The modern state of the ecosystem in the Volga River delta ecotone and dynamics of the changes in water availability conditions

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Abstract. We prove that an abrupt amount of water-soluble salts in soils occurs due to rapid increase in heat provision under decrease in precipitation amount for the period with the temperatures above 10°C (under the integrated index of territories aridity, the G.T. Selyaninov coefficient is up to 0.3 or less). Based on the results of investigations from 137 model sites at the Volga River delta in the years with water availability contrast conditions (2014 and 2015 are years with little water and 2016 and 2017 are water-abundant years), we indicate a decrease in the volume of river runoff according to the landscape-ecological complex of soil-plant cover. We also show the toxicity level due to the increase in toxic Cl, Na and Mg ions under simultaneous decrease in the content of SO₄²⁻ and Ca²⁺ ions. Moreover, there is a change in soil salinization type from chloride-sulphatic to sulphatic-chloride, which directly affects plant cover: total biomass and foliage cover decrease on all deltoid landscapes of high levels, the participation of sedge and herbs decreases, and role of forbs increases. These processes are blocked due to the rise of the subsequent conditions of abrupt water availability and move back. The greatest and the most rapid changes are observed within particularly extended alluvial natural boundaries of low level in the vegetation classes Phragmitetalia R. Tx. Et Preising 1942 and Bolboschoenetea maritime Vicher et R. Tx. 1969 ex R. Tx. et Hulb. 1971 at the level of associations and types.

1. Introduction
Estuarine natural systems and alluvial landscapes are unique natural objects, which are characterized by a richness of natural resources and, hence, increased population density and different trends in a high degree of anthropogenic load. Interrelation processes of water and terrestrial compartment in the Volga River delta define ecotone area, which structure consists of several relatively sustainable discrete units, whose specific functioning defines a degree and wetness period, terrain relief, ground-water conditions, earth leakage phenomenon, etc. Knowledge of specific functioning features of units with the different structure on the Volga River is a necessary intrazonal aspect for landscape control and its biodiversity protection [1-3].

2. Objects, data and methods
Investigations of soil-vegetation cover dynamics in the Volga delta ecotone systems were conducted at 126 sites of 2x2-m stationary sections and 11 stationary areas of 400 km². They were located in the centers of islands in the eastern part of the Volga delta. There, anthropogenic changes in the
hydrological regime and vegetation cover are less than in the western part. The altitude of all points above normal water level and their position towards roads near the water stage gauges was defined using levelling box. The altitude range of model monitoring areas (from 0.67 to 3.23 m above streamflow at normal water level) was limited by habitual area from swamp vegetation up to transitive one to semi-desert and did not include typical water and zonal semi-desert vegetation habitual area.

Grassland vegetation was classified according to J. Braun-Blanquet approaches, vegetation abundance in the field was defined in foliage cover per cents, with the following conversion into points: + < 1%; 1 – 1-5%; 2 – 6-15%; 3 – 16-25%; 4 – 26-50%; 5 > 50%. Names of higher plants are given according to their list in Flora Europaea [4]. In addition to geobotanical descriptions, grass stand top was cut down; fresh samples were sorted in laboratories according to the types and fractures, dried on the air (14-15% humidity) and weighed in investigation areas.

Soil samples selection on stationary section was carried out from 0-15-cm topsoils, in stationary areas – from a meter-deep soil layer with 25 cm gration. Humus content, active forms of phosphorus and potassium, nitrogen, ions, and water-soluble salts were determined from soil samples per dry soil under laboratory conditions according to the commonly used state standards [5-7].

Years of 2014, 2015, 2016, and 2017 were chosen as models to reveal soil-vegetation cover dynamics trends under abrupt changes in water availability at the Volga delta since extremely high volume differences in spring-summer floods (84, 63, 127, and 109 km³ respectively) were observed in these years; discharge hydrograph also showed significant range during the floods.

Flood volume in 2004 (86 km³) was below multiannual average (110 km³); maximum discharge rate was 25 000 m³, and duration was only 7 days, which does not provide exudation at all levels of deltoid territories.

The year of 2015 was the most low-water period since 1996; the maximum water discharge rate in the flood period was 16000 m³, which is more profitable for power economy needs but not sufficient for the efficient functioning of the deltoid ecosystem. The flooding began late. Its peak was observed on 9 May, and on 5 June, the water discharge rate was low.

The year of 2016 was water-abundant; water discharge rate, discharge hydrograph and flood character were maximum close to natural (unregulated) period, due to which all accumulative competences were filled with water.

The year of 2017 was average in terms of hydraulicity; however, flood duration was long (an increase in water discharge rate continued until mid-August).

Natural boundaries of not only of low but also partly mid-level were inundated due to little volume of the flooding, low water hoisting and not the highest maximum discharge rates in 2014-2015. Flood characteristics were close to long-term annual average values in 2016-2017. For this reason, delta territory was much better provided with natural resources.

Active temperature amounts for the period with a temperature higher than 10°C under annual average directional growth of air temperature (period of intensive grass regrowth on the grounds) in 2015 were the lowest (3737); in 2016 and 2017, values differed insignificantly [2, 5].

Hydrothermal coefficient, according to the G.T. Selyaninov, showing territory aridity degree, in 2014 and 2015 conformed to the long-term annual average; in 2017, it was lower, and in 2016, it was two times higher than the norm (table 1).

A decrease in delta water availability in 2014-2015 influenced an increase in soil-cover salinity at all levels of natural boundaries.

3. Results and discussion
In comparison with previously fixed low values of 2002, total salt content, toxicity and Cl-/SO2-
relation [2] increased practically twice in 2015 but did not exceed values of 1979 (the beginning of soil-vegetation monitoring), which is associated with some decrease in gradation of economic influence in the territory.

