Forecast of the State and Management of Bioresources of the Volga Basin

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Abstract. In the article, the authors give a brief description of EIS REGION, designed to build predictive models of changes in the parameters of biological resources of territories from environmental factors and anthropogenic impacts. On the example of a large region (the Volga basin), a forecast of changes in primary biological productivity under conditions of global climate warming was carried out using EIS REGION. Some variants of influence on bioproductivity of anthropogenic pollution and the level of economic development of the subjects of the region are considered. The authors that in conditions of climate change with an increasing thermal trend, an increase in the primary biological productivity is predicted for all-natural zones of the Volga basin. In this regard, we specifically forecast that an increase in temperature and a decrease in climate humidity will relatively favourably affect the ecosystems of the taiga zone - a zone of lack of heat and excess moisture. The predicted climate change will be less favourable for the forest-steppe and steppe zones, since an even greater climate aridization is expected here.

1. Introduction

Any science in the process of cognition of the surrounding world and its development goes through, at least, three main stages. The first is the stage of accumulation of empirical knowledge (descriptive, inventory), the second one is conceptual-theoretical (the formation of a list of scientific concepts, hypotheses about the structure and mechanisms of functioning of the described systems), and finally, the third one is the formalization of these ideas in the language of mathematics. Ecology is no exception to this general rule: an ecologist wants to know what ecosystems surround him, how they are arranged and functioning, how they can be classified, how to evaluate their boundaries, how to describe, optimize and manage their productivity, on what principles to create artificial ecosystems, etc. It should not be forgotten that "the most important tasks of hydrobiology and hydroecology (and ecology in general. - Authors) can be considered the assessment of the state and forecasting of possible changes in aquatic ecosystems under the influence of external, especially anthropogenic, factors, determination optimal conditions and degree of ecosystem exploitation" [1, p. 7]. Naturally, the solution of these problems is possible only with a sufficient degree of development of the conceptual and formal theoretical stages.

Any natural science theory performs several functions, among which the most important are the functions of explanation (establishment of cause-and-effect relationships) and prediction of the ob-
served phenomena in the studied class of systems. The separation of the functions of explanation and forecasting for complex systems within the framework of at least two models nullifies the whole discussion about the primacy of simplicity or complexity in ecology. Simple models are needed for an explanation, for ecological forecasting the complexity of the model is fundamentally necessary (according to the expression of the Ukrainian academician A G Ivakhnenko, “another cat is be the best model of a cat”). Thus, the role of a constructive systematic approach in the creation of an ecological theory is reduced to the assignment of a "complete list" of ecosystems and their complex characteristics and to the construction of formalized relations both between these two sets and between the elements of the first of them for the purposes of explanation or forecasting.

The development of ideas about the means and methods of solving information problems led to the emergence of geographic information systems (GIS) and eco-information systems (EIS), which provide storage and online access to a set of data and knowledge about ecosystems, about the interaction of nature and society. EIS-assessment of the environmental quality of a large region (including the basin of a large river) is intended primarily to study the spatial distribution of the values of its parameters various abiotic and biotic components and the degree of impact on them of human economic activity (anthropogenic load).

2. Materials and Methods
The Volga basin occupies an area of about 1.36 million km² (62% of the European part of Russia, 8% of all Russia, or almost 13% of the entire territory of Europe) and includes 41 administrative units (regions, republics and our capital - Moscow), two of them are in Kazakhstan, the rest are in Russia (see also the Preface in this issue of Conference series), forest-steppe (Samara and Saratov), steppe (up to Volgograd) and semi-desert zones.

In terms of emissions of harmful substances into the atmosphere, one can distinguish the zones of Moscow, Yaroslavl and Tula regions and the Middle Volga region (Tatarstan, Udmurtia, Samara region). Large industrial centers are also distinguished (for example, Saratov, Volgograd, Ufa). The industrial load should also include the impact on water bodies. The zones of increased pollution are again Moscow, Tula, Nizhny Novgorod, Samara and Perm regions, Bashkortostan.

