Long-term changes of plant community structure in eutrophic shallow reservoir and perspectives of its restoration

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Reservoir
Sestroretskiy Razliv

Reservoir Sestroretskiy Razliv is located on the south-west of the Karelian Isthmus.

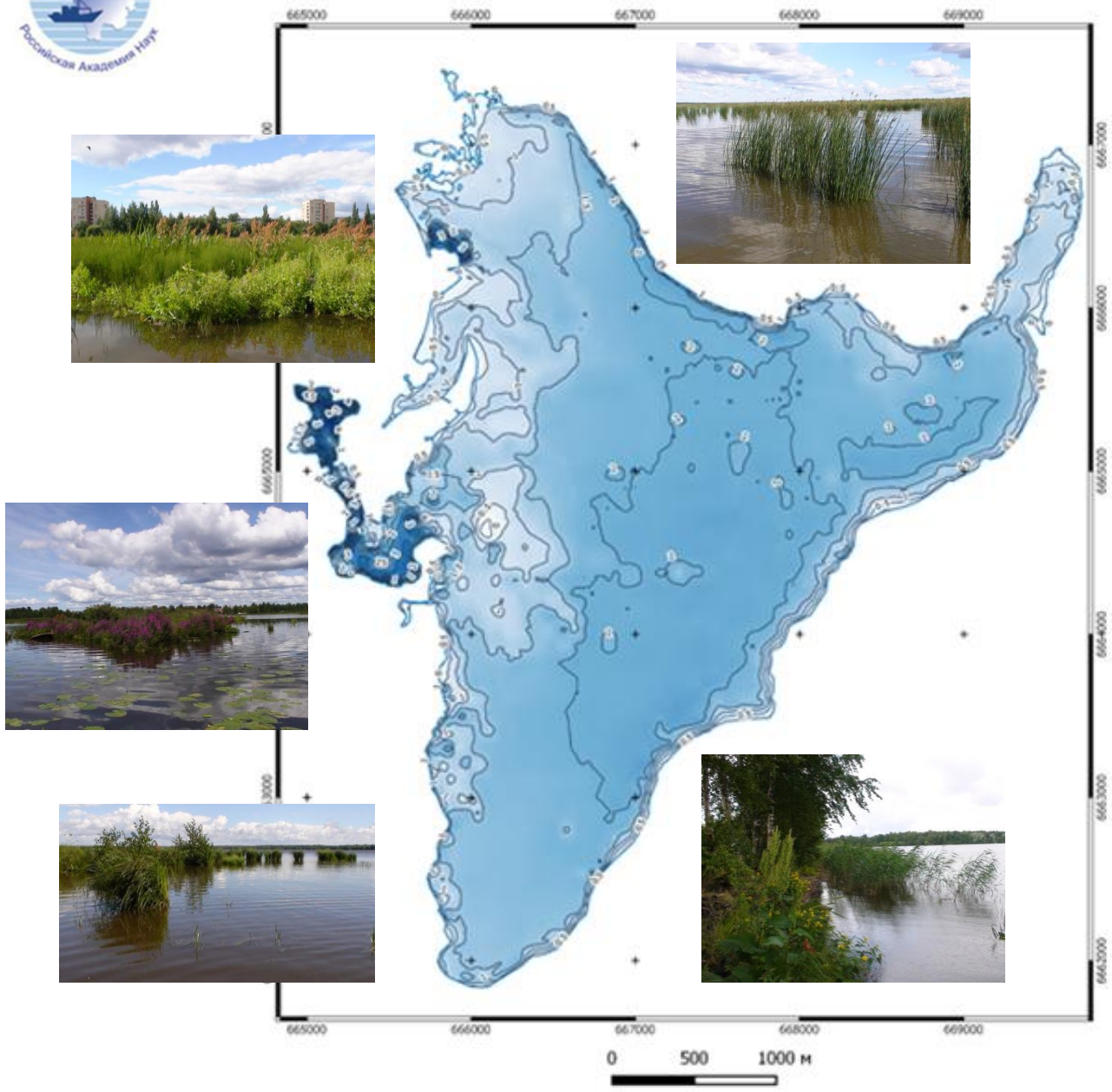
- Catchment area - 566 km^2
- Water area – 10.3 km^2
- Water volume – $19 \cdot 10^6$ m^3
- Coastline length – 20 km
- Depth: mean – 2.2 m
  max – 4.6 m
- Water exchange rate –
  10 $year^{-1}$

Two main tributaries:

Sestra (length – 75 km; catchment area – 399 km^2) and Chernaya (35 km; 126 km^2).

