The Development of Shallow Lakes in Different Landscapes of Vologda Region (North-Western Russia)

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ABSTRACT

The unique territory as regards the diversity of landscape structure with the shallow lakes of the Vologda region located in the north-west of European Russia is review. The area was a margin of the Valdaysky Glacier, consequently the formation of the lake ecosystems are related to historical processes. The formation of water communities is connected by location of the territory at the watershed of the Caspian, Baltic and White Seas. It’s show the results of long-term (1970–2000s) investigations, that anthropogenic pressures lead to the rapid transformation of the shallow lakes ecosystems. The general trends are toward the changes of ionic composition of water, eutrophication and the toxification of lakes. The communities have exhibited a decline in biodiversity. The changes of the communities diverse are connected with disappearance of some species as unique whitefish’s populations and invasions of others. It is concluded that the ways of regulation of the community according to the «trophical cascade» hypothesis determine the rate of structural changes in the communities. The main reasons of the deterioration of the abiotic conditions and the changes of the trophic level structure were analyzed. The problem of preservation biodiversity, the conservation habitat and of lake ecosystems and their drainage areas due to including in protected area network are discussed.

Keywords: landscapes, anthropogenic transformation, shallow lakes, Vologda region, protection.

INTRODUCTION

The analysis touch upon the problem of the development of lake ecosystems is included the examination of historical natural and anthropogenic factors. The territory genesis and landscapes formation are historical causes of the origination of the lakes. The natural conditions of territory stipulate the formation and development of characteristics lake communities. Natural processes of freshwater ecosystem evolution normally occur under the influence of climatic changes in time scales of hundreds and thousands of years. Considerable quantitative and qualitative changes in various systematic groups of aquatic animals are shown to have occurred in the water bodies during the last 50 years due to the human impact (Ramm, 1988; Noest, et al., 1997, et al.). The anthropogenic factors change the natural processes in lake ecosystems and it intensifies such natural phenomenon as eutrophication (Smith, 1998). Such acceleration is especially harmful to geologically young and vulnerable ecosystems like inland water bodies of North of Europe with their extremely low capacity for self purification (Ryzhkov, 1996; Bolotova, 1999).

Vologda region is located in the north-west of European Russia (at 61° 36'- 58°21'N, 34°40'-47°10'E) within the Russian plain (Fig.1). Vologda region has square 145, 7 km, it maximum stretch is 650 km west to east, and 385 km – north to south.

Composition of water biota in this region was greatly affected by Pleistocene and post-Pleistocene events. During that time, the area was a margin of the Valdaysky Glacier. The shallow lakes had arisen due to retreat of the glacier.

![Figure 1. Vologda region is located in the North-West of the European Russia (61° 36'- 58°21'N, 34°40'-47°10'E).](image)
the basins of Caspian, Baltic and the Whites seas became the main factors of fish distribution. The communities were formed from the fish of the main faunistic complexes including boreal, arctic and caspian complex.

Lying at the boundary of middle and southern taiga, the region is also marginal in relation to the largest drainage basins of Eurasia. The Eurasian drainage divide between the Arctic Ocean (White Sea – Severnaya Dvina River), Atlantic Ocean (Baltic Sea – Lake Onego) and inland drainage (Caspian Sea – Volga River) basins cuts across the territory (Fig.2). The feature of this territory is high diversity of landscape structure (Fig.3) and consequently there is diversity of lake ecosystems. Any lake is accumulative element of the landscapes drainage area, that way the state of shallow lake depend on the landscapes characteristics particularly (Bolotova, et al., 2004).

Figure 2. The map of basin drainage allocation on territory of Vologda region

Figure 3. The map of landscape zoning of Vologda region
Human activity on the watershed causes the negative processes in lakes particularly quickly. Long-term monitoring suggests that the pollution of water have increased as a result of anthropogenic pressure on the watershed (Bolotova, 1999, 2002a, Bolotova, Borisov, 2006). Agricultural land and cities are concentrated near of reservoir usually, that intensifies the human influence on them. The lakes are exploited for fishery, water consumption, recreational use, waste water disposal, and navigation and timber floating. Anthropogenic pressure leads to the rapid transformation of the natural processes and the deterioration of abiotic conditions in the shallow lakes.

