УДК: 581.5; 58.009

DYNAMICS OF THE ABOVEGROUND PHYTOMASS OF THE OB FLOODPLAIN MEADOWS IN THE AREA OF THE TOMSK CARBON POLYGON (KAIBASOVO)

Shepeleva L.F.[1,2*], Kolesnichenko L.G. [1], Pudova M.S. [1]

[1] *Federal State Autonomous Educational Institution of Higher Education "National Research Tomsk State University, Tomsk*
[2] *Sakhalin Research Institute of Agriculture. Yuzhno-Sakhalinsk*

[*] *shepelevalf@mail.ru*

Citation: Shepeleva L.F., Kolesnichenko L.G., Pudova M.S. 2022. Dynamics of the aboveground phytomass of the Ob floodplain meadows in the area of the Tomsk carbon polygon (Kaibasovo) // Environmental dynamics and global climate change. V. 13. N. 2. P. 104-119.

DOI: 10.18822/edgcc119054

Text of the article in Russian: https://edgccjournal.org/EDGCC/article/view/119054

Summary. *In this study, conducted over five years, we explored the year-to-year variability of the Middle Ob floodplain meadows in four trial plots at the Kaibasovo site of Tomsk carbon polygon (Krivosheinsky district, Tomsk region). The aboveground phytomass, the composition of dominant species, ecological and biological groups, and the number of species in meadow vegetation were analyzed. Weather conditions and the pattern of meadow flooding over 2017–2021 are presented. The dynamics of the meadow vegetation and the relationship between the productivity and the aboveground mortmass decomposition in hydroclimatic conditions are described. It is shown that dead plant residues tend to accumulate in arid conditions. Decomposition of plant litter is most active in humid and warm spring conditions.*

Keywords. *Western Siberia, Ob floodplain, meadow vegetation, dynamics, phytomass, mortmass*

INTRODUCTION

Herbage phytocenoses have been comprehensively studied, yet they are still being explored primarily as fodder lands [Study and preservation…, 2013; Rothero et al., 2016; Thornley and Cannell, 1997; Altome et al., 2020]. Meadow vegetation is highly responsive to environmental factors [Rabotnov, 1974]; therefore, it can be used as adequate model objects for analysis of various impacts, which is fully exploited by foreign scientists. In particular, experiments are underway to study the impact of extreme climatic factors on vegetation growth [Zhang L. et al., 2021; Hossain et al., 2021] to maintain stable functioning of plant ecosystems.

In recent years, the studies of meadows have involved the analysis of the impact of climatic and hydrological factors on biodiversity [Zelnik and Carni, 2013, Zhang L. et al., 2021; Hossain et al., 2021] and the net primary productivity of meadows to study the global carbon cycle [Moore et al., 2013; Zhang F. et al., 2017; Zhang B. et al., 2019; Quan et al., 2020].

In 2022, Tomsk carbon polygon was launched in the system of Russian carbon polygons to develop and adapt mathematical models of productivity, CO_2 exchange between the ecosystem and the atmosphere, and other carbon balance parameters in the southern taiga (https://minobrnauki.gov.ru/action/ polygony/). One of the polygon sites (Kaibasovo) is located in a floodplain ecosystem characterized by fertile soils, high productivity, and biodiversity (Shepeleva, 2019). Over 2017–2021, we studied year-to-year changes in the productivity of floodplain meadow phytocenoses in four permanent trial plots (Figs 1–3) to assess the carbon cycle parameters and elucidate the impact of weather conditions and floods on the growth of the aboveground phytomass.

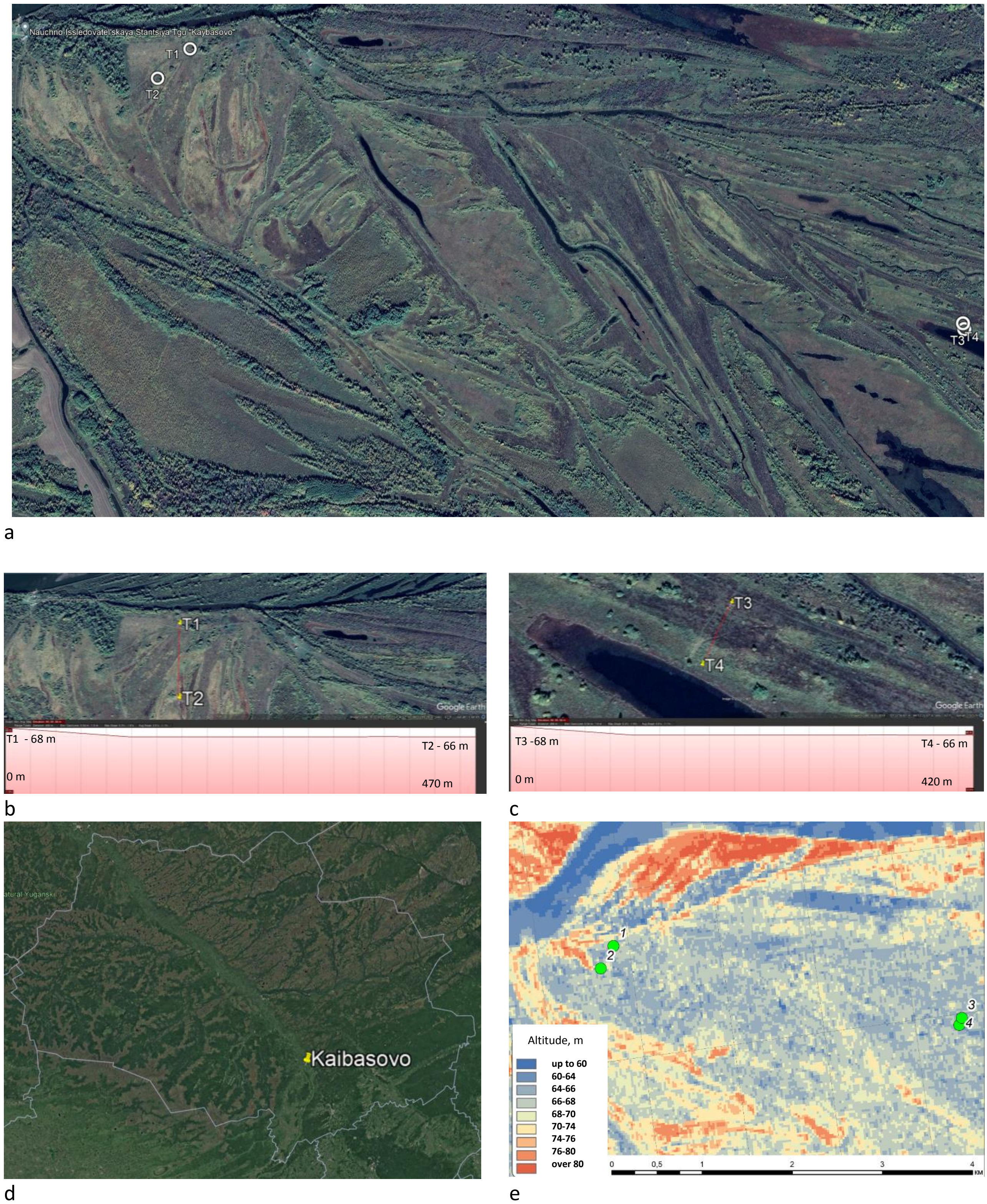


Figure 1 Study area: a – satelitte image of the site location (Google Earth), b – location and relief profile in trial plots 1 and 2 (Google Earth), c – location and relief profile in trial plots 3 and 4 (Google Earth), d – location of the trial plots in the Tomsk region, e – height marks in the trial plots (https://www.eorc.jaxa.jp/)

Figure 2 Location of the Kaibasovo site, Tomsk carbon polygon, relative to the settlements in Krivosheinsky district, Tomsk region (Google Earth)

Figure 3 Floodplain phytocenoses in the territory of Tomsk carbon polygon (Photo by A. Nikolenko)

OBJECTS AND METHODS OF RESEARCH

The study area is located in the southern taiga subzone of the forest zone [Shumilova, 1962]. According to the scheme of natural zoning of the Ob floodplain provided by Yu.A. Lvov [1963], this area belongs to the Shegarsky floodplain zone, namely, to its northern part, where the floodplain expands due to the confluence of the Tom river. Permanent trial plots were laid in the central floodplain on high crests (T1, T3) in the altitude range of 68–70 m of the Baltic coordinate system (hereinafter referred to as mBs), and in the areas of the middle (T4) and low (T2) altitude levels in the range of 66–68 mBs (Fig. 1). Due to the fact that the site is embanked from the side of the Ob river bed and by shafts of secondary watercourses, phytocenoses (T2, T4) are flooded along hollows in years of high and medium floods, T3 is flooded only in years of high floods, and T1 is not flooded.