When analyzing the agricultural load in the region, the Republics of Bashkortostan and Tatarstan should be highlighted, which practically by all indicators exert the maximum "pressure" on the environment, as well as Moscow, Vladimir, Ivanovo and Kostroma regions. In general, with the stabilization of the gross harvest of grain crops over the past 15 years, the growth of industrial (by 30%) and fodder crops (by 25%), a slight decrease in "pressure" on the soil can be noted due to a decrease in the "carry-over" of nutrients with the crop for Saratov, Volgograd, Samara, Perm and Moscow regions. The livestock load, on the contrary, increased in Saratov, Kirov and Tver regions. Melioration (including the application of mineral fertilizers), with a general tendency to growth (the application of fertilizers in Russia over the past 10 years increased by 40%, the area of irrigated and drained lands - by 25%) decreased in Bashkortostan, Astrakhan, Perm regions, but increased in Mordovia, Kaluga and Kirov regions. The change in the generalized agricultural load allows us to conclude that it is increasing in Kirov region, Tatarstan, Mordovia, Ulyanovsk and Ryazan regions, and decreasing in Volgograd, Tver and Vladimir regions.

The assessment of the transport load on the basin included indicators of the density of the road network, the "density" of vehicles in the territory, the number of road traffic accidents, etc. Naturally, Moscow region experiences the greatest traffic load. This is followed by Samara, Nizhny Novgorod, Tula regions, Tatarstan. Over the past 20 years, a decrease in traffic load has been observed in most of the basin, but especially in Yaroslavl region; the increase occurred in Saratov and Astrakhan regions.

All this makes the region of the Volga basin one of the most stressful in terms of the ecological situation [2].

In the context of this study, the main attention is paid to bioresource indicators (primary biological productivity of forest ecosystems [t/ha per year], the number of certain animal species, etc.).
EIS REGION, developed at IEVRB RAS [2-5], is one of the first experiments in the complex analysis of spatially distributed information, meets all the requirements for expert systems, and is designed for collecting, storing data, analyzing and visualization of processing results. EIS REGION is a complex of integrated programs that allow in the process of interactive work with the user to select any information objects (spatial or digital) available in the information support of the system and perform various operations on them.

EIS REGION represents 24 administrative units of Russia, which cover more than 90% of the entire territory of the Volga basin. Within EIS REGION, the study area is divided into 210 areas, for which more than 600 indicators were digitized in the database [2-4]. A comprehensive analysis of the available information using the modules of the expert system makes it possible to assess the ecological state of the Volga basin in terms of ecological, economic and social indicators.

The EIS software includes the following main blocks that implement the functions of data processing and visualization:

- multidimensional search and formation in the dialogue mode of a subset of indicators according to the available fields of the rubricator;
- graphic display of cartograms of the spatial distribution of each indicator of the base by areas of the territory;
- obtaining calculation tables for assessing structural and model characteristics (for example, components of technogenic and bioenergy flows);
- construction of new (integral) indicators by a linear combination of a subset of indicators available in the database, or by other calculation formulas;
- mathematical processing of base indicators for the purpose of ecological zoning of the analyzed territory, identification of areas subject to the greatest anthropogenic impact, assessment of the biotic and geochemical state of individual natural complexes.

There is a transfer of diverse indicators that have different units of measurement and are expressed in the form of absolute values, intervals, ranks, etc., into a normalized scale of points to obtain adequate processing results. The choice of the rationing method depends on the nature of the distribution of the indicator and the presence of an ecological optimum. The allocation of areas of the same type (zoning) of the territory according to the selected set of indicators is carried out by standard procedures of cluster analysis. As a criterion for the natural classification of data, several approaches (algorithms) of cluster analysis are applied. If the results obtained are close, then they are adequate to reality. Otherwise, it is assumed that there is no natural classification or it is too vague and the problem of cluster analysis has no solution.

Methods of factor analysis, selection of principal components, multidimensional scaling, neural network modeling, etc. are used to reduce the dimension of the initial information (data reduction). The complex application of these processing methods makes it possible to identify the main regularities inherent in a data set: its internal structure, division into classes (if any), the existence of various dependencies between indicators, etc. The implementation of multidimensional scaling procedures, factorial and cluster analysis is carried out using standard and original programs.

The main task of the EIS is not only to accumulate current or retrospective information, but also to carry out a comprehensive analysis of the state of the region's ecosystems, to forecast the conditions for sustainable socio-ecological development of the territory. For this, a developed library of methods and algorithms for studying causal relationships between factors of the ecological and economic system has been formed as part of the system software.

Methods of multiple regression analysis, pattern recognition, self-organization models (evolutionary and neural network modeling, method of group consideration of arguments) are used to assess scenarios of possible development of territories under various anthropogenic impacts and modeling relationships. The block "Modeling links" provides ample opportunities for building statistical models of different types and levels of complexity. As an add-on to the library of methods, a heuristic procedure for forming a "collective" of predictors has been developed, the effectiveness of which is almost always much higher than any of its members [4-6]. Structural connections in the "collective" are chosen.
in such a way that the positive properties of a particular model complement each other, and the negative ones are compensated (that is, the effect of a systemic nature of the "whole is greater than the sum of its parts" would work).

