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SYSTEMATIC STUDY
OF ARID TERRITORIES

Functioning of Ecotone Systems at the Tsimlyansk Reservoir Shores

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Abstract—The paper describes changes in environmental factors (reservoir water level, depths of groundwaters and their mineralization) of the “water-terrestrial” ecotone system and the ecosystem components (soils and vegetation) at various types of Tsimlyansk reservoir coastal areas. The study is based on field monitoring surveys conducted from 2004–2013. It was revealed that maximal levels of the reservoir water exhibit trended toward a decrease, while the minimal and medium trended toward an increase. The amplitude of the water level fluctuations over the last few years seldom exceeded 2 m and showed a tendency to decrease. The aforementioned dynamics facilitate continuation of the abrasion processes and a decrease in the areas of short-term flooded territories outside the coastline. This endangers the belt forest formed at the shores at the height of 35.5 m above the sea level. No statistically significant dependence of the groundwater level on atmospheric precipitation was revealed, but the resevoir level of the did not expand past the coastline over the last few years, with below-average annual precipitation values. Multiannual and seasonal fluctuations in the depths of groundwaters relate to the reservoir water level. Areas situated at a distance of not more than 200 m from the coastline are subject to flooding. In total, 157 species of vascular plants (11 species are trees and shrubs) were recorded at the reservoir shore area. Maximal species richness (110 species) was found at shore areas subject to short-term flooding (the dynamic block). Maximal values of primary production were registered in the amphibial block, within the belt of reed marshes.

Keywords: reservoir, level, coast, “water-terrestrial” ecotone system, functional blocks, fluctuation, directed changes, abrasion, groundwaters, gleization, soil salinization, ecological groups of vegetation, hydromorphization, halophytization

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INTRODUCTION

Reservoirs represent an important component of modern territories of arid regions in the European part of Russia. Modern research (Balyuk and Kutuzov, 2006; Novikova and Ulanova, 2102) shows that reservoirs became an important factor supporting the ecological base and biological diversity at the regional level and that the reservoir coastal territories play an important role in their formation. However, despite numerous works covering long study periods, these problems are poorly described in the scientific literature and existing publications lack knowledge about the structural and functional organizations of the coastal natural complexes and their temporal dynamics. This is why the problem of the development and functioning of these natural complexes is undoubtedly relevant. The present study aims to analyze, using the example of the Tsimlyansk reservoir, trends in temporal changes in the leading transforming factor, the reservoir water level, and related seasonal changes in the levels of groundwaters and the mineralization and chemical composition of the reservoir and groundwaters. The dynamics of the resources of overground phytomass and the species composition of vegetation at the shores under the conditions of various types of coastal areas are analyzed as the functioning of the ecosystems in years differing by weather conditions.

Study area

The Tsimlyansk reservoir was built midstream in the Don River, on the territories of the Volgogradskaya and Rostovskaya oblasts (47°33′–49°10′ N; 42°07′–44°03′ E), with long-term regulation. It was filled in 1953, when the planned mark of the normal maximum operating level (NOL) of 36.0 m above the sea level was achieved. The reservoir waters flooded the Don valley floodplain and terraces, as well as the mouths of the river’s tributaries. The reservoir’s backwater continues upstream to the mouth of the large Don tributary, the Ilovlya River.

The Tsimlyansk reservoir serves many purposes, with the generation of hydroelectric power (81%) being the primary goal of its creation. The list of important consumers includes agriculture (irrigation, additional water supply for the Manych cascade of reservoirs, desalination of the Sal River water (16%), water supply for municipal purposes and industry

(0.4%), a nuclear power station (0.2%), and fisheries (0.14%) (*Otchet*..., 2007). In recent years shipping has become a leading user of the reservoir. The reservoir water level is determined by the natural inflow of the Don River and use of the water for agriculture and industry. This is why maximal filling and the maximal reservoir water level approaching NOL occurs at the end of May to beginning of June; the minimal occurs in December. The minimal reservoir water level, the dead volume (31 m above the sea level), is maintained to provide shipping traffic. This means that fluctuations in the water level reaching 5 m is a characteristic of the reservoir.

The watershed area of the reservoir is situated within the zone of the geographic macro-regional ecotone of steppe and desert-steppe landscapes, which have high values of warmth provision and low values of humidification (a hydrothermic coefficient of 0.5–0.6) and low tolerance to anthropogenic impact. These factors, along with a low percentage of the forest-covered area (<3%), the widespread of loess-like bedrocks and alluvial-fluvioglacial sands, and the wide application of ecologically nonadaptive land-use practices, facilitate activation of exogenous processes (abrasion, landslides, solid flux, siltation, etc.).

The coastline is highly indented and abounds in bays and small coves. The length of the coastline (excluding the coasts of bays formed in the mouths of sunken river channels) is 641 km. Only within the southern part of the reservoir is the length of abrasion shores more than 200 km; the length of accumulative shores is only 25. In the central part of the reservoir the proportion is opposite and low flat shores prevail (*Tsimlyanskoe*..., 1977). Following the creation of the resrvoir, its coastal territory was declared a water-protection area with limited land use. This suggests that the processes developing at the coastal territory are determined by direct and indirect impacts of this man-made lake. The following factors play the leading roles in the modern dynamics of natural complexes of terrestrial landscapes in the coastal area: annual fluctuations of the reservoir water level, along with directed changes (trends) in the maximal, medium, and minimal values of these fluctuations, which determine abrasion and accumulation; changes in the level of groundwaters; and changes in human activity.