The general trends are toward the changes of ionic composition of water, the toxification and eutrophication of lakes. An increase in total amount of nutrients is taking place, which was demonstrated by the calculations of phosphorus load (Bolotova, 2002a). As a result of the deterioration abiotic conditions the changing of the trophic level the structure are observed. Anthropogenic influence reflect alterations in species composition of communities and interpopulation variations, including the formation of the fast an slow-growing groups of fish with predominant small specimens, which accounted for the increase in the part of predatory fish. Predators play an ever greater role in the community, being an effective mechanism for regulation of food relationships. It may be considered as pathways for maintaining functional ties and for supporting the system stability. It is concluded that the ways of regulation of the community («bottom-up» or «top-down») according to the «trophical cascade» hypothesis determine the rate of its structural changes in the shallow lakes.

The changes of the community’s diversity are connected with disappearance of some species and invasions of others, and mass development a few of several species. The communities have exhibited a decline in biodiversity in shallow lakes. Creation protected areas on the lakes and its watershed is the main way of water conservation and biodiversity of Vologda region.

The estimation of transformation of shallow lake ecosystems in different landscapes of Vologda region was the main goal of our investigation. The tasks were determining:

- zoning of the territory of Vologda region for creation the landscape map and specification of the allocation shallow lakes in different landscapes;
- analysing the impact of different landscape structure of drainage areas upon the large lakes;
- detection of the trends of quality lake water and communities changes, including fish population;
- examination impact drainage area natural features on the eutrophication and pollution and the pH water;
- revealing of the way conservation and protection of lake ecosystems and biological diversity.

STUDY AREA AND MONITORING DATA

The examination drainage areas effects on lakes are in need of analysis landscape structure. The landscape map for zoning of the territory of Vologda region, which has a natural scale 1: 200 000, was compiled on base of series maps (fig. 3). There are relief, overburden, woodland, geomorphologic and hydrographic maps.

The large lakes (Kubenskoe, Vozhe, Beloe) within the different landscapes on drainage areas were selected for long-term monitoring. There are shallow lakes are formed 10 000 years ago after the digression of the Valdaysky glacier. The Kubenskoe and Vozhe lakes have the same area of 417-418 km² and about 2 m deep. Beloe Lake has an area of 1284 km², a mean depth of 4 m owing to the construction of a dam.

The anthropogenic pressures on these lakes are distinguishing. Beloe Lake experiences relatively more anthropogenic impacts but it is larger and deeper than the Kubenskoe Lake and Vozhe Lake.

The lakes are exploited for fishery, water consumption, recreational use, waste water disposal and navigation. The Beloe Lake experiences of most of the pressure, because it is a part of the Volga-Baltic Route. The Kubenskoe Lake is a part of the Northern Dvina’ Route. Vozhe Lake is located in a marshy area, far away from industrial centers. There is no navigation, timber floating and waste water disposal. The intensities of human pressure are different among the lakes, but pollution and eutrophication are observed in all of them. Atmospheric deposition contributes much to these processes. The toxic load in the lakes is higher, than environmentally safe levels in terms of heavy metals, oil products and other dangerous substances. Ionic composition has trend to the increasing of the concentration of sulfates and chlorides, which take the place of hydrocarbonates, it is the dangerous tendency for the development of the acidification’s processes in the lakes.