Geobotanical descriptions [Program and method …, 1974] and selection of the mowed grass to determine the aboveground phytomass were performed in the trial plots during the period of most active growth of vegetation (from June 28 to July 5). The descriptions were made for the area of 100 m^2, including the total projective cover of the meadow vegetation (TPC), its height, floristic composition, and abundance of plant species. These parameters were used to assess the mass share of individual species in the community, since the study focused on the integral indicator – phytomass. Mowing was performed in the area of 0.25 m^2 in 4 replicates with extrapolation of each mow per 1 m^2 and subsequent data averaging. The aboveground dead phytomass (aboveground mortmass, including plant litter) was assessed separately [Biological productivity…, 1988]. The mowed grass was sorted by species in the field to assess its abundance, and then it was air-dried and weighed; the aboveground green phytomass was determined by summing the masses of individual species.

Further, the average indicators of phytocenosis were determined per 1 m^2 – productivity (g/m^2), biodiversity of the trial plot (species composition, dominant species composition, total number of species, composition and ratio of various fractions – biological (grasses, sedges, forbs, legumes) and ecological groups – in the green phytomass. The affinity of plant species to ecological groups was determined based on bioindicative ecological scales developed by L.G. Ramensky [Ramensky et al., 1956; Shepeleva, 2019]. In terms of soil fertility (trophicity), groups were distinguished and named in accordance with the work by Ramensky [Ramensky, 1938]. Hydroecological groups were identified and named according to Yu.A. Lvov et al. [1987]. Species names were taken in compliance with the WFO Plant List (https://wfoplantlist.org/plant-list). Statistical analysis was performed using the Statistica 6.0 software. Mortmass data for 2017–2018 were not included in the analysis due to haymaking in August 2017, which could have affected the mortmass of 2018.

For soil type determination, soil profiles from the key plots were taken and described by methods used in soil science.

The studied phytocenoses were as follows (Fig. 1):

T1 Forb-grass meadow is located on a high crest. The soils are alluvial sod-meadow loamy. TPC is about 80%.

T2 Reedgrass-sedge meadow is located in the lower flat part of the slope near the lake. The soils are alluvial-meadow. TPC is about 95%.

T3 Forb (elecampane) meadow is located in alluvial meadow loamy soils; it is of a fallow origin. TPC is 75%.

T4 Forb-soddy-sedge meadow is located on the slope of the crest. The soils are meadow-marsh. TPC is 95%.

The characteristics of the flooding pattern of habitats and assessment of weather conditions were provided based on data from the weather station in the settlement of Molchanovo (https://meteoinfo.ru/, https://rp5.ru) and the Nikolskoye hydropost (https://allrivers.info/gauge/ob-nikolskoe). In addition, the soil temperature was assessed based on data from the Kaibasovo weather station (IMCES SB RAS), and the surface moisture was assessed based on Modis Satellite images and the site https://eos.com/ru/make-an-analysis/ndmi/.

RESULTS AND DISCUSSION

Hydroclimatic conditions in 2017–2021

During the 5-year period preceding the study (until 2017), high crests in the Kaibasovsko-Podoba floodplain zone were flooded with hollow waters in 2013 and in 2015. Medium and low altitude areas with height marks in the range of 66–67 mBs were flooded annually.

Maximum flood levels in 2017–2018 and in 2020–2021 were slightly above the average level (Fig. 4), so the floodplain was flooded along hollows and channels; high crests (T3) were not flooded, and the flood was caused by the groundwater rise.

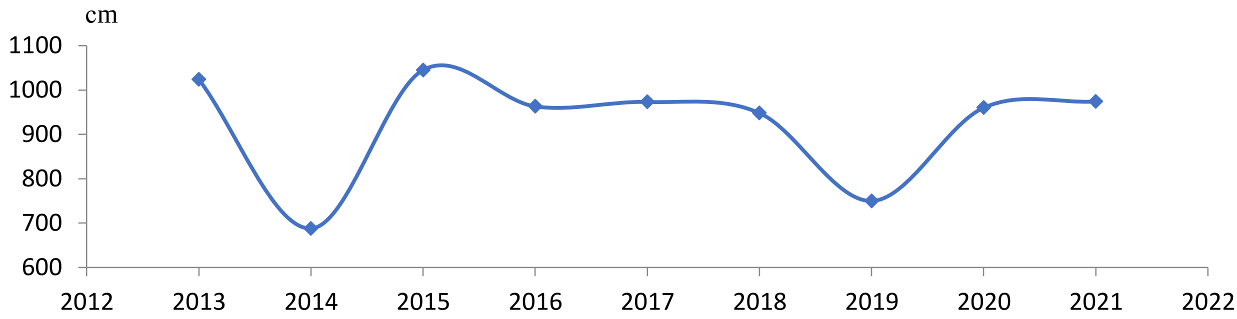


Figure 4 The maximum flood levels above 0 at the gauging station (61.20 m of the Baltic coordinate system) in the Ob river, the vicinity of Nikolskoye settlement, 2013–2019

In 2019, the maximum flood levels in the Ob river were below the long-term average. Only hollow areas were flooded. The trial plots were not affected by the flood that year.

The flood of 2020 was short, and its water level was similar to that in 2018 (Fig. 4). Hollows, low crests, and slopes of medium crests were flooded for about 10 days (T2, T4). The flood of 2021 was longer (Fig. 5) and the trial plots T2 and T4 were flooded for 20–30 days.

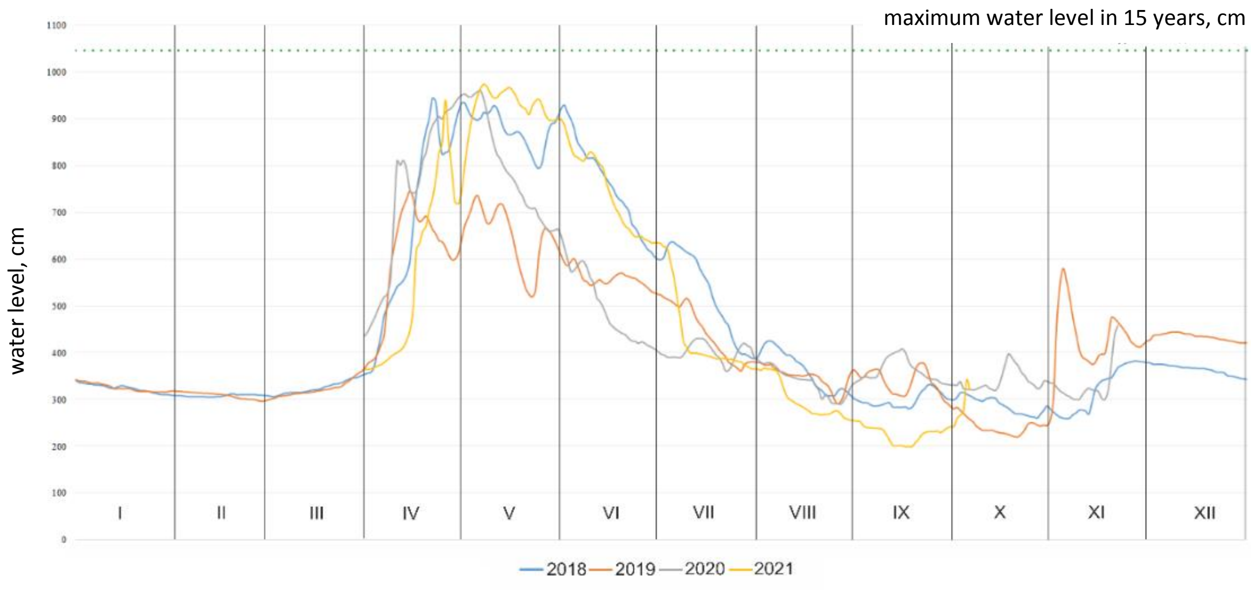


Figure 5 Graphs of changes in water levels for 2018–2021 in the riverbed of the Ob, the vicinity of Nikolskoye settlement

The weather in 2017 in Russia was warm and wet [Bulygina et al., 2018]. In Western Siberia, the spring was generally cool and wet; the third decade of April was abnormally hot, the air warmed up to 22–25 °C in the daytime. May and June were rainy and warm; the average monthly temperature was 1–2 °C above the climatic norm. July was very rainy and cool; the air temperature was 0.5–2 °C below the norm. August was warm, and in the second decade the temperature dropped. In September, the average monthly air temperature was 0.5–2 °C below the norm; the precipitation norm was exceeded more than 2-fold. In October, there was a precipitation deficit. According to the calculated G.T. Selyaninov's hydrothermal coefficient (HTC equal to the ratio of the amount of precipitation in mm for a period with average daily temperature above 10 °C to the sum of temperatures for this period reduced 10-fold) [Agricultural....1989] and according to data from the weather station in the settlement of Molchanovo, Tomsk region, the growing season of 2017 is estimated as wet (HTC = 1.6).

