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DETERMINATION OF HYDRO-ECOLOGICAL FACTORS OF THE VOLGA-CASPIAN AQUATIC ECOSYSTEMS STABILITY IN DESIGNING THEIR PROTECTION

ABSTRACT

This paper discusses possible consequences of changes in the Volga-Caspian aquatic ecosystems resulting from climate change according to the data scenarios of the Worldwide Meteorological Organization. Main hydro-ecological factors of stability of the Northern Caspian Sea ecosystems have been determined. It appears that ecosystem stability in the Northern Caspian Sea is primarily affected by natural conditions. It is essential to model riparian ecosystem processes and winter regime of reservoirs to develop strategies for mitigation of negative impacts of climate change. Such measures may include improvement of existing dams in the Volga region.

KEY WORDS: Volga River, the Caspian Sea, aquatic ecosystems stability, hydro-ecological factors, climate change, sturgeon distribution.

Various scenarios of the Worldwide Meteorological Organization predict that mean annual air temperatures may rise by 4 to 8 °C [IPCC, 2001] during the nearest several decades in the region of the Caspian Sea and its watershed area. This climate warming may cause the volume of the annual water flow of the Volga to increase by 15–20%. However, this volume will not be evenly distributed through the year. During the spring flooding caused by snow melting, the volume of flow may be 40% higher than today, while during the summer rain floods, the volume of flow may decrease by 20% compared to the current values [Kuchment et al., 1990]. These processes will influence aquatic ecosystems causing changes that may be region specific.

In the area of the Upper Volga (Fig. 1.), increase in the flow due to snow melting and temperature rise together with greater precipitation and changes in snow melting processes may cause serious inundation. Inundation will widen the zones of underflooding, which may rise the ground water table and lead to expansion of swamp areas. This situation may negatively influence the aquatic flora and fauna. The region of the Upper Volga has vast wetland areas that may be very sensitive to climate fluctuations. In fact, according to E.V. Meyerner [1971] the characteristic feature of the Upper Volga reservoirs is the presence in their beds of a significant number of swamps. After navigation ends and waterways freeze and through the spring floods, the reservoirs are drawn down. For example, in Ivankovo reservoir, the uppermost reservoir on the Volga River, the water drop reaches six meters. The water from the shallow floodplain territories, including the wetland areas, flows into the deep channel part of the reservoirs causing oxygen deficit and massive fish kill. Therefore, it is very important to work-out a