Analysis of long-term trends of the ecosystems requires monitoring data. This monitoring is done in support of synoptic and long-term biological impact studies. From the early 1970’s, the observations were conducted on these lakes of the Laboratory of the Institute of Lake and River Fisheries. Data obtained by collaborators, including the author, presented in the funded material of laboratory. The aim of my test is to compare of all obtained characteristics of lakes (Beloe, Kubenskoe, Vozhe) were averaged for on each several decade, because the data are eventually entered in the computer (data management system), including the data come from the archives of the laboratory, public services (Agency -GIDROMET, National Resources Department) and own data. P-loading of these lakes
was calculated using empirical model from Vollenweider (1976) (Bolotova, 2002a). A total of 21-35 chemical parameters were measured on each water sample by the methods used by the National Agency. Monitoring is based upon synoptic lake water quality surveys coupled with the long-term (results of over 25 years investigations) monitoring of biota. The full research programme was carried out during vegetation periods from May to October. The standard hydrochemical and biological methods were used for collecting and the analyses were performed by conventional method. This report summarizes the basis of the investigations using the ecosystem approach. For this we will analyze a suite of physical and chemical features (water movement and turnover time, temperature, Secchi disc transparency, color pH, oxygen content, nutrients, humic substances alkalinity, salinity, toxic elements, etc.) and the sampling of plankton, zoobenthos (species composition and size structure, abundance and biomass) and fish (size-age composition, growth rate and morphometric features, feeding, reproduction, numbers and fishery statistics (from 1938 to 2006). We have been focused to make the picture complex and a practical definition of the trends of the communities based on averaged empirical data.

RESULTS AND DISCUSSION

The Vologda region territory is subdivided into 33 physiographical distinct, 3 physiographical regions, 2 subzones (Bolotova et al., 2004). The prevalent genetic types of landscapes are glaciolacustine and flatland morainic types: 8 landscapes districts each (Fig. 2). Widely represented in all landscape regions are hilly morainic landscapes (7 districts). Fairly uncommon in the Vologda region are hilly lacustrine morainic landscapes, which had formed during the last deglaciation (3 districts) in the North-western landscape region and the glacioaqueous landscapes of the Sukhona-Dvina and Upper Volga physiographical region. There are a total of 6 genetic landscape types in the Vologda region. Zonally, 16 of the 33 individual landscapes distinct belong to mid taiga, and 17 – to southern taiga. Most landscapes form on medium –elevation levels (100 to 200 m) of relief in the region. Lower layers (below 100m), where regional accumulation is most intensive, are situated in the Prionezhskiy and Nizhne-Vazhskiy landscape districts. The main regional denudation layer (250-300 m) is quite inexplicit, occurring in the Megorsko-Andomskiy, Andomskiy and Verkhne-Yugskiy landscapes.

There are a abundant hydrological net with numerous rives and small lakes (5272) and 3 large shallow lakes (Beloe, Kubenskoe, Vozhe) and 2 reservoirs (Sheksninskoe and the part of Rybinskoe). Besides the part of the Lake Onega belong to the Vologda region.

The majority of the lakes are shallow waterbodies with depth from 1 to 15 m (some 25-27 m) and their formation depends on the landscapes genesis. The most of them are located in north-western part of Vologda region and have lake hollow of glacial origin. These shallow lakes are remarkable for the hollow configuration.
Valdaysky Glacier and they are represented the chain of small lakes connected flow channel (Fig. 8).

The general peculiarities of drainage areas wish different landscape structure influence on elements flower in the lakes. Prevailing of forests as runoff factor on the watershed determine and streamflow formation. Diversity of soils on the drainage areas determines specific of flow migration and the distribution of elements. There are the large part of marshes that stimulates getting of organics and eutrophication of lakes. Carbonate landscapes provide neutralization of acidification of drainage area and the lakes and helps to accumulate nutrients in soils. Thus, a “key” mechanism for the system functioning “drainage area-lake” are migrations of elements, their distribution and accumulation. Specifics of functioning of this system are determined by natural peculiarities of drainage area, character of human pressure.

Figure 6. Vozhe Lake: photo and schema of draining area

Figure 7. The small lake (Luchtozero) is located in hilly lacustrine morainic landscape

Figure 8. The small lake (Dolgoe) is located in valley of river.

The orientation of regional economy on using of rich aquatic resources, creation of large transportation systems, and transformation of watersheds has brought to the large-scale anthropogenic transformation of ecosystems. A significant part of surface waters is being utilized in different sectors of the regional economy. Anthropogenic load is the heaviest on the waterbodies belong to the basins of the Caspian, and the White Seas., since they harbour large industrial centers (Cherepovets, Vologda, Sokol) with ferrous metal production, chemical and pulp-&-paper industries, which pose a threat to aquatic ecosystems. Effluents have lately increased, contaminated wastewater making up 40% of total effluents. Deterioration of the quality of water and habitat for the organisms are the result of exhaustive exploitation of lakes. The concentrations of humic substances and water color have increased, but transparency and concentration of oxygen have decrease.