Sestroretskiy Razliv is the largest water-body located within a suburban area of Saint- Petersburg. It is an important element of city landscape and recreational object.

Bathymetric map of Sestroretskiy Razliv



- Depth:

mean – 2.2 m

max – 4.6 m

The water-body is shallow, polymictic with rather high water exchange rate.

Territories adjacent to northern shore are extended waterlogged lands and bogs.

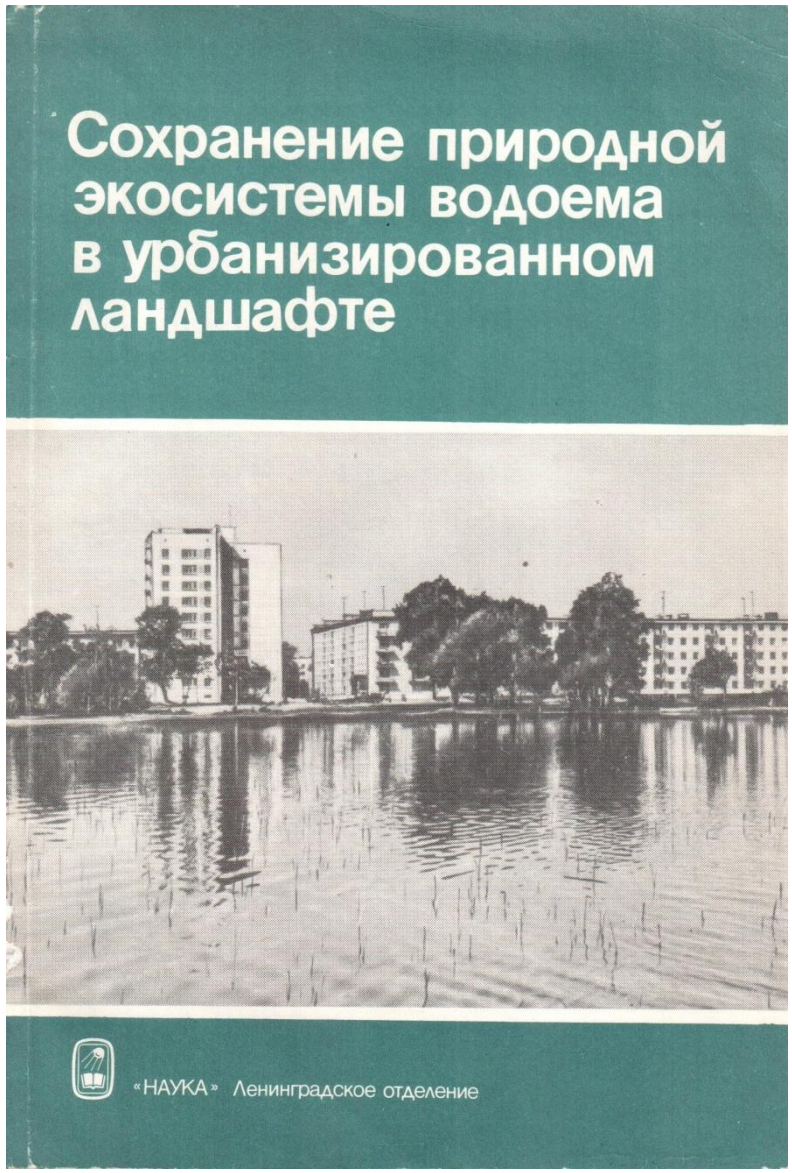
Deciduous and coniferous forests cover the eastern coast.

Sestroretsk town is located on the western coast.