MATERIALS AND METHODS

The following materials served as a basis for the present paper: data obtained during our original studies, carried out in 2004–2013 on the coasts of the Tsimlyansk reservoir; data from the archives of the Directorate of Water Resources of the Tsimlyansk reservoir for a series of years starting from 1985; and data from numerous scientific publications.

The studies follow the landscape-ecological approach—an analysis of the natural complexes of modern coastal areas at the local level with consideration of their attachment to a specific type of landscape (Fig. 1). This approach allows correlation of the specific characteristics of natural territorial complexes subject to the impact from reservoir with the enclosing landscapes. The obtained information can be used as an analog for forecasting.

The Tsimlyansk reservoir is situated within the steppe zone. Adjacent landscapes of eight types (Fig. 1) were modified to various extents, either by direct or indirect impact of the reservoir. The direct impacts include all processes and phenomena related to the effects of surf waves of the water masses and periodical flooding or drying of the coastal zone at the reservoir water drawdown; the indirect include the processes and phenomena related to land waterlogging and the hydrostatic upthrust of the underground layers of groundwater, as well as changes in the climatic parameters and land-use practices (*Tsimlyanskoe*..., 1977).

The experimental data were collected along the topo-ecological profiles in each of the coastal landscapes, allowing us to correlate data on various components of natural complexes at the observation points. In 2004 and 2006, 18 profiles were studied instrumentally. One to eight wells were drilled in each profile to characterize the level and chemical composition of groundwaters, the morphological properties of soils, and the specificity of vegetation. In 2008, 2009, 2010, 2012, and 2013 the monitoring observations were repeated at the same points. The present paper focuses on the three main functional types of landscapes: accumulative (profile **TsP2**), abrasion-accumulative (profiles **TsP4**, **TsP5** and **TsP12**), and abrasion (profiles **TsP3** and **TsP6**). These regularly surveyed parts of the coastal area are situated in the landscapes shown in Fig. 1: **TsP—255 v**, **TsP3—239 b**; **TsP4—255 o**, **TsP5—255 o**, **TsP6—239 b**, **TsP12—255 v**.

In the analysis of the spatial structure of coastal landscapes, we defined three types of areas subject to different impacts of the reservoir, which correspond to the three blocks of the ecotone systems according to V.S. Zaletayev (1997): 1. Long-term flooded bottom exposed during a water drawdown to a level at which the leading role is played by the wave-driven impact of water masses on the open coasts; in lagoons, the accumulation of sediments (amphibial block) is most important. 2. Short-term flooded part of the coastal zone (dynamic block). 3. Waterlogged coastal territory, which is not subject to flooding. The borders of the above territories were related to the reservoir level (distant block). Near the Tsimlyansk reservoir, the border between nonflooded and flooded territories lies at the height of 36.0 m above sea level, i.e., the reservoir water level should not rise above this height. The border between the reservoir bottom and the territory subject to flooding is marked by the belt forest formed after the creation of the reservoir at heights of 35.4–36.0 m above sea level. The mark of 35.4 above sea level corresponds to 50% of the flooding probability, as calculated on the basis of data on the yearly maximal level