Field studies suggest that the pollution of water due to an increase in plant nutrients and consequent changes in the physical, chemical and biological characteristics is generally referred to as eutrophication. The addition of excessive amounts of nutrient elements, especially phosphorus, to the lakes was an important cause of accelerated eutrophication. Nutrient inputs have increased as a result of human pressure on the watershed. There are observed the considerable elevation in water P concentration (specially mineral phosphorus) and dramatic increase of N concentration (including total ammonia, nitrate, nitrite) to 1990’s that obviously is caused by external loading. In the lakes with decelerated current the main factor determining the high internal loading is the morphometric parameters, rapid utilization of nutrients by aquatic macrophytes often results in development of plants.

Phosphorous and nitrate were mobilized in the lakes during by partial anaerobic conditions in the
sediment according to high autotrophic production of organic matter and their decay. Thus, eutrophication of these lakes is favorable to “bottom up” principle and have resulted in abundant macrophytes growth and accumulation of silt. In addition, an increase in the total amount of nutrients and other organic substances has accompanied by oxygen deficiency. Ionic composition has trend to acidification’s processes in the lakes. The turbidity increase, erosion of shores is getting worse and other negative changes of abiotic conditions are taking place.

In spite of weak human impact on Vozhe Lake negative processes as eutrophication and pollution are observed (Bolotova et al., 2005b; Bolotova, Borisov, 2006). Consequently, the anthropogenic transformation of this lake is accelerated by natural features of the drainage area and due to deposition atmospheric precipitation. The lake inflow and precipitations are the main way of inputs of organics and biogenic substances and toxicants in Vozhe Lake. Long winter determines significant role of snow for accumulation of elements on the drainage area of Vozhe Lake. Negative role of atmospheric emission is observed for the ph water rise of amplitude. In spring the indicator of pH water in inflow for a short time is lowering due to snow pH lowering up to 5.0. Accumulation of heavy metals in snow leads to big amplitude of its getting into water bodies in spring. It’s demonstrate, that in the lakes intensity of season migration of elements in lakes is regulated by climate.

However drainage area is “buffer” against changes pH water and ionic composition. Drainage area of Vozhe Lake has a stable significance for ionic composition and pH water due to high content of carbonates. Diversity of soils of drainage area determines the redistribution of elements flow to the lake. The rate of accumulation nutrients is distinguished in different zones of drainage area. Marshy soils and soils with high content carbonates delay elements. The rising of the content of phosphorus in the soils determined the rising of P-content in water of tributary Vozhega and Vozhe Lake (Bolotova, et al., 2005b). This example demonstrates the important role of rivers for eutrophication of lakes and other negative processes in them.

In all investigated shallow lakes eutrophication processes had effects on structural and quantitative indices at all levels of communities. As a result of the deterioration abiotic conditions, the communities has exhibited a decline in biodiversity and the replacement of the sensitive species by the tolerant species to pollution, turbid water with reduced Secchi depths and oxygen deficit. The changes of taxonomic composition with loss of the diverse due to mass development a few of several species and the size structure to prevalence of small forms and the shift to r-strategy are common trends for all trophic levels. In addition, the increasing of the fluctuation of the dynamic of biomass and abundance of alga and animal has observed in the lakes.

Phosphorus is the main nutrient factor for the autotrophic production in the lakes and high concentration of dissolved silica indicates the development of the diatoms. Earlier in investigated lakes Diatomeae dominate in phytoplankton and the development of Cyanobacteria limited due to the destruction its colonial forms in turbulent water. At present, Cyanobacteria become abundant with a mass development of the Cryptomonade-species (Cryptomonas erosa/ovata) and the apparent increase in abundance of previously rare species (Bolotova, 1999).