Formally, REGION can be classified as a “non-classical” type of GIS. Its main difference from the "classical" GIS is the refusal to detail the purely geographical aspects of the territory. An indicator of arbitrary etiology (ecological, economic, climatic and even purely geographical) is "tied" to a certain area of a square or rectangular shape, which often has a fairly large area. Each of these areas is roughly displayed on a schematic map of the region, keeping in mind the exact geographic coordinates or landscape elements. Having sacrificed geographical aesthetics, which in relation to spatially blurred ("dirty") data is hardly justified by necessity, such an EIS acquires no less attractive qualities: cheapness, economy in resources, ease of mastering, operation and interpretation of the output data.

Finally, the development of a wide range of issues related to ecosystem services is actively beginning today: definition, functions, assessment, compensation mechanisms, the formation of markets for these services, the identification of potential sellers and buyers. Ecosystem services are all the benefits that humanity derives from ecosystems. In other words, these are ecosystem services to provide humanity with natural resources, a healthy living environment, and other ecologically and economically significant “products”. Among the numerous ecosystem services, there are: supplying (food, water, forest, raw materials), regulating (impact on climate, control over floods, natural disasters, water quality, etc.), cultural (recreational resources, aesthetic and spiritual values of nature) and supporting services (soil formation, photosynthesis, nitrogen cycle, etc.).

It is not possible to create an adequate market for each of the above ecosystem services. Numerous studies have shown that currently there are several categories of ecosystem services for which it is realistic to use compensation payments and create markets. These are, first of all, services for the provision of fresh water of proper quality, carbon sequestration (maintenance of biological productivity), preservation of biodiversity and aesthetic properties of landscapes. These four "products" (each includes a whole range of services) today have a relatively easy-to-calculate economic value that can be "sold" if properly "advertised".

Thus, in order to achieve sustainable development, ecosystem services and natural resources must be included in the economic mechanism of nature management as goods. To do this, it is necessary to establish their values comparable to the values of products and services created by labor [7]. Environmental economics requires us to define:

- how many of the natural life support systems we need we can allow to irrevocably lose,
- to what extent natural capital can be replaced by capital produced by labor and how much of this natural capital is irreplaceable.

At each time interval, it is necessary that natural resources are allocated on the basis of their real value in a given time period.

3. Results and Discussion

3.1 The state of productivity of forest ecosystems in the Volga basin at the end of the twentieth century

In accordance with the scheme of dividing the Earth's land into thermal zones and bioclimatic regions, the boreal and subboreal thermal zones are distinguished within the Volga basin. Forests are confined to the boreal belt, humid and semi-humid bio-climatic regions of the subboreal belt.

Vast areas of the northern reaches of the Volga basin are occupied by the formation of spruce forests. The middle taiga zone is located here. In its western part, European spruce (Picea abies (L.) H. KARST., 1881) dominates; in the eastern part - Siberian spruce (Picea obovata LEDEB., 1833). Spruce forests are widespread outside the taiga zone, penetrating south into the broad-leaved-coniferous zone. Herb spruce forests dominate here, sometimes shrub-herbal ones. It should be noted that the maximum productivity of spruce forests is noted precisely on the southern border of the area of their distribution. This is completely determined by the potential of this breed and natural condi-
tions, first of all, by the richness of soils, to which the spruce is especially sensitive, as well as by the low level of waterlogging, since spruce avoids gley soils.

Broad-leaved-coniferous forests in a wide strip, gradually narrowing from west to east towards the Urals, extend from the western borders of the Volga basin, covering the Smolensk-Moscow Upland and the Vyatka-Kama basin in the east. The species of broad-leaved-coniferous forests include the pedunculate oak (Quercus robur L., 1753), often the heart-leaved linden (Tilia cordata MILL., 1768), and other broad-leaved species. Broad-leaved-coniferous forests do not extend as a continuous strip, they are characterized by interspersions in the same zone of spruce, pine, small-leaved coniferous and small-leaved forests. The productivity of oak-linden-spruce herbal forests in the western part of the basin of the zone of broad-leaved-coniferous forests is quite high [8, 9].

