The current problems of Lake Baikal ecosystem conservation

Olga M. Kozhova and Eugene A. Silow
Scientific Research Institute of Biology, State University of Irkutsk, 664003, PO Box 24, Irkutsk, Russia

Abstract
The greatest world reservoir of fresh water, the unique Lake Baikal, is at risk from anthropogenic influence. Three stages of economic activity in the lake region can be distinguished: (i) poor economic uses, (ii) increase of economic uses after the construction of the hydropower station dam on the outflow of the lake, and (iii) intensive increase of economic activity, characterized by the intensive use of mineral fertilizers, transportation, log rafting, growth of population around Baikal, mass development of tourism, the construction of the Baikal–Amur railroad and pulp combines. Chemical and biological pollution of the lake, fishing and hunting, the state of coasts and protected areas are discussed. The regions most affected are listed. The greater long-term influence is an increase in the mineralization of tributary waters due to forest cutting and land cultivation. Though the influence does not cause a decline in water quality, the properties of the Baikalian water in local sites of pollution can significantly differ from their initial state. The quality of water, however, is within the limits of requirements for fresh drinking water.

Key words
biological, chemical pollution, conservation, influence of dam, Lake Baikal, pollution.

INTRODUCTION

Lake Baikal is a unique water-body lying in the middle of Eurasia between 103°47′–109°54′ E longitude and 51°20′–55°52′ N latitude (Fig. 1). Its watershed covers an area of 546 000 km^2. The lake lies in a mountainous region and its water-level is at 455.6 m.a.s.l. The surface of the lake has an area of 31,500 km^2, the maximum length of the lake is 636 km, and its maximum breadth is 79.4 km. Baikal is the deepest lake in the world (maximum depth is 1741 m, average 730 m), and the largest reservoir of fresh water (its volume is 23 600 km^3). The water of Baikal is extremely low in minerals, 96 mg L^{-1}.

Life in the lake occurs even at maximum depths, being favoured specifically by high oxygen content down the whole water column. Photosynthesis takes place in the upper 50-m water layer, the richest in life. Below 250 m depth, the abiotic conditions in the lake are constant at any season; there is no light and temperature is constant, 3.3–3.4°C. The fauna and flora of the lake are marked by pronounced endemism, the number of endemic animal species being 1055 (more than half the total number of species of 1870); the number of endemic plant species amounts to one-third of the total number of plant species (Kozhov 1997).

Two peaks in phytoplankton abundance occur during the year. In spring, a plankton dominated by diatoms develops in abundance under the ice, and at the end of summer a picoplankton of blue–green and green algae develops (Kozhova 1987). Periods of maximum quantities of zooplankton, as well as the maximum development of the bacterial plankton follows phytoplankton peaks. Zooplankton contains many species of Rotifera, *Cyclops kolensis*, pelagic Amphipoda (*Macrohectopus branickii* being relatively abundant), but the main zooplankton species is an endemic species of Copepoda, *Epischura baicalensis*.

The ichthyofauna of the lake is mainly represented by the sculpins and Comephorus family, the endemic species of Baikal. Pelagic sculpins (two species), as well as Comephorus, feed on zooplankton and fish fry, being, in turn, the main food for *Coregonus autumnalis migratorius* (omul, the main fish of commercial importance) and the seal *Phoca sibirica*. In the lake, there are also numerous benthos-feeding fishes: most species of sculpins, and sigs, graylings and sturgeon.

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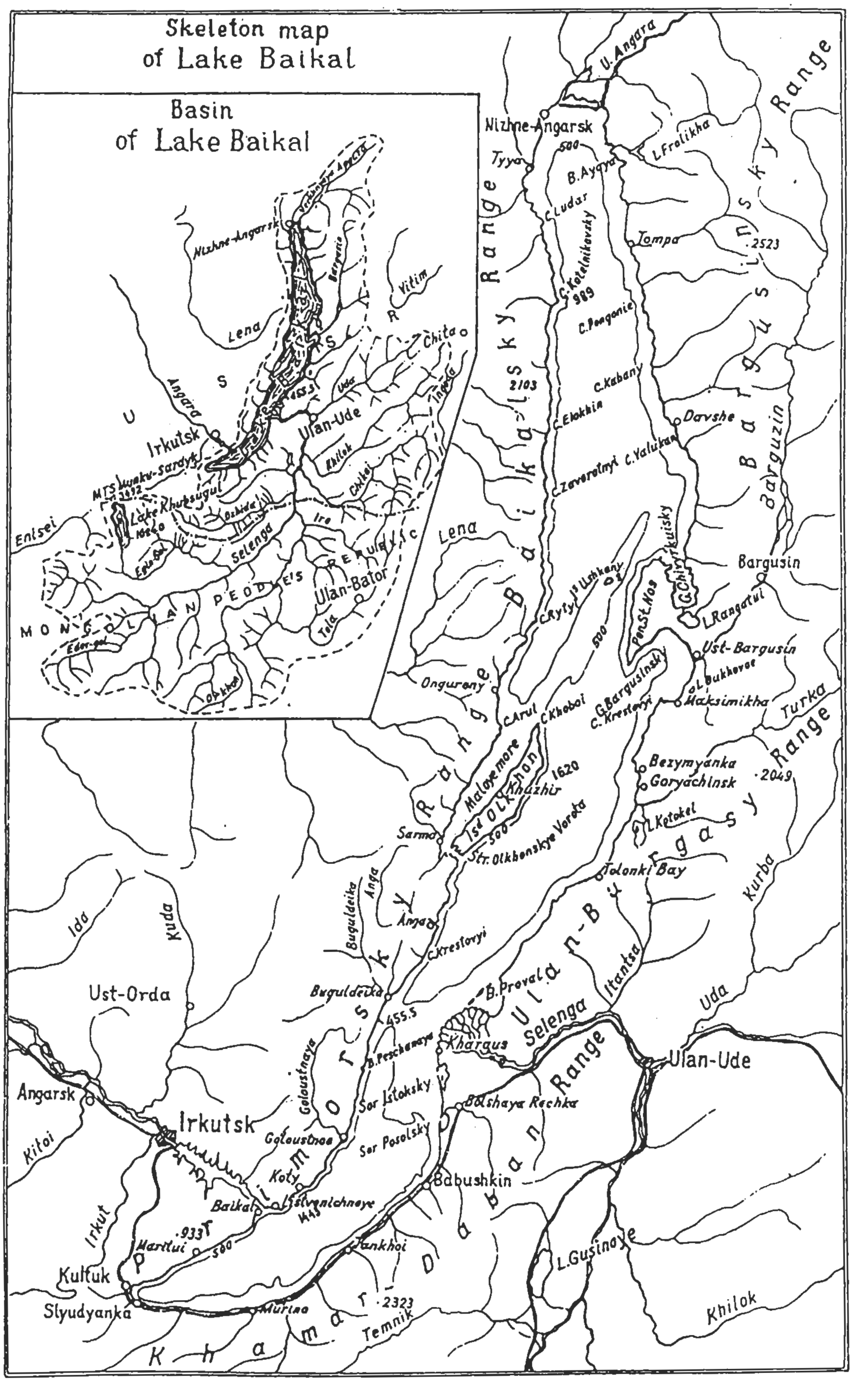

Fig. 1. Map of Lake Baikal and its basin.

The stages of anthropogenic influence on the lake

Anthropogenic influences on Lake Baikal have developed more slowly than elsewhere in Russia.