Investigation has shown the changes of zooplankton abundance and species composition in all lakes. A decline of number of the dominant species was recorded and the suite of the dominant has been change. Small cladoceran species (e.g. Bosmina, Chydorus) and cyclopoid (Mesocyclops) prevailed in the zooplankton and an increase in the percentage of rotifers is characteristic of these lakes. As result, the zooplankton biomass is decreasing (up to 1, 0 g/m).

A decline in the biomass, numbers of benthic animals and the changes of the structure of zoobenthos was observed in all lakes, but the degree and the mechanisms of these changes was different. The occurrence and distribution of individual species is determined by complex factors. In 1980’s, when benthivorous as most abundant among the fish feed on zoobenthos, they become the major factor regulating the numbers and biomass of benthic animals. Since the moment of full biomass of benthos due to the deterioration of abiotic conditions (silt, turbid, oxygen deficit) in these lakes fish began to feed on the other food. The most development of insect’s larvae and large mollusks are observed in the lakes. Important factor of changes of the zoobenthos structure was the invasion of Dreissena polymorpha in Kubenskoe Lake and Gmelinoides fasciatus in Beloe Lake that its densities increased during 1990-2000’s. Different form of perturbation to the food web has occurred with the invasion in lakes by these benthic animals that could impact sustainable fisheries stocks.

The structural changes in fish communities are governed by changes in the composition of faunistic complexes to depression of species of the arctic complex and a increasing of the caspian complex species (Fig.9). Cyprinids and Percids became dominant forms in fish communities. The stages of the fish community’s evolution in the following pattern: salmonids -coregonids - smelt - perch - cyprinids. In fish populations division into groups of slow- and fast growing individuals is distinctly pronounced and the feeding spectrum a changes influence on the food webs. Under conditions of deteriorating environmental quality, compensatory mechanism for the population dynamics of the stocks
includes increased reproductive power, early maturity, and decreased life expectancy.

The dominance small fishes that consume mainly zooplankton makes prerequisites for an increase in the numbers and biomass of predatory fishes and it caused a redistribution of the energy flow towards planktonic pathway. One of the more surprising results of this study was the remarkable difference between the changes community structure of the three lakes in order “Vozhe> Kubenskoe> Beloe”, though according the degree of human pressure on lakes they are ranged so: “Beloe> Kubenskoe> Vozhe. This discrepancy can be the distinction of the morphometric and hydraulic characteristics of the investigated lakes correlated the processes of the transformation of phosphorus. The internal P–loading mechanisms often contribute considerably to observe lake P–concentration and developed “bottom-up effect”. Top-down regulation is determined the composition and abundance of piscivorous species passed through “key-predators” and the criteria of this control is stability of community on the whole. Top-down effects have little impact on the community of Lake Vozhe but are significant in lake Beloe. The intense predation from planktivorous fish removes the large zooplankton, especially the large cladocerans leaving only small zooplankton like rotifers, bosminids, cyclopids in all lakes. Indirect influence of benthivorous fishes may play an important role in the regulation of a planktonic community in shallow lakes. The test of the relationship between size distribution and biomass of the levels community is very important to our understanding of energy and material flow in food webs. The energy flow redistributed along food networks towards planktonic mode of feeding.

Ichthyofauna of the Vologda region is represented by 52 species and with landlocked forms by 67 varieties of, from 17groups, also in reservoirs live 3 species of lampreys. Among water vertebrates more than half (38 species) are rare to some extent. A part of their populations - 13 species and varieties are offered for including in the Red Data Book (among them 8 species are included in the Red Data Book of the Russian Federation), and 25 species demand zoological control (Bolotova et al., 2005a). The basic reasons of reduction of the number of vulnerable species of the fish are qualities of water environment deterioration, adverse reproduction, and also illegal fishing.

The occurring changes ichthyofauna define a urgency of revealing of the display importance of those or other indicators as key parameters with the purposes of monitoring a biodiversity. The traditional approach is reduced to supervision over a status of disappearing populations of fishes, to which in northern reservoirs the usually valuable representatives of Acipenseridae, Salmonidae, Coregonidae as most sensitive species to anthropogenic impact. Environmental factors such as oxygen deficiency, temperature, depth and spawning area are vital determinants for these populations. As example, population of rare species of Coregonidae disappeared in Kubenskoe Lake (Bolotova, 2002b, 2004a). There are land-locked forms of the inconnu, Stenodus leucichthys nelma (Pallas), and Coregonus lavaretus nelmuschka (Pravdin), is an endemic glacial relic form of whitefish. Thus among the species suggested to be included into the Red Data Book valuable populations prevail, as they are in depression because of overfishing, eutrophication and pollution.

