ECOLOGY: ECOSYSTEMS AND DYNAMICS, 2020, Vol. 4, No. 3, Pp. 34-60

STRUCTURAL ORGANIZATION OF ECOSYSTEMS AND PATTERNS OF THEIR DISTRIBUTION

UDC 574.45

STRUCTURE AND DISTRIBUTION OF ABOVE-GROUND PHYTOMASS OF THE TUNDRA COMMUNITIES OF WESTERN SIBERIA

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Received July 18, 2020. After revision August 30, 2020. Accepted September 01, 2020.

In this article we summarize the quantitative data on the aboveground phytomass of tundra communities collected during the expeditions of the Russian Center for Arctic Development on the Yamal, Taz and Gydan Peninsulas in 2017-2018. The phytomass was studied within formations of various plant communities of three subzones of the West Siberian tundra: arctic, typical and southern tundra. Aboveground phytomass is one of the sources of organic matter in the soil; therefore, the study of its accumulation in tundra communities is of great importance for the further studies of the processes of carbon deposition. In this regard, it is necessary to obtain data on the ratio between living phytomass and mortmass in different geographic conditions and in different types of plant communities, while identification of the fractional composition of living phytomass makes it possible to understand the features of living matter accumulation and carbon deposition. This study revealed some general patterns of aboveground phytomass accumulation, such as an increase in its value as it moves from north to south, from the arctic tundra subzone to the southern tundra subzone. The accumulation of phytomass varies significantly due to the nature of vegetation. The maximum values of total phytomass are common for dwarf willow and sedge-cotton grass communities in the arctic tundra; for shrub willow, alder and dwarf birch communities within the typical tundra and southern tundra subzones. Analysis of the fractional composition of living phytomass within the subzones showed that fraction of mosses prevails in the arctic tundra; shrubs and dwarf shrubs prevail in the typical tundra, with a high amount of mosses; and the absolute predominance of shrubs is common for the southern tundra. The ratio of mortmass and living phytomass in communities depends mainly on the plant formation within each subzone. Our results can be used to compile a map of phytomass storage and structure within the tundra communities of Western Siberia, which will make it possible to assess the reindeer capacity of local pastures, and to account the carbon deposition in the poorly studied areas.

Keywords: above-ground phytomass, tundra communities, living phytomass, mortmass, fractional composition, subzonal differences.
DOI: 10.24411/2542-2006-2020-10064

Production processes of the tundra of West Siberian are still insufficiently explored. Tundra ecosystems are among the most significant terrestrial biomes because of their two main carbon pools (carbon stocks in soil and in phytomass), which they gained due to extremely slow decomposition of plant residues. Tundra communities accumulate the largest amount of soil carbon per unit of area, while the indices of primary production remain the lowest in comparison to other terrestrial ecosystems (Billings, 1987; Bolin, 1986; Melillo, 1993).

Aboveground phytomass is one of the sources of organic matter in soil; therefore, the assessment of its accumulation in tundra communities is significant for the further studies of carbon deposition processes (Karelin et al., 1995). Meanwhile, an intense anthropogenic load, such as reindeer grazing, development of hydrocarbon deposits and other activities, causes vast and long-term changes of vegetation cover in this territory and, respectively, of phytomass production (Klokov, 2013).

With tundra territories being little-studied and hard-to-reach, currently there is a severe lack of data on the condition of their vegetation and quantitative assessment of production processes, which play an important role in the state of ecosystems in changing environment.

In this study we present the generalized field data, collected in the tundra communities of West Siberia to determine the structure and fractional composition of aboveground phytomass of plant communities in relation to ecological-geographic factors. For this goal we analyzed the features of living phytomass and mortmass accumulation in plant communities of the Arctic, typical and southern tundra subzones, as well as the fractional composition of living phytomass of plant formations according to their subzonal aspect.

Materials and Methods

This study is based on the materials obtained during the expeditions of the Russian Center for Arctic Development, which took place in 2017-2018 and were focused on vegetation of reindeer pastures of the Yamal, Gydan and Taz Peninsulas, as well as on stocks of aboveground phytomass and productivity of tundra communities.

According to the “Physical Geography of the USSR” (Milkov, Gvozdetsky, 1970), the Yamal, Gydan and Taz Peninsulas belong to the tundra zone of West Siberia. Many researchers marked them out as 3 independent provinces of Yamal, Gydan and Taz, respectively (Makunina, 1985; Gvozdetsky, Mikhailov, 1987; Rakovskaya, Davydova, 2001). Besides, the similar type of their relief, same latitudinal and sectorial location with alike climatic conditions, related soils and vegetation cover allow us to study this territory as one unit of Yamal-Gydan Region (Simonov, 1977).

The overall geological history of this territory started with sea transgressions which led to formation of different-leveled sea terraces and determined the plain relief for the peninsulas. *Lowland seaside depositional plains* (photo 1) are the most widespread landscapes of Yamal, the northern and southwestern parts of Gydan and northern part of Taz. Their surface is formed by the rows of flat bogged sandy and sandy-loamy sea terraces with numerous watercourses, residual and thermokarst lakes; their true altitude is 50-80 m AMSL (sometimes reaching 120 m). The elevated inner parts of the peninsulas (Gydan Ridge, Central Yamal) have *lowland moraine* or *glacial-marine plains* in the area of middle quaternary glaciation. The relief there is wavy or gently hilly, or ridge-like sometimes, the ALT in Yamal is never higher than 100 m AMSL, and 180 m AMSL in Gydan (photo 2, 3).

Their high-latitudinal location, impact of the continental massif of Eurasia and closeness of the Kara Sea cause extremely severe climatic conditions, which mainly determine development of soil and vegetation covers of the peninsulas. The differences between Yamal, Gydan and Taz are not significant; however, the Gydan Peninsula is more continental, with a colder winter (down to –60°C). Phytomass accumulation strongly depends on climatic differences in the subzonal aspect, such as heat availability level, sum of active temperatures and duration of vegetation period (table 1).

This territory is located in a zone of ubiquitous long-term permafrost, the depth of which changes due to geomorphological conditions and can reach down to 300-400 m. The local soils are tundra cryosolic. The activity of permafrost processes around the territory causes disturbances of integrity of soil cover, makes it mosaic and micro-complex, which in its turn affects the structure of vegetation cover.

The expeditionary researches took place on the key sites in the typical conditions of various subzones of the peninsulas. Each of them was chosen according to the obtained data on geobotanical state of exploration of the territory, so in the little-studied areas we chose the sites with the highest landscape diversity to include as many plant communities as possible.

Photo 1. Flat waterlogged plains with lakes and bogs of Northern Yamal (photo by N.B. Leonova).

Photo 2. Central Yamal (photo by D.A. Sorochinskaya).

The research was carried out on 11 key sites in the subzones of the arctic tundra (Yamal-1, Gydan-1, Gydan-2), typical tundra (Yamal-2, Gydan-3, Gydan-4, Ural-4) and southern hypoartctic tundra (Yamal-3, Yamal-4, Taz-1, Ural-3; fig. 1, table. 2).