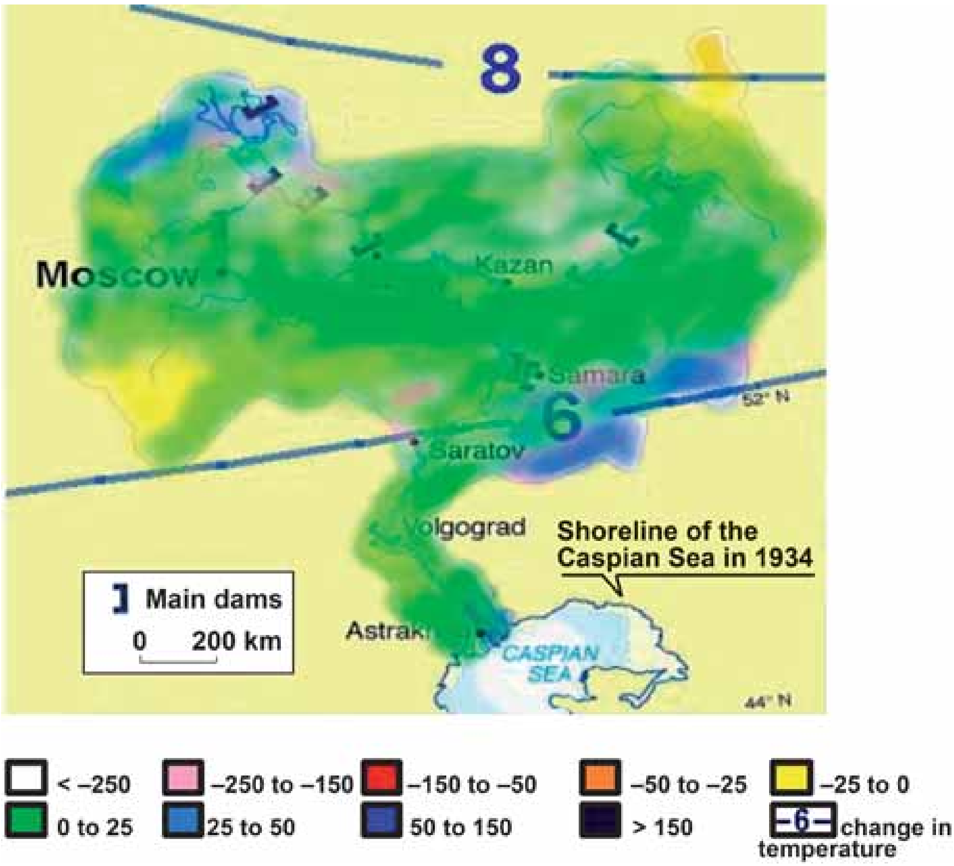

Fig. 1. Change in average annual runoff by 2050 in mm yr^{-1} and the change of annual mean temperature (isolines) in °C for the Volga River basin (according to [IPCC, 2001])

proper drawdown regime for the reservoirs considering possible riparian swamping and hydro-meteorological conditions.

Biodiversity and water quality may be also affected by climate change and by its impact on the aquatic ecosystems [IPCC, 1996]. Some researchers indicate that in the Middle Volga River region, higher water temperature may increase nitrogen and ammonium levels while decreasing the level of dissolved oxygen, especially during the dry and warm periods of the year [Ivanov, et. al., 2001] which ultimately leads to river water pollution. However, there is a lack of modeling efforts of river water quality under changing climate.

In the region of the Lower Volga, existing problems may intensify and new problems may arise. Thus, the projected temperature increase and decrease in the surface flow during summer may cause a greater demand for water in irrigated areas, which suffer from droughts even now. Climate change may lead to additional increase in water consumption [Ivanov, et. al., 2001] as water demand rises with population growth and economic development. In some countries, these two factors are considered more important than consequences of climate change. Changes in the level of inner waters may influence navigation regime, endanger fisheries, and alter spawning of existing and promote expansion of more heat-loving species of fish.

Parameters of the Caspian Sea hydrologic regime are determined by the global macro-circulation processes within the Atlantic-

European sector. The hydrological regime of the Caspian Sea has been projected through 2015 using a statistic model of the linear Marcov processes [Ivanov et al., 2001]. The Caspian Sea level that has been increasing in recent years (by 0,8–1,0 m over the last 10 to 15 years) due to the increase in the average air temperatures, the inflow of fresh waters, and the increase in the winters' severity is expected to stabilize at the average mark of 27,44 m by 2013. At the same time, decrease in salinity and increase in the surface sea stratum temperature will take place and will worsen the deep strata ventilation. Over the nearest years, complete oxygen depletion, emergence of the reduced form of sulfur and, possibly, free hydrogen sulfide in the deep-sea waters may be anticipated. Reduction in the thickness of a quasi-homogeneous layer and intensification of the summer thermocline as well as weakening of the autumn-winter convection will promote the lower delusion of polluted surface waters, which may endanger the Caspian Sea ecosystems.

Anthropogenic impact in the Caspian Sea is mostly associated with hydrocarbon and heavy metal pollution. This impact will inevitably intensify with growth of resources utilization and increase in oil pollution of the Caspian Sea surface.