Several stages in economic activity on and around Baikal can be distinguished:

1. A stage of low economic use (e.g. forest clearing for pastures, occasional forest fire, traditional agriculture, fishery, etc).
2. A stage of gradual increase in economic use after the construction of the Irkutsk Hydropower station and dam on the Angara River in 1956. The rise in water-level played a major negative role resulting in the restructuring of coastlines, particularly in shallow regions of the lake, the reorganization of coastal biocoenoses, and a change in the breeding grounds of *Cottocomephorus grewingki.*
3. A stage in the intensification of regional economic activities. This began with the construction of the Baikalisk Pulp and Paper Combinat (BPPC) in 1966. This stage is characterized by intensive use of mineral fertilizers, the development of transportation, log rafting, mass tourism, growth of population on the coasts of Baikal, increase in coal consumption (the construction of heat and power stations in the Baikal region), and the construction of the Baikal–Amur railroad. The pollution of the largest tributary, the Selenga River, increased due to the impact of wastewater from the Selenginsk Pulp and Cardboard Combinat (SPCC). This combinat is located 60 km from the Selenga mouth, and began operation in 1974, discharging wastewater at a rate of 40 000 m^3 day^{-1}.

Hence, the problem of monitoring, analysis and prognosis for the state of ecosystems in this region has arisen. The Scientific Research Institute of Biology attached to Irkutsk State University, Institutes of the Academy of Sciences and of the State Committee for Hydrometeorology and Environmental Control and other scientific and industrial organizations were engaged to address this problem.

The large area of the lake's watershed in the Buryat Republic, Chita and Irkutsk regions and Mongolia are the major sources of anthropogenic influence. The greatest number of pollutants comes into the lake with the tributaries. During only the last 40 years, capital investment has increased by 22 times, population three times, and the area of arable lands twice in Buryatia (Borzhonov 1985). Forestry (0.4% of the basin per year) and land cultivation led to increased washout of mineral substances from the soil. This is the greatest long-term anthropogenic load on the lake. Votintsev (1978) believes that high water mineralization of the tributaries of the lake has occurred during the past 150–200 years due to deforestation and land cultivation. The input of mineral substances affects the concentration of particular ions in the water. The input of anthropogenic organic matter into the lake is currently approximately 5% of the natural input.

CHEMICAL POLLUTION

The input of toxic substances is the most direct type of anthropogenic influence. Oil products, phenol compounds and metals are the main pollutants by amount and toxicity. Oil products are preserved in the lake for a long time due to its low temperature (Table 1). They are hazardous because they create a film on the surface of the water. The input of oil products in low concentrations results in the development of bacteria. The number of hydrocarbon-oxidizing bacteria in the water can reach 100 cells mL^{-1}. Deepwater natural sources of oil products also exist in the lake (Taliev & Molozhavaya 1986).

Phenolic compounds from industrial and municipal waste water and rain also present a danger for the ecosystem. Water quality control agencies are concerned only with the content of volatile phenolic compounds in water, but soluble diphenols (resorcine, hydroquinone and pyrocatekhine) are more dangerous as toxic agents and a food supply for bacteria. Phenol-oxidizing bacteria widely spread over Baikal is evidence of the presence of phenolic

Table 1. Concentrations of oil products in the water-mass of South Baikal in Spring (mg L^{-1}).

Year	Concentration
1971	0.05 ± 0.02
1972	0.75 ± 0.39
1973	0.20 ± 0.10
1974	0.10 ± 0.10
1975	0.18 ± 0.23
1976	0.21 ± 0.07
1977	0.28 ± 0.02
1978	0.34 ± 0.11
1979	0.14 ± 0.09

After Izrael *et al.* 1985.

Table 2. Share of various pollutants in the total input of oil products and phenols in Baikal.

Source of pollution	Oil products (%)	Phenols (%)
River inflow	92	79
Input from the atmosphere	—	19
Input from the coast	0.2	1
Region of Baikal–Amur Railroad	4.8	—
Water transport	3.0	—

After Dombrovsky *et al.* 1983.

compounds formed during phytoplankton senescence (Goman 1985). The proportion of various sources of oils and phenols is presented in Table 2.

Input of heavy metals is also a danger for the ecosystem due to their conservative nature and bioaccumulation. They are either carried away by the Angara River (0.25% per year) deposited in bottom sediments. They may enter the lake in the dead bodies of aquatic organisms, be converted into organic metal compounds that are more toxic than metal ions, and be released into bottom water layers.

Note that significant amounts of heavy metals come from the air (Table 3). This is because air-borne suspended particles come from outside the boundary of the basin. The input of BPPC from wastewaters (Table 4), is extremely small compared to inputs from tributaries and the air.

Input of biogenic elements is also an important external impact. Most come into waterways from agricultural wastewater (i.e., wash-out from fertilized fields, wastes from livestock breeding farms) and domestic wastes. An average resident of the Baikalian region produces 2.18 g of phosphorus and 10.8 g of nitrogen per day. The other important source of nitrogen is atmospheric precipitation.

Table 3. Input of heavy metals and microelements into Baikal with atmospheric precipitation (kg $km^{-2} yr^{-1}$)

Element	South Baikal	Middle Baikal	North Baikal
Al	16	68	—
Sc	0.09	0.055	0.04
Cr	0.7	1.3	1.0
Mn	2.5	3.7	—
Fe	19.3	35.8	74
Co	0.1	0.02	0.03
Cu	0.45	0.55	—
Zn	2.5	0.6	1.1
Se	0.01	0.0052	—
Br	0.1	0.3	0.15
Rb	0.4	0.08	0.18
Mo	0.04	0.07	—
Sb	0.06	0.016	0.03
Ba	4.8	1.6	2.4
Ce	0.4	0.07	0.18
Hg	0.06	0.06	—
Pb	1.0	1.2	—
U	0.08	0.03	0.24

After Vetrov *et al.* 1983.

Table 4. Input of particular substances (tons yr^{-1}) with wastewater from Baikalsk Pulp and Paper Combinat into Baikal

Mineral compounds	$(49.7 \pm 1.0) \times 10^3$
Organic matter	$(5.6 \pm 0.1) \times 10^3$
Suspended matter	672 ± 32
Volatile phenols	1.6 ± 0.05
Organic sulfur compounds	12.3 ± 0.7

After Anikanova *et al.* 1985.

Characterizing briefly the regions of anthropogenic influences on Lake Baikal, the following conclusions are drawn (Kozhova 1982, 1983; Anikanova *et al.* 1985; Matveev & Anikanova 1985). The main source of pollution is the River Selenga, where increased concentrations of mineral compounds, suspended matter, oil products, phenols and heavy metals have been recorded. There has also been an increase of pollution in the traditionally 'clean' North Baikal, due to the development of industry along the Baikal–Amur Railway (Nizhneangarsk, Severobaikalsk), and the destruction of soil cover there. Another important source of pollution is atmospheric precipitation, so that the lake is subject to the impact of pollutant discharge not only from BPPC, SPPC, Trans-Siberian and Baikal–Amur railways, but also from other industrial plants in eastern Siberia.

BPPC is located on the east coast of the southern part of Baikal in the town of Baikalsk in the Irkutsk region. The Trans-Siberian railroad and Siberian highway run through the town. The population of the town is 16 000. The combinat produces sulfateached cellulose for chemical treatment. Annual production rates are: cord cellulose 80 000 tons yr^{-1}, viscose cellulose 80 000 tons yr^{-1}, packing paper 120 000 tons yr^{-1}, turpentine 120 000 tons yr^{-1}, volume of timber processing 1 380 000 $m^3 yr^{-1}$.