The negative aspect is an increase in toxic anion Cl⁻ content in water extract as well as a decrease in less toxic SO₄²⁻ in 2014 and 2015. We recorded proceeding to more toxic sulfate-chloride type.
under low and mid-chloride-sulfate salinization type in the entire multiyear deltoid territories in 2015. Conversion type of soil salinization in this trend is geochemically explained by predominance of exudation hydrological regime over percolate in the delta due to closeness of highly mineralized groundwaters to daylight surface and high territory aridization in 2014-2015. The leading factor for high natural boundaries level, which defines a decrease in the total amount of water-soluble salts in soils and their toxic degree, is an increase in precipitation amount during the warm season.

**Table 1.** Meteorological and hydrological indices in investigated years according to the Astrakhan Hydrometeorological Center.

| Year | Precipitation amount, mm | Aqueous runoff volume in Volzhsky power site, km³ | Date of the beginning of the flood peak | Maximum level of water rush during the flood, cm | Maximum discharge rate, thou m³/s | Annual average air temperature, °C | Active temperatures amount for the period with the temperature above 10°C | Selyaninov hydrothermal index |
|------|--------------------------|-------------------------------------------------|----------------------------------------|-----------------------------------------------|----------------------------------|-------------------------------------|---------------------------------|-----------------------------|
| 2014 | 184 115 224 86           |                                                 | 05 May                                 | 245                                           | 26.0                             | 10.1                                | 3848                            | 0.30                         |
| 2015 | 192 123 198 63           |                                                 | 09 May                                 | 151                                           | 16.0                             | 10.1                                | 3737                            | 0.33                         |
| 2016 | 392 280 266 127         |                                                 | 24 April 11 May                        | 319                                           | 27.0                             | 11.3                                | 3844                            | 0.73                         |
| 2017 | 196 90 289 109          |                                                 | 26 May                                 | 265                                           | 25.7                             | 11.5                                | 3822                            | 0.24                         |

Great changes occurred in phytocoenosis content of the *Phragmitetea R. Tx. EtPreising 1942* class in delta vegetation cover (the class combines phytocoenosis of coastal types, whose ecotopes are wetted well, diagnostic types: *Stachys palustris, Phalaroides arundinacea, Oenanthe aquatica, Typha angustifolia, Polygonum hydropiper, Sparganium erectum, Butomis umbellatus, and Lysimachia vulgaris*), and *Bolboschoenetea maritimi (R. Tx. 1969) VichereketR. Tx. (1969)*, combining phytocoenosis of wet and flabby meadows with surface saline soils (class of diagnostic types: *Bolboschoenus maritimus, Polygonum pulchellum, and Althaea officinalis*) [6, 7].

The abrupt decrease in water availability of 2014-2015 together with the increase in water-soluble salts content in soils and their toxic degree led to a direct reduction in the delta of plants types that belonged to the previously dominating association *Sparganio erecti-Typhetum angustifoliae*.

Change in the dominance of plant types was recorded in stationary observation sites with low and mid-levels under decrease in moisture indices: decrease in sedge and herbs existence and increase in graminoids. In addition to changes in moisture level, change in the state of grass stand was defined by dynamics of water-soluble salts in soil at the site No.13, which belongs to white alkali meadow: representativeness of herb groups reduced due to direct toxic decrease by 2016 (halophytes *Suaeda confusa* and *Petrisimonia oppositifolia*); graminoids became dominating group (62.3% of the total biomass).

The productivity of legume group abruptly increased by 2016 at the sites No. 9 and 10 (phytocoenosis belongs to *subass. Lepidio-Čynodontetum juncetosum Golub et Mirkin 1986*). However, at the site No. 10, where legumes completely excluded graminoids group, such phenomenon belongs to syngenetic change, whereas this process can be referred to fluctuation dynamic at the site No. 9. At the site No.14 (high-level natural boundaries; phytocoenosis belongs to *ass. Suaeda-Petrosimonietum Golub 1986*),
under the periodic change in dominating halophyte types *Suaeda confusa* and *Petrisimoni aoppositifolia*, herb group, which these types belonged to, was dominant in investigated years. Productivity leap of *Artemisia lerchiana* type (up to 13% of total productivity in 2016) belonged to fluctuation dynamics.

![Figure 1](image)

**Figure 1.** The Volga delta flooding in investigated years (a – 2014, b – 2015, c – 2016, and d – 2017).

4. **Conclusion**

In general, we have shown productivity values of maximum biomass for the entire investigated period at model observation sites in 2016. This is due to a definite water pass during the spring-summer floods at the Volzhskaya power station site, maximum approximation of duration, volume and levels of water rise in unregulated period (before 1961 when the Volzhskaya power station began operating), and very high amount of precipitation for the vegetation period (Selyaninov hydrothermal index was 0.73, which coincides with the steppe sludging zone) [2, 6, 8-10].

Low-level natural boundaries were inundated for 60 days. In this case, there were uncut areas occupied with dry sprouts *Typha angustifolia* in the first decade of May in the delta, which were carried away by high waters and substituted by phytocoenosis of *Phalarioidea-Scirpetum* in the second decade of June, which usually spreads higher in relation to the complex altitude gradient. Long-term flood in 2017 led to soil desalinization of extended and average alluvial territories, decrease in representativeness of graminoid and herbs, for which long exudation is inhibiting factor; increase in *Eleocharis palustris, Scirpus lacustris, Carex riparia* and other sedge abundance also negatively affects productivity and foliage cover of high-level natural boundaries, which some rise in level of
groundwaters in 2016-2017 and aridity high level in 2017 explain (Selyaninov hydrothermal index was 0.24). Consequently, intensive coning of groundwaters occurred on the surface, and the water-soluble salts accumulated in topsoil.

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