The fish communities development to domination perch in lakes located into landscapes with abundance of marshes. In lakes located in “carbonate” landscapes the fish communities development to domination roach.

Besides, strong influence on changing on water and communities in incurred by acclimatization of animals, by fishing, including poaching. The widespread watersheds and exploitation of the shores have direct impact on the condition of the basins. Economic importance of the water basins, traditionally dense population on the shores makes it hardly possible to withdraw them from economic use. The areas with large sources of disturbance and profound transformation of natural biota, restoration of ecosystems appears problematic.

There are 166 protected areas in the Vologda region. The protected areas network comprises a group of unique lakes located within the Megorsk-Andom landscape territory, which have received the status of hydrological reserves (Bolotova et al., 2004b). It’s show the status of hydrological reserves
(with water protection area of 0.2-1.0 km) is not sufficient to ensure the presentation of the unique lakes. It is imperative to include the drainage area of lakes into the PA (protected areas) network.

CONCLUSIONS

The feature of the region is its location at the watershed of the Caspian, Baltic and White Seas, which initially influenced on formation of water communities. The basic factor of spreading fish of Baltic and Arctic faunas was the alternate connection of the lakes with basins of different seas during the retreat of the Valdaysky Glacier. As a result ichthyofauna was formed from 3 main fauna complexes: boreal, arctic and caspian. Due to the deterioration abiotic conditions, the communities have exhibited a decline in biodiversity. Human-induced transformation leads to changes in the fish population of Vologda region waters; the species richness has decreased in fauna. Many species have moved into the endangered and rare categories (Bolotova, et. al., 2002). Communities in the Beloe, Kubenskoe, Vozhe lake of northwest of European Russia have been changing considerably since the 1970’s as a combined result of the pollution, eutrophication, the changes of food web determined by the vector of regulation.

Drainage areas with different landscapes have different influence on the shallow lakes. They stimulate processes of eutrophication and toxification ecosystem. However drainage area of Vozhe Lake is “buffer” against changes pH water and ionic composition. Marshy soils and soils with high content carbonates delay elements. Migrations of elements, its distribution and accumulation are a key mechanism for the system functioning “drainage area-lake”.

The quality water of investigated lakes is deteriorated. The concentration of humic substances and water color have increased, but transparency and concentration of oxygen have decrease. The communities’ responses in the wake of environmental changes brought on by the rapid eutrophication of shallow northern lakes. During the last 50 years the lake communities have exhibited a decline in biodiversity due to the human impact. The fish part of the society degrades step by step through the following phases: Salmonidae – Osmeridae – Coregonidae – Percidae – Cyprinidae. The occurring changes ichthyofauna define a urgency of revealing the display importance of those or other indicators as key parameters with the purposes of monitoring a biodiversity.

Different biotopes have their typical and specific species complexes, requiring different ways of protection. A great role for regional fauna preservation plays the founded protected area network, including biosphere Darwin Preserve, the Russian North National Park. But the efficiency of the network is not sufficient for regional fauna biodiversity preservation. Regions with unique biodiversity not included into the protected area network have been revealed. It’s necessary to found and to protect the most vulnerable waterbodies habitats. Special attention should be paid to the valleys of waterbodies by which many introzonal species penetrate into the region. Optimization of preservation activities should take into account biological and ecological specialties of animals as well as nature management. It is necessary to adopt measures to rehabilitate the lakes, to reduce the impact on the watersheds and improve protection of it and the small rivers (Bolotova, 2004). Long-term monitoring suggests that the pollution of water have increased as a result of human pressure on the watershed. The way of sustainable using this territory with nice landscapes is ecological tourism. The assessments are important tools for protection strategies that can be used in international monitoring.

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REFERENCES