A total area of major and subsidiary facilities of the combinat is 473 000 m^2. It has its own heat and power plant (turbogenerator capacity 105 MW, electric and thermal capacity 990 GCal h^{-1}), and its own station of pure water with drainage volume of 250 000 $m^3 day^{-1}$. The amounts of disposals and residuals of the production are as follows: purified wastewaters 240 000 $m^3 day^{-1}$, sludge-lignin-silt 550 tons day^{-1}, bark 79 100 tons yr^{-1}, and ash 113 000 tons yr^{-1}. Input of substances with wastewaters from BPPC is shown in Table 4.

Table 5. Discharge of pollutants into the atmosphere from industrial plants (10^3 t yr^{-1}). Data from various institutions

	Particulate matter (dust)	Sulfurous gas
BPPC	15–28.4	6.5–7.0
Angarsk	115.1	153.6
Irkutsk	15.5	16.2
Shelekhov	19.9	4.0
Usolye-Sibirskoe	36.3	14.3
Cheremkhovo	13.4	7.3
Sum without BPPC	200	200
Contribution of BPPC (%)	14	3

Table 6. Comparison of amounts of anthropogenic substances (10^3 t yr^{-1}) entering Baikal from various sources. Data from various institutions

Substances	Irkutsk–Angarsk complex	Timber rafting	Selenga River	Other tributaries	Total	BPPC PWW	BPPC AID
Total mineral compounds	30	—	414	55.4	559.4	46	14
Including							
chlorine-ion	—	—	14	5.4	26.7	7.3	—
sodium	25	—	200	50	312	26	11
sulfates							
Total organic compounds	—	5	140	20	172.5	4.5	3
Suspended matter	200	—	1800	160	2175.7	0.7	15

PWW, purified wastewaters; AID, aero-industrial discharges.

Table 7. Balance of total dissolved mineral substances (10^6 tons yr^{-1}). Data from various institutions

Input:	
Contained in tributaries	7–8
Contained in precipitation	0.1
From the BPPC	
Into the atmosphere	0.0005
With industrial purified wastewater	0.05–0.122
Consumed by organisms and buried in bottom sediments	1.9
Carried away by Angara River	6–7
Left in Baikal	1.378
Amount of dissolved mineral substances in Baikal	2162–2360

Baikal is also polluted by the emissions of contaminated substances into the atmosphere. A greater part of the emission occurs from cities located along the Angara valley (Table 5). By far the most important is the impact of the industrial centres of Buryatia on the Selenga River (Table 6). The balance of dissolved inorganic substances in Baikal is shown in Tables 7 and 8 together with the contribution of BPPC. The rates of decomposition of some organic materials and pollutants under conditions near to those in Baikal are shown in Table 9.

Kozhov (1970, 1971) began comprehensive investigations on the bio-communities of the southern part of Baikal in 1961, long before the start of BPPC operation, and could thereby assess the influence of wastewater from BPPC. Ecological evaluation of the limnetic region has shown that water transparency (Fig. 2), temperature and chlorophyll *a* concentration (Fig. 3) were not affected by wastewater.

Eutrophication was not observed. However, changes in the composition of both planktonic and benthic communities were recorded at the point of wastewater discharge. Close to the point of affluent inflow and in zones of its spread, the number of some planktonic species of algae decreased, and mortality of *Epischura baicalensis* and *Macrochectopus branickii* increased. Also, the number of bacteria growing on fish-peptone agar, and cellulose decomposition was much larger than in the lake beyond the inflow. The influence of wastewater on bottom communities (Figs 4, 5) was particularly marked. The bottom area where the composition of zoobenthos has dramatically changed (strongly polluted sediments) is shown in Fig. 6.

The sensitivity of Baikalian aquatic organisms, including the endemics, to wastewater from the BPPC was determined experimentally (Table 10).

Fluctuation in fish and seal populations

The population of omul, the main commercial species of fish, fluctuates dramatically. Instability of omul catches has been recorded since the beginning of commercial fisheries in Baikal. Yearly average catch was about 3500 tons for the period of 1900–68, but ranged from 800 to 1000 tons in 1905–12 and 1965–68, and 9000 tons in 1937–43. In the 19th century, the range of annual catch was also 8000 tons: from 600–1000 tons in 1888–91 to 8700 tons in 1840.

Water volume and water-level regimes of Baikal and its tributaries play a significant role in controlling population numbers of omul (Kozhov 1947). Smirnov (1977) has found a relatively high positive correlation between the size of the Seleginskaya population and the water flux of the Selenga river in the year preceding larval output from spawning grounds ($r = 0.79$), between the generations of the North-baikalian population and the water flux of the Upper Angara in May–August in the year of larval and fry migration into the lake ($r = 0.61$), and between the generations of the Posolskaya population and the level of Baikal water in the year of larval migration ($r = 0.88$).

During productive periods, generations of the abundant population of omul develop. Positive correlation is observed between the water-level of Baikal and omul catches (for the

Table 8. Indices of substance balance in Lake Baikal (10^3 tons yr^{-1}). According to data of the Limnological Institute

Substance	In Baikal	Input from Rivers	Input from Air	Input from BPPC	Outflow through the Angara river	Buried in the sediments
Nitrogen						
Organic	1035	23.8	—	—	9.9	13.9
Mineral	—	12.3	—	—	8.0	4.3
Nitrate	—	22.8	5.5	—	18.3	10.0
Phosphorus						
Organic	552	4.2	—	—	1.2	3.0
Mineral	—	1.3	—	—	1.1	0.2
Phosphate	3.5	0.4	1.6	—	2.4	—
Chloride-ion[a]	13 800	74.4	—	7–8	44.1	30.3
Sulfate-ion[a]	119 600	373–552	—	26–28	255–306	231

[a]Algae consumed (tons yr^{-1}): sulfate 116–140, chloride 56–460 000.

Table 9. Comparison of decomposition rates of some substances *in situ*

Substance	Day	Degree of decay	t, °C	Authors
Labile fractions of organic matter of Peridinea	30	Complete	4.25	Tarasova 1982
Labile fractions of organic matter of Diatomea (*Synedra* sp.)	60	Complete	4.25	Tarasova 1982
Hard-decomposed fraction of organic matter of phytoplankton	360	80%	4.25	Tarasova 1982
Organic sulfides, demethyldesulfide	7	80%	10	Sudakova 1982
	20	90%	6–7	Sudakova 1982
Organic sulfides, methylmercaptan	3	Concentration begins to decrease		Sudakova 1982

Table 10. Vital dilution of industrial purified waste water from the Baikalsk Pulp and Paper Combinat

Species	Dilution	Authors
Aulacoseira baicalensis	by 4–6 times	Votintsev *et al.* 1970
Epischura baicalensis	by 50–100 times	Izrael 1983
Cyclops kolensis	by 1–6 times	Izrael 1983
Chydorus sp.	by 2–10 times	Izrael 1983
Thymallus arcticus baicalensis	by 5 times	Sukhachev 1983

Table 11. The proportion of different races of omul (%) in the Selenga River (data of Siberian Fishing Institute (SFI))

Years	Selenga race	North Baikalian race	Posolsk race	Total 10^6 ind.
1981	90.80	3.10	6.10	2.56
1982	87.20	3.90	8.90	2.90
1983	98.20	0.33	1.65	3.72
1984	97.09	0.74	1.57	3.44
1985	97.59	1.12	1.29	1.80
1986	95.16	0.52	4.32	1.20
1987	84.00	2.38	13.65	0.85

period of 1923–61; $r = 0.72$). The commercial omul catch increases 3–5 years after each maximum of lake water-level (Fig. 7).