Brief history of reservoir Sestroretskiy Razliv

Event	Year	Description
Construction of a dam on river Sestra in 5 km from its inflowing into the Gulf of Finland.	1723	For providing energy needs of Sestroretsk toolmaking factory.
Construction of a dam designed by engineer K.F. Gausman.	1863	
Construction of water purification plant	1889	Water supply
Complete drying of reservoir	1934	Climatic causes
Construction of a new water supply plant ($13 \cdot 10^3$ m^3/day tap water)	1966	Water supply and sanitation
Organisation of wildlife protected area on the northern coast	1990	Wildlife conservation and protection
Sestroretskiy Razliv is no longer used as water supply reservoir	2000	

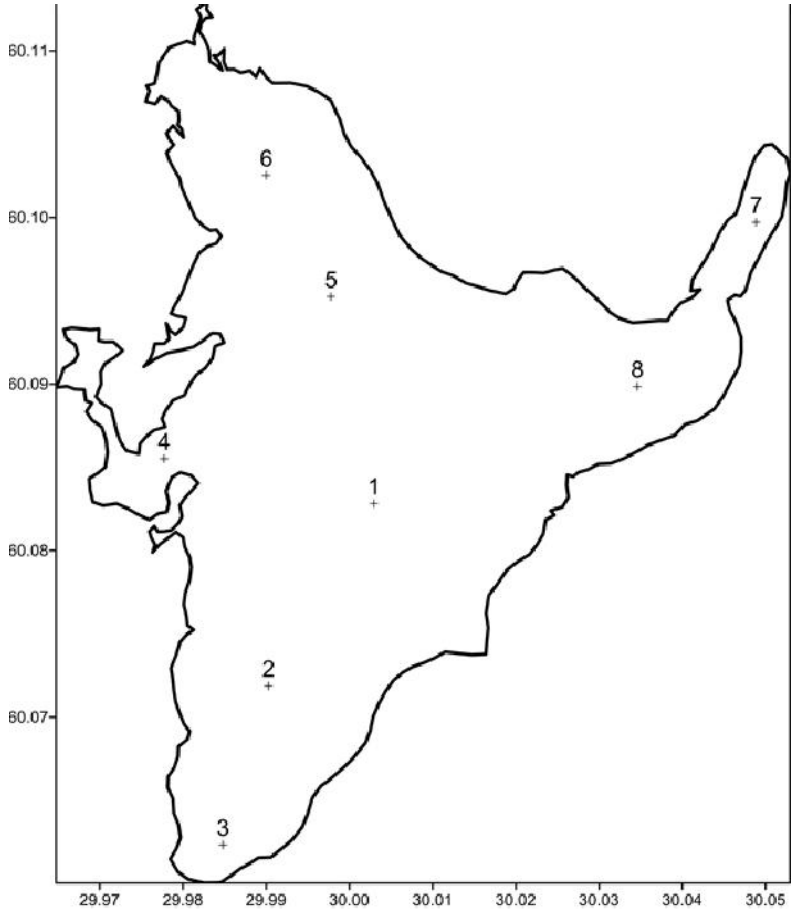
Ecological studies of Sestroretskiy Razliv



- Regular monitoring of water quality parameters was initiated in 1966 when a new water supply plant was constructed and the reservoir had begun to be used for supply of drinking water.
- The first complex ecological investigation of the reservoir was undertaken by Institute of Limnology in 1980-1981. The results were published in the monography “Conservation of natural ecosystem of reservoir in urban landscape” (1984).
- The second complex investigation of the reservoir was carried out by Institute of Limnology in 2002.
- The third assessment of ecological conditions in Sestroretskiy Rasliv was done in 2015-2016. Long-term changes in water quality characteristics and dynamics of phytoplankton and macrophyte communities were analyzed.

Material and methods

- Seasonal water samples for chemical analysis were taken in 1980-1981, 2002 and 2015-2016 from eight stations .
- Phytoplankton was studied in 1980-1981, 2002 and 2015-2016 from May to October monthly at eight stations.
- Macrophyte community was analyzed in 1980-1981 and 2015-2016 during the period of maximum vegetative growth. In 2015-2016, the total area of helophyte vegetation were estimated using satellite images Landsat.
- In September 2015 and May 2016, fish community was investigated by studying fish abundance, biomass and community composition (data was provided by the Berg State Research Institute on Lake and River Fisheries).