To assess the aboveground phytomass storage we mowed and collected 290 triplicate samples from the sample plots (table 3). We made a full geobotanical description of each community inside of which a sample was taken. The 44 samples of phytomass were harvested in the arctic tundra (geobotanical descriptions and sampling were carried out by K.A. Yermokhina, E. Troyeva and M. Telyatnikov); 96 in the typical tundra (descriptions by O.V. Khitun, I.S. Zhdanov, V.A. Zemlyanskiy, N.E. Koroleva and D.A. Sorochinskaya; sampling by D.A. Sorochinskaya, D.A. Kashev, Ya.I. Gunin and D. Krasnitskaya); and 150 in the southern tundra (descriptions by O.V. Khitun, V.A. Zemlyanskiy, N.E. Koroleva and S.I. Plyusin; sampling by D.A. Sorochinskaya, D.A. Kashev, Ya.I. Gunin, V.A. Kazantsev and L.A. Krivenok).

Photo 3. Typical tundra near the Baydaratskaya Bay (photo by D.A. Sorochinskaya).

The studied key sites were round, with a radius of 10 km. On each of them the geobotanical profiles were studied, laid out perpendicularly to the riverbed, from the watershed to the floodplain. The amount of profiles varied from 2 to 6, stretching for 1.5-5 km. The profiles were set specifically to include all typical plant communities. The phytomass samples were collected exactly where the sample plots were described within the said profiles (fig. 2). The marking of the profiles on the relief was made according to the mapping sourced provided by our client (satellite imagery of Landsat 7.8, topographical maps of the territory at the scale of 1:100,000).

The stocks of aboveground phytomass were assessed by the mowing method (Andreyashkina, 1971; Bazilevich, Titlyanova, 1978). The triplicate samples were collected from the randomly chosen sample plots of 25x25 cm, inside the plant community described in the profile (photo 4). Herbaceous plants and dwarf shrubs were cut down at the level of green and brown parts of mosses, while the sod formed by lichens and mosses was extracted intact. The samples were stored into the packages made of craft paper, and marked with labels.

In a laboratory the samples were divided into fractions, such as forage groups: shrubs (separate trunks, branches and leaves), cereals, sedges, mixed grasses, dwarf shrubs (by species), lichens (by species, if possible), mosses, and dead (brown) parts of mosses and lichens, mortmass. These materials were air-dried and weighted with an accuracy of 0.1 gram. The obtained values were put into Microsoft Excel tables, the average values of phytomass stocks (in g/m^2) were calculated for 3 mowing plots limited by one community. This work was performed in the Laboratory of Biogeocenology of the A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences, by D.A. Sorochinskaya, V.A. Zemlyanskiy, Ya.I. Gunin, D. Krasnitskaya and S. Derkacheva.

Table 1. Bioclimatic characteristics are shown according to the "Database of High Spatial Resolution Global Weather and Climate Data" (2020).

Bioclimatic characteristics	**Yamal**			**Taz**	**Gydan**	
	Arctic tundra	**Typical tundra**	**Southern tundra**	**Southern tundra**	**Arctic tundra**	**Typical tundra**
Average air temperature, °C	-9.9	-8.7	-6.4	-7.5	-10.3	-9
Average air temperature in July, °C	7.1	10.2	12.2	12.2	8.7	10.7
Average air temperature in January, °C	-24.3	-24.4	-22.2	-23.4	-25.7	-24.8
Average air temperature for the warm period, °C	8.9	12.1	17.6	16.0	12.1	16.2
Average air temperature for the cold period, °C	-30.4	-29.2	-29.1	-30.9	-32.4	-32.6
Annual sum of precipitation, mm	228	290	370	345	310	330
Sum of precipitation for the warm period, mm	80	104	127	126	116	122
Sum of precipitation for the cold period, mm	46	56	68	58	63	62

Geobotanical descriptions for the communities where the mowing was preformed were compiled according to the standard methods (Yunatov, 1964) and with consideration of the features of the studied habitats. They were carried out on the sample plots of 100 m^2, taking into account the complexity of tundra vegetation cover (including descriptions of microcenoses, with their size no less than 10 m^2). The descriptions included a full species composition of communities, with vascular plants, bryophytes and lichens; the species that could not be identified directly in the field were collected to be identified later and added to the lists. To assess the species abundance the Braun-Blanquet scale was used, in percent of the total projective cover.

Within the sample plots the following habitats characteristics were registered and then used in the analysis of phytomass distribution: the general surface slope (in degrees), slopes exposure (in degrees), location on the relief, nature of the surface deposits (of the mineral soil horizon, if it was possible to determine), nature and degree of moisture, depth of the organic horizon.

The projective cover of vegetation cover was determined in percent, including such features as the total projective cover of vegetation cover on the plot, cover of the shrub layer, cover of the herbs-dwarf shrubs layer, cover of the moss-lichen layer. We also determined the average height of layers and vegetation cover in general.

On the sample plots and mowing plots the accurate geographical coordinates were determined with the use of GPS-receivers, such as GARMIN GPSMAP 78S RUSSIA, and the height above mean sea level. In addition, we took photographs of plant communities and sample plots.

The summary tables with geobotanical descriptions and their processing were compiled in Turboveg 2.122 and Microsoft Office Excel. Based on the data of geobotanical descriptions, in

2018 a classification of plant communities was created (Zemlyanskiy, 2018; Sorochinskaya, 2018), and its species were later used to analyze the phytomass distribution in the groups of plant communities.