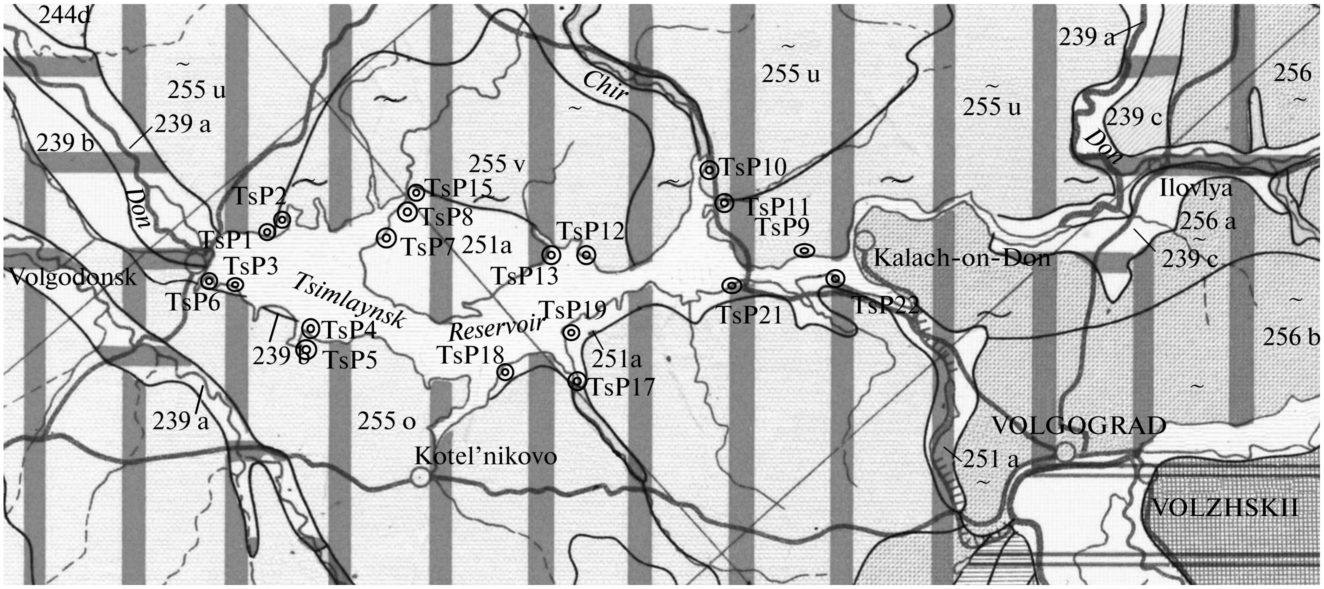

Fig. 1. Fragment of the landscape map (*Landshaftnaya karta*..., 1987) of the reservoir territory and positions of study sites.
Legends: *Types of landscapes*. **Steppe.**

Real steppes

Alluvial accumulative. 239 b. The above-floodplain terraces of large rivers, flat and wavy, in some places with gullies, with agricultural lands, areas of deciduous-pine and flat-leaved forests. **239 c**. Flat plains, wavy (the complex of high terraces), with numerous ravines and gullies near the valleys, agricultural lands, areas of near-valley ravine deciduous-pine forests and grassy bogs.

Dry steppes

Alluvial accumulative. 251 a. Floodplains and low terraces, flat, in some places mane-depressive, with riverbeds, channels, former riverbed lakes, with meadows, deciduous forests, reed bogs.

Loess-accumulative. 255 n. Flat and gently waved plains, with wide gullies, ravines near the valleys, erosion furrows, depressive micro-relief, with agricultural lands, areas of gramineous and wormwood-gramineous steppes.

Loess-accumulative-denudation. 255 u. Gently wavy plains with gullies near the valleys. **255 c**. Gently ridged plains, with deep gullies and ravines near valleys, with depression micro-relief, with agricultural lands, areas of gramineous steppes. **255 v**. Plains predominantly flat, with deep gullies and short network of ravines, with agricultural lands, areas of gramineous and wormwood-gramineous steppes.

Mixed-origin accumulative-denudation. 256 b. Plains hilly ridged, with gullies near the valleys, with ravines, depression micro-relief, landslides with agricultural lands, areas of gramineous steppes.

of the reservoir for the entire period since its creation. The theoretical border between the main water-covered area, never-dry bottom, and the amphibial block should be situated at the mark of the reservoir dead volume level. However, the height of 32.6 m above sea level may be considered as the above border. This level occurred in 2011, when the reservoir level was minimal for 27 years of the reservoir existence. The outer limit of the reservoir impact was defined empirically based on the depth of groundwater less than 3 m from the surface in springtime.

The following criteria were used to assess the extent of the transformation of natural assemblages of the initial landscapes under reservoir impact. Changes in the water regime were assessed by groundwater depth (300 cm is the border between the hydromorphic and automorphic complexes). Soil changes were assessed based upon the analysis of the soil profile (an increase in the depth of humus layer with additional humidification was an indication of prairiefication; mechanical destruction—erosion of the upper layer or accumulation—was an indication of the presence of new deposits on the surface of the humus layer). There were also changes in the morphological characteristics of soils. When the level of the groundwater or its capillary fringe rises, blue-gray, gypsum, carbonate "mold" or fuzzy pale-yellow spots ($CaCO_3$) appear. Another criterion was the presence of ferrous and manganese neoformations and their form (Fe + Mn). Ferrous hydroxide coating (ochrous spots) indicate the modern process of modifying oxidation-reduction conditions. The Fe and Mn "beans" may originate from past conditions of the formation of soil-ground layer (Novikova and Nazarenko, 2007).

The following parameters were analyzed to characterize changes in vegetation as affected by water-related factors: the ecology of dominant and associated species in the communities—the dominance of hygrophytes, hydrophytes, and mesophytes, as well as of species indicating disturbances in vegetation.

Table 1. The position of the reservoir water level on the observation dates in various years

Characteristiscs	Years of observation							
	2004	2006*	2008	2009	2011	2012		2013
Annual sum of atmospheric precipitation, mm	702	408	418	449	398	323		251
Date of observations, days—months	15—25.7	18—22.6	18—22.8	14—26.8	13—24.8	09—12.6	20—24.8	24—26.8
Reservoir water level, m	35.3	35.6	34.7	33.5	32.6	34.83	33.93	34.07
relative to 2004	0	+0.3	−0.6	−1.8	−2.7	−0,6	−1.4	−1.2
relative to NOL	−0.7	−0.4	−1.3	−2.5	−3.4	−1.17	−2.07	−1.93

* Not all profiles were studied.