Changes of water parameters in Sestroretskiy Razliv in 1980-1981, 2002 and 2015-2016

Parameter	1980-1981	2002	2015-2016
Transparency (m)	0.6–1.0	0.25–0.5	0.25–0.3
Water color (Pt-Co units)	79-181	-	77-240
Mineralization (mg/L)	37–121	-	46–148
pH	8.6–9.7	-	6.3–7.9

- Comparison of data from different period of investigation showed gradual decrease in water transparency.
- Comparison of the 80's and 2015-2016 showed higher values of mineralization in 2015-2016. The highest values of mineralization were recorded close to the delta of river Chernaya.
- Maximum values of water color were higher in 2015-2016 than in 80's.
- A decrease in pH in 2015-2016 compared to the 80's was a result of high loading of allochthonous organic matter due to heavy precipitation.

Changes in TP and TN in Sestroretskiy Razliv during open water period in 1980-1981, 2002 and 2015-2016

Parameter	1980-1981	2002	2015-2016
TP (mg P/L, range/mean)	80–160 73	94–230 142	38–314 103
TN (mg N/L, range/mean)	0.37–1.40 1.18	0.69–0.87	0.39–0.94 0.72
N:P ratio (mean)	16	-	6

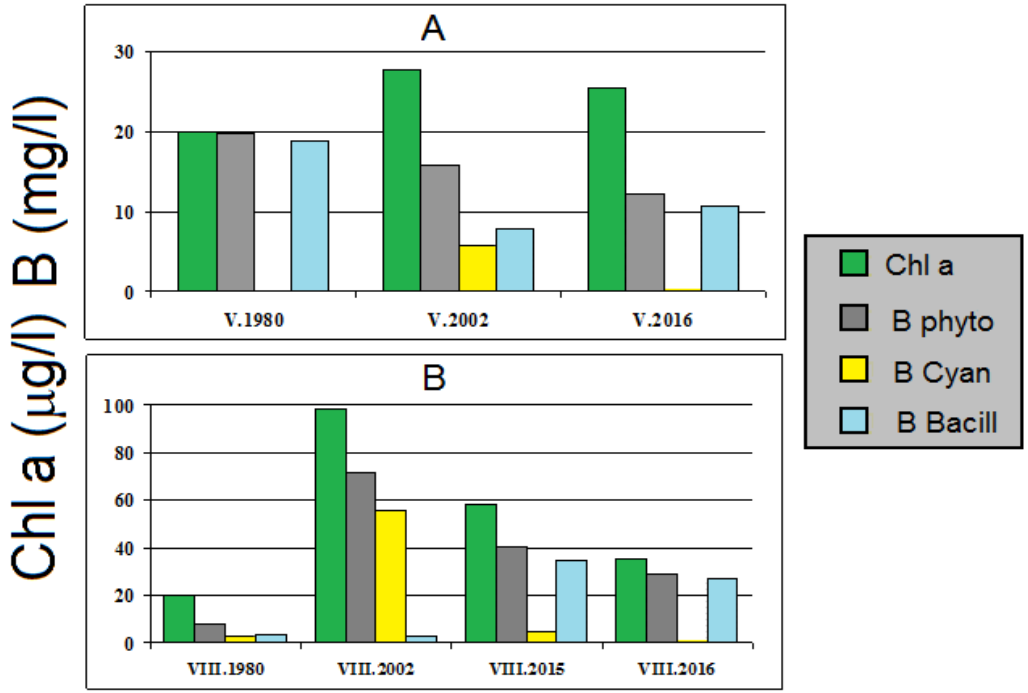
- Average year concentration of TP increased from 73 μg L^{-1} in the 80's to 142 μg L^{-1} in 2002 and 103 μg L^{-1} in 2015-2016 indicating eutrophic conditions in the reservoir nowadays .
- In comparison to the 80's, a decrease in NT occurred in 2002 and 2015-2016 probably as a result of a reduction in agricultural activity in the catchment.
- Decrease in N:P ratio from 16 in the 80's to 6 in 2015-2016 indicates shift from phosphorus to nitrogen limitation of phytoplankton growth.