The zone of deciduous forests within the Volga basin extends in an increasingly narrowing strip from west to east. It consists mainly of oak groves of pedunculate oak, partly lime forests of cordifolia. Linden forests are mainly to the east. However, deciduous forests are also found outside the deciduous forest zone. Their large tracts are not uncommon in the zone of deciduous-coniferous forests, in the forest-steppe zone. Some of their massifs enter the zone of real steppes. In this regard, the productivity indicators of deciduous forests vary quite widely. Nevertheless, there is a general trend towards an increase in annual productivity from the zone of deciduous-coniferous forests to the zone of broad-leaved forests and a slight decrease in the indicator in the forest-steppe zone and especially in the steppe zone. Deciduous forests are much more productive within the zone of deciduous forests proper. The highest productivity is in forests at the age of 70-80 years. It falls noticeably in over-mature oak forests, where litter and mortality exceed production, which indicates the destruction of these oak forests. The productivity of deciduous forests within the steppe zone, where it is formed both in the bayraks and in the interfluves, according to average indicators, is even more reduced in comparison with deciduous forests in the zone of deciduous forests proper.

Primary and derivative forests of Scots pine (Pinus sylvestris L., 1753) are extremely widespread, from the northern borders of the Volga basin to the zone of true steppes, inclusive. For the most part, they are confined to sands or bedrock outcrops. The productivity of pine forests within the same zones is quite close to the productivity of indigenous spruce forests and larch forests. Pine forests in the zone of deciduous-coniferous forests occupy vast outwash plains; productivity is relatively low. In the zone of deciduous forests, pine forests are also quite widespread. The general indicators of productivity of pine forests of all types are decreasing here, which, apparently, is associated with less favorable moisture conditions.

Small-leaved and small-leaved-coniferous forests, predominantly from the birch (Betula pendula ROTH) and aspen, are extremely widespread from the middle taiga to the steppe zone, inclusive. Most small-leaved and small-leaved-coniferous forests are secondary in the place of felled primary forests.

In the southern taiga zone, birch and spruce-birch forests are widespread, since primary forests have undergone especially intensive felling here. In the Upper Volga basin, the lowest productivity is in dwarf birch forests. In all types of birch forests, products are formed mainly due to green assimilating organs. The relationship between the values of productivity and the age of forests is traced and it is revealed that the maximum productivity in dwarf and grass-dwarf birch forests is inherent in forests at the age of 50-60 years, and in grass birch forests at the age of 40 years.

Along with birch, mainly secondary forests, aspen forests are widespread in the southern taiga zone. Aspen forests, mainly grass, are more productive than birch forests. Aspen is the most productive secondary species; its productivity is usually higher than the productivity of primary forests of the same habitats. The maximum values of productivity are traced in aspen forests at the age of 40-45 years, which is also true for herbal birch forests. However, unlike them, wood plays a leading role in the production of aspen forests, which puts them on a par with deciduous forests.

Summarizing the regularities of the distribution of productivity indicators for various types of forests, common in the Volga basin, we can say that higher productivity is observed in the primary forests of all zones found here. It is characteristic that, within each province, the maximum productivity of boreal formations of both primary and secondary forests was noted in the southern taiga zone. They decrease
somewhat in the zone of deciduous-coniferous forests and noticeably fall in the forest-steppe and steppe zones. The most productive subboreal broad-leaved forests are in the zone of broad-leaved forests. Their productivity decreases in the forest-steppe and steppe zones [10]. The productivity of derivative pine forests is everywhere or equal to or somewhat lower than the productivity of primary forests. The productivity of small-leaved primary and secondary forests, especially secondary birch forests, is significantly lower than the productivity of coniferous primary forests, as well as pine forests. In this case, the productivity of aspen forests is usually higher than the productivity of birch forests.

Within the Volga basin, steppe vegetation is represented by a zone of meadow steppes and a zone of real moderately arid steppes. The vegetation cover of the steppes is of the same type and is composed of representatives of rhizome and turf grasses, and steppe mesoxerophilic and xerophilic forbs. The steppes are now almost completely plowed up, areas of natural steppe vegetation have been preserved only in the territories of reserves, in the gullies and on the edges of the forest. The productivity of meadow steppes, which are mainly distributed in the southwest of the Volga basin, is formed mainly by underground organs. The productivity of moderately arid steppes on the territory of the Volga basin is represented mainly in the south of the Samara region and partially in the south-east of Bashkortostan. The productivity of moderately arid steppes is much less than in meadow steppes, which is due to the longer duration of the summer pause.

Meadows, both mainland and floodplain, occupy quite significant areas in the steppe zone. Continental meadows are formed along forest clearings and edges (forest-steppe), on the slopes of steppe ravines, in depressions near the girders, along lake depressions. They are characterized by high productivity rates [11]. It should be noted that in the zone of real moderately arid steppes, there are the same types of meadows as in the zone of meadow steppe. In the left-bank part of the middle Volga basin, the total productivity of meso-phytic meadows is lower than in the zonal steppes, and the significance of the green part in them is also greater. Solonetz meadows in the zone of moderately arid steppes on meadow crust solonetzes are characterized by significantly lower indicators than similar meadows in the meadow steppes zone.