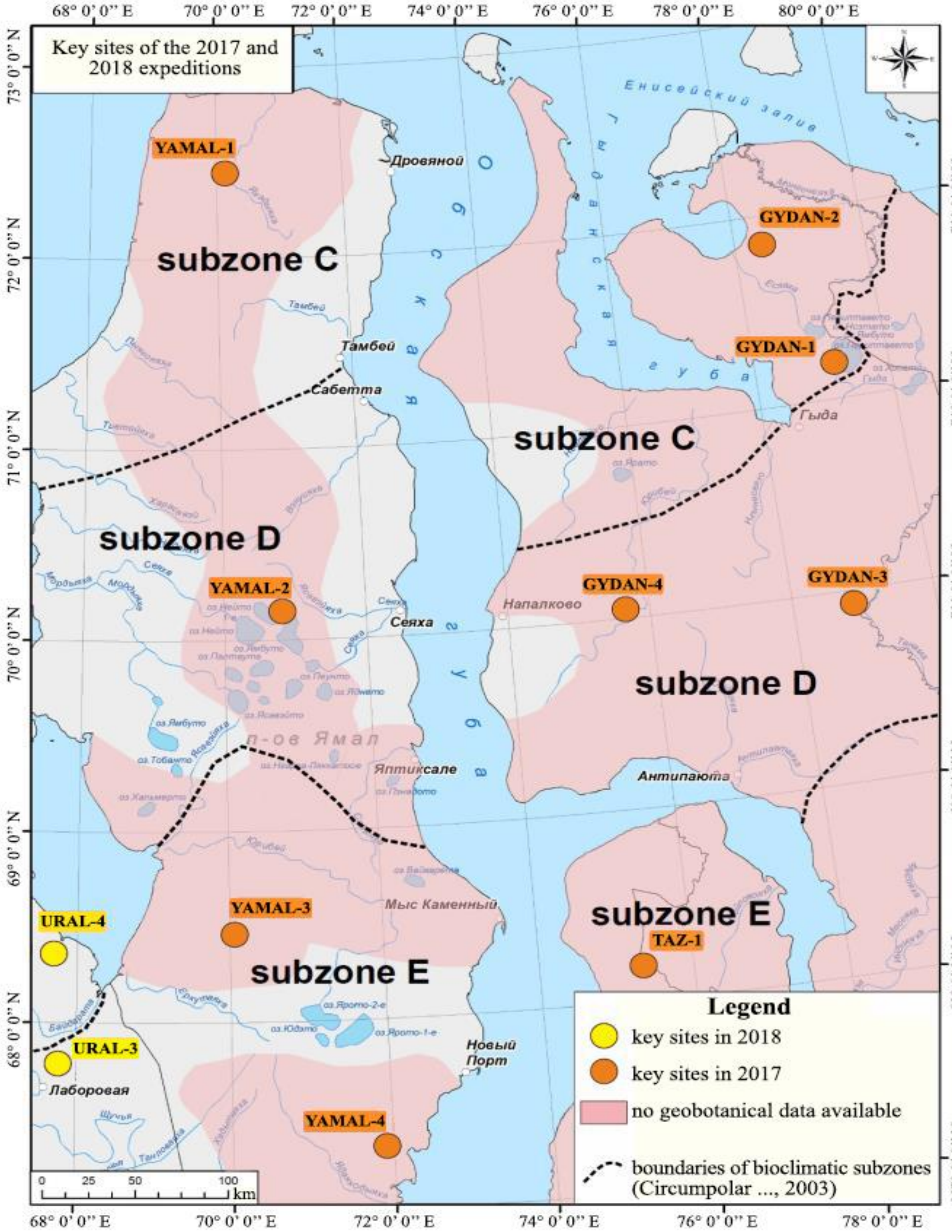

Fig. 1. Locations of the key sites. The boundaries of the arctic, typical and southern tundra (subzones C, D, E) are given according to the map of bioclimatic subzones (Circumpolar ..., 2003).

Table 2. Geographic coordinates of the key sites.

No.	Number of a key site	N	E
1	Y1	72.47594	70.1501
2	Y2	70.20466	70.82072
3	Y3	68.43693	70.04951
4	Y4	67.381	72.082
5	G1	71.21799	79.27374
6	G2	71.91361	78.67611
7	G3	69.95845	78.79057
8	G4	70.09156	75.62321
9	T1	68.218948	75.212345
10	U3	67.98981	67.62839
11	U4	68.86311	66.71322

The classification was created according to the ecological-morphological approach of E.M. Lavrenko (1959; Aleksandrova, 1969). Its main principles are the systematization of plant communities on the basis of the dominant species' unity of a certain life form within the main community layers; the main classification unit of the analysis is formation of communities. The formations are distinguished by the unity of edifiers in the dominant layer, and are grouped into classes of formations, corresponding to the type of tundra vegetation by the dominant life form. The distribution of the main formations is described in accordance with the geobotanical map of the Yamalo-Nenets Autonomous Okrug (Research Work Report ..., 2017), the legend of which is based on the classification of plant communities.

The values of phytomass stocks were calculated for communities of various formations in the subzonal aspect (Zones and Types ..., 1999). In addition, we assessed the structure of the total value of the phytomass stock in some communities by determining the phytomass of various fractions (shrubs, dwarf shrubs, sedges, cereals, grasses, lichens and mosses). In Excel the histograms of the phytomass distribution of the selected fractions were created, as well as histograms to show the ratio between the total phytomass, living aboveground phytomass and mortmass.

Table 3. Number of phytomass samples within subzones and key sites.

Subzone	Number of samples on the key sites	Total for a subzone
Arctic tundra	11 (Yamal-1), 14 (Gydan-1), 19 (Gydan-2)	44
Typical tundra	24 (Yamal-2), 21 (Gydan-3), 25 (Gydan-4), 26 (Ural-4)	96
Southern hypoarctic tundra	44 (Yamal-3), 53 (Yamal-4), 24 (Taz-1), 29 (Ural-3)	150
Total		**290**

Results and Discussion

The analysis of the fractions' composition of the living aboveground phytomass and of the ratio between the living phytomass and mortmass was carried out in the communities of various tundra formations in the subzonal aspect.