The main fishery regions are Maloye More, the Selenga and the Upper Angara shallows, where omul concentrates for feeding (Maloye More) and before spawning (Tables 11, 12).

The size of the commercial omul catch in the fattening stage is considerably affected by peculiarities in the seasonal warming of lake water. The less the pelagic layers warmed in the summer of the previous year, the greater the quantity of omul during the current year migrate into shallower regions for feeding. Inverse relations occur between the average temperature of the water during August–November of the previous year and the average catch of omul in June of the current year (the Maloye More) (Fig. 8). The later the warming of coastal waters starts, the longer the omul stays in shallow regions, and the larger are commercial catches during the summer period in the regions of fattening ($r = 0.76$) (Fig. 9). The relationships observed can be used to improve fishery management (i.e. for prognosis and planning of commercial load both for the entire area of Baikal and in several regions of commercial fishing).

Pollution of spawning grounds by wastewater and log rafting, particularly in the Selenga River, decreases the

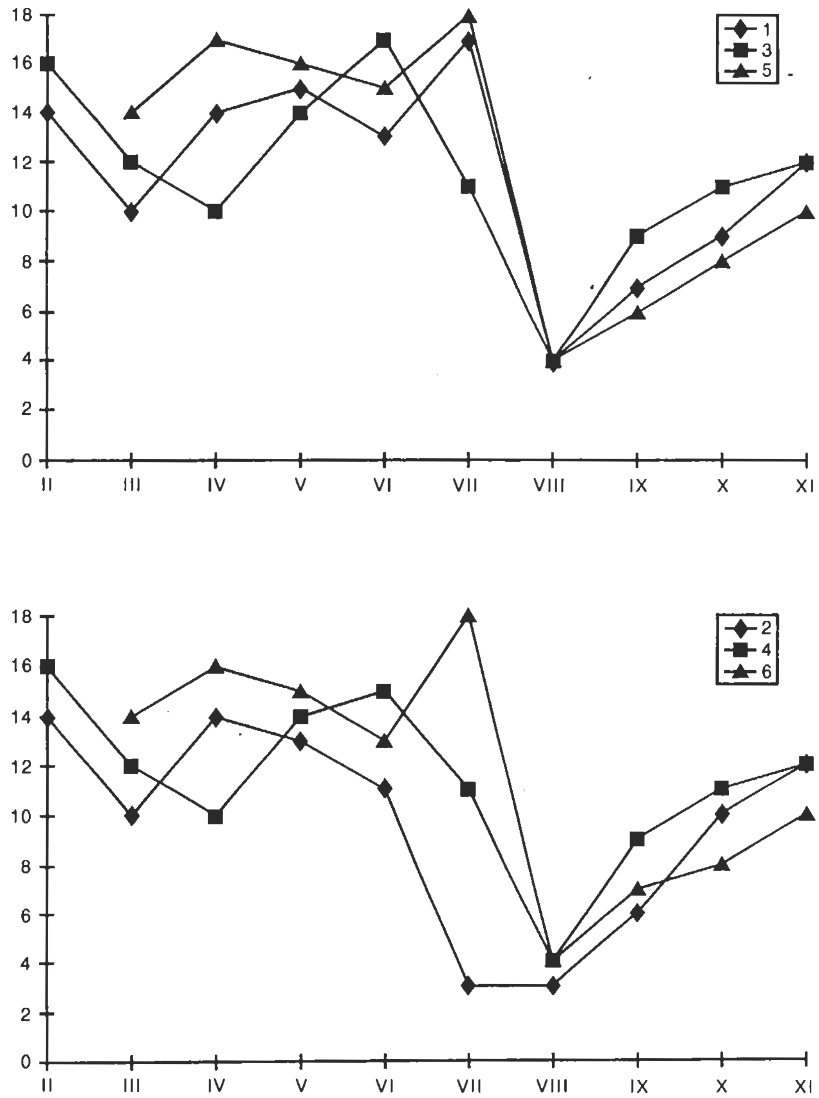

Fig. 2. Seasonal trends of water transparency (m) at Baikalsk. South Baikal. 1, shelf sampling site 5 km to the east from outlet of wastewaters of BPPC (station 1); 2, the same (station 2); 3, shelf sampling site near the outlet of wastewaters of BPPC (station 1); 4, the same (station 2); 5, pelagic sampling site (station 1); 6, the same (station 2).

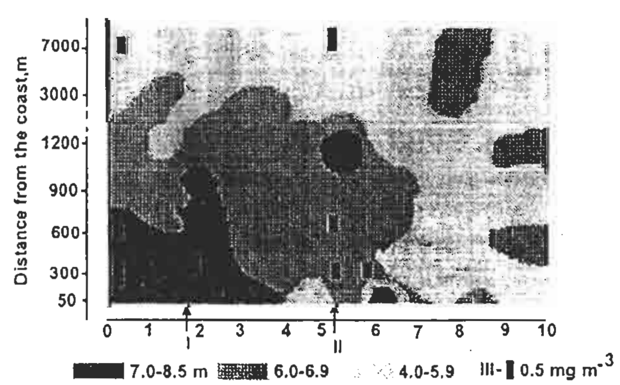

Fig. 3. Water transparency (m, Secchi disk) and chlorophyll *a* concentration (mg m^{-3}) at Baikalsk, South Baikal, 1988. I (as marked on the figure), 2 km from discharge of conditionally pure waters, II, 5 km from discharge of industrial purified wastewater from BPPC, III, chlorophyll *a* concentration.

number of omul. It is believed that intense fishing in the 1940–50s, as well as a decline in the quality of spawning grounds, resulted in the depression of omul numbers. They began slowly to increase after a ban on commercial fishing in 1969, but have still not reached maximum values. This can be partially explained by poaching and sports fishing. In future, sport fishing, provided necessary recomendations are observed, may become the only way of catching omul. Results of autumn–spring investigations of omul spawning grounds in the River Selenga in 1984–85 are shown in Table 13. The number of other species of commercial fish, *Coregonus lavaretus* and *Thymallus arcticus baicalensis*, decreased dramatically due to poaching, especially beginning in the 60s.