The Volga River runoff is the most important pollution factor in the Northern Caspian Sea due to the river mouth location. River mouth areas represent natural complexes that have characteristic landscape structure which formation is influenced by mixing of fresh and marine waters, by complicated system of currents, and by dynamics of sediments. The important components of these complexes are the unique freshwater-marine ecosystems. Special hydro-chemical regime, biogen material brought by the rivers, and well-heated shallow-waters promote high bio-productivity of the river mouths that play major role in development of these ecosystems and have important ecological significance for large areas occupied by the river systems and seas. At the same time, the river mouths are especially sensible to anthropogenic impacts on the river basins and, first of all, to anthropogenic changes in the runoff. Even in the regions of sparsely populated seacoasts where industrial activities are absent, the consequences of anthropogenic impact on the runoff and water quality can lead to a noticeable degradation of the ecosystems of the mouth areas. Besides, natural resources of the sea shallows and the shelf oil fields, in particular, are the primary targets for intensive exploitation. This exploitation undoubtedly contributes to the deterioration and pollution of the adjacent river mouth areas.

The purpose of this work was to define factors of stability to anthropogenic impact of the most productive Northern Caspian ecosystems in order to design environmental protection measures. The term "stability" includes the ability of the ecosystem to maintain its structure, i.e., a set of components and their interworking, under anthropogenic load by changing individual parameters and properties and compensating for consequences that arise from incorporation of new elements different in origin [Odum, 1975; Reimers, 1990]. According to the founder of the modern hydrobiology academician S.A. Zernov [1949], conditions favorable for valuable commercial fish are also favorable, as a rule, to the entire biocenosis. Sturgeon species (*Acipenseridae*) are extremely long-lived commercial fish that are at the upper trophic level of the Caspian Sea. These fish are currently experiencing strong anthropogenic impact. Therefore, conditions that provide for stable existence of ***Acipenserida*** over its entire life cycle are also assumed to characterize stability of aquatic ecosystems of the northern part of the Caspian Sea. According to A. Poddubny [1971], even during volleys of sewage, some fish can identify the danger and escape from the polluted zone, which is possible as the oil pollution is still mosaic. It is possible that the ability to identify the polluted zone and to escape from this region makes the "factor of anthropogenic load" not so significant for the distribution of the *Acipenseridae*.

Table 1. Factors selected for analysis

Hydro-ecological factors	Factor load, %	Variables that have load on the factor (r > 0,6)	Factor characteristics
Natural conditions	39,7	X3 (–0,74) X4 (–0,63) X5 (0,79) X6 (0,71) X10 (–0,61) X11 (0,70)	Characterizes the influence of hydro-chemical, natural-climatic, biotic, and food supply features of the Caspian Sea on the distribution of sturgeon fish
Wintering/post-wintering	15,5	X1 (0,85) X2 (–0,67) X7 (0,65) X9 (0,69)	Enables assessment of the influence of temperature, drops of depth (presence of wintering pits), ice cover, and abundance of zooplankton on the distribution of sturgeon fish during the winter.
Anthropogenic load	12,7	X8 (–0,70) X12 (–0,81) X13 (0,72)	Shows the determining influence of the Volga River flow on the influx and spread of pollutants in the water body of the Northern Caspian Sea