We studied the following phenomena as leading factors in modern dynamics of the natural complexes of terrestrial coastal landscapes: annual fluctuations and directed changes (trends) of the reservoir water level (maximal, medium and minimal values), abrasion-accumulation processes, directed changes in the groundwater level, and changes in human activity.

The impact of the reservoir water level upon the coastal complexes is especially strong during the vegetation period (April—October). During this period the water level fluctuates within the diapason of 32.50—36.01 m (according to data for over ten years). In 2004—2013 field studies were carried out in summer (Table 1). In 2008 the observations were carried out in early summer; in the other years, they occurred in late summer. In 2012 the observations were carried out in both periods.

During the period of field observations, the highest levels were recorded in 2006, 2004, and June 2012, and they approximately fall in the first half of summer. In 2008—2013 the observations were carried out on about the same dates in the second half of August. At that time the reservoir water level was lower relative to the level observed in 2004 (Table 1). The lowest level was observed in August 2011. In 2009 and 2013, the reservoir water level was below the coastline, and the dynamic block area was not flooded for several years in a row.

Analysis of a possible correlation between the annual sum of atmospheric precipitation and the maximal and medium reservoir water levels revealed no statistically significant correlation. However, the data in Table 1 show that the reservoir water level was higher in the years with the highest annual sum precipitation. For instance, at the mean long-term annual sum of precipitation (for the period of 1953 to 2013) of 433, the precipitates in 2006—2008 and 2011—2013 were characterized by lower atmospheric humidification.

To characterize the coastal natural complexes, we selected the data for the years with most contrasting dynamics of the reservoir water level (Fig. 2): 2004, with the maximally high level for the whole span of the observation period, which was accompanied by a rise of the water above the normal coastline and flooding of

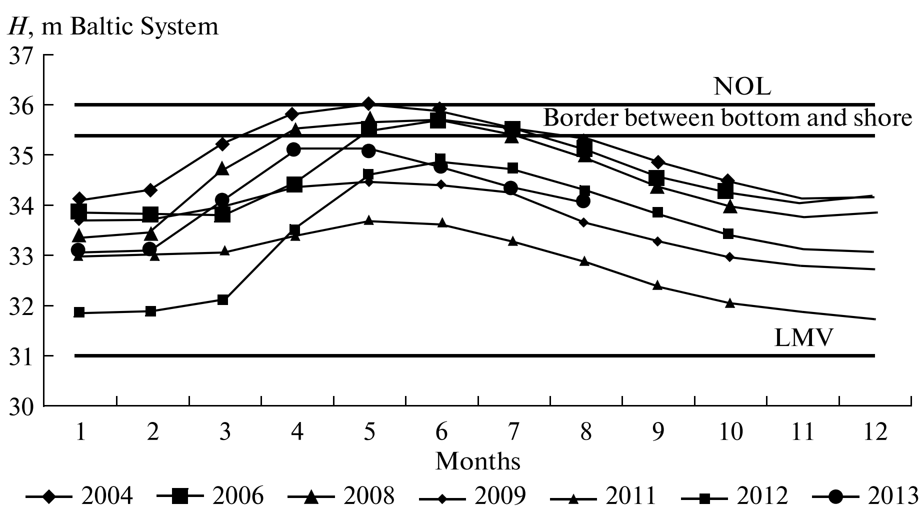

Fig. 2. Changes in the reservoir water level in observation years.

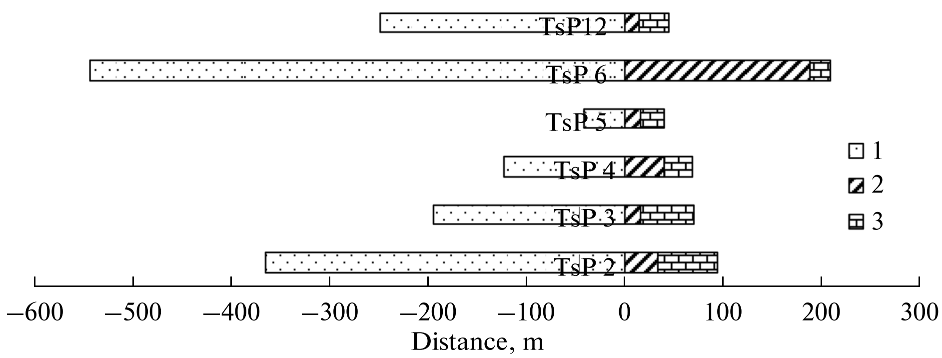

Fig. 3. The extensions of the "water-terrestrial" ecotone system blocks at the Tsimlyansk reservoir: (1) Exposed bottom (amphibial block); (2) Short-term flooded territory (dynamic block); (3) Nonflooded territory with shallow-level groundwater (distant block).

the coastal areas; and 2011, with one of the lowest levels for several years, in which the water did not reach the coastline. In addition, the latter year follows two preceding years in which the coastal territories were not flooded and the water level in the vegetation period dropped to 2.8 m below the coastline. 2012 was a year with a medium level in which the water did not cross the normal coastline. The functioning of the ecotone system was analyzed in blocks reflecting various impacts of the reservoir on the water-covered and coastal areas: amphibial—periodically exposed bottom; dynamic—short-term flooding; distant—unflooded territory with a groundwater depth of about 3 m.