Particular scientific attention has attended the high mortality of the seal, *Phoca sibirica*, in 1987. An earlier ban on the shooting of seal led to a concentration of the seal within its habitats. Stress has become a factor regulating numbers; it created favourable conditions for disease and seal

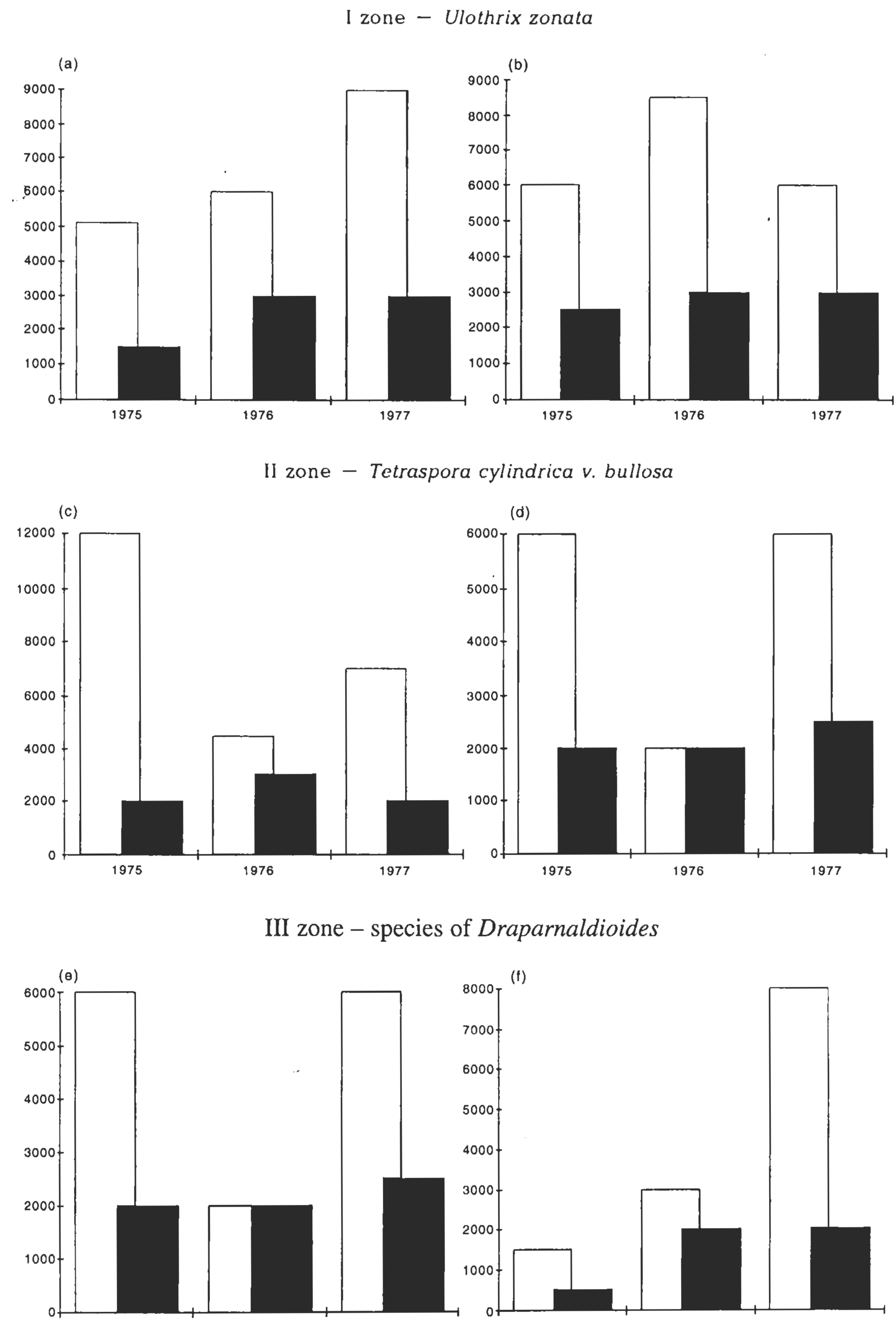

Fig. 4. Number of zoobenthos (ind. m^{-2}) in the region of discharge of wastewaters from the BPPC (Baikalsk; a, c, e) and on the control sections (b, d, f) in various plant zones. □, number of total zoobenthos, ■, number of Chironomidae.

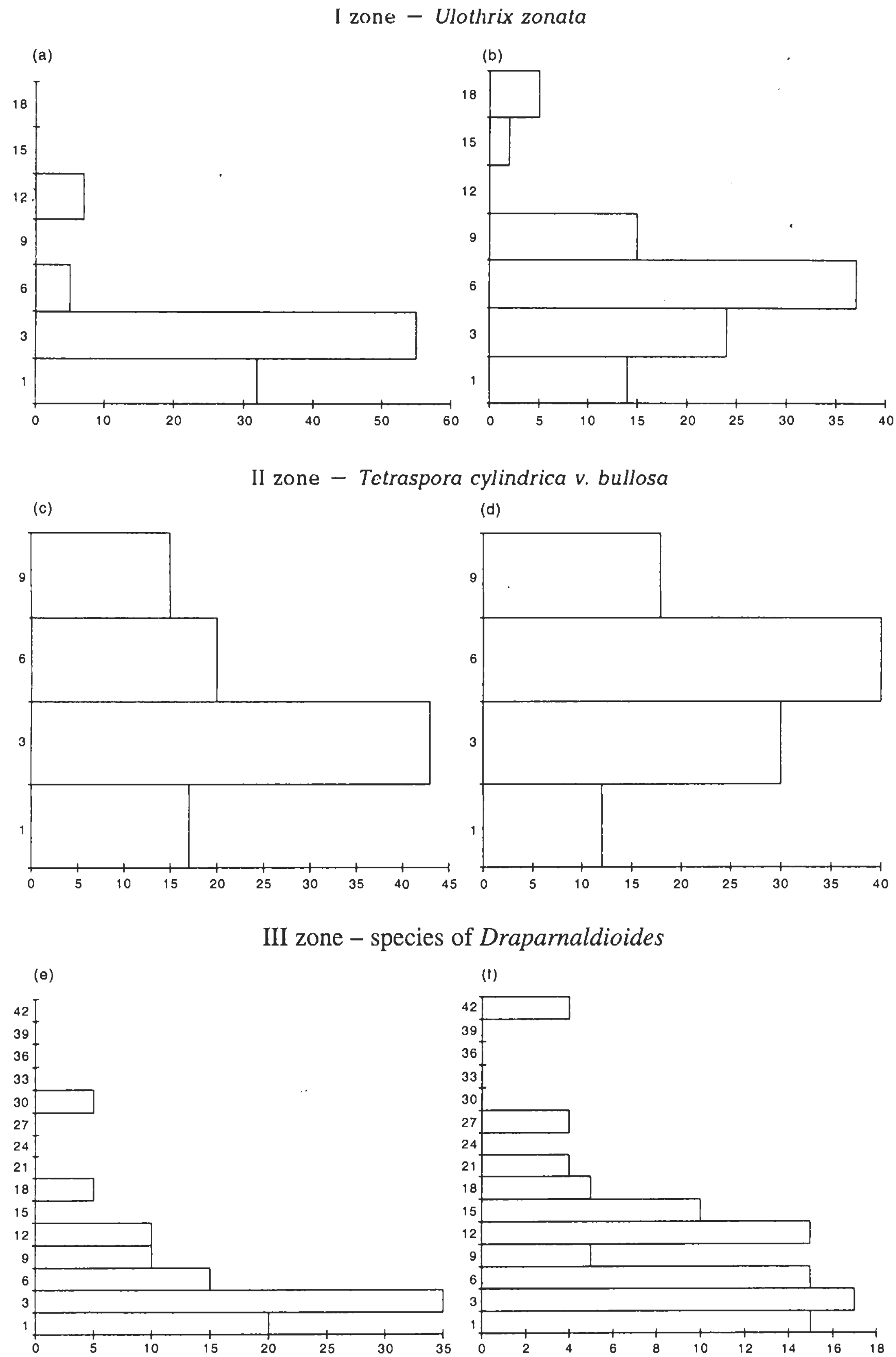

Fig. 5. Occurrence frequency (%) of macrozoobenthos biomass (g m^{-2}) in various plant zones in the area of discharge of industrial purified wastewaters from BPPC (a,c,e) and in the control sections (b,d,f).