The year of 2018 was marked by cold wet spring. In April–May, the monthly precipitation norm was exceeded 1.5–2-fold. In May, the monthly average air temperature was 0.5–4.0 °C below the climatic norm. Warm weather in June was accompanied by heavy precipitation (up to 3 climatic norms in the Tomsk region). In cool dry July, the amount of precipitation was 80% of the climatic norm. The average temperature in August was 0.5–1.5 °C above the climatic norm, the precipitation was within the normal range [Korshunova et al. Weather… 2019]. The autumn period (September, October) was abnormally warm; the monthly average temperature of 2–4 °C exceeded the norm [Korshunova et al. Estimates…, 2019]. The upper soil layers suffered from moisture deficit. The HTC indicated the growing season as generally wet (HTC=1.40).

The growing season of 2019 was dry and very warm; however, spring and early summer (June) were cool and rainy [Arzhanova et al., 2020]. According to our calculations of precipitation indicators compared to 2018 (Table 1), in April, May, June, August, and September, the average monthly precipitation was 1.5–2-fold lower. An exception was the second decade of July with showers, which slightly alleviated the drought. HTC of the growing season was 1.07.

Table 1 Monthly average precipitation in April–September 2018–2021, mm

Year	April	May	June	July	August	September
2017	32,3	54,1	88,2	101,5	52,5	51,3
2018	74,0	81,3	102,7	39,6	79,8	29,4
2019	31,6	26,3	58,3	83,4	31,0	31,3
2020	13,4	82,4	49,9	58,8	38,0	80,9
2021	41,2	28,6	23,5	53,9	85,8	55,1

In 2019, the spring was warmer compared to 2018 (Table 2). Significant differences were evidenced by the temperature in the first decade of May. The average monthly air temperature in May 2019 was 7 °C higher than that in May 2018. The upper soil layers were naturally warmed up by the end of May. The average temperature in June was 3 °C lower. July and August were hotter; the differences in the average monthly air temperatures amounted to 2.5–3 °C. The first two decades of September were also warm.

Table 2 Monthly average temperature in April–September 2018–2021, ^{o}C

Year	April	May	June	July	August	September
2017	3,9	9,7	18,6	17,5	16,3	6,9
2018	3,0	3,1	20,0	18,7	15,5	10,2
2019	2,5	10,5	17,0	20,6	18,3	10,6
2020	8,6	14,2	15,5	18,8	17,9	10,1
2021	3,1	11,5	15,1	19,1	16,7	7,7

The growing season of 2020 was wetter than that in 2019. The spring was very warm; in April–May, the average monthly temperature was about 3 °C higher than that in April–May 2019. The summer months were cool (Table 2). The average monthly precipitation indicated the spring months as considerably wet, June–July were moderately wet, August was dry, and September was wet (Table 1). The HTC of the growing season was 1.24, which corresponds to slightly dry weather.

The growing season of 2021 (HTC=1.1), compared to 2020, was notable for cool and rather dry spring. The temperature in May was 3 °C lower. Precipitation on average corresponded to the indicators of 2019; in May, the last decade was the driest. June, compared to 2018–2020, was cooler and abnormally dry. The temperature in the second and third decades was 2–4 °C lower than that in 2020; the amount of precipitation was the lowest within the observation period. July and August were moderately hot and wet, and the third decade of September was characterized by low temperatures (Tables 1–2).

The general assessment of hydroclimatic conditions indicated the period of 2017–2018 as warm, wet, with average water level; 2019 was dry and hot, the floodplain was not flooded; 2020 was warm, slightly arid, with average water level; 2021 was cool and dry, with relatively high and long floods.

Dynamics of meadow vegetation

The average green phytomass of the studied phytocenoses in the Middle Ob was 402.6 g/m^2 (standard deviation was 164.5 g/m^2). The mortmass in some years exceeded green phytomass and averaged 587.4 g/m^2 (standard deviation was 296.3 g/m^2).

In 2017, 14 species were recorded in **the forb-grass meadow (T1),** *Bromus inermis* Leyss. (25%) and *Poa angustifolia* L. (31%) dominated. Among grasses, *Elymus repens* (L.) Gould and *Dactylis glomerata* L. were found in significant amount (9–10%). The dominating species among forbs were *Cirsium arvense* (L.) Scop. (8%) and *Equisetum arvense* L. (13%). The productivity of the meadow vegetation was 219.9 g/m^2. Grasses and forbs prevailed among the biological groups; sedges and legumes were also recorded (about 1%) (Table 3).

Table 3 Structural indicators of the aboveground phytomass in the Kaibasovo zone of the Middle Ob floodplain, 2017–2021

Phytocenosis	Year	Above-ground biomass, g/m^2		Number of species	Predominant species		Biogroups,%			
		Plant biomass	Mortmass		Composition	%	Grasses	Forbs	Legumes	Sedges
Forb-grass, T.1 (57°14'40.31"C 84°11'50.37"B)	2017	220,0± 17,6	* no data	14	*Bromus inermis,* *Poa angustifolia,* *Equisetum arvense*	24,8 31,3 13,1	74,1	24,2	0,1	1,6
	2018	320,0± 54,7	no data	14	*Dactylis glomerata* *Poa angustifolia* *Equisetum arvense*	41,4 33,5 11,4	76,0	23,1	+	0,9
	2019	318,9± 23,3	622,6± 165,0	14	*Bromus inermis* *Alopecurus pratensis* *Poa angustifolia* *Elymus repens* *Dactylis glomerata*	19,2 18,2 17,8 14,9 11,9	82,0	17,9	0,1	+
	2020	221,4± 11,1	406,4± 54,3	22	*Bromus inermis* *Dactylis glomerata* *Poa angustifolia*	30,9 22,5 34,7	90,1	7,5	1,4	0,1
	2021	223,4± 64,2	440,0± 50,2	18	*Poa angustifolia* *Bromus inermis*	51,8 28,4	83,2	10,6	0,3	5,8
Elecampane, T3 (57°13'56.22"C 84°15'28.55"B)	2017	250,0± 64,6	no data	26	*Pentanema salicinum*	52,5	10,2	89,6	0,2	0,4
	2018	539,5± 27,4	no data	24	*Pentanema salicinum* *Bromus inermis* *Sanguisorba officinalis*	44,8 10,0 12,9	12,1	86,8	1,0	0,1
	2019	292,4± 5,1	613,3± 77,7	29	*Pentanema salicinum* *Thalictrum simplex* *Sanguisorba officinalis*	31,9 28,7 11,1	6,8	91,8	1,0	0,4
	2020	333,7± 28,3	284,1± 20,16	37	*Pentanema salicinum* *Thalictrum simplex*	24,4 35,7	8,0	90,6	1,0	0,04
	2021	406,5± 69,3	633,3± 78,95	35	*Pentanema salicinum* *Thalictrum simplex* *Phleum pratense*	28,7 17,6 10,5	23,7	67,6	8,7	0,02

Phytocenosis	Year	Above-ground biomass, g/m^2		Number of species	Predominant species		Biogroups,%			
		Plant biomass	Mortmass		Composition	%	Grasses	Forbs	Legumes	Sedges
Forb-soddy-sedge, T4 (57°13'55.35"C 84°15'28.74"B)	2017	659,1± 118,1	no data	21	*Carex cespitosa* *Phalaroides arundinacea*	43,5 10,3	18,1	33,4	3,6	44,9
	2018	573,9± 36,1	no data	27	*Calamagrostis purpurea* *Carex cespitosa* *Phalaroides arundinacea*	23,2 9,4 13,8	51,3	30,7	2,8	15,2
	2019	302,9± 44,6	533,4± 49,4	24	*Calamagrostis purpurea* *Carex cespitosa*	45,1 28,6	49,5	20,2	1,7	28,6
	2020	404,3± 57,0	329,2± 29,0	30	*Calamagrostis purpurea* *Carex cespitosa* *Phalaroides arundinacea*	30,3 10,1 15,8	52,6	33,5	2,0	11,9
	2021	402,2± 71,2	786,9± 155,2	27	*Calamagrostis purpurea* *Carex cespitosa* *Phalaroides arundinacea*	16,6 27,5 19,0	44,7	25,6	1,9	27,8
Reedgrass-sedge, T2 (57°14'34.61"C 84°11'42.09"B)	2017	438,3± 86,9	no data	11	*Calamagrostis purpurea* *Carexatherodes*	72,6 19,6	72,6	7,1	0,1	19,6
	2018	500,7± 119,6	no data	17	*Carex riparia* *Carex atherodes,* *Carex cespitosa*	20,4 14,0 41,2	16,9	7,4	0,1	75,6
	2019	389,1± 41,0	864,6± 68,6	10	*Calamagrostis purpurea* *Phalaroides arundinacea* *Carex atherodes*	56,9 21 12	77,9	1,4	+	20,7
	2020	667,8± 73,1	389,2± 169,7	9	*Calamagrostis purpurea* *Phalaroides arundinacea* *Carex atherodes*	53,6 21,4 22,7	75,0	1,2	+	23,8
	2021	592,5± 163,3	1237,6± 261,85	6	*Calamagrostis purpurea* *Phalaroides arundinacea*	75,4 16,8	92,3	3,0	-	4,8