Steppe landscapes are distinguished by a high contrast of biological productivity indicators between zonal and intro-zonal formations, rather than forest landscapes. The most productive are meadow steppes, and as they move to the south and soil salinization, their productivity decreases. The structure of production of steppe formations is dominated by underground organs.

The high level of productivity in herbaceous ecosystems is explained by the fact that, being in the area of maximum fluctuation of hydrothermal indicators over the years, they strive to fully use the conditions of the growing season, giving each time the maximum productivity at given temperatures and moisture. To the north and south, this indicator rapidly decreases, since already in dry steppes, productivity is limited by water reserves or its salinity. Forest ecosystems, successively more mature and growing in a more stable climate of the North, are characterized by the formation of a larger stock of phytomass, rather than maximum production.

3.2 Forecasting the productivity of forest ecosystems

Predicted climate changes must inevitably have a significant impact on natural ecosystems, displacement of natural zones. To predict such changes, various methods and paleo-analog scenarios of the future climate are used [12]. The synthesis of multiple regression equations using the EIS REGION makes it possible to analyze various dependences of indicators of bioresources and biological diversity with natural parameters and anthropogenic factors for the territory of the Volga basin.

From the REGION database, to assess the productivity of forest ecosystems in the Volga basin, we used hydroclimatic parameters (such as average temperatures in January and July, annual total radiation and precipitation amounts for cold and warm periods, etc., calculated for the base period - the average for the XX century). For all areas, the average value of the indicator was calculated, which was adopted for each point of the selected area. The Volga basin covers the most industrially developed part of the European territory of the country, where there is a very high level of anthropogenic pres-
sure on natural ecosystems. The REGION database contains many indicators based on the data of the anthropogenic component, the accounting of which is a distinctive feature of the model we have built.

To build a predictive model of changes in primary biological productivity in a changing climate and an increase in anthropogenic impact on ecosystems, we used a multiple correlation regression algorithm with the exclusion of insignificant indicators by the method of I Ya Liepa [13], available in the REGION expert system. Using the hydroclimatic information of the base period, as well as some parameters of anthropogenic impact on the territory of the Volga basin, the equation (model) \( Y = f(X_1, X_2, \ldots, X_n) \), is obtained, presented in table 1.

### Table 1. Factors affecting the change in primary bioproductivity (Y)

| Factors included in the regression model                  | Regression coefficients | Share of influence |
|-----------------------------------------------------------|-------------------------|--------------------|
| Free member                                               | -2.180                  |                    |
| January temperature, 0C (X_1)                             | 0.113                   | 5.30               |
| July temperature, 0C (X_2)                               | 0.249                   | 11.33              |
| The amount of precipitation for the cold period, mm (X_3) | 0.015                   | 19.71              |
| The amount of precipitation for the warm period, mm (X_4) | 0.014                   | 35.91              |
| Annual total radiation, MJ/m2 (X_5)                      | 0.0001                  | 1.15               |
| Gross regional product in 2019, million rubles/person (X_6)| -0.014                  | 3.78               |
| Total emissions of pollutants into the atmosphere         | -0.046                  | 1.47               |

| Accumulated sum of specific influence of factors, %      | 78.65                   |
| Multiple correlation coefficient                         | 0.875                   |

The results obtained indicate that the greatest contribution (35.9%) to the level of bioproductivity of forest plant formations is made by the amount of precipitation for the warm period (X_4). This can be explained by the fact that during the active growing season, the water consumption of plants reaches its maximum values, and in July, herbaceous plants go through the phases of stemming, heading (for cereals) and flowering, and in the stands, the formation of early wood is completed and late wood is laid. The share of influence (19.7%) of precipitation during the cold period (X_3) is high, since the degree of production moisture in the meter layer of soil in the spring, when the period of active vegetation begins, depends on their amount. An important factor for primary bioproductivity is the average July temperature (11.3%). The fact is that in the process of regional forecasting and ecological studies, close relationships were established empirically between the July reserves of productive moisture in the soil with the moisture coefficient of N.N. Ivanova - G.N. Vysotsky [13]. In turn, this indicator is determined almost exclusively by the average July temperature.