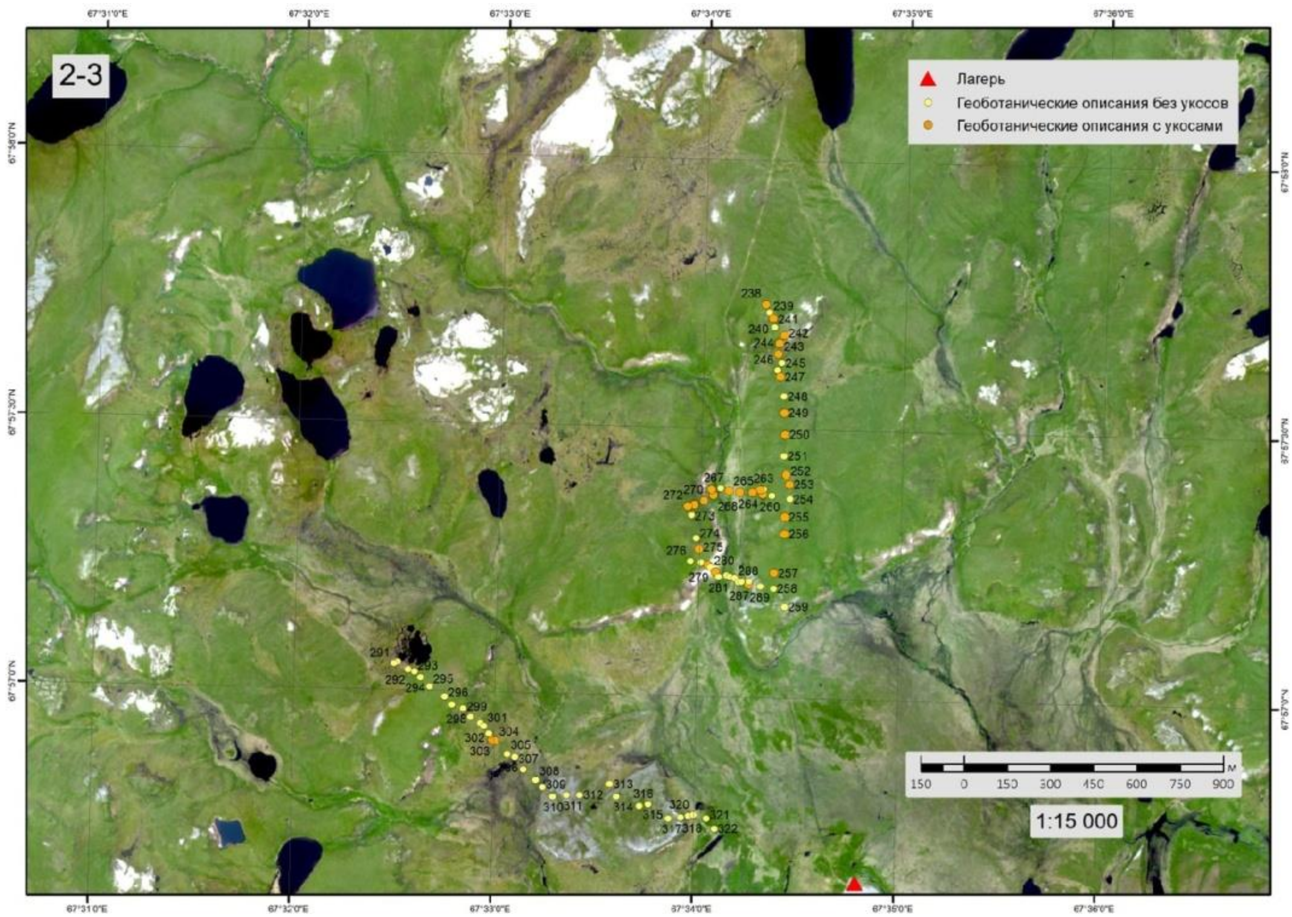

Fig. 2. The key site Ural-3 in the southern tundra subzone. *Legend:* yellow − geobotanical descriptions plots, orange − sampling sites.

Arctic Tundra

In the previously made classification (Zemlyanskiy, 2018; Sorochinskaya, 2018) the 11 formations of 5 groups (types of tundra vegetation) were determined for the arctic tundra of Yamal and Gydan: 1) dwarf shrub tundra, 2) grass (sedge and cotton grass) tundra and bogs, 3) mesophytic meadows, 4) hygrophytic (coastal-water) meadows, 5) psammophytes communities and groups (fig. 3).

More than half of the territory of the arctic tundra is occupied by a group of dwarf shrubs tundra formations (almost 65% of the area; photo 5). In addition to dwarf tundra, a significant part of the territory is covered with sedge and cotton grass tundra and bogs (20.8%), as well as hygrophytic meadows (12.6%). Mesophytic meadows occupy small areas (1.4%). The psammophytes communities and groups are least widespread, occupying less than 0.5% of the territory.

The data on the aboveground phytomass stock in the arctic tundra were collected and analyzed for 9 plant formations, combined into 4 groups: dwarf shrub tundra, grass and sedge tundra, mesophytic meadows and hygrophytic (coastal-water) meadows. This data, such as the values of the total phytomass, living phytomass and mormass within the main formations, are shown in Figure 4, and the share of various fractions in the phytomass structure is shown in Figure 5.

The total phytomass stocks in the studied plant communities vary from 695 to 2070 g/m^2 in dry weight (fig. 4). The biggest stocks were found in the cotton grass-sedge (2070 g/m^2) and willow (1800 g/m^2) tundra. Generally, the differences between the values of the total phytomass stock are insignificant and mostly are about 900-1300 g/m^2.

Photo 4. A mowing test site in a dwarf birch community of the typical tundra (photo by D.A. Sorochinskaya).

As it was mentioned above, communities of *cotton grass-sedge tundra* (*Eriophorum angustifolium*, *Carex rotundata*) formation, play a major role in the structure of the arctic tundra vegetation cover. These communities occupy the river valleys, waterlogged territories with lakes and bogs, gentle slopes of watersheds, terraces, slopes and bottoms of lake depressions, shallow gullies and runoff streaks. Cotton grass-sedge tundra is widespread throughout northern Yamal, in the south of Yavay, on the Bely, Shokalsky and Oleny Islands. Its grass stand is quite dense and high for the arctic tundra conditions, its projective cover is 20-50%, the average height is 25 cm, and it consists of *Carex stans, Eriophorum polystachion, E. scheuchzeri* in various proportions. Sometimes the bulgy-swampy complexes can be found there as well.

Communities of *dwarf shrubs willow tundra* (*Salix lanata, S. reptans*) formation are more local (about 6%) and mostly concentrated in the northwest of Yamal and southeast of the arctic tundra subzone of the Gydan Peninsula. They can be also found on the sandy river terraces, along the creeks, on the slopes of valleys, depressions, gullies and ridges. Usually, they are represented with sedge-moss willow forests with dominant *Salix lanata*, which can grow up to 80 cm.

The largest areas of tundra with dwarf shrubs (almost 40% of total territory) are occupied with formation of *willow tundra* (*Salix nummularia, S. polaris*). Their total phytomass stocks are not very high (861 g/m^2), the stocks of living phytomass (505 g/m^2) are 30% higher than mortmass (356 g/m^2). Willow kinds of tundra are widespread, covering especially big territories in the arctic tundra of

Northern Yamal, Yavay and Oleny Peninsulas, Shokalsky and Oleny Islands. They are mostly common for the leveled slopes of watersheds, lake depressions, river valleys, gullies, depressions and ravines with loamy soils, can be found on top of the ridges, and sometimes directly on the watersheds.

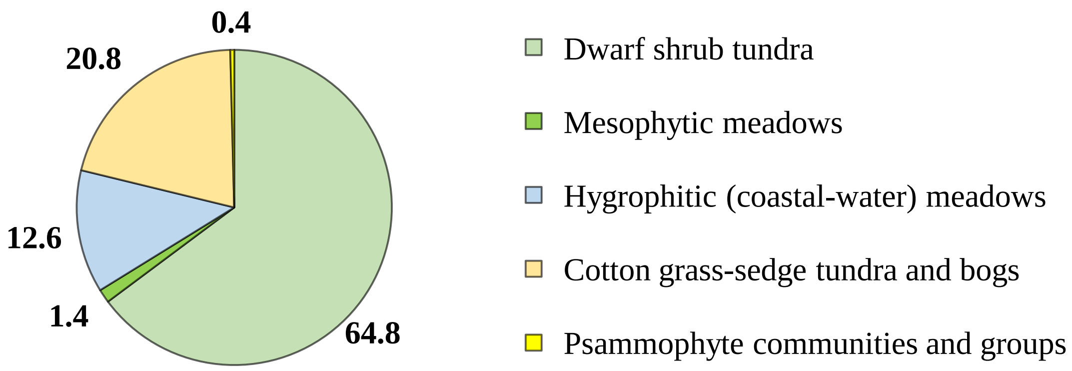

Fig. 3. Ratio between the areas occupied with different groups of formations of tundra communities in the arctic tundra subzone (%).

Photo 5. Dwarf shrub community with *Cassiope tetragona* (L.) D. Don in the arctic tundra subzone (photo by N.B. Leonova).