Note: for Table 3 and Table 4, the symbol "+" indicates the presence of species in the amount less than 0.1%, the symbol "–" indicates the absence of species of a particular group. * "no data" indicates the absence of quantitative data

In the ecological structure of the phytocenosis, mesophytes and xeromesophytes prevailed (49% and 33%, respectively) in the hydroecological groups; the share of eumesophytes was about 16%. In terms of trophicity, eutrophs and subeutrophs dominated (35%) among the groups; the groups less demanding of soil fertility accounted for 21%. (Table 4).

In 2018, the number of species in the meadow vegetation did not change, *Dactylis glomerata* became dominant (about 40%), the abundance of *Poa angustifolia* and *Cirsium arvense* slightly increased (33.5% and 10.3%, respectively). The vegetation mass increased, the ratio of the biological groups did not change, and the amount of legumes decreased.

Table 4 Ecological structure of meadow phytocenoses at the Kaibasovo-Podoba site in the Middle Ob floodplain, 2017–2021

Фитоценоз	Год	**Ecological groups of plants, %**										
		moisture						**trophicity**				
		км	м	эм	гм	сг	аг	мт	пм	сэ	э	пэ
Forb-grass, T1	2017	35,0	48,7	16,3					21,0	9,0	35,0	35,0
	2018	34,8	53,7	11,5					53,3	11,1	34,4	1,2
	2019	18,8	43,9	37,3	0				21,3	8,6	36,0	34,1
	2020	35,6	58,2	6,0	0,2			0,1	26,6	5,2	34,8	33,3
	2021	55,5	39.3	5,0	0,3	+			4,8	5,6	51,8	37,7
Elecampane, T3	2017	63,5	26,8	8,9	0,2	0,6		0,3	73,8	14,7	6,1	5,1
	2018	53,0	29,0	16,0	1,7				73,3	14,5	0,8	11,4
	2019	45,4	41,3	11,9	1,4	0		1,4	82,2	12,1	3,6	0,7
	2020	43,6	47,2	7,2	1,6	0,5		1,0	72,5	17,1	6,7	2,8
	2021	51,6	37,4	9,1	1,5	0,4		6,0	53,9	22,2	13,6	4,2
Forb-soddy-sedge, T4	2017	10,0	14,5	4,6	9,3	60,2	1,4	8,2	31,0	49,1	11,7	
	2018	2,9	21,5	15,6	34,3	25,7		23,2	23,1	24,6	21,6	7,5
	2019	1,1	6,2	10,7	46,5	35,0	0,5	45,1	11,1	38,9	4,9	
	2020	2,6	10,4	13,5	40,0	33,5		30,3	21,8	24,5	15,9	7,5
	2021	2.0	8.1	18,1	21,6	50,1		16,8	13,9	42,5	23,4	3,4
Reedgrass-sedge, T2	2017		1,0	0,2	77,4	1,8	19,6	72,7	5,6	1,5	20,2	
	2018		0	0,7	7,7	57,0	34,6	7,2	2,9	44,6	44,9	0,4
	2019		0,1	0,5	57,4	29,2	12,8	57,0	0,6	8,7	33,7	
	2020		0,4	0	54,2	22,5	22,9	53,6	1,0	1,1	44,3	
	2021			0,9	77,1	17,1	4,8	75,4	2,1	0,9	21,6	

Symbols: moisture content (Lvov et al., 1987): km – xeromesophytes, with optimum development at moisture content varying in the range of 53–63 estimated by the Ramensky moisture scale; m – mesophytes (64–68); em – eumesophytes (69–76); hm – hydromesophytes (77–88); sh – subhydrophytes (89–95); ah – aerohydrophytes (96–103); ah – aerohydrophytes (104–120). Trophicity (Ramensky, 1938): mt – mesotrophs (6.5–9.5); pm – permesotrophs (9.5–11.5); se – subeutrophs (11.5–13.5); e – eutrophs (13.5–15.5); pe – pereutrophs (15.5–18).

The ratio of hydroecological groups shows an increased amount of mesophytes (53.7%) and xeromesophytes (35%), and a decreased share of more moisture-loving eumesophytes (11%). In terms of trophicity, the content of relatively undemanding permesotrophs increased (53%), which indicates deteriorated environmental conditions.

In 2019, *Bromus inermis*, *Poa angustifolia*, *Elymus repens*, *Alopecurus pratensis* L., and *Dactylis glomerata* dominated in the meadow vegetation (Table 3). In the forb group, *Equisetum arvense* prevailed (8.4%). The average abundance (3–5%) was represented by *Cirsium arvense* and *Geranium pratense* L. The vegetation mass was 318.8 g/m^2, whereas the total aboveground dry biomass (with mortmass) was about 923 g/m^2. Grasses (82%) and forbs (17.9%) dominated in the biological groups; sedges and legumes were sporadic.

The ratio of the ecological groups in the meadow vegetation (Table 4) indicates favorable moisture and nutrition conditions. In the hydroecological groups, mesophytes prevailed (44%), the share of xeromesophytes was 18.8%, and that of eumesophytes was about 37%. In terms of trophicity, eutrophs and pereutrophs dominated (about 35%); permesotrophs, less demanding of soil fertility, accounted for 21%.

In 2020, the aboveground phytomass, both live and dead, decreased; the total number of species in the meadow vegetation increased. The dominant structure of the meadow vegetation changed significantly. The share of grasses increased. In 2019, the meadow vegetation was polydominant; in 2020, species from two ecological groups, mesophytes (*Dactylis glomerata*, *Bromus inermis*) and xeromesophytes (*Poa angustifolia*), dominated. The share of *Alopecurus pratensis*, grass from the eumesophyte group, sharply decreased. In this ecological group, *Cirsium arvense* and *Sanguisorba officinalis* L., eumesophytes from the forb group, prevailed.

In general, the amount of forbs decreased, and the meadow vegetation was represented mainly by grasses. The amount of legumes slightly increased. The ratio of the ecological groups in terms of trophicity virtually did not change; in terms of moisture, the amount of xeromesophytes increased, and the mesophyte group became dominant. These changes indicate increased moisture conditions. Under such conditions, the most competitive were grasses, mesophytes, which was earlier reported for other xeromesophilic-mesophilic meadow phytocenoses [Shepeleva, 2019].

In 2021, the aboveground phytomass slightly increased, mainly due to the mortmass, and the number of species decreased. Two species, *Bromus inermis* and *Poa angustifolia*, dominated in the meadow vegetation, and the amount of xeromesophyte *Carex praecox* Schreb. increased significantly. In general, the share of grasses decreased, and that of forbs and sedges increased due to the increased number of eutrophic xeromesophytes (Tables 3, 4). In 2021, the forb-grass (T1) phytocenosis was not flooded, so the aridity and relatively low temperatures in May–June could have affected the growth of plants of this phytocenosis.

T3. Forb (elecampane) meadow. In 2017, 26 species were recorded in the meadow vegetation, and most of them belonged to the forb group, which phytomass attained 89.6%. Sedges (*Carex praecox*) and legumes (*Lathyrus pratensis L.*) were sporadic. The share of grasses (*Poa angustifolia*, *Elymus repens*, *Bromus inermis,* and *Melica nutans* L.) was about 10%. The total aboveground mass was 560.7 g/m^2; the share of the dead phytomass exceeded 50%, and the vegetation mass was 250.1 g/m^2.

The ecological group of permesotrophic xeromesophytes dominanted in the community and included the main dominant species – *Pentanema salicinum* (L) D. Gut. Larr., Santos-Vicente, Anderb., E. Rico & M.M. Mart. Ort. The codominant group included subeutrophic mesophytes, mainly representatives of short-rhizome plants (*Geranium pratense*).