Table 12. Average age (years) and number (10^3 ind.) of omul caught in Baikal (according to data of SFI)

Years	Selenga population		North Baikal population		Posolsk population	
	Age	Number	Age	Number	Age	Number
1982	7.83 ± 0.48	390.4	6.43 ± 0.16	3296.0	10.68 ± 0.21	511.0
1983	7.51 ± 0.18	3306.6	5.92 ± 0.15	4121.0	10.69 ± 0.22	2218.0
1984	7.62 ± 0.16	2624.4	6.08 ± 0.16	4793.8	10.70 ± 0.21	200.0
1985	7.45 ± 0.22	3283.6	5.96 ± 0.17	3853.3	10.15 ± 0.20	619.7
1986	7.53 ± 0.16	3986.1	5.79 ± 0.17	4457.4	9.32 ± 0.18	223.3
1987	7.20 ± 0.20	4652.8	5.65 ± 0.19	5893.5	10.24 ± 0.22	151.6

Table 13. Results of autumn–spring investigations of omul spawning grounds in the River Selenga in 1984–85. Data of Regional Fishery Committee (RFC)

	Total eggs m^{-2}		Live eggs m^{-2}		Dead eggs (%)		Survival of live eggs (%)
	Autumn	Spring	Autumn	Spring	Autumn	Spring	
Novoselenginsk	0	0	*	*	*	*	*
Gansurino	0	0	*	*	*	*	*
Omulevka	0	0	*	*	*	*	*
Vakhmistrovo	0	1.7	0	1.7	0	0	—
Ulan-Ude	1.0	—	0	—	100	0	—
Oshurkovo	0.5	—	0	—	100	—	—
Elovka	3.0	4.3	1.5	1.7	50	60	57
Tataurovo	199.0	—	190.0	—	4	—	—
Ilyinka	634.0	566.9	617.5	104.5	3	82	16
Selenginsk PPC	502.0	458.6	496.2	413.1	1	10	82
Kabansk	19.0	—	14.6	—	23	—	—
Fofanovo	—	2.5	—	0.4	—	86	—
Kolesovo	239.0	182.4	213.0	87.6	11	52	37
Mursino	26.0	17.3	17.3	10.2	33	41	39

*Not recorded. Survival of eggs was calculated by B. K. Pavlov from data given in the table.

Table 14. Area and phytomass of *Elodea canadensis* at different sites of Baikal. After Kozhova and Izhboldina, 1993

General area (ha)	Phytomass (tons)			Areas with phytomass density ((m^{-2}); %)			Average phytomass density (g m^{-2})		
	Fresh	Dry	C_{org}	0.1–10	10–100	100–1000	Fresh	Dry	C_{org}
Posolsky Sor									
VI, 1064 1984	166	28	10	35	65	—	15	2	0
IX, 1064 1984	425	68	24	45	43	12	40	7	2
In Olkhonsky Gates and Maloye More straits									
VI, 963 1984	2840	474	172	32	47	15	294	49	18
VIII 1261 1985	3795	634	230	29	56	10	30	50	18
VIII 1189 1986	3344	558	202	30	35	26	281	47	17

mortality. Specialists who studied *Phoca sibirica* disease concluded that morbillivirus infection was also significant. In the opinion of Pastukhov (1993), about 6.5×10^3 seals from a total of 70×10^3 died during the autumn–winter season. It has been established that the baikalian morbillivirus is close to the European one, which causes diseases in northern European seals. Symptoms of the disease are poor mobility (paralysis of the hind flappers) and abundant epiphora.

Variations in the number and intensity of hunting of the Baikalian seal can be characterized as follows. In the second half of the 19th century, the annual harvest was about 2×10^3 individuals. From the beginning of the 20th century, the number of individuals shot increased to a yearly average, 1931–36, of 5680. The maximum harvest reached 6468 individuals per year.

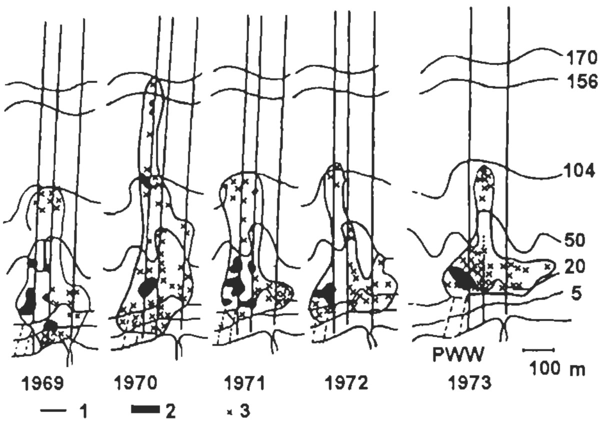

Fig. 6. A schematic diagram of an area of polluted bottom sediments in the area of discharge of industrial purified wastewaters from BPPC. Data of the Scientific Research Institute of Biology. 1, total area of polluted bottom sediments; 2, area covered by suspended anthropogenic substances; 3, sediments with a defined smell.

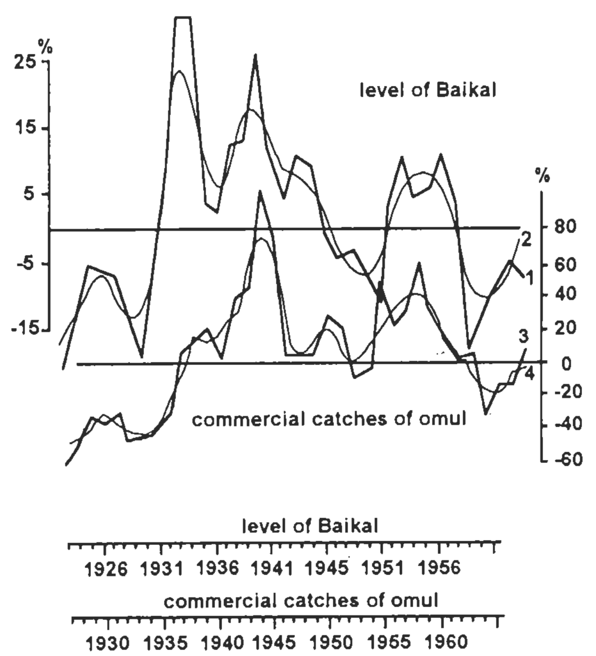

Fig. 7. Long-term variations of level of Baikal and commercial catches of omul (deviations from the average during 1923–62). After Smirnov 1977. 1 and 3, annual values; 2 and 4, averaged from 3 years.

Introduction of exotic flora and fauna ('biological pollution')

'Biological pollution' in the form of introduced species also provides risks for the lake. The main pollutant is *Elodea canadensis* Michx., which invaded the lake in the middle of the 70s (Kozhova & Izhboldina 1993). Its distribution in the lake is shown in Fig. 10, and the role played by it in bottom communities is shown in Table 14.

A key role in the biocoenoses of the River Selenga delta is now filled by *Percottus glehni*. This was first observed at the beginning of the 80s. It spawns in the second half of June. The number of eggs can reach 5350 per nest (Skryabin 1988). This fish served as a significant source of food for predatory waterfowl.

Peled (*Coregonus peled*) was recorded in the Posolsky Sor in 1987 (Tyutrina 1988). A possible source of its appearance is the fish-breeding plant located in the Sor. If there is a successful spread of the peled in the lake, it may become the main competitor to the baikalian omul (*Coregonus autumnalis migratorius*), the major commercial fish in Baikal.