RESULTS AND DISCUSSION

The long-term observations yielded data on the extent and functioning of the main blocks of "water-terrestrial" ecotone systems at the Tsimlyansk reservoir coast. The amphibial block has the largest extension at 40–540 m (Fig. 3), as compared to other blocks, but the frequency of its full release is low. The dynamic block (15–189 m) follows in terms of extent and is characterized by short-term flooding. In years with a rate of atmospheric precipitation below the norm, this block is not flooded as a rule. Such a situation may be observed for several years running. The distant block is weakly pronounced, owing to widespread steep slopes at the coastal territories. The width of this block ranges from 20 m to 60 m in various landscapes. As a result of coastal abrasion, the trend in reformation of the relief is such that the territory of the dynamic block is reduced at the shores and the narrow strip of reservoir bottom in front of the coastal escarpment takes on the role of this block. Such a situation occurred at coastal landscape 239b (Fig. 1) and was observed at profiles TsP3 and TsP6. According to instrumental observations over ten years (2004–2014), the extent of the shore failure is 3 m.

The exposed bottom (amphibial block of the ecotone) within the zone of the reservoir water drawdown varies over the years in terms of the extent and depending on the water level. During our observations the maximal span of the exposed bottom (varying from 40 m to 530 m) was noted in August 2011 at a reservoir water level of 32.6 m above sea level. The highest values were noted at the shores near the dam (TsP6 profile). For the open coasts of the abrasion and abrasion-accumulative types, the soils and vegetation of the initial landscape were destroyed, and part of bedrock was washed out. The transition from the bottom to the shore was marked by a varying-height terrace. The clayey cemented surface is exposed at the dried bottom. The groundwater is situated at a depth of 50–120 cm; the groundwater mineralization differs in various landscapes and fluctuates from 2 to 7 g/L, which is not always lower than mineralization of groundwater at shores within the same landscape. Plant overgrowth runs from previously dried shores. Plant shoots were noted at a distance of 30–280 m from the water edge, depending on the slope steepness. The species diversity is low: only 52 plant species were recorded during the study period. For different areas of the shores, the number of species varies from 5 to 20. Shoots of the tree species occur most often on the shores: black poplar (*Populus nigra*[1]), white willow (*Salix alba*), and Russian olive (*Elaeagnus angustifolia*), along with the pigweed species (*Chenopodium rubrum*, *C. urbicum*, and *C. glaucum*). In the years when the maximal reservoir water level does not exceed 35.4 m, the coastal shafts to 50 cm in height and 1–1.5 m in width, are appeared along the border with the shoreline. At the northern shores, these shafts are formed with sand; at the southern shores and near the dam, they are formed with mollusk shell debris.

In lagoons of accumulative-type shores, the exposed territory is occupied by monospecies high-grass communities dominated by broadleaf cattail (*Typha latifolia*) and common reed (*Phragmites australis*). Old trees of white willow occur on low shore swells. Shrubby willows (*S. viminalis*, *S. triandra*) appear closer to the shore in the reed overgrowths. In these habitats, the highest for the shore, primary pro-

[1] Scientific names are given according to S.K. Cherepanov (1995).

duction is formed. The biomass totals 3.4 kg/m^2 dry weight. In comparison, the biomass of the lush tall-weed grass vegetation on the shore swells reach about 1 kg/m^2; on other areas closer to the coastline, it is no more than 20 g/m^2. Most often, the transition from the bottom to the shore on the open coasts is marked by various height terraces; in the lagoon vegetation, this transition is quite clearly pronounced by the sharp end of three-meter-high reed overgrowths.

The flooded shores (dynamic block of the ecotone) are situated at heights of 35.4–36.0 m above sea level. Their width is very small, being limited to a few tenths of meters on the majority of the shores. The highest width of 189 m is in the primarily hydromorphic alluvial landscape of high floodplain terrace of the Don River (Fig. 1, contour 239 b, profile TsP-6) near the dam and in the upstream reach in the eastern part of the reservoir in the transformed alluvial accumulative landscape of floodplains and low terraces (Fig. 1, contour 251 a, profile TsP21). In spring the groundwater depths range from 70 cm to 100 cm, decreasing to 3 m in fall. Our studies revealed that the groundwater depths follow the dynamics of the reservoir water level (Novikova et al., 2011), since the groundwater is subject to the reservoir water upthrust in the above landscapes and in the other parts of the shores. In this territory the dark chestnut-colored or chestnut-colored soils of the initial landscapes are preserved. Often these soils are either not saline or low saline (from weakly to medium saline, Table 2). Despite flooding and the presence of groundwater close to the land surface, the soils are weakly transformed. Erosion of the upper soil layers and their covering by weak sandy-shell detritus is usually noted for the accumulative types of shores. The features of modern hydromorphism, manifested as ochrous and blue-gray color of the upper soil layers, are present in locations where the surface water may be stagnant. This territory of the shores has highest plant species diversity, with 110 plant species, including 11 species of trees and shrubs recorded. Up to 30 species were found for the geobotanic 10 m × 10 m test site. The vegetation is represented by a meadow-type community dominated by graminoids: bush grass (*Calamagrostis epigeios*), quack grass (*Elytrigia repens*), narrow-leaf meadow grass (*Poa angustifolia*), with admixture of *Glycyrrhiza echinata*, holy grass (*Hierochloe odorata*), field mint (*Mentha arvense*), etc. In terms of plant ecology, mesophytes and xeromesophytes prevail. The natural belt forests formed in spring along the edge of intermittently flooded areas are characteristic for the vegetation of this territory. These forests are dominated by black poplar and white willow. In some parts of the shores, tamarisk (*Tamarix ramosissima*) and Russian olive (*Eleagnus angustifolia*) occur. The formation of new tree communities was noted, along with the already present belt forests in years with low water level. The transition from flooded to nonflooded territory is gradual but in some places is marked by a low terrace.