Changes in phytoplankton biomass and chlorophyll-*a* among periods of investigation

Parameter	1980-1981	2002	2015-2016
Biomass of phytoplankton (mg/L, range/mean)	0.5-20 5.7	18-96 43.5	8-40 20
Chlorophyll-*a* (mg/L, mean)	20	84	52

- Mean seasonal phytoplankton biomass increased from 5.7 mg L^{-1} in the 80's to 43.5 mg L^{-1} in 2002 and 20 mg L^{-1} in 2015-2016.
- There was a marked increase in an average spring-summer concentration of chlorophyll-*a* from 14 μg L^{-1} in the 80's to 84 μg L^{-1} in 2002. In 2015–2016, high concentrations of chlorophyll-*a* (average 52 μg L^{-1}) were observed constantly during spring and summer.
- In the 80's, according to the low phytoplankton productivity the reservoir was in the mesotrophic state. In 2002, the trophic status of the reservoir abruptly changed from meso- to hypertrophic. In spite of lower level of phytoplankton development in 2015-2016 if compared with 2002, it remains at the high level corresponding to eutrophic water bodies.

Changes in chlorophyll-*a*, total phytoplankton biomass and biomass of Cyanobacteria and Bacillariophyta in spring (A) and summer (B) phytoplankton



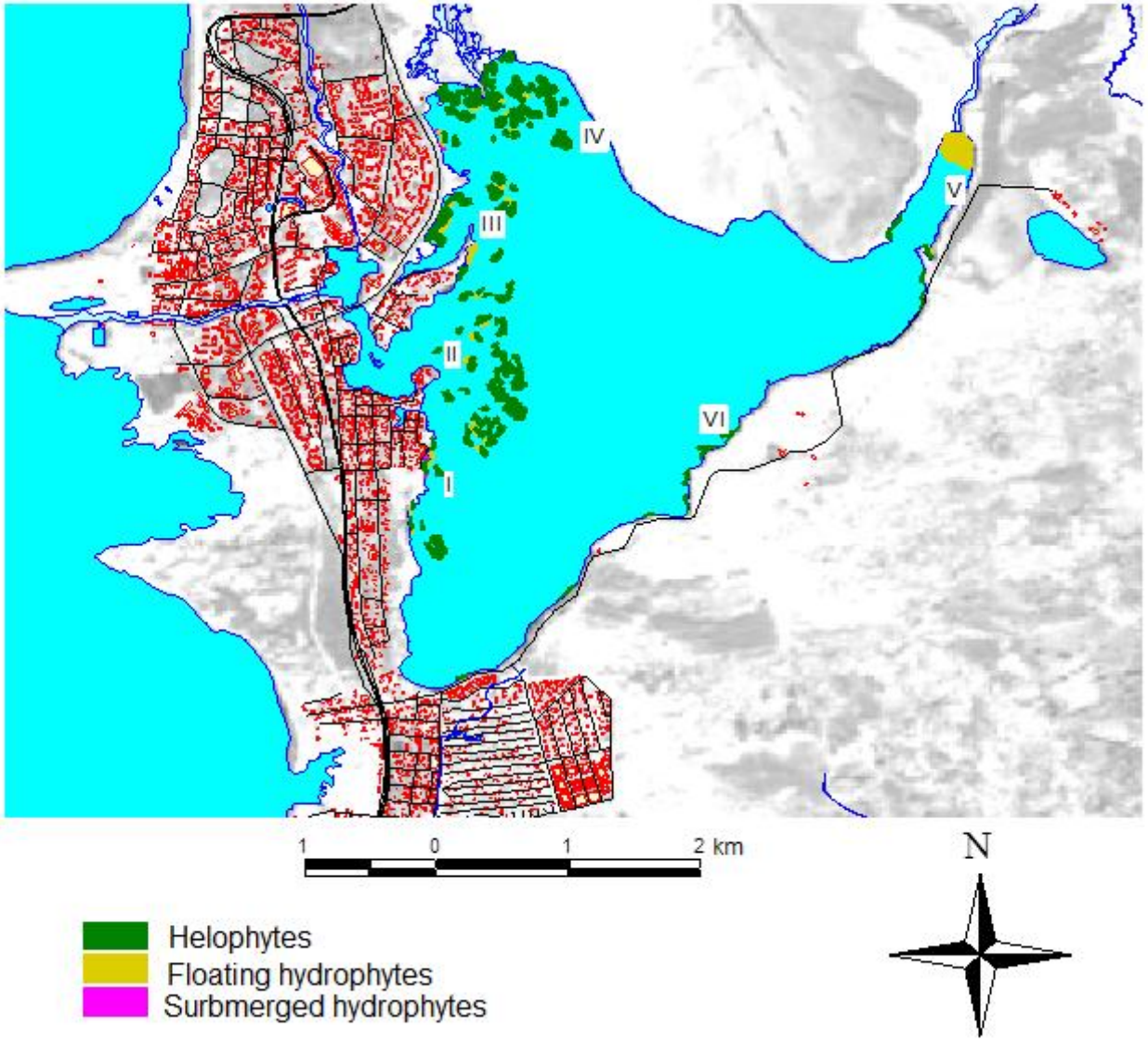
- In the 80's, the maximum in phytoplankton biomass was during spring. The spring bloom was dominated by diatoms .
- In 2002, the phytoplankton biomass maximum was in summer. In spring, diatoms and cyanobacteria dominated, while cyanobacteria completely prevailed in summer.
- In 2015-2016, summer phytoplankton biomass maximum was attributed to diatoms. Low abundance of cyanobacteria despite of high nutrient level was caused by low temperature and high water mixing and turbidity.