In 2018, the total aboveground phytomass increased (652.4 g/m^2), with the share of the dead part being only 17.3%. The weather conditions of that year were apparently more favorable for decomposition of plant residues and for plant growth (green part of 539.6 g/m^2), which was probably due to the cool rainy weather in early summer.

The number of species in the meadow vegetation decreased slightly (24 species); the ecological structure did not change; xeromesophytes, permesotrophs, and subeutrophs remained dominant. At the same time, the amount of moisture-loving species from mesophyte and eumesophyte groups increased; the share of these groups was 29% and 16%, respectively, which indicates increased moisture conditions. In the mesophyte group, the amount of *Bromus inermis* increased (up to 10%), and in the eumesophyte group, the amount of *Sanguisorba officinalis* increased (up to 12%). In general, increased moisture conditions increased the aboveground phytomass.

In 2019, the meadow vegetation included 29 species except for the main dominant *Pentanema salicinum*; the dominant species were *Thalictrum simplex* L. and *Sanguisorba officinalis* (Table 3). The share of *Poa angustifolia*, *Tanacetum vulgare*.L. *Hieracium umbellatum* L., and *Equisetum arvense* was relatively large (3–5%). Other species were sporadic. The live to dead part ratio of the aboveground phytomass was approximately similar. Forbs dominated in the biological groups, and xeromesophytes and permesotrophic mesophytes prevailed in the ecological groups (Table 4).

In 2020, the aboveground phytomass and the number of species in the meadow vegetation increased. P*entanema salicinum* and *Thalictrum simplex* remained dominant, and the amount of *Thalictrum simplex* even increased. The ratio of biological groups in the meadow vegetation did not change significantly. The hydroecological structure showed a decreased number of xeromesophytes and eumesophytes, whereas the amount of mesophytes increased. The trophoecological structure did not change. The change in the structure of the meadow vegetation indicated slightly increased moisture conditions.

In 2021, the groundwater level during the flood period increased, and during dry and cool spring, it had a positive effect on the growth of the aboveground mass, and the amount of grasses and legumes. The total number of species and the amount of forbs decreased slightly. *Phleum pratense* L. was also among the dominant species in the meadow vegetation. Xeromesophytes and mesophytes remained dominant ecological groups in terms of moisture; however, the amount of moisture-loving eumesophytes increased, and the share of eutrophs grew among the trophic groups (Tables 3, 4).

The fallow origin was evidenced by the dynamics of the elecampane phytocenosis, when increased moisture conditions in 2020 naturally increased not only the grass (Shepeleva, 2019), but also the forb share in the meadow vegetation. Only two wet years after the extreme drought, the amount of grasses and legumes started to grow, yet the phytocenosis retained its forb status.

T4. Forb-soddy-sedge meadow located on the slope of the crest was not flooded by hollow waters in 2019, it was flooded for about 10 days in 2020, and the flood lasted for 20–30 days in 2021.

In 2017, 21 species were recorded in the meadow vegetation. The total aboveground phytomass attained 659 g/m^2, plant litter accounted for 51.3%. The dominant species was *Carex cespitosa* L. (43.5%), and *Phalaroides arundinacea* codominated (10.3%). *Calamagrostis purpurea*, *Veronica longifolia* L., *Anemonastrum dichotomum* (L.) Mosyakin, and *Pentanema salicinum* were observed in significant amount (6–9.6%). The representatives of legumes, *Vicia cracca* L. and *Lathyrus pratensis* (3.5%), were found in the meadow vegetation.

The hydroecological structure of the phytocenosis was dominated by subhydrophytes (60%) and mesophytes (14.5%). In the ecological groups, in terms of soil fertility, subeutrophs and permesotrophs prevailed. The predominant biological group was sedges (45%), and the share of grasses accounted for about 18% (Table 3).

In 2018, 27 species were recorded in the meadow vegetation. The total vegetation mass was 583.2 g/m^2, and the green mass accounted for 574 g/m^2. The share of grasses increased (51.3%), especially *Calamagrostis purpurea* Trin., while the amount of sedges was observed to decrease. In the ecological structure, three groups of species dominated in terms of moisture – subhydrophytes, hydromesophytes, and mesophytes. Eutrophs, subeutrophs, permesotrophs, and mesoeutrophs were dominant in terms of soil fertility, their ratio being virtually similar. All this indicates favorable conditions for development of this community in 2018.

The year of 2019 was less favorable. The live part of the aboveground phytomass decreased, its dead part increased correspondingly (57.4%), and the number of species decreased slightly. A total of 24 species were recorded, and the live part of the phytomass attained 300 g/m^2. The main dominants were reedgrass and soddy sedge. *Sanguisorba officinalis, Cirsium arvense,* and *Phalaroides arundinacea* Rausch were found in significant amount (3–6%). The representatives of legumes, *Vicia cracca* and *Lathyrus pratensis,* were sporadic.

The hydroecological structure of the phytocenosis was dominated by hydromesophytes (46.5%), subhydrophytes (35%), and eumesophytes (10.7%). In the ecological groups, subeutrophs and mesotrophs dominated in terms of soil fertility. The ratio of the groups indicates drainage and depletion of the habitat. Grasses were the predominant biological group, sedges accounted for about 29%, and forbs were abundant (Table 3).

In 2020, the number of species grew up, and the amount of *Phalaroides arundinacea* increased – it became one of the main dominants. In the forbs group, the amount of *Cirsium arvense* and *Thalictrum flavum* L increased. Apparently, the increased amount of *Phalaroides arundinacea* and large forb species in the meadow vegetation caused an increase in the aboveground phytomass. No significant changes in the ecological structure of the phytocenosis were observed. The change in the ratio of biological groups was more significant; the amount of grasses and forbs increased, while the share of sedges decreased. Probably, in this phytocenosis, the increased moisture conditions induced the potential changes of the previous year.

In 2021, the state of the soddy-sedge phytocenosis changed insignificantly: the dominant species, the productivity of the meadow vegetation, and the number of species did not change. The amount of soddy sedge and the number of species from the groups of moisture-loving hydromesophytes and subhydrophytes increased. Apparently, due to the long water stagnation, the conditions for decomposition of the aboveground mortmass worsened and its amount increased.

T2. Reedgrass-sedge meadow is located in the lower flat part of the slope near the lake. In 2019, the area was not flooded. In 2018 and 2020, it was flooded for about 30 days, the longest flood lasted more than 30 days in 2021.

In 2017, 11 species were recorded in the meadow vegetation. The total aboveground phytomass attained 672.2 g/m^2, with the share of mortmass equal to 34%. The dominant species were *Calamagrostis purpurea* and *Carex atherodes* Spreng. (Table 3). *Thalictrum flavum* prevailed (4.7%) among forbs. Legumes (*Vicia cracca, Lathyrus palustris* L.) were sporadic. The ecological structure of the meadow vegetation was dominated by mesotrophic hydromesophytes and eutrophic aerohydrophytes.

In 2018, the number of species increased to 17, and the phytomass was 696.2 g/m^2 (mortmass accounted for 28%). Sedge species, in particular *Carex riparia* Curt., *C. atherodes,* and *C. cespitosa*, began to prevail, with the share being equal to 72.6%. The amount of grasses (Calamagrostis *purpurea*, *Phalaroides arundinacea*) reduced to 16%. The ecological structure exhibited an increased amount of moisture-loving aerohydrophytes and subeutrophic subhydrophytes (Table 4), which was probably due long water stagnation and soil degradation.

In 2019, 10 species were recorded in the meadow vegetation. The total aboveground phytomass was 1141.6 g/m^2, with the share of dead plant material equal to 69% (Table 3). The dominating species were *Calamagrostis purpurea, Carex atherodes,* and *Phalaroides arundinacea*. The amount of *Carex cespitosa* was negligible (8%). Other species were found sporadically. The ecological structure of the meadow vegetation was dominated by hydromesophytes and mesotrophic subhydrophytes, with the amount exceeding 50%.

In 2019, the reedgrass-sedge phytocenosis was apparently affected by arid conditions, which hampered the growth of moisture-loving sedges. Grasses suffered to a lesser extent and dominated in the meadow vegetation. Yet, the number of species and the live aboveground mass of the phytocenosis decreased significantly compared to the previous year, and the share of the dead aboveground mass increased (Table 3).

The increased moisture conditions in 2020 led to a 2-fold increase in the aboveground phytomass and increased the share of the hydrophilic *Carex atherodes* in the meadow vegetation. The ratio of biological and ecological groups in the meadow vegetation changed slightly – the content of eutrophic aerohydrophytes increased slightly, which indicates the improved conditions of the habitat.