As parameters of anthropogenic impact, the model includes the total emissions of pollutants (X_5), which consist of carbon monoxide, nitrogen oxide, sulfur dioxide, etc. (the contribution of this indicator to the overall variation is extremely low, although it is reliable, - less than 1.5%). For calculations, the model considers two options for the levels of pollutants 20% and 50% higher than the average for 1995-2019.

Another anthropogenic factor is the gross regional product, which is assumed to be 2 times higher than the level of 2018. The higher the gross product in the region, the higher the level of development of industry and agriculture and, therefore, the higher the anthropogenic load on the territory. The share of these indicators, although not high, nevertheless, they have a negative effect on bioproductivity (i.e., reduce it).

Figure 1 shows the forecasts of the productivity of forest ecosystems of the Volga basin according to the regression model \( Y = f(X_1, X_2, \ldots, X_n) \), presented in table 1.
If we analyze the change in the level of productivity in natural zones within the Volga basin, then in 2030 aridization of the forest-steppe and steppe zones is expected. Summer temperatures here will rise more significantly than throughout the Volga basin (by 2.4°C compared to the base period). The amount of annual precipitation will increase less than twice as compared to the taiga zone. Although the winters will become warmer, the snow cover will not increase much. Therefore, the increase in primary productivity is predicted to be less than in other zones. In the steppe zone, productivity will increase by 1.7 t / ha / year, and in the forest-steppe zone - by 1.9 t / ha / year. The greatest increase in the level of bioproductivity is expected in the southern taiga zone - by 2.8 t / ha / year compared to the base period. Since the taiga zone is a zone of insufficient heat supply, an increase in summer temperatures by 2°C can have a positive effect on increasing the productivity of spruce forests in the southern taiga zone, which are very sensitive to waterlogged soils.

Base period (average for the XX century)  Forecast for 2030

Forecast for 2050

Figure 1. Primary biological productivity of the ecosystems of the Volga basin, t / ha per year.

In the zone of middle taiga, mixed and deciduous forests, an increase in the level of productivity is expected by 2.4 t / ha / year. July temperatures here will increase by an average of 2°C, slightly less in the middle taiga - by 1.7°C. Average annual precipitation in the mixed and deciduous forest zone will increase by a little more than 100 mm / year, while in the middle taiga zone, more precipitation is ex-
pected - closer to 130 mm/year. It should be noted that winter will also get warmer here than in other zones and the level of annual total radiation will increase the most - by more than 500 MJ/m².

Climate warming, expected in 2050, will be most favorable for the bioproductivity of the middle and southern taiga zones. Here it will increase by 3.7 t/ha/year and 3.8 t/ha/year, respectively. July temperatures will rise in the taiga zone by 2.4-2.8°C. Significant warming is expected in winter, especially in the middle taiga zone (it is assumed that here the January temperature will rise by 5.7°C, which is much higher than in other zones). Annual precipitation will increase from 200 to 220 mm/year. The level of annual total radiation will again increase most of all in the middle taiga zone - by 640 MJ/m².

In the zone of mixed and deciduous forests, changes in hydroclimatic indicators will occur at approximately the same level: the July temperature will increase by 2.8-2.9°C, winter temperatures - by 4.1-4.3°C, the amount of annual precipitation will increase at 165-170 mm/year. With such climate changes, the level of productivity will increase by 3.3 t/ha/year.

In the zone of the forest-steppe and northern steppe, the level of productivity by 2050, as well as in the forest zone, will increase by the same amount - 2.8 t/ha/year. The July temperature in both zones will increase by 3.1°C, while the annual precipitation in the forest-steppe zone will be 20 mm/year higher. It should be noted that climate humidity will increase throughout the Volga basin by 2050.

Summarizing the above, we can say that in conditions of climate change with an increasing thermal trend, an increase in the primary biological productivity is predicted for all natural zones of the Volga basin. For the period of 2030, a steady increase in productivity is predicted in areas of mixed and deciduous forests. In the southern taiga zone, the highest level of increase in this period is observed - by 2.8 t/ha/year relative to the base period. And in the zone of middle taiga, the increase is assumed to be the same as in the zone of nemoral forests - by 2.4 t/ha/year. The lowest level of increase in the indicator is expected in the steppe zone, obviously because this period is expected to be the driest here. With an increase in July temperatures by 2.4°C, precipitation will increase slightly. For the period of 2050, the largest increase in the indicator relative to the base period is assumed in the southern taiga zone - by 3.8 t/ha/year, and relative to the previous period (2030) - a larger increase in the middle taiga zone (by 1.3 t/ha/year, while in other zones by 0.9-1.0 t/ha/year).