Changes in dominant algal species among periods of investigation

Season	1980-1981	2002	2015-2016
Spring (May)	*Aulacosira islandica*	*Aulacosira ambigua*	*Aulacoseira granulata var. muzzanensis*
	Aulacosira ambigua	*Plankthotrix agardhii*	
	Asterionella formosa		
	Fragilaria berolinensis		
Summer (August)	*Aulacosira ambigua*	*Plankthotrix agardhii*	*Aulacoseira granulata var. muzzanensis*
	Microcystis aeruginosa	*Aphanizomenon flos-aquae*	
	Aphanizomenon flos-aquae	*Anabaena lemmermannii*	
		Anabaena spiroides	

- In the 1980s, phytoplankton was dominated by diatoms (*Aulacoseira ambigua*, *A. islandica*, *A. subarctica*). In 2002, cyanobacteria *Planktothrix agardhii* was dominant in phytoplankton all year round. In 2015–2016, diatoms (mainly *Aulacoseira muzzanensis*) were dominant presumably due to unfavourable weather conditions. *Aulacoseira muzzanensis* is taxon indicative of shallow eutrophic waters with high water mixing and turbidity.

Spatial distribution of aquatic vegetation in Sestroretskiy Razliv



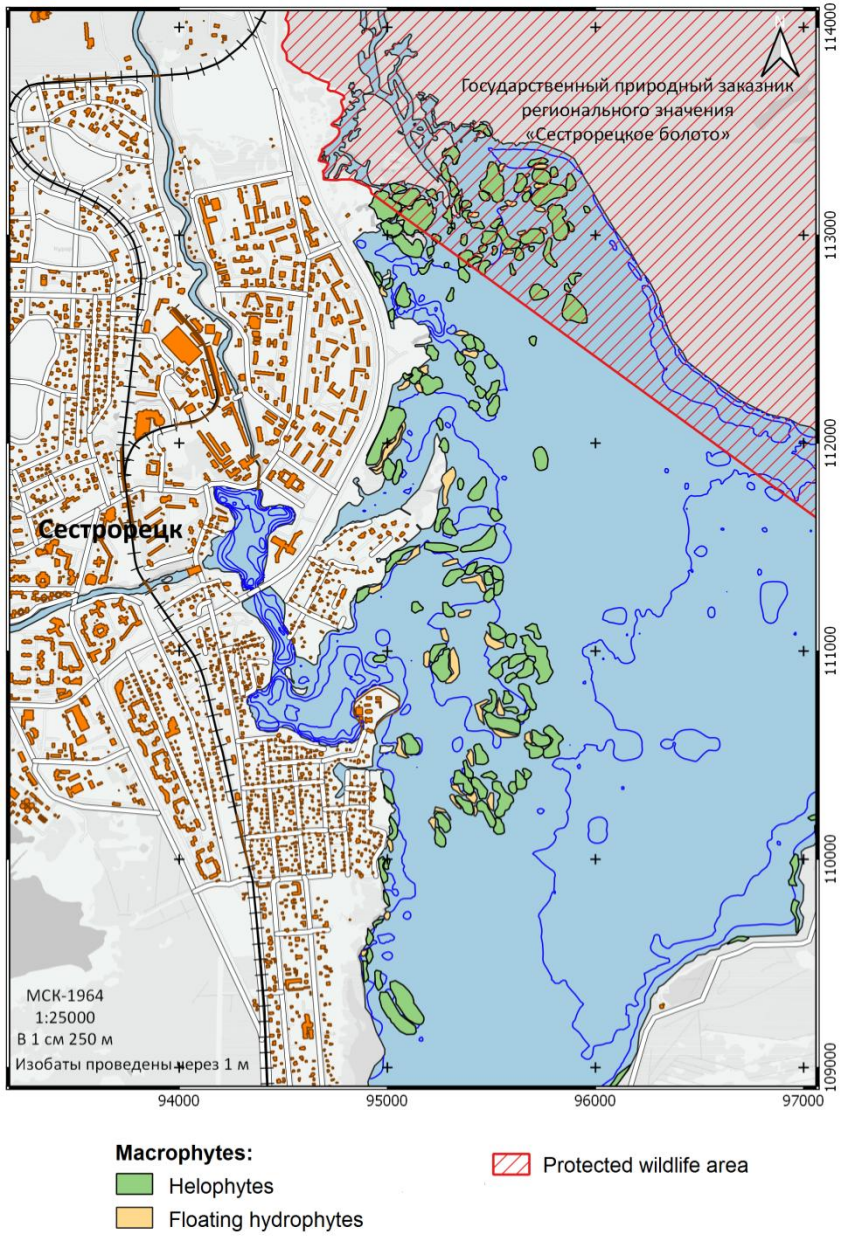
- The main part of aquatic vegetation is located along western coast and in northern part of the reservoir near delta of river Sestra. These helophyte stands are mainly composed of reed (*Phragmites australis*) and bulrush (*Scirpus lacustris*).
- Floating hydrophytes mostly represented by *Nuphar lutea* and *Potamogeton natans* developed dense canopies in a bay near river Chernaya delta.
- Submerged hydrophytes (mainly *Potamogeton perpholiatus*) have a very restricted distribution within helophyte stands.