The number of common carp acclimatized earlier in the lake (introduced artificially in 1944 from the Amur River) and other fish inhabiting the coastal zone and sors increased during the 1960s following a rise of water-level, whereas the number of endemic fish decreased (Table 15).

During the past two decades, Pronin (1982) has identified large numbers of parasitic invertebrate species not observed previously. These too may be explained by anthropogenic introduction.

Changes in microbiological indices are convincing evidence of the pollution of the lake by humans. In this context, *Escherichia coli* is found near settlements and along shipping routes.

The state of coasts and protected territories

Economic development of the Baikalian region has proven unfavourable for the state of the Baikal coast.

In 1956, the dam of the Irkutsk hydro-power plant was built at the Angara River, and later, the dams of Bratsk and Ust-Ilimsk plants. These dams have caused oscillations of Baikal level now to depend on the operation of these dams. The elevation of water-level after the creation of the Irkutsk dam caused significant coastal reformation. The input of large

Table 15. Fish introduced into Baikal

Species	Region from which it was brought	Regions of settings (initial years)	Year and place of occurring in Baikal
Parasuilurus asotus	The Amur basin	Ivano-Arakhleyskye lakes, 1938	The 40th
Cyprinus carpio	The Amur basin	Ivano-Arakhleyskye, Eravno-Kharginskye, Gusino-Ubykunskye lakes, 1934–1936	Posolsky Sor, the Proval Bay, Selenga Shallow, the 40th
Coregonus albula	The Urals	Eravno-Kharginskye, Gusino-Ubykunskye lakes, 1954–1963	The Selenga region 1971–1973
Coregonus peled	The Urals	Schuchye lake, 1968–1970	The Selenga region, 1971–1973
Percottus glehni	The Amur basin	Gusinoye lake	The Selenga region 1970
Abramis brama	Ubinskoye Lake	Gusinoye lake, 1954	The Selenga region, 1989–1992

After Kozhov and Misharin 1958; Karasev 1974, 1977.

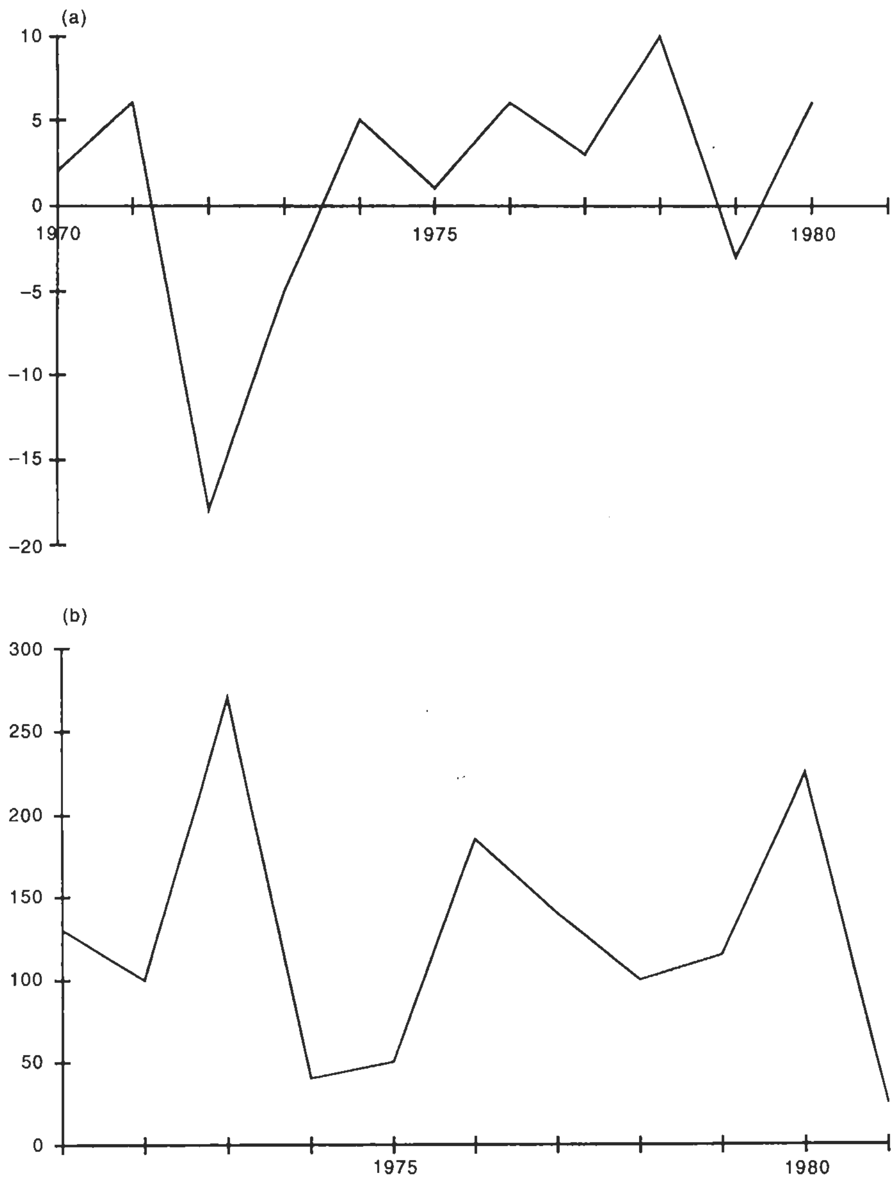

Fig. 8. Interannual variations in the intensity of warming of Baikal surface in August and September and numbers of omul in the Maloye More strait in spring the following year. (a) Temperature of the lake surface according to meteostation data in the Peschanaya Bay in VIII-XI (deviations from the average during 1970–80), (b) omul catch using 300 m of gillnets with mesh size 14–40 mm for one cast. After Smirnov, unpubl. data.

amounts of suspended material resulted from this reformation. For example, in 1984 this input, due to coastal erosion, was 400 000 tons. The changes in coastal structure have impacted on the migration of omul in the River Selenga mouth and on the state of spawning places for *Cottocomephorus grewinki* (the main food source of omul) around the lake.

The highest anthropogenic pressure is observed in the southern part of Baikal, where 60–70% of the population is concentrated. This region is also affected by atmospheric pollutants from the industries of Irkutsk, Angarsk, Usolye-Sibirskoe and Shelekhov, all located in the Angara River valley (Table 16).

The forests of North Baikal (except the region of the Baikal-Amur Railway, about 30 km of the coastline) retain their natural state with their inherent peculiarities of succession. In the middle and southern parts, natural successions are suppressed by anthropogenic pressure.

Among the reasons for deterioration in the state of forests, one of the most important is the impact of atmospheric pollution; this affects 6% of the forested area. The impacts of forest pests affect only 0.12% of the territory. The forests damaged by fires do not exceed 0.3% in area.