Their dominant species are *Salix polaris*, *S. nummularia*, *Vaccinium vitis-idaea* and *Dryas* spp. (projective cover is 20%, average height is up to 30 cm). The dominant grass is *Carex arctisibirica*, while the mixed grasses are not abundant (projective cover is only 5-8%, height is 15-20 cm), but quite diverse, consisting of *Stellaria peduncularis, Bistorta vivipara, Myosotis asiatica, Valeriana capitata, Pedicularis oederi*, etc. The projective cover of moss layer is 100%, and its most abundant species are *Tomentypnum nitens, Hylocomium splendens, Aulacomnium turgidum, A. palustre, Ptilidium ciliare*. Lichens are also presented there (projective cover is up to 30%), their most prevalent species are *Cetraria islandica, Cladonia arbuscula, C. rangiferina, Thamnolia vermicularis, Dactilina arctica.* The horizontal structure is characterized by the high total projective cover, smoothed-hilly and lumpy microrelief with small humps. The territory with willow tundra is highly matted; patches of bare ground are not pronounced.

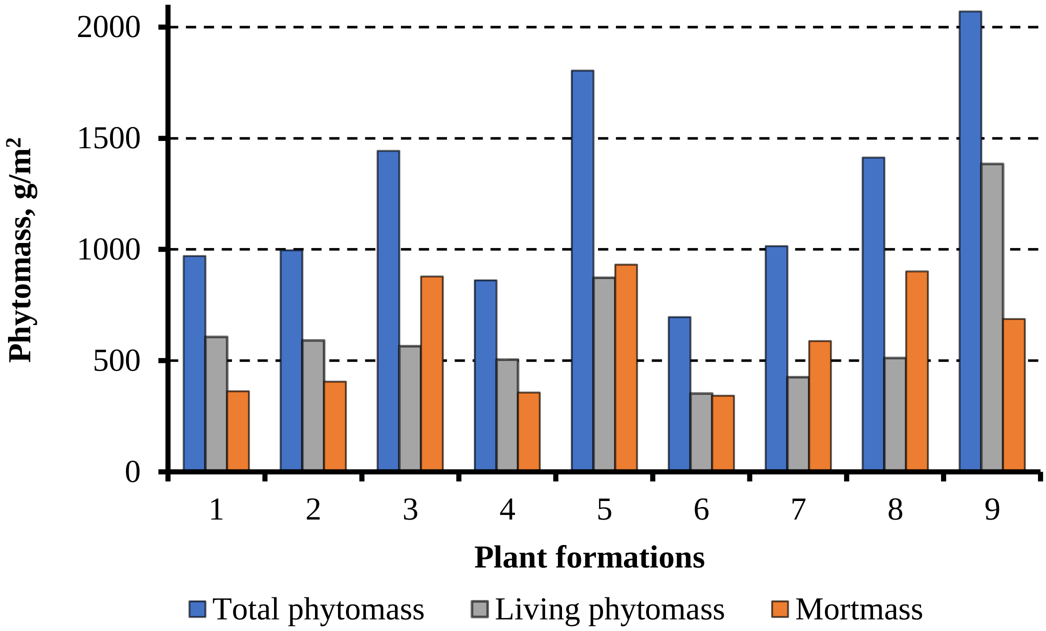

Fig. 4. Values of the total phytomass, living phytomass and mortmass for the formations of the arctic tundra subzone (dry weight, g/m^2). *Legend for Fig. 4-5.* Plant formations. Dwarf shrub tundra: 1 – *Vaccinium vitis-idaea* ssp. *minus* (Lodd.) Hult., 2 – *Dryas punctata* Juz., *D. octopetala* L., 3 – *Betula nana* L., 4 – *Salix nummularia* Anderss., *S. polaris* Wahlenb., 5 – *Salix lanata* L., *S. reptans* Rupr., 6 – *Cassiope tetragona* (L.) D. Don. Mesophytic meadows: 7 − *Equisetum arvense* ssp. *boreale* (Bong.) Tolm. Hygrophytic (coastal-water) meadows: 8 – *Carex aquatilis* Wahlenb., *C. concolor* R. Br. Cotton-grass and sedge tundra and bogs: 9 – *Eriophorum angustifolium* Honck., *Carex rotundata* Wahlenb.

The significant part of the territory (more than 17%) is covered with *mountain cranberry* formation (*Vaccinium vitis-idaea* ssp. *minus*) of dwarf shrubs tundra. The value of its total phytomass is 970 g/m^2, the stocks of living phytomass are 607 g/m^2 and are exceeding the stocks of mortmass (363 g/m^2) the same way like in the willow communities. Mountain cranberry communities are widespread all around Yamal, in the north of the Yavay Peninsula, on the Mammoth Peninsula and in the northeast of Gydan. This formation is common for the gentle-bulging watersheds with prominent lumpiness, watershed slopes, tops and slopes of the loamy ridges. In the dwarf shrubs layer the dominants are *Vaccinium vitis-idaea, Salix polaris, Dryas punctata* (total projective cover is 20%, average height is 10 cm); the dominant of the grass layer is *Carex arctisibirica*; the mixed grasses are diverse just like in the willow communities, but is not abundant. The projective cover of mosses is 95%, their dominants are *Tomentypnum nitens, Hylocomium splendens, Ptilidium ciliare.* The lichens are diverse, but their projective cover is only up to 10%, the most frequent species are *Cladonia* spp. and *Peltigera* spp.

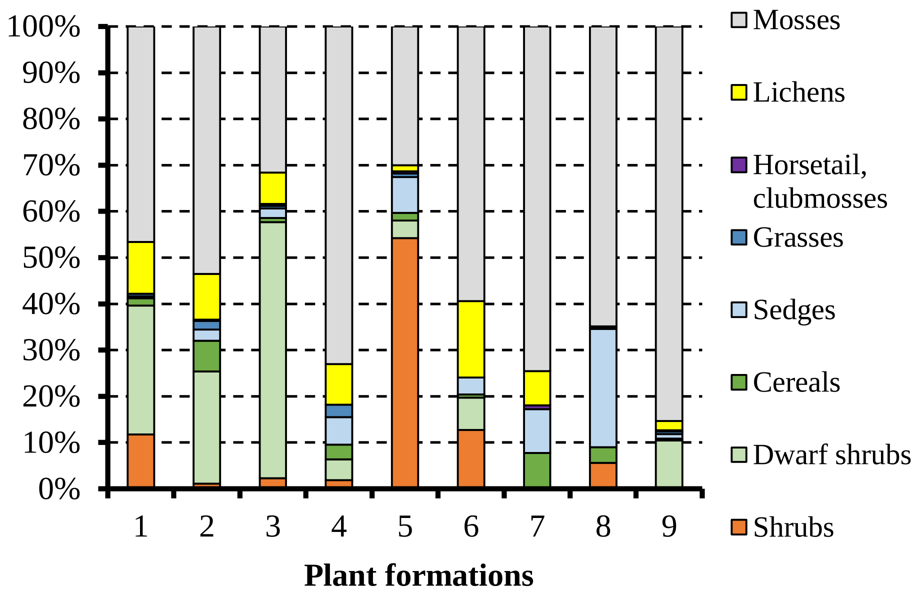

Fig. 5. Proportion of phytomass of various fractions in the formations of the arctic tundra subzone.