In this regard, it can be assumed that the conditions of an increase in temperature and a decrease in climate humidity will relatively favourably affect the ecosystems of the taiga zone - a zone of lack of heat and excess moisture. The predicted climate change will be less favourable for the forest-steppe and steppe zones, since an even greater climate aridization is expected here.

3.3 Forecasting the state of bioresources in the Volga basin

We used EIS REGION as an example of the processing algorithms’ efficiency, various dependences of the biodiversity indicator (figure 2), assessed by the Shannon index, with natural parameters and anthropogenic factors. A complete statistical processing of the spatially distributed information was carried out, the regression equations were built.

The distribution of terrestrial vertebrate species over the territory of the Volga region is uneven, which is explained by the large area of the region and its considerable length from north to south and, to a lesser extent, from west to east, and related changes in temperature and humidity. In general, the diversity of mammalian species, increasing from north to south, reaches its maximum in the central regions of the Volga basin and further to the south decreases again. The same pattern is typical for amphibians. Reptiles show a clear increase in diversity from north to south. In the north, low temperatures are the limiting factor in the distribution of terrestrial vertebrates. This is especially true for amphibians and reptiles.

Impact analysis allows us to conclude that the factors affecting biodiversity are “important” (see table 2; here 1 is the most “important” factor). In all cases, the most significant indicators were the temperature regime of the territory; the “average impact” on the biodiversity of all objects is provided by forest cover, population density and fertilizers applied to agricultural fields. The rest of the parameters play an insignificant but specific role.
Figure 2. Distribution of species diversity of different organisms (in points) on the territory of the Volga basin (1 - low; 3 - high)

a - mammals, b - amphibians, c - reptiles

Linear regression equations for predicting the diversity parameters of mammals, reptiles and amphibians of the Volga basin are as follows:

\[
Y_1 = -3.56 + 0.24X_1 + 0.82X_2 + 0.37X_3 - 0.27X_5 + 0.21X_6 + 0.27X_7 + 0.42X_8,
\]

\[
Y_2 = 1.63 + 0.29X_1 + 0.29X_2 + 0.20X_3 - 0.14X_4 - 0.19X_5 - 0.07X_7,
\]

\[
Y_3 = -0.80 + 0.43X_1 - 0.25X_5 + 0.14X_7 + 0.33X_9 + 0.32X_9 + 0.41X_{10},
\]

where \(Y_1, Y_2\) and \(Y_3\) are Shannon biodiversity indices for mammals, reptiles and amphibians of the Volga basin, respectively; parameters \(X_i\) - see table 2.

The nature of the distribution of the species diversity of each of the administrative units in the Volga basin positively correlates with their landscape diversity, depending on the area and geographical location of the region. The latter is most pronounced in the Middle Volga and the Urals (Mordovia, Tatarstan, Bashkortostan, Ulyanovsk, Samara regions), at the junction of forest (mixed and deciduous forests) and treeless (steppe and semi-desert) landscapes. The distribution of reptiles deviates from the above - their diversity increases from north to south, reaching a maximum in Astrakhan region.
Regression equations allow one to "play out" different scenarios of impact on biodiversity. For example, an increase in forest cover for Samara region (X7) by 10% with the average values of other indicators leads to an increase in the Shannon index for mammals (Y1) by 3-4%; for Bashkortostan, a 20% decrease in the generalized effect of fertilizers (X5) will increase this Shannon index (Y1) by 4-5%.

Table 2. Scoring the importance of influencing factors on biological diversity

| Parameter                                      | Mammals | Reptiles | Amphibians |
|-----------------------------------------------|---------|----------|------------|
| Average annual air temperature - X1          | 6       | 1        | 1          |
| Absolute max air temperature - X2             | 1       | 2        |            |
| Absolute min air temperature - X3            | 2       | 4        |            |
| Average annual precipitation, mm - X4        |         |          | 6          |
| Generalized indicator of the effect of fertilizers, points - X5 | 4   | 3        | 6          |
| Generalized indicator of transport load, points - X6 | 7   |          |            |
| Forest cover, percent - X7                    | 3       | 5        | 5          |
| Population density, people / km² - X8        | 5       |          | 3          |
| Discharge of polluted water / area, thousand m³/km² - X9 | 4   |          |            |
| Generalized pesticide load, points - X10     |         |          | 2          |

3.4 Ecosystem services and their forecasting for forest ecosystems

Some researchers argue that it is impossible to establish the economic value of such "intangible" categories as human life, the aesthetic aspects of the natural environment, or long-term ecological services. Simple market solutions are also very difficult in the presence of common ownership of many natural resources (for example, the common ownership of several states in sea areas). But in life we face similar problems every day. To conserve our natural capital, we must accept the need for difficult choices and valuation rather than deny their existence. Ecological economics recognizes several different independent approaches in determining the values of natural resources, although they all carry a high degree of uncertainty [14,15].