The autumn drought in 2020 in combination with long water stagnationin 2021 decreased the green mass and the total number of species of reedgrass-sedge phytocenosis, while the total aboveground mass increased due to the mortmass. The share of grasses increased significantly, especially *Calamagrostis purpurea*, which, apparently, was most resistant to these conditions.

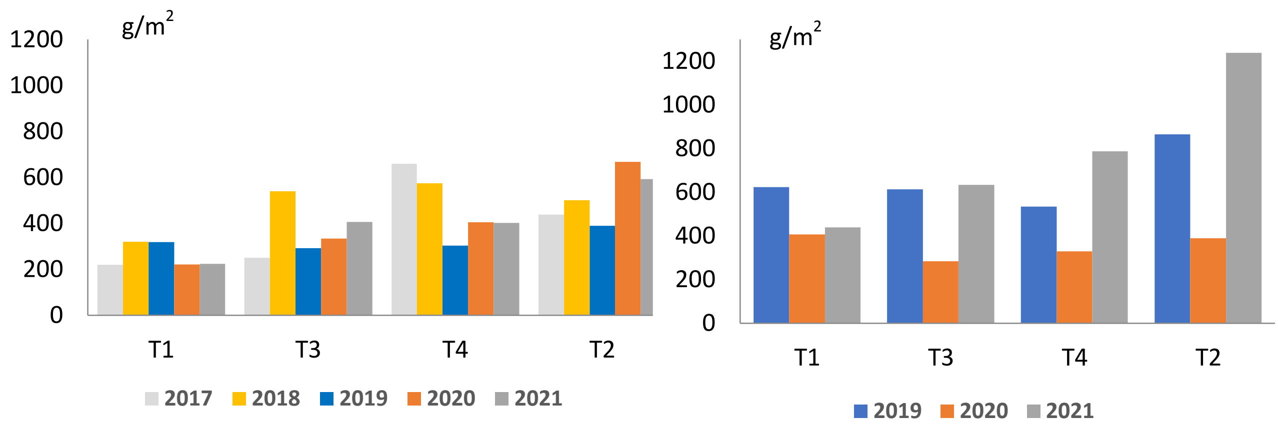
DISCUSSION

Meadows of the Middle Ob floodplain in the Tomsk region were extensively studied in 1960–1970 to assess the forage base for development of animal husbandry. In 1980–1990, the study focus was on the patterns of their natural long-term dynamics in order to predict year-to-year conditions in terms of productivity and plant composition; the results were reported by L.F. Shepeleva [2019]. The studies assessing the biological productivity of meadow ecosystems in the vast territory of the floodplain have been and remain so far sporadic and isolated (Titlyanova et al., 1996).

At present, most of the meadows of the Kaibasovo site in the Middle Ob floodplain are not mowed, which makes this territory appropriate for analysis of the production and destruction processes of the meadow vegetation. The trial plots show the patterns of the dynamics of meadows of the upper (T1, T3), medium-low (T4) and low (T2) altitude levels of the floodplain. Meadows are characterized by pronounced year-to-year variability in the aboveground phytomass, the composition of dominant species, and the ecological and biological structure of the meadow phytocenoses.

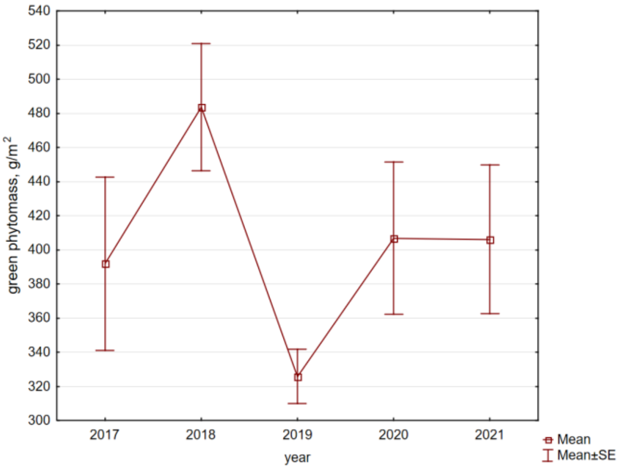
The changed status of the forb-grass phytocenosis (T1) was due to the dynamics of weather conditions. The range of changes in the productivity of the meadow vegetation was the smallest (Fig. 6) owing to good adaptation of the phytocenosis to these conditions. This is due to the variety of vegetatively mobile long-rhizome grasses from the ecological groups of xeromesophytes, mesophytes and eumesophytes, which are able to develop new shoots and maintain phytomass.

The status of other studied communities depended not only on weather conditions, but also on meadow floods and groundwater rise. Their productivity was found to be higher, and the range of fluctuations in the aboveground phytomass over the years was wider (on average, 2-fold). Elecampane and forb-soddy-sedge phytocenoses exhibited the highest productivity of the meadow vegetation in the mid-water and humid 2018, and the long-term flooded hydrophilic reed-sedge phytocenosis showed the highest yield in wet and warm 2020 (Figs 6–8). In 2019, the phytomass of the phytocenoses (T2, T3, T4) was relatively small due to the dry summer of 2019 and September of 2018, and no flooding effects.

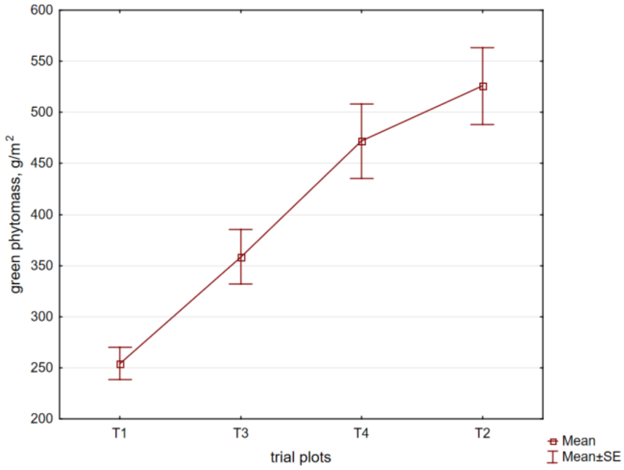


a b

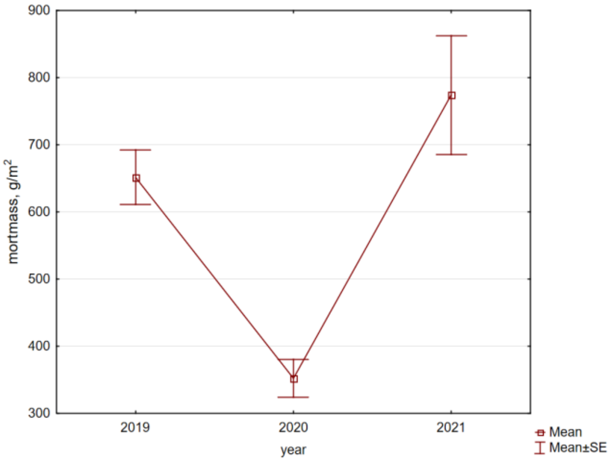
Figure 6 Changes in the aboveground biomass of meadows at the key site of Kaibasovo, 2017–2021 (a – plant biomass; b – mortmass *)*



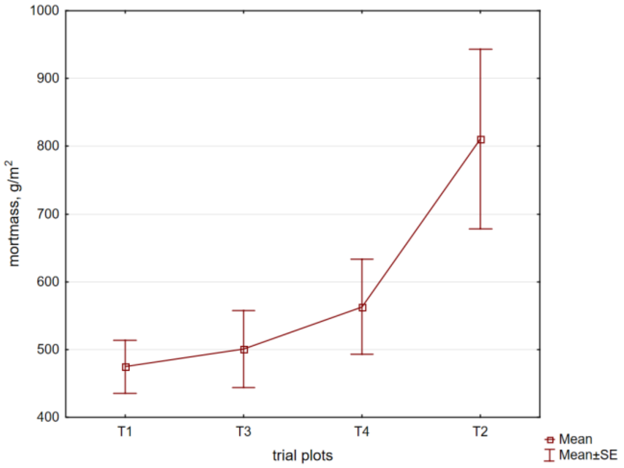
a



b



c



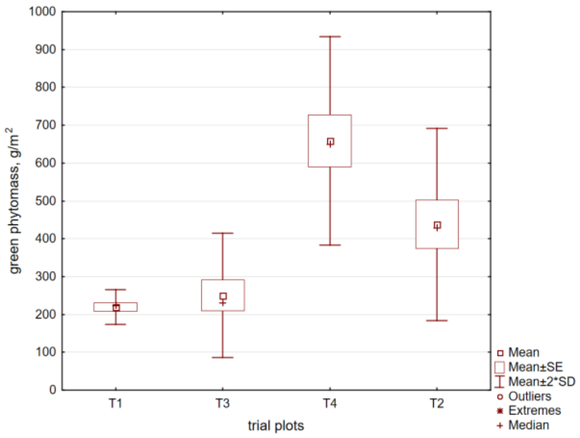
d

a – distribution of green phytomass by years (F=1.45; p=0.2); b – distribution of green phytomass in the trial plots (F=15.8; p=0.0000); c – distribution of mortmass by years (F=13.4, p=0.00003); d – distribution of mortmass in the trial plots (F=3.5, p=0.03)