The minimal values of phytomass stocks are common for the *heather* (*Cassiope tetragona*) communities (695 g/m^2). They are sporadically and limitedly spread and can be mostly found in Yamal, and sometimes on the Gydan Peninsula. Their main habitats are sandy slopes of watersheds with good drainage, gullies and ravines. Mostly they are patchy dwarf shrub-moss-lichen tundra with lumpy microrelief and flooded patches. The layer of dwarf shrubs includes *Salix polaris*, *S. nummularia*, *Vaccinium vitis-idaea* ssp. *minus* (projective cover of dwarf shrubs and grasses is 25%, average height is 15 cm); the moss-lichen layer consists of *Polytrichum piliferum*, *Cladonia amaurocraea*, *C. arbuscula*, *Flavocetraria nivalis*, *Sphaerophorus globosus* (cover is 50%).

The ratio between the living phytomass and mortmass, accumulated in the communities of different formation, is worth noting. These indicators are very important for assessment of carbon deposits in tundra communities. In the monograph of N.I. Bazilevich (1993) written on the ecosystems productivity of Northern Eurasia, it was noted that the content of mortmass and living phytomass is approximately the same in the communities of the arctic tundra. In the formations that we have studied, this ratio can also be seen; however, its disturbance is typical for waterlogged sedge communities and bogs.

Among the dwarf shrub tundra in the formations of mountain cranberry, Dryas and willow, the stock of living phytomass exceeds the stock of mortmass by 30-40% (due to the high share of mosses in the living phytomass), while in the Cassiope formation this ratio is almost 1:1. In the cotton grass-sedge tundra the indices of the living phytomass exceed the mortmass more than 2 times due to the high share of mosses in the phytomass, and the mortmass consists mostly of the dead grass residues of cotton grass and sedges, which can quickly decompose.

The opposite trend with the mortmass exceeding the living phytomass can be seen in the formations of dwarf birch (*Betula nana*) and willow, as well as in mesophytic horsetail and hygrophytic water-sedge (*Carex aquatilis*, *C. concolor*) plant communities. In dwarf birch tundra the mortmass values are 35% higher, due to intense defoliation at the end of the vegetation period, which is common for the summer-green shrubs and withering of hard-to-decompose ligneous sprouts; in willow tundra this excess is lower and is about 7%.

In water-sedge communities the mortmass values are almost 2 times higher than those of living phytomass; the mortmass mostly consists of dead mosses, sedges and shrubs. Due to the fact that waterlogged habitats slow down decomposition of organic matter, they also accumulate more mortmass. In horsetail meadows mortmass is higher than living phytomass by almost 20% due to the high proportion of poorly decomposed horsetail litter (fig. 4).

Fractional composition of living aboveground phytomass of the arctic tundra communities. The fraction of mosses plays the leading role (from 30 to 85%) in almost all plant formations, which is a distinctive feature of tundra communities (fig. 5). It is especially high in cotton grass-sedge, willow and horsetail formations (75-85%). Its value is the lowest in the dwarf birch and willow formations (about 30%), where the main part is occupied by shrubs and dwarf shrubs (55-60%).

In dwarf shrub communities, excluding willow tundra with mosses reaching 73%, the share of shrubs and dwarf shrubs is high (20-50%). The fraction of sedges and cotton grass is at its highest in herbaceous communities, such as horsetail meadows (10%), water-sedge meadows (25%) and cotton grass-sedge tundra (8%); their share is also significant in willow and dwarf willow communities (about 5%). The fraction of cereals is registered in most formations, but its share does not exceed 7%. The phytomass of all communities contains a fraction of lichens, and it reaches its highest values of 16% in Cassiope formation.

Therefore, we can note that the total phytomass stock in the arctic tundra is not quite high, reaching no more than 2100 g/m^2. The largest phytomass stock is common for the dwarf (willow) and sedge-cotton grass tundra. The fractional composition is dominated by mosses, while some communities (formations of mountain cranberry, Dryas, dwarf birch, willow) have a large share of shrubs and dwarf shrubs. We also found some communities (dwarf birch, willow, horsetail, water-sedge) with mortmass values exceeding those of living phytomass in various ratios.

Typical Tundra

The typical tundra consists of 19 plant formations of 6 groups, with the exception of dwarf shrubs, cotton grass-sedge, mesophytic and hygrophytic meadows, psammophyte communities. Formations of shrub tundra are widespread in these territories.

Dwarf shrub tundra occupies the largest areas of the typical tundra subzone (38.8% of the territory), while shrub tundra occupies only 22.1% (fig. 6). A significant part of the territory is covered with sedge and cotton grass tundra and bogs (25.8%). Mesophytic and hygrophytic meadows are much less common (8.6 and 4.1% respectively). The same way as it is throughout the entire tundra zone, the smallest areas are occupied by communities and groups of psammophytes (0.6%), however, in the typical tundra they are more common than in other subzones. Excessive pasture and industrial loads on tundra territories (construction of oil and gas facilities, roads and active transport usage) lead to destruction of native vegetation, spread of deflationary outcrops (sand bulge) and landslides, the open sands create habitats for the development of psammophytes communities and groups of extremely low density and poor species composition (photo 6). In the typical tundra the values of phytomass stock were analyzed for 15 plant formations within 5 classes.

The total phytomass stocks in the studied formations differ significantly, from 87 g/m^2 in horsetail meadows (*Equisetum arvense*) to 3080 g/m^2 in willow tundra (*Salix glauca, S. lanata*; fig. 7). The high values are also common for the dwarf birch, alder (*Alnus viridis*) and Labrador tea communities (2480, 2413 and 1630 g/m^2 respectively).

Willow (*Salix glauca*, *S. lanata*) tundra plays the main role in the group of <u>shrub tundra</u> formation, covering 21.9% of the territory (photo 7). Willow communities occupy vast areas in the west of Yamal, are spread through the southeast of the subzone, in the south of the Gydan Peninsula due to more severe climatic conditions, and along the Gydan Ridge as well, moving along the rivers to the north. They grow on the sandy river terraces, along the creeks, on the slopes of valleys, depressions, gullies and ridges, but avoid the watersheds; however, sometimes they can be found on the flat interfluves in the south, in the shrub tundra. These are mainly mixed grasses-horsetail-moss willow forests with dominant *Salix lanata* and *S. glauca*, which can grow up to 100 cm. These communities usually have the maximal total phytomass stock (3080 g/m^2). The stock of living phytomass (2500 g/m^2) is more than 4 times higher than mortmass (581 g/m^2; fig. 7).

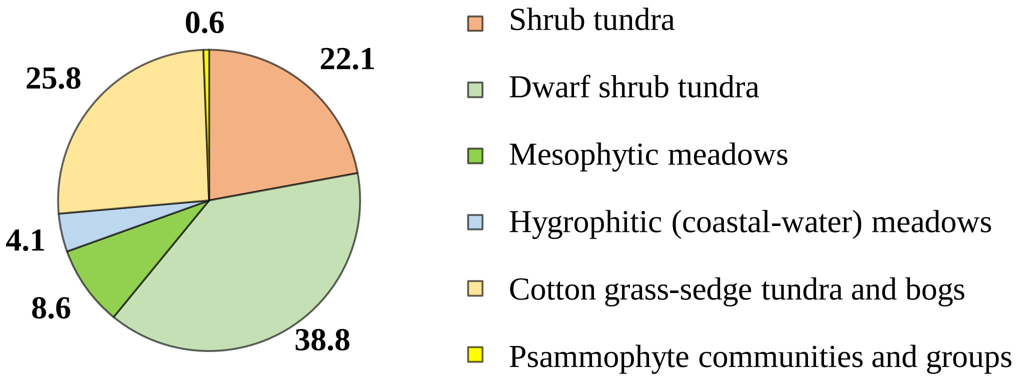

Fig. 6. Ratio between the areas occupied by different groups of tundra vegetation formations in the typical tundra subzone (%).