Table 2. Salinity of soils in the dynamic block in various landscape conditions

Land-scape*	Extent of salinity by dry residue, % (the soils of chloride-sulfate type of salinity)			
	no salinity (0–0.25)	weak (0.25–0.5)	medium (0.5–1)	high (>1.1)
(239 b)		0.08–0.34		
(251 a)			0.04–0.72	
(255 n)			0.05–1.12	
(255 v)			0.02–0.67	
(255 x)	0.06–0.12			

* Extent of salinity by dry residue, % (the soils of chloride-sulfate type of salinity).

Waterlogged territory (distant block of the ecotone) is a nonflooded territory with low-depth groundwater. The width of this territory is low, fluctuating in various landscapes within a few dosens of meters (Fig. 3). In spring in medium-water years the groundwater lies at depths of 180–200 cm, declining to 300–400 cm along with a decrease in the reservoir water level in fall. In low water (e.g. in 2011), the water lies deeper than 5 m from the land surface. The mineralization of groundwater is close to that of the flooded territory. The soils remains a feature of the original landscape, but gypsum presents in their profile at depth of 3 m or more, which may be related to the groundwater edge. The elements of meadow type are still manifested in vegetation, but the xeromesophytes and mesoxerophytes (the species of the original landscape) are dominant.

Changes in the components of natural complexes in various years are determined by the changes in humidification and primarily relate to fluctuations of the reservoir water level and the depth of the groundwater layer. During 2004–2011 (Fig. 4), with the subsequent drop of the water level from 35.3 m to 32.6 m (i.e., almost by 3 m, Table 1), the level of groundwater decreased considerably in all wells at the shores as compared to 2004.

The groundwater level was relatively stable in the early years in wells close to the coastline (because of the support by the reservoir water), but it sharply dropped in 2011. In other wells, the deepening of the groundwater took place gradually following a decrease in the reservoir water level, i.e. as was expected in the flooded (dynamic) block, the relation between the ground and reservoir waters was closer.

The hydrogenic transformation of soils is very slow. This is why the features of modern hydromorphism were not noted in any one well for all type of shores. The soil salination is a characteristic feature of landscapes subject to a deficiency of atmospheric humidi-

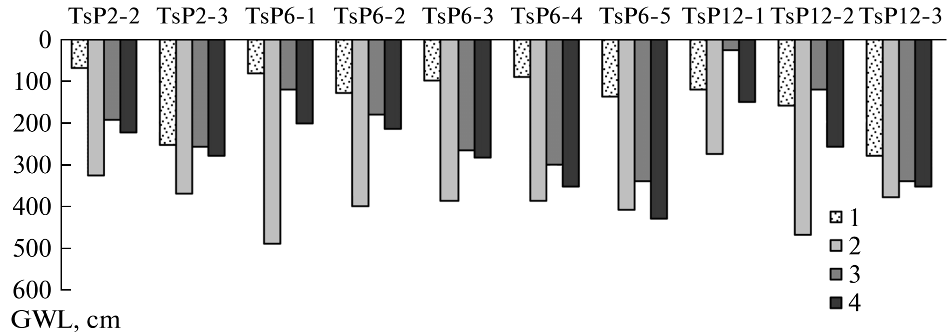

Fig. 4. Changes in the level of groundwater in wells at the topo-ecological profiles in various years at various levels of the reservoir during the observation period: (1) 2004 (the highest); (2) 2011 (the lowest); (3) 2012 (medium level, sans flooding of the coasts), June; (4) 2012, August.

fication. In the steppe zone, the extent of transformation of the soils at the territories subject to the impacts of large reservoirs largely depends on the bedrocks building the bottom and shores of a man-made lake in a specific landscape. Our studies revealed that salination is practically absent in all landscapes of the subzone of real steppes (Fig. 1, landscape 239 b, c, d) but reaches a medium extent in the dry steppe landscapes. At the same time, in the dry steppe sub-zone (Fig. 1 Table 2, landscape 255 v), under the impact of the Tsimlyansk reservoir freshwaters, the soils are also not saline, which may be related to the regional specificity.