Six species and one subspecies of sturgeon population in the Caspian Sea, which belong to two genera, i.e., ***Huso*** and ***Acipenser***, were selected to study and assess principal hydro-ecological factors that influence the distribution of *Acipenseridae* in the northern part of the Caspian Sea. For each location (we studied 260 location points in the Northern Caspian Sea), we received data on 76 parameters, including physical-geographical, hydro-chemical, hydro-biological characteristics, which have been analyzed using a pair correlation method. The results of these analyses were used to select several main hydro-ecological variables that characterize the ecosystem according to its principal functional features. These variables are: X1 – average long-term temperature of the water surface during February (°C); X2 – ice cover distribution (specifically, thickness of ice during harsh and mild winters entered with numeric scores); X3 – NO_2 on the sea surface (mkg NO_2/l); X4 – O_2 (mg/l) on the sea surface; X5 – average annual salinity (°/oo) in the water body; X6 – radiation balance per year (MJ/m^2); X7 – depth, (m); X8 – distance from the Volga-Caspian main canal (km); X9 – total zooplankton biomass (g/m^2) in the Caspian Sea; X10 – phytoplankton biomass (mg/m^3) in the Caspian Sea; X11 – biomass of zoobentos (g/m^2); X12 – average annual content of phenols (mg/l) in the water body; X13 – average annual distribution of oil hydrocarbons (mg/l) in the water body; X14 – average annual data on five sturgeon species catch. In order to assess the influence of abiotic environmental factors on the survival of ***Acipenseridae,*** we processed the obtained basic variables that characterize the integral state of ecosystems using factor analyses, where the dependent variable У = catch of *Acipenseridae*. We assigned factor loads of 13 parameters on three common factors received using the method of principle components. Then, the final factor loads were received in the result of three rotations. The rotations were performed for more accurate estimation of the loads of individual variables of the main components. The analysis showed that all significant variables (1 to 13) can be combined into three integral hydro-ecological factors according to the loads (Table 1).

Each group of parameters contributes to some factor and has its own meaning. Factor 1 has the greatest value of the total dispersion in the factor matrix – it defines 39.7% of the variables. Variables X3, X4, X5, X6, X10, and X11 have the highest load on the factor. Taking into consideration the meaning of the parameters included into this factor, we can say that this factor characterizes the influence of hydro-chemical, natural-climatic, biotic, and food supply properties of the Caspian Sea on the distribution of

Acipenseridae. We defined this factor as "natural conditions".

Factor 2 has the second degree of importance; it defines 15,5% of the total dispersion (Table 1). Variables X1, X2, X7, and X9 have the highest significance which enabled us to define it as "wintering/post-wintering" factor. This factor evaluates the influence of temperature, drops of depth (presence of wintering pits), ice cover distribution, and abundance of zooplankton on the distribution of sturgeon during winter. This factor defines the seasonal migration of sturgeon in the Caspian Sea water as well as the conditions of formation of the food supply for the next feeding period.

Factor 3 represents the third significant factor. Its input to the total dispersion in the factor matrix is 12,7%. The maximum load of variables ($r > 0,7$) of parameters X8, X12, and X13 on this factor indicates that it could be defined as "anthropogenic load" factor. This factor includes not only variables that characterize distribution of oil and phenols in the water body, but the variables that characterize the influence of the Volga flow as well. Our studies show that the annual dynamics of oil hydrocarbon content in the Volga and the Northern Caspian Sea are synchronized. Fluctuations in concentrations of oil hydrocarbons and phenols in the Volga River during each specific year are accompanied by a similar trend in changes of concentrations of these substances in the Northern Caspian Sea.

CONCLUSIONS

It is possible to mitigate negative impact of climate change. The following measures may contribute to development of such policies:

- modeling the processes of riparian swamping and winter regime of the reservoirs drawdown in the Upper Volga River region under climate change;
- reconstruction of existing dams in the Middle and Lower Volga River regions that are essential for conservation of water resources for consumption and for enhancing water quality (dilution of industrial, municipal, and agricultural waste) as well as for maintenance of spawning areas;
- urgent measures for reduction of man-caused impact on the Caspian Sea environment.

The main hydro-ecological factor of ecosystem stability in the Northern Caspian Sea is the "natural conditions" factor. It means that the process of dynamics of natural conditions in the region (including climate change) can lead to the most significant changes in the ecosystems. It is also important to model the influence of climate change on sub-aquatic conditions which may lead to changes in aquatic ecosystem composition and their health and stability.

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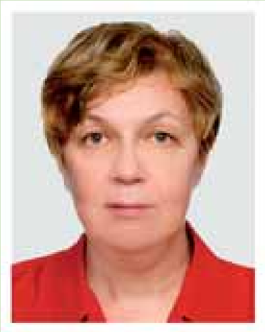

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