Photo 6. Sand swells at the camping site of reindeer herders in northern Yamal (photo by N.B. Leonova).

Alder communities (*Alnus viridis*) are more local (less than 0.5% of the territory). They occupy covered areas of river valleys near the southern border of the typical tundra, which has a better heat availability, deep long-term permafrost, good drainage and thick snow cover. Alder usually grows up to 1.5-1.8 m, forming the upper shrub layer, but some shrubs can be about 3 m. The lower shrub layer is usually formed by *Betula nana* or *Salix lanata*. Grass cover is thin (5-10%), consisting mostly of *Carex concolor*, *Equisetum arvense* and mixed grasses, such as *Polemonium acutiflorum*, *Valeriana capitata*, *Stellaria* spp. Moss layer is fragmented around the margins (but the ground under the large shrubs is covered only with forest litter). Despite the fact that alder communities occupy small territories, they make a significant contribution to the phytomass accumulation. Their total phytomass stocks are the 3rd largest ones in the subzone of the typical tundra (after willow and dwarf birch formations). The indices of living phytomass (1720 g/m^2) are 2.5 higher than those of mortmass (693 g/m^2).

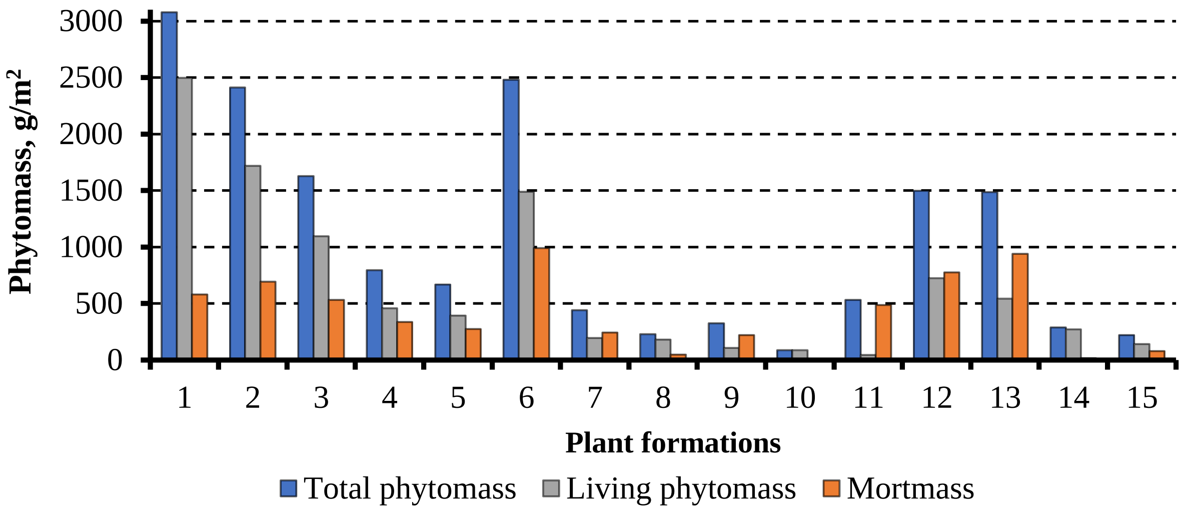

Fig. 7. Values of the total phytomass, living phytomass and mortmass for formations of the subzone of typical tundra (dry weight, g/m^2). *Legend for Fig. 7-8.* Plant formations. Shrub tundra: 1 − *Salix glauca* L., *S. lanata* L., 2 − *Alnus viridis* (Ehrh.) Pouzar. Dwarf shrub tundra: 3 − *Ledum palustre* ssp. *decumbens* (Ait.) Hult.), 4 − *Vaccinium vitis-idaea* ssp. *minus* (Lodd.) Hult.), 5 − *Dryas punctata* Juz., *D. octopetala* L., 6 − *Betula nana* L., 7 − *Salix nummularia* Anderss., *S. polaris* Wahlenb., 8 − *Empetrum nigrum* L. Mesophytic meadows: 9 − *Bistorta vivipara* (L.) Delarbre, *Tanacetum bipinnatum* (L.) Sch. Bip., *Poa* spp., *Festuca* spp., 10 − *Equisetum arvense* ssp. *boreale* (Bong.) Tolm. Cotton-grass-sedge tundra and bogs: 11 − *Carex aquatilis* Wahlenb., *C. concolor* R. Br., 12 − *Carex* spp., *Eriophorum* spp., 13 − *Eriophorum* spp. Hygrophytic (coastal-water) meadows: 14 – *Arctophila fulva* (Trin.) Anderss, 15 − *Comarum palustre* L.

Photo 7. Willow (*Salix glauca* L., *S. lanata* L.) formation in the typical tundra of the Gydan Peninsula (photo by D.A. Sorochinskaya).

In dwarf shrub tundra the *Ledum palustre* (*Ledum palustre* ssp. *decumbens*) formation is the most widespread, occupying 14.4% of the territory. They are primarily common on the Gydan Peninsula, while in Yamal the similar habitats are usually occupied by willow formations of shrub tundra, which can be related to the less continental climate. These communities grow on a wide belt between the Taz Bay and the Yenisey Gulf, stretching along the Gydan and Yuribey Ridges. Labrador tea tundra can be found on the gentle slopes of the valleys, lakes, on the slopes and tops of the ridges. The most significant dwarf shrubs are *Betula nana*, *Vaccinium uliginosum, V. vitis-idaea* ssp. *minus, Salix glauca, Andromeda polifolia.* The grass dominants are *Carex concolor*, *C. rotundata*, *Eriophorum polystachion.* The projective cover of mosses is up to 80%, with *Sphagnum* spp. and *Dicranum* spp. prevailing; the species composition of lichens (cover up to 50%) is very diverse, but the projective cover of individual species is not high. Some species such as *Cladonia* spp., *Bryocaulon divergens, Flavocetraria nivalis* can be found there. The phytomass stock of *Ledum* tundra is 1628 g/m^2, stocks of living phytomass are 1096 g/m^2, which is almost 2 times higher than those of mortmass (532 g/m^2) .