The vegetation of the Tsimlyansk reservoir region belongs to the type of dry steppes with fescue-feather grass communities with poor forbs and wormwood admixtures. White wormwood-crested wheat steppes with spots of black wormwood, chamomile,and vitex communites remain in some locations of the right bank. The white wormwood-chamomile steppes, with considerable participation of black wormwood and camphorosma spots, are still present at the left bank (*Rastitel'nost'*..., 1980).

During the studies on the topo-ecological profiles, we prepared a list of the found plant species. The list includes 157 species of higher vascular plants of 29 families. The leading role belongs to plants of families typical for the steppe zone: Asteraceae, Poaceae, Fabaceae, Chenopodiaceae, Labiatae, and Polygonaceae.

In the various blocks of the ecotone territory, the vegetation responded to the general trend in decreased humidification via a decrease in the total plant projection in the communities (from 100% to 90% and 80%), a decrease in the abundance of hydrophilic species, the disappearance from the community of some species typical for the conditions of medium-humidified meadows (*Hierochloe odorata*, *Bolboshoenus maritimus*, etc.), and the introduction of invasive species (*Melilotus album*, *Xanthium strumatium*, etc.). In the dynamic block, the dominance of *Bromopsis inermis* (2004) was substituted by dominance by (*Calamagrostis epigeios*) (2008–2011). The number of species recorded on the standard 10 m × 10 m test areas decreased from 16–21 to 8–10. On the nonflooded area (distant block), the changes in the vegetation were less pronounced but were also manifested as a decrease in total plant projections. Thus, our observations suggest that, with directed fluctuation of the reservoir water level over various years, the most pronounced changes occur in the position of the groundwater level (GWL) and in the vegetation of the dynamic block; the changes gradually decline in the direction from the coastline.

The impact of the reservoir on the vegetation is clear: the amphibial block is devoid of both soil and constant vegetation. When this block dries out, the plant shoots appear very rapidly. If the land is not flooded again for two to three years, tall-weed grass communities develop on the temporary forms of relief, the near-channel swells. The close-canopy willow-black polar community was formed over a long time on the dynamic block in conditions of flooding and the active accumulation of sand. The vegetation of this block is subject to constant disturbances and includes the adventive species trees yellowwood (*Morus nigra*) and tamarisk (*Tamarix ramosissima*), along with shrub golden current (*Ribes aureum*). The distant block lacks woody vegetation; the grass cover is represented by tall-weed grasses that developed through disturbances with the use of arable land situated within the marginal block, which is not subject to the hydrogenic impact of the reservoir.

Several typical spatial rows may be defined in the coastal ecotone territories of the freshwater bodies: on the accumulative shores of steppen and dry-steppen landscapes: cattail-reed communities on the silty-bog soils of the amphibial block—narrow leaved meadow grass-wheat grass-willow on the chernozem-meadow soils of the dynamic block—bush grass-forbs on the meadow-chernozem and chernozem soils of the distant block. The coastline is often marked by sparse bushes of tamarisk species (*Tamarix elongata*, *T. hispida* and *T. ramosissima*). In the distant block the domi-

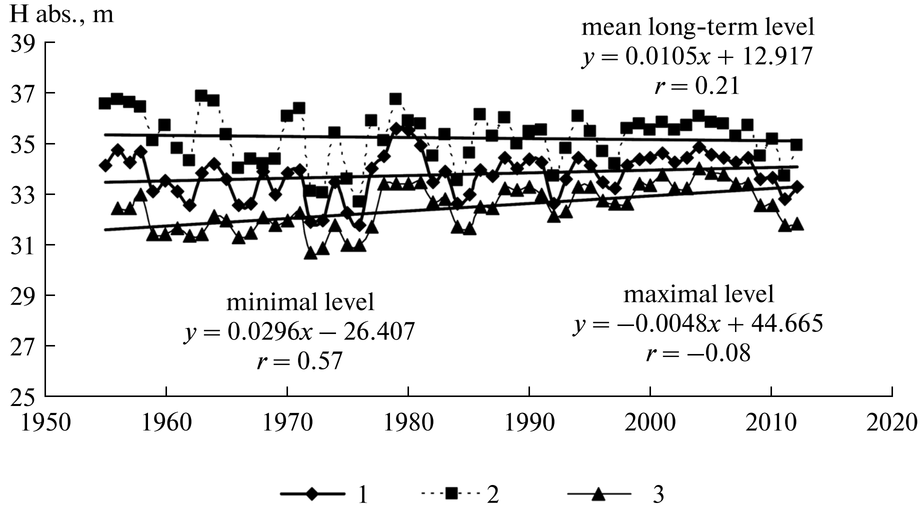

Fig. 5. Changes in the Tsimlyansk reservoir water level from 1953 to 2013: (1) Mean annual values; (2) Absolute annual maximum; (3) Absolute annual minimum and their linear trends.

nants are fesque grass (*Festuca valesiaca*), steppe forbs, and feather grass appears in the vegetation.

