Spirogyra Link and Stigeoclonium Ktz / (Chlorophyta) in the coastal area of South Baikal // Gidrobiol. Zhurn. 2014. Vol. 10 (5), pp. 15–26 [in Russian].

Bell P. R. F., Elmetri I., and Lapointe B. E. Evidence of large-scale chronic eutrophication in the Great Barrier Reef: quantification of chlorophyll "a" thresholds for sustaining coral reef communities // AMBIO. 2014. Vol. 43, pp. 361–376.

NOAA Coral Reef Conservation Program National Oceanic and Atmospheric Administration, U. S. Department of Commerce // http://coris.noaa.gov/about/diseases/welcome.html

Timoshkin O. A. et al. Is the concept of a universal monitoring system realistic? Landscape-ecological investigations on Lake Baikal (East Siberia) as a possible model // Verh. Internat. Verein. Limnol. 2005. Vol. 29, N 1, pp. 315–320.

Timoshkin O. A. et al. 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 // Izv. Irkutsk. Gos. Univ. Ser. Biol. Ekol., 2012. Vol. 5, N 3, pp. 33–46.

Yamamuro M., Kayanne H., and Yamano H. $\delta^{15}N$ of seagrass leaves for monitoring anthropogenic nutrient increases in coral reef ecosystems. //Marine Pollution Bulletin, 2003. V. 46, pp. 452–458.

The authors thank the LIN SB RAS Director Academician M. A. Grachev for his encouragement and financial support of the expeditions and initiating the interdisciplinary studies; S. Ihnken (Netherlands) for his assistance in underwater research and photo/video materials; Prof. M. Yamamuro (University of Tokyo, Japan) for the fruitful discussions; and the LIN SB RAS staff who directly participated in the expeditions and research