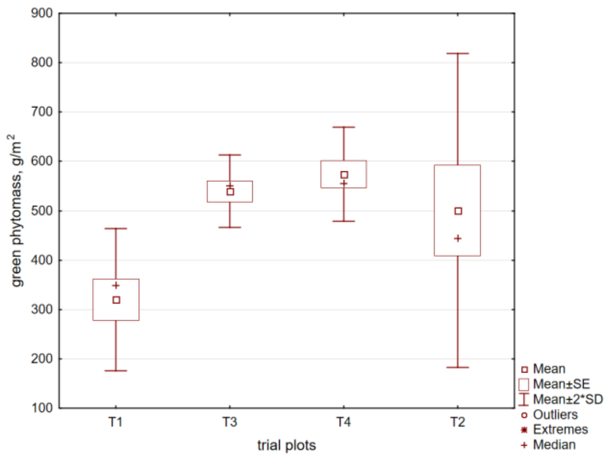
Figure 7 Average biomass value in the trial plots of Kaibasovo, 2017–2019

Our results obtained on year-to-year variability of the phytomass of the meadow phytocenoses at different floodplain altitude levels are generally consistent with previously published data on the effect of various environmental factors on the productivity [Shepeleva, 1986; Skulkin, 1992; Tyurin, 2017, 2018; Cherepinskaya and Shepeleva, 2017). It is shown that the effect of precipitation, air temperature, meadow biodiversity, floods and groundwater levels (Tyurin, 2018), HTC, soil temperature, and the ecological structure of the meadow vegetation (Shepeleva et al., 1995) on the productivity varies for different altitude levels.

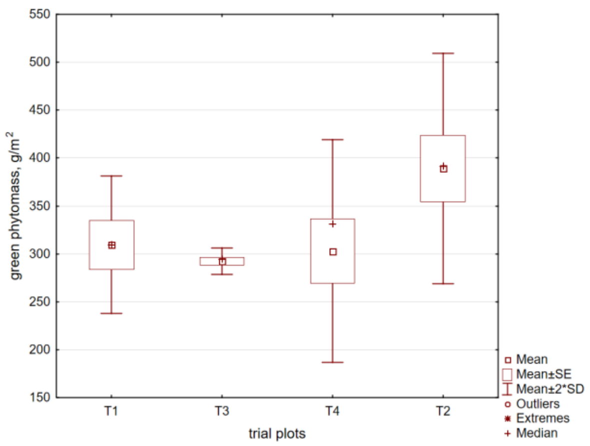
As mentioned above, virtually no data are available on the patterns of the aboveground mortmass dynamics, which show the production and destruction processes and the carbon cycle in floodplain meadow ecosystems. Our study results provide few data on these patterns. In the extremely dry and hot year of 2019, without meadow floods, a large amount of dead plant residues was found on the soil surface in the studied meadow phytocenoses (Table 3, Fig. 6). This combination of environmental factors seemingly hampered not only the development of meadow vegetation, but also the decomposition of mortmass. The study [Productivity of meadow communities, 1978] showed that the increased amount of dead plant residues was due to summer droughts. In wetter conditions of 2020–2021, these communities exhibited grassland restoration and phytomass growth.



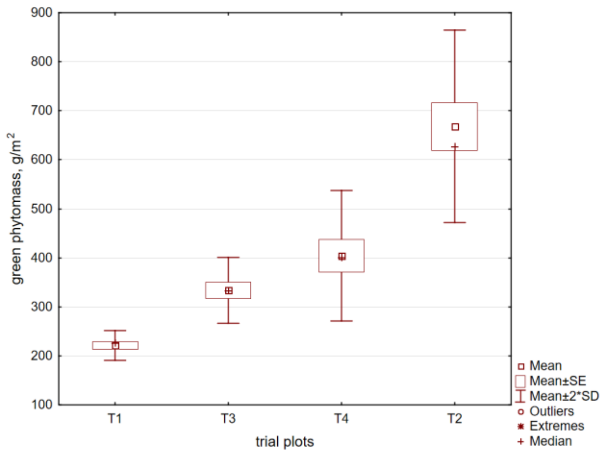
a



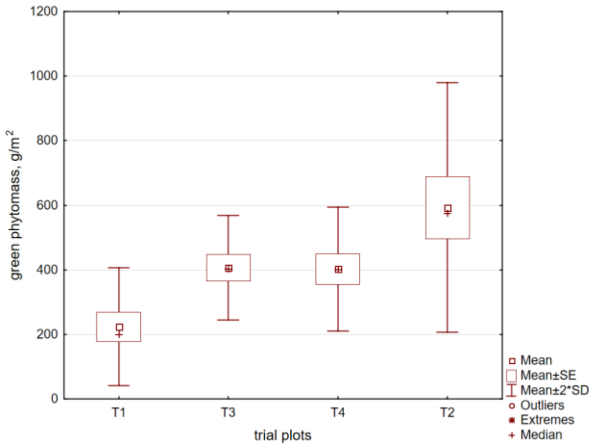
b



c



d



e

a – average biomass, 2017, g/m^2; b – average biomass, 2018, g/m^2; c – average biomass, 2019, g/m^2; d – average biomass, 2020, g/m^2; e – average biomass, 2021, g/m^2

Figure 8 Distribution of green phytomass in the trial plots, 2017–2021

We assume that wet years provide most appropriate conditions for the decomposition of mortmass in the studied phytocenoses. The dry conditions of 2019 were not favorable for plant material destruction, which was most evident at the highest and lowest altitude levels of the floodplain (phytocenoses T1 and T2).

The warm and humid spring of 2020 accelerated the decomposition of mortmass (Fig. 6), while the dry autumn and dry, cool conditions at the beginning of the growing season of 2021 caused its accumulation on the soil surface.

Changes in the ecological and biological structure of phytocenoses during relatively wet 2020–2021 indicate the improved moisture and nutrition conditions, which was evidenced by the increased share of hydrophilic and eutrophic species in the meadow vegetation.

The structure of the meadow vegetation in 2020–2021 was affected by the arid conditions of the previous year. In particular, in 2020–2021, the elecampane phytocenosis (T3) exhibited the increased mass of drought-resistant xeromesophytes and mesophytes, whereas the soddy-sedge phytocenosis (T4) showed the increased amount of grasses and the decreased share of sedges.

It should be noted that the average values of the phytomass and aboveground mortmass obtained in this study differ from those published for the Ob floodplain [Titlyanova et al., 1996], in particular, the mortmass exceeds the phytomass 2-fold. This rather corresponds to the conditions of steppe meadows and steppes [Biological productivity…, 1988; Grass Ecosystem Productivity: Handbook, 2020]. The latter may be due to the fact that the floodplain area at the Kaibasovo site has existed for about 50 years in the regime of the regulated flow of the Ob river, and the meadows of the upper altitude levels are flooded only in extremely high-water years. In addition, the so-called preservation regime currently established in large areas of the Ob floodplain also contributes to accumulation of the aboveground mortmass [Zvereva, 2022].

CONCLUSIONS

The dynamics of the meadow vegetation at the Kaibasovo site in the Ob floodplain is strongly affected by weather conditions in the current and previous years, including floods and groundwater levels, which is evidenced by changes in the aboveground mass, the ratio of dominants, and the ecological and biological groups in the meadow vegetation.

The increased moisture conditions increase the aboveground phytomass of the communities in the upper and middle altitude zones, increase the phytomass, and decrease the share of dead plant matter. Aridity leads to accumulation of dead plant residues, decreases the vegetation mass, and increases the share of forbs and grasses.

The productivity of medium-low and low sedge phytocenoses is observed to grow in years with floods. In this case, the amount of moisture-loving grasses and sedges increases. Dead plant matter is accumulated in dry years.