The total plant projections and number of species in the ecotone system tend to increase in the direction from the shoreline. This is presumably due to an increase in the diversity of conditions in the biotope and a decrease in the impact of extreme factors. It is worth noting one fundamental property of the ecotones: the ecosystems, including the plant communities, are open. This makes them prone to easy introduction, spreading, and periodical outbreaks of the abundance of invasive species, predominantly annual plants: cockleburs (*Xantium strumarium* and *X. albinum*), sumpfweed (*Cyclachaene xanthiifolia*), spear thistle (*Cirsium vulgare*), yellow melilot (*Melilotus officinalis*), etc.

The reservoir water level is the main external factor determining the dynamics of the processes in the coastal natural complexes under direct and indirect impacts.

The mineralization of the Tsimlyansk reservoir waters fluctuates within the limits of 0.28–0.86 g/L and belongs to the category of freshwaters. The water salinity is of Cl-SO_4 type.

The reservoir water is hydraulically connected to the underground waters of the adjacent territories. They often produce upthrust and are less mineralized in this area of the steppe zone. They desalinate the groundwater. Our studies confirm this. In general, medium mineralization of groundwater is a characteristic of the landscapes of the Tsimlyansk reservoir shores. The type of chemical composition changes from the chloride-sulfate to sulfate-chloride.

The change in the reservoir water level reflects to the highest extent the specificity of its functioning and suggests various types of impacts on the coastal territories. From the ecological aspect, the absolute annual maximal and minimal values of the level are important, since these values determine the territory subject to flooding. In addition, changes in the reservoir water level over a series of years determine the frequency and duration of flooding at the certain height. The changes in the aforementioned parameters of the reservoir water level allow for the determination of trends in changes of the spatial structure of the shores (widths of the blocks) and of ecological conditions, not only on the territories of amphibial and dynamic blocks but on the distant block as well, since our studies of the Tsimlyansk reservoir have shown that the depths of the groundwater and its chemical composition relate to the fluctuation of the reservoir water level.

However, the reservoir level widely changes in various years, and stabile changes may result in the modification of the blocks' borders and of the structure of the ecotone system. The analysis of long-term data revealed statistically insignificant trends of a decrease in the maximal values and a rise of the medium values of the water level (Fig. 5). At the same time, the minimal levels increased from 31.5 m to 33.2 m above sea level.

The reasons for the reservoir water level changes relate to the increase in the importance of the reservoir with respect to ship traffic and the consequent need to maintain a high water level upon filling of the reservoir's depression by sediments and the low annual amplitude of the level dynamics. The revealed trend of a directed increase in the flooded heights and a decrease in the amplitude of the reservoir water level fluctuations is important for understanding why the borders of the amphibial and dynamic blocks continue to move toward the land, i.e., why the abrasion of shores and the destruction of belt forests (which fix the shoreline) continues as well. The width of the flooded area (dynamic block) on open shores decreases. When the height marks of the coastline become higher than NOL, this block will shift to the reservoir bottom. Such a phenomenon has recently been observed for the TsP3 profile, where each season after the spring drawdown there is a good overgrowth of the exposed (dried out) bottom as a result of seed regeneration of trees species, along with perennial and annual grasses. However, wave activity destroys all plant shoots upon the new seasonal increase in the water level. In conditions of low water, an undergrowth of trees may be formed, which with time will form again the edge of belt forests along the reservoir shores.

CONCLUSIONS

Sixty years after the creation of the Tsimlyansk reservoir, the natural complexes on its shores are still at the stage of development. The changes taking place in various years, which depend on fluctuations of the reservoir water level, result in the reformation of the relief and changes in the groundwater level, and they support self-development of the biological components of the ecosystems. Short-lived processes develop in all areas differing in the specificity of the reservoir impact. These processes facilitate fluctuations of the vegetation and soils as a component of natural complexes.

Long-term observations determined the widths of the functional blocks of the “water-terrestrial” ecotone system from the coastline towards the land. It was found that the water descends to 200–500 m from the coastline in years when the water level drops during the vegetation period by 3.4 m below NOL to the height 32.6 m (2011). The maximal values are characteristic of the areas adjacent to the dam. When the water retreats, on the dried bottom of reservoir in all types of landscapes of coast in addition to seedlings of herbaceous species there are lots of seedlings of woody species—black poplar and white willow.

The maximal values of the reservoir water level tend to decrease, while the minimal and medium tend to increase. The amplitude of the annual fluctuation seldom tends to decrease, exceeding 2 m in recent years. All of the aforementioned events facilitate the development of abrasion processes and shrinking of the short-term flooded territory. These processes endanger the belt forests formed on the coasts at a height of 35.5 m above sea level. No statistically significant dependence of the groundwater level on atmospheric precipitation was revealed. However, the reservoir water level did not cross the coastline over the last ten years, when the atmospheric precipitation was below the long-term annual values.

Yearly and seasonal fluctuations in groundwater depth relate to the reservoir water level and diminish in the direction from the coastline. The area at a distance of 200 m from the coastline is subject to waterlogging.

In total, 157 species of vascular plants were recorded at the reservoir shores, with eleven of these being trees and shrubs. The maximal plant species diversity (110 species) was found at shore areas subject to short-term flooding (dynamic block). The maximal primary production (3.4 kg/m^2) is registered for the amphibial block within the reed belt.

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