The first most famous experience of the global assessment of ecosystem services [7], which caused numerous discussions, gave the total annual estimate of the accounted functions of the planet's natural ecosystems on average $33 trillion, which is almost twice the GNP created by mankind ($18 trillion/year).

The simplest way to assess the ecosystem services of a particular territory can be reduced to determining its share in the total area of the Earth and, in proportion, to $33 trillion. Thus, the area of the Volga basin (1.36 million km²) is 0.2667% of the Earth's surface area (510.072 million km²); thus, the cost of a "full package" of ecosystem services for the Volga Basin is approximately $88 billion; taking into account the inflation of the American dollar for 30 years (on average, 2.2% per year), this estimate has practically doubled and we can take it equal today to $160 billion.

And the last thing. In an earlier study [16], an assessment of the recreational services of forest ecosystems for Samara region was made. In a similar way, we will calculate the same estimate for the entire territory of the Volga basin. The total area of forests in the Volga-North Caspian region is 94.2 million hectares (1.7 hectares per person), including 81.5 million hectares directly covered by forest. The average forest cover of the entire basin in 1696 was more than 54%, and in 1914 - 31%. Today the forest cover in the whole region is 35% (for Russia - 45%), but it is distributed extremely unevenly: from 0.2% in Kalmykia and 2% in the Astrakhan region to 70% in the Kostroma and Vologda regions [2, p. 195]. Each inhabitant of Russia, on average, spends in the forest approximately 52 hours a year [2, p. 284]. The average salary in Russia in 2020 amounted to 49.5 thousand rubles / month (ranging from 117 thousand in the Chukotka Autonomous Okrug to 29 thousand in the Republic of Dagestan). Assuming that the forest, "providing" residents with recreational services, just like us, "receives" a
corresponding payment, we have that each inhabitant of the Volga basin must "pay" about 10 thousand rubles / year. The population of the Volga basin is approximately 55 million people. Consequently, only the annual recreational services of the forests of the Volga basin should be estimated today at 550 billion rubles. ($ 7.3 billion), and if we assume that the "side" use of forests (picking berries, mushrooms, hunting) is estimated at 10-12% of recreation, then the "recreational cost" of using the forests of the Volga basin can be estimated at $ 8 billion, i.e., 1.5% of the value of all ecosystem services. Direct income from the timber industry (more precisely, the export revenue of the Russian timber industry in 2019) amounted to about $ 12.3 billion - that is, a figure comparable to the estimate of only (!) Recreational services of the Volga basin forests.

4. Conclusions
The drainage basin of the Volga River is a huge, dynamic and complex ecosystem that requires detailed study, modeling and development of measures to adapt to climate change, as well as optimal management of available freshwater and natural resources in order to reduce the negative consequences of its change. The study showed that the forest ecosystems of the Volga basin (with the implementation of the "climate warming" scenario) will increase their productivity by about 30% (by the middle of the XXI century). True, this increase will not occur in the "south-north" direction (as it is easier to assume), but taking into account the change in humidity, - “southeast-northwest” (see the forecast for 2050 in figure 1).

Adaptation to climate change differs by area, scale and impact. For a complete assessment of the biodiversity of ecosystems, ecosystem services and natural capital of the Volga basin as a whole and its individual regions, it is necessary to perform a number of special (service), sufficiently detailed studies:

- to estimate the share of the territory of the Volga basin (region) occupied by certain types of ecosystems (biomes);
- to define (clarify, adapt) the list of parameters of bioproductivity and ecosystem services (and here the so-called local indicators or innate knowledge plays a significant role) [17];
- for each type of ecosystem, estimate the value of all selected ecosystem services;
- determine the "weighting functions" of the contribution to natural capital of certain ecosystem services (again, local indicators can be integrated into short-term and long-term forecasts and adaptation strategies);
- finally, build a model for a complete assessment of bioproductivity and ecosystem services on the territory of the Volga basin (regression models of biodiversity of mammals, amphibians, reptiles and other groups of animals for the Volga basin were discussed above and see [18]; construct their predictive models of bio-productivity not difficult - there would be information ...).

The main and quite obvious conclusion that can be drawn even on the basis of these preliminary studies and reasoning is that the quality of our life and our economy should significantly depend on the state of biological resources, assessments of risks and damages, "natural capital", which should be evaluated and introduced into the system of economic relations.

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