Changes in vegetation cover of macrophytes between 1980-1981 and 2015-2016

Ecological group	1980-1981		2015-2016	
	Area, ha	% of lake area	Area, ha	% of lake area
Helophytes	126.4	11.9	61.3	5.5
Floating hydrophytes	28.4	2.7	14.0	1.3
Submerged hydrophytes	2.5	0.2	0.6	0.1
Total area:	157.3	14.8	76.0	6.8

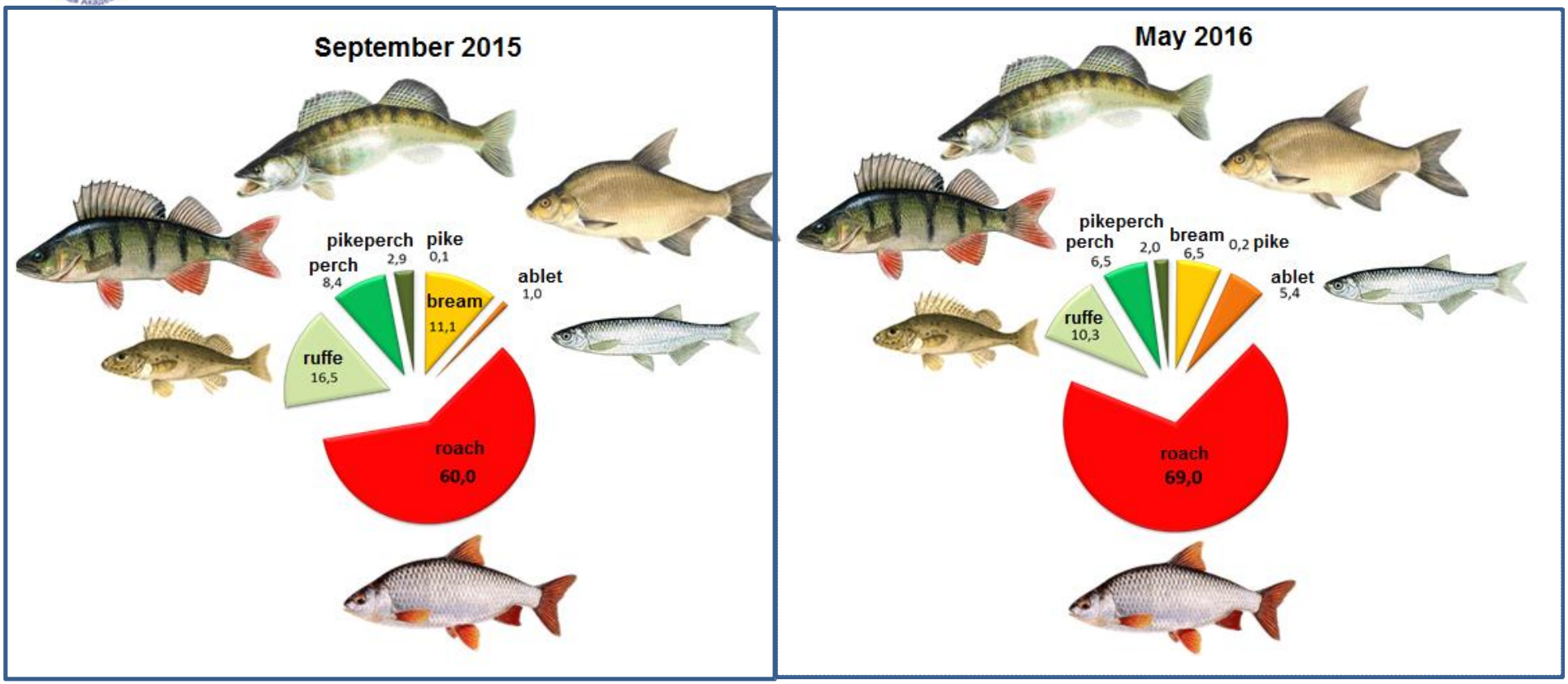
- Total area of aquatic vegetation declined from 157 ha in the 1980s to 76 ha in 2015–2016.
- Submerged macrophytes showed the highest decrease in vegetation cover (by a factor of four). The propagation border of submerged plants shifted from 1-1.2 m to 0.5-0.6 m.
- The decline of vegetation cover of the macrophyte community within 30 yeas was possibly a result of increase in phytoplankton biomass and water turbidity.

Macrophyte distribution along the western coast of Sestroretskiy Razliv



- Comparison of the current distribution of aquatic plants with those of the 80's showed that the main reed stands continue to grow at the same locations.
- In the delta of river Sestra, *Phragmites* stands was replaced by sedge vegetation (*Carex* spp.) indicating intensive siltation.
- Among helophytes there was increase in area of vegetation covers of *Typha latifolia, Sparganium erectum*, and *S. emersum,* taxa indicative of eutrophication.
- Among floating macrophytes there was change in dominant species from *Persicaria amphibia* to *Nuphar lutea.*

Structure of fish community in Sestroretskiy Razliv



- The core of the fish community consists of roach, bream, ruff, perch and pikeperch.
- Roach was the most abundant species achieving 69% in relative abundance.