Acknowledgements. The field work by L.F. Shepeleva was supported by the RFBR grant No. 18-00-01654 (K), 18-00-01493 and the state order, project No. 0721-2020-0019. The research by M.S. Pudova was supported by the Development Program of Tomsk State University (Priority-2030). The research by L.G. Kolesnichenko was supported by the Russian Science Foundation, project No. 18-17-00237-P. The work was carried out using the equipment of the unique TSU scientific facility "System of experimental bases located along the latitudinal gradient" with the financial support of the Ministry of Education and Science of Russia (RF-2296.61321X0043, 13.UNU.21.0005, contract No. 075-15-2021-672). We are grateful to the reviewers for their valuable comments, which allowed us to significantly improve the quality of this work.

REFERENCES

Arzhanova N.M., Davletshin S.G., Dementieva T.V., Kleshchenko L.K., Korshunova N.N. 2020. Weather on the territory of the Russian Federation in 2019. Department of Climatology. 34 p

Biological productivity of grass ecosystems. Geographical patterns and ecological features / Titlyanova A.A., Bazilevich N.I., Snytko V.A. etc. Novosibirsk: Nauka. 1988. 134 p.

Bulygina O.N., Korshunova N.N., Dementieva T.V., Kleshchenko L.K., Davletshin S.G. 2018. Weather on the territory of the Russian Federation in 2017 // Federal Service for Hydrometeorological Monitoring of the Environment, 55 p. URL http://meteo.ru/pogoda-i-klimat/93-klimaticheskie-usloviya/179-klimaticheskie-usloviya-na-territorii-rossii

Zvereva G.K. 2022. Dynamics of aboveground phytomass in the communities of the Ob River forest-steppe and Northern Kulunda during protective regime //Problems of botany of Southern Siberia and Mongolia. Vol. 21, No. 1. Pp. 81-85.

Study and conservation of floodplain meadows: Proceedings of the International Meeting, Kaluga, June 26-28, 2013. 2013. Kaluga: Noosphere LLC. 180 p.

Korshunova N.N., Dementieva T.V., Kleshchenko L.K., Davletshin S.G. 2019. Weather on the territory of the Russian Federation in 2018 // Federal Service for Hydrometeorological Monitoring of the Environment URL. http://meteo.ru/pogoda-i-klimat/93-klimaticheskie-usloviya/179-klimaticheskie-usloviya-na-territorii-rossii

Korshunova N.N., Bulygina O.N., Razuvaev V.N., Davletshin S.G. 2019. Estimates of the extremes of the temperature regime and precipitation regime for the territory of the Russian Federation and its regions in 2018 // Federal Service for Hydrometeorological Monitoring of the Environment. URL http://meteo.ru/pogoda-i-klimat/196-extremclim

Lvov Yu.A., Shepeleva L.F., Lapshina E.D. 1987. Assessment of floodplain meadows by the fluctuation ability of their vegetation cover // Bot.journal. Vol. 72, No. 5. pp. 599-609.
Lvov Yu.A. 1963. On the characteristics of vegetation of the floodplain of the Ob River // Trudy Vol. un-ta. T. 152. pp. 258-267.
Program and methodology of biogeocenological research. 1974. Moscow: Nauka. 403 pp.
Productivity of meadow communities. 1978. L.: Nauka. 287 p.
Productivity of grass ecosystems: guide. 2020 / compiled by A.A. Titlyanova, S.V. Shibareva. M.: IBA Publishing House LLC. 100 s.
Rabotnov T.A. 1974. Meadow science. M.: Publishing house of the Moscow State University. 384 p
Ramensky L.G. 1938. Introduction to the complex soil-geobotanical study of lands. Moscow: Selhozgiz. 620 pp.
Ramensky L.G., Tsatsenkin I.A., Chizhikov O.N., Antipin N.A. 1956. Ecological assessment of forage lands by vegetation cover. M.: Publishing house of agricultural literature. 472 p.
Agricultural Encyclopedic Dictionary / Ed. V.K. Months. M.: Sov. encyclopedia, 1989. 656 p.
Skulkin M.I. 1992. Productivity of floodplain meadows and its dynamics // Nature of the floodplain of the Lower Ob. Terrestrial ecosystems. Yekaterinburg.: UrO RAS. Vol. 1. pp. 76-91.
Titlyanova A.A., Kosykh N.P., Mironycheva-Tokareva N.P., Romanova I.P. 1996. Underground plant organs in grass ecosystems. N.: Nauka. 128 p.
Tyurin V.N. 2017. The results of long-term observations of the productivity dynamics of grass communities of coastal shoals (Surgut section of the Ob River) // Izv. Samara Scientific Center of the Russian Academy of Sciences. Vol. 19. No. 2(3). pp. 570-577.
Tyurin V.N. 2018. The experience of estimating the aboveground productivity dynamics of grass communities in the Malaya Sosva River floodplain (Nature Reserve "Malaya Sosva") taking into account weather, climate and hydrological features // Environmental dynamics and global climate change. V. 9. № 2. P. 17-27.
Cherepinskaya A.N., Shepeleva L.F. 2017. Fluctuations of floodplain meadows of the Bolshoy Yugan River // Bulletin of KrasGAU. № 12. Biological Sciences. pp. 170-178.
Shepeleva L.F. 1986. On the effect of high water on the productivity of floodplain meadows //Ecology. No. 2. – pp. 3-8
Shepeleva L.F., Pashneva G.E., Moskovkina E.V., Nesvetailo V.D. 1995. Influence of dynamics of ecological factors on productivity of meadow phytocenoses and annual growth of woody plants in the floodplain of the Middle Ob // Siberian Ecological journal. No. 4. pp. 368-372.
Shepeleva L.F. Structure and dynamics of meadow communities of the floodplain of the Middle Ob. 2019. Tomsk: Publishing House Vol. un-ta. 348 p.
Shumilova L.V. 1962. Botanical geography of Siberia. Tomsk: Publishing House of Tomsk State University. 439 p.
Altome A. I., Hou L., Yan R., Xin X., Zainelabdeen Y. 2020. The Joint Effect of Grazing Intensity and Soil Factors on Aboveground Net Primary Production in Hulunber Grasslands Meadow Steppe // Agriculture. V. 10 (263). doi:10.3390/agriculture10070263
Hossain L., Kabir H., Nila U. S., Rubaiyat A. 2021. Response of grassland net primary productivity to dry and wet climatic events in four grassland types in Inner Mongolia // Plant-Environment Interactions. V. 2 (5). PP. 250-262. doi: 10.1002/pei3.10064
Moore P. E., van Wagtendonk J. W., Yee J. L., McClaran M. P., Cole D. N., McDougald N. K., Brooks M. L. 2013. Net primary productivity of subalpine meadows in yosemite national park in relation to climate variability // Western North American Naturalist. V. 73(4). PP. 409–418. URL. http://www.jstor.org/stable/24644074 (the data of access: 1 Mar. 2022).
Quan Q., Zhang F., Meng C., Ma F., Zhou Q., Sun F., Niu S. 2020. Shifting biomass allocation determines community water use efficiency under climate warming // Environmental Research Letters. V.15. doi: 10.1088/1748-9326/aba472
Rothero, E., Lake, S. and Gowing, D. (eds) 2016. Floodplain Meadows – Beauty and Utility. A Technical Handbook. Milton Keynes, Floodplain Meadows Partnership. UK: The Open University PP. 10-24, 38-55
Thornley J.H.M., Cannell M.G.R. 1997. Temperate Grassland Responses to Climate Change: an Analysis using the Hurley Pasture Model. // Annals of Botany. V. 80. PP. 205-221. doi:10.1006/anbo.1997.0430
Zelnik I., Carni A. 2013. Plant species diversity and composition of wet grasslands in relation to environmental factors // Biodiversity and Conservation. V. 22 (10). doi:10.1007/s10531-013-0448-x
Zhan L., Gao J., Tang Z., Jiao K. 2021. Quantifying the ecosystem vulnerability to drought based on data integration and processes coupling // Agricultural and Forest Meteorology. V. 301-302. doi:10.1016 /j. agrformet.2021.1083
Zhang B., Cadotte M., Chen S., Tan X., You C., Ren T., Chen M., Wang S., Li W., Chu C., Jiang L., Bai Y., Huang J., Han X.-G. 2019. Plants alter their vertical root distribution rather than biomass allocation in response to changing precipitation // Ecology. V. 100. doi: 10.1002/ecy.2828
Zhang F., Quan Q., Song B., Sun J., Chen Y., Zhou Q., Niu S. 2017. Net primary productivity and its partitioning in response to precipitation gradient in an alpine meadow // Scientific Reports. V. 7(1). doi:10.1038/s41598-017-15580-6

Поступила в редакцию: 25.08.2022
Переработанный вариант: 16.11.2022
Опубликовано: 16.12.2022