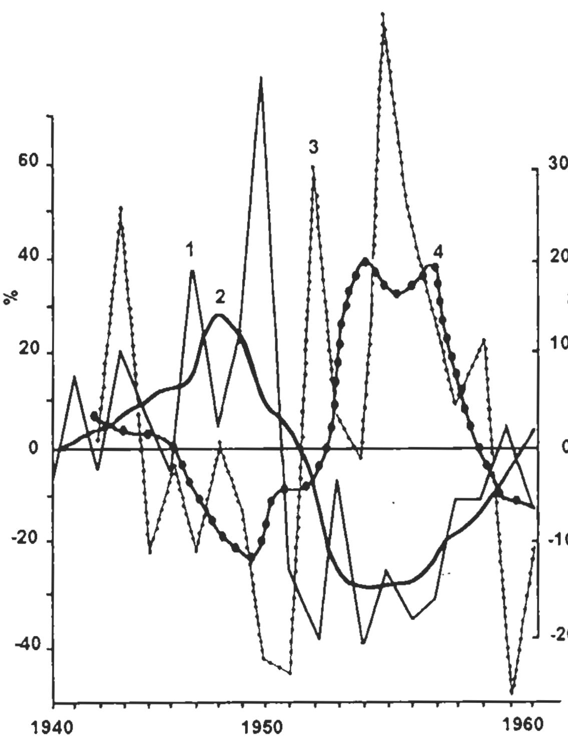

Fig. 9. Long-term changes in water surface temperature in May (Peschanaya Bay), and summer commercial catches of omul in the regions of fattening (deviations from the average longterm during 1940–60). 1, annual temperature values; 2, temperature values averaged for 5 years; 3, annual values of commercial omul catches; 4, commercial omul catches averaged for 5 years. After Smirnov, unpubl. data.

The directions of anthropogenic pressure and natural successions of evergreen coniferous forests of South Baikal, those most subject to anthropogenic pressure, coincide. The natural process of replacement of monodominant fir forests (*Abies sibirica*) by polydominant cedar forests (*Pinus sibirica*) with an admixture of spruce (*Picia obovata*) and fir-tree (*Abies sibirica*) is proceeding at an increased rate.

Changes to natural environments on the coasts of Baikal have given a new impetus to conservation of protected areas.

Three reserves and two national parks are located on the coasts of Baikal. The oldest is the Barguzin reserve. It is situated on the eastern coast of the northern part of Baikal,

Table 16. State of forests on the coasts of middle and south Baikal (%). Data from B. K. Pavlov

Region	Slightly decayed	Badly decayed	Drying	Dead
Middle Baikal				
Eastern coast	3.0	0.3	0.1	1.5
Western coast	7.4	0.8	—	3.0
South Baikal				
Eastern coast	5.4	0.5	0.1	0.2
Western coast	0.8	0.4	—	—
South coast	5.0	0.1	—	—

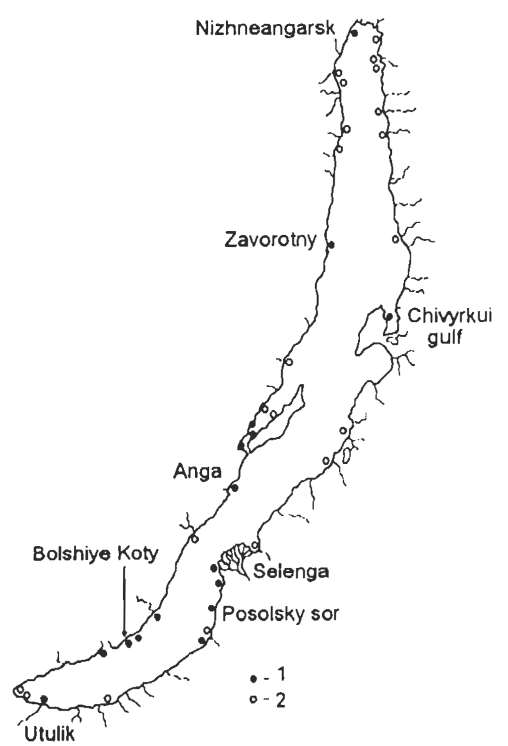

Fig. 10. *Elodea canadensis* distribution in Baikal. 1, points of discovery; 2, points free of *E. canadensis*. After Kozhova & Izhboldina, 1993.

occupying the western slopes of the Barguzin Range. Its boundaries include 45 km of the coastline. Its territory extends far into the mountains from 30 km in the southern part to 60 km in the northern. The total area is 263 200 ha. The reserve was created in 1917 to protect the sable (*Martes zibellina*). At present it is designated as a Biosphere Reserve.

The Baikalian Reserve is on the southern coast of Baikal. It was established in 1970 to preserve a natural complex of the Khamar-Daban Range, which is famous for a great number of endemic and relict plant species. Along the coastline, its territory stretches 49 km and into the mountains to 45 km. The total area is 165 700 ha. In 1993, the Baikalsk Reserve was given the status of a Biosphere Reserve.

The Leno-Baikalsky reserve is located on the western coast of the middle part of Baikal. It stretches along the coast, a distance of 90 km, and deep into the mountains, up to 60 km. The total area is 659 500 ha. The aim of the reserve is to protect natural complexes of the upper reaches of the Lena River and the western coast of Baikal.

Pribaikalsky National Park is located along the western coast of South and Middle Baikal. Along the coast, the park stretches a distance of 335 km (including the Olkhon island), and into the mountains from 5 to 25 km.

The Zabaikalsky National Park is on the eastern coast of Baikal, in its middle part. It stretches 75 km along the coast (including Svyatoi Nos peninsula and Ushkany Islands), and extends into the mountains to 25 km.

Many plants growing on the coasts of Baikal are on lists of rare and disappearing species. For example, 96 species (from 1800 higher plants of the flora of Irkutsk region) are included on such lists.

Conclusions

At present, Lake Baikal is affected by the following anthropogenic influences:

(i) regulation of water-level by hydropower station dams,

(ii) commercial fisheries and sport fishing as well as wildlife manipulation including hunting, and

(iii) discharge of chemical contaminants from in-flowing rivers, atmospheric precipitation, coastline erosion, industrial wastewater and transport-related pollution.

The last type of impact is the most important, and manifests itself in the form of local (e.g. the Selenga shallow, region of BPPC) increases of concentrations of alien substances, or global (e.g. water mineralization, sulfate concentration) increases to levels unusual for Baikal substances. The main pollutants of the lake are general mineralization (in particular, sulfates), non-toxic allochthonous organic matter, nutrients, toxic substances (phenolic compounds), oil products, and metal ions.

Recognizing where effluents enter the lake in relation to their significance, we can arrange them in the following sequence: waters of the rivers (Selenga, Upper Angara and Barguzin), atmospheric precipitation, region of the Baikal–Amur Railroad, source region of BPPC. The contaminated substances coming into the lake with tributaries are from settlements, industrial and agricultural enterprises located within the water basin, and pollutants transported with air currents and generated by industrial activities outside the water basin.

The greatest long-term influence is an increase in the mineralization of tributary waters due to deforestation and land cultivation. The most dangerous for the ecosystem is eutrophication, due to the input of nutrients and non-toxic organic matter, and toxification caused by phenolic compounds. The input of heavy metals is also dangerous, as these can be accumulated by aquatic organisms. These influences can cause a decline in water quality, but at present the quality of water is within the limits of requirements for potable drinking water.

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Olga Mikhailovna Kozhova is Professor of invertebrate zoology and aquatic ecology chair of Irkutsk State University and Director of the Scientific Research Institute of Biology at Irkutsk State University. Her list of publications exceeds 400. Her main fields of interest are general ecology, ecological monitoring, aquatic biology, environmental science and theory of evolution.

Eugene Anatolievich Silow is working in the Institute of Biology as senior researcher. His field of interests covers both theoretical and applied ecology. He has worked in the development of bio-assays, field experiments with mesocosms, mathematical modelling of ecosystems.