- Cyprinids (roach and bream) attained highest abundance in open deepest part of the reservoir. In contrast, percid fishes (ruffe, perch and pikeperch) were more abundant in macrophyte stands (Pedchenko et al., 2017).

Overall conclusions

- The increase in phosphorus concentration in the Sestrorecki Razliv has caused increase in phytoplankton biomass and shift in dominance from diatoms to cyanobacteria.
- Based on analysis of phytoplankton biomass and species composition, the reservoir has been classified as hypertrophic.
- Gradual decline in water transparency coinciding with phytoplankton biomass increase was revealed.
- The decline of vegetation cover of the macrophyte community up to 6% of the total reservoir area was possibly a result of increase in phytoplankton biomass and water turbidity.
- In fish community, planktivores are dominate species.
- According to the alternative stable state concept, the reservoir can be considered as phytoplankton-dominated system.

Proposed recommendations for reservoir restoration

- As the first step of restoration program, reduction of nutrient loading to two tributaries (rivers Sestra and Chernaya) was proposed.
- Besides reduction of nutrient loading the restoration program includes the following measures:

Biomanipulation as a technique used to restore eutrophic lakes:

- Removal of planktivorous fishes by seining.
- Introduction of native predatory species (piscivores) such as pike and pikeperch.

Manipulation with macrophyte community:

- Planting of reed along the western coastline
  (total length 1200 m, width 3-5 m).
- Cutting and removal of the dried stems of reed at the end of growing season (area 50 ha).


Thanks for attention!