Dwarf birch kinds of tundra (*Betula nana*) occupy 11.7% of the total territory, from everywhere in Yamal, especially in the eastern part of the peninsula, to the south of the Gydan Peninsula, the Gydan Ridge and Tanam Elevation. They grow on the gentle slopes of watersheds, river valleys, ridges, ravines, gullies, lake depressions, on sands and loams. They are very diverse, but mostly represented by mountain cranberry-dwarf birch or willow-mountain cranberry-dwarf-moss communities, sedge-moss, cloudberry-moss and moss-lichen communities. The projective cover of *Betula nana* is 30-90%, the average community height vary from 20 to 50 cm. The dominants of the dwarf shrub layer are *Salix glauca, S. lanata, Vaccinium vitis-idaea* ssp. *minus*; the grasses are represented mostly by *Carex* spp., *Eriophorum* spp. and *Equisetum arvense*; the projective cover of mosses is 90-100%, consisting of *Sphagnum* spp., *Hylocomium splendens, Polytrichum* spp., *Dicranum* spp.; the projective cover of lichens is low (5-10%), consisting of *Bryocaulon divergens, Thamnolia vermicularis, Sphaerophorus globosus.* Among the dwarf shrub formations group this one has the largest stocks of total phytomass (2480 g/m^2), which makes dwarf birch tundra the 2nd in the subzone of the typical tundra (after willow community). The stocks of living phytomass (1407 g/m^2) are 1.5 times higher than those of mortmass (990 g/m^2).

Mesophytic meadows are a specific type of tundra vegetation, where the main role is played by mesophytic grasses and the moss-lichen cover is poorly developed. These meadows are represented by *horsetail* (*Equisetum arvense*) and *mixed grasses-cereals* (*Bistorta vivipara, Tanacetum bipinnatum, Poas* spp., *Festuca* spp.) formations (photo 8). They can be found everywhere, but do not occupy vast territories, spreading gradually throughout the typical tundra in the areas with the most favorable conditions of heat availability, snow accumulation and soils thawing: on the landslide surfaces, terraces and valley slopes. Sometimes they form as the result of the anthropogenic impact and shrubs deforestation. In the subzone of the typical tundra these meadows have the lowest phytomass stocks: 87 g/m^2 for horsetail and 326 g/m^2 for mixed grasses-cereals. The mixed grass-cereals meadows usually have high mortmass indices (220 g/m^2), which is 2 times higher than living phytomass (106 g/m^2) due to the high amount of dead cereals residuals.

Hygrophytic (coastal-water) meadows are represented by *pendant grass* (*Arctophila fulva*) and *purple marshlocks* (*Comarum palustre*) formations, occupying small areas in the river valleys, on the bogged and waterlogged territories in the eastern Yamal, on the Gydan Peninsula along the both sides of the Gydan Ridge. The pendant grass formations spread in the hollows, overgrowing channels, former riverbed, depression bottoms and lake depressions. Aside from *Arctophila fulva* they consist of *Carex chordorrhiza* and *Carex concolor*; the share of mosses is rather high, represented by *Dicranum* spp., *Anastrophyllum minutum, Polytrichum* spp., *Sphagnum* spp.; the lichens are sparse. The grass layer of the purple marshlocks communities is dominated by *Carex* spp. and *Comarum palustre*; the moss layer includes *Calliergon* spp., *Sphagnum* spp., *Warnstorfia* spp. The coastal-water meadows have rather small phytomass stocks (288 g/m^2 in pendant grass communities and 221 g/m^2 in the purple marshlocks ones), the mortmass values are low.

Photo 8. Horsetail (*Equisetum arvense* ssp. *boreale* (Bong.) Tolm.) meadow in the typical tundra of Central Yamal (photo by D.A. Sorochinskaya).

The group of cotton grass-sedge tundra and bogs formations occupy 25% of the typical tundra territory, including water-sedge (*Carex aquatilis, C. concolor*), sedge-cotton grass (*Carex* spp., *Eriophorum* spp.) and cotton grass (*Eriophorum* spp.) formations with total phytomass stocks of 531, 1500 and 1485 g/m^2 respectively. The mortmass of these formations exceeds the living phytomass, which is especially noticeable in the water-sedge communities (10:1, with a high amount of mosses and litter in the mortmass composition). The almost similar ratio was also registered in the monograph of N.I. Bazilevich (1993) for the sedge-cotton grass communities and the bogs of the southern and typical tundra. The sedge-cotton grass tundra are widespread, from the Gydan Peninsula where they are the most abundant, to the vast territories of the northern and southeastern parts of the peninsula (photo 9), while in Yamal they are not so common.

The sedge-cotton grass communities occupy the most depressed, waterlogged and bogged territories on sands, can be found in hollows, on the bottom of lake depression, former riverbeds, on the gentle slopes, lake and river terraces, on the flat tops of ridges. The various grass-moss bogs have formed in the large lake depressions with dominant sedge species which differ depending on the flooding level. The overgrowing lakes are dominated with *Carex concolor*, and the moss cover is usually absent. The most depressed and flooded areas are occupied by sedge-feather mosses bogs with *Carex rotundata, C. rariflora, C. concolor, C. chordorrhiza*, as well as by sedge-cotton grass-sphagnum bogs with variety of sphagnum species (*Sphagnum balticum, S. lenense, S. fimbriatum, S. steerei, S. compactum, S. squarrosum*). There can be also found bogs with abundant *Betula nana*, transforming into the bogged dwarf shrub tundra. The grass height is up to 30 cm, the height of dwarf shrubs is 20 cm, the projective cover is high (90-100%), but some communities have patches of bare ground and open water. Their microrelief is lumpy, knob-and-kettle, bulgy-swampy, with small tussocks, sometimes with polygonal fracturing and bulges and swamps. As it was mentioned before, their phytomass is quite high (1500 g/m^2), and due to the fact that they occupy large areas, their contribution to the organic matter production in the subzone is very significant.

Photo 9. Sedge-cotton grass (*Carex* spp., *Eriophorum* spp.) formation in the typical tundra on the Gydan Peninsula (photo by D.A. Sorochinskaya).

Fractional composition of living aboveground phytomass of the typical tundra communities. The woody plants are predominant in the fractional composition of the most plant communities of shrub and dwarf shrub groups of formations (fig. 8). Their share is 80-95% in shrub communities, as well as in dwarf shrubs Dryas (*Dryas octopetala, D. punctata*) and crowberries (*Empetrum nigrum*) tundra, with a high projective cover of the dwarf shrub layer and a low one of the moss-lichen layer. In the formations of Labrador tea (*Ledum palustre* ssp. *decumbens*), mountain cranberry (*Vaccinium vitis-idaea* ssp. *minus*), dwarf birch and willow (*Salix nummularia, S. polaris*) the share of mosses is still high (40-60%), while the share of shrubs and dwarf shrubs is about 30%.

In the meadow communities the fractions of cereals are very abundant (40% in the mixed grasses-cereal communities (*Bistorta vivipara, Tanacetum bipinnatum, Poa* spp., *Festuca* spp.), 20% on the horsetail meadows), as well as grasses (8-15%), horsetails and clubmosses (10%). A significant part of the horsetail meadows is occupied by the fraction of dwarf shrubs (45%), while the total phytomass stock remains low (fig. 7).

In the sedge-cotton grass and cotton grass tundra the most abundant fraction is mosses (55-65%), with shrubs and dwarf shrubs (20%), and sedges and cotton grass produce about 10-15% of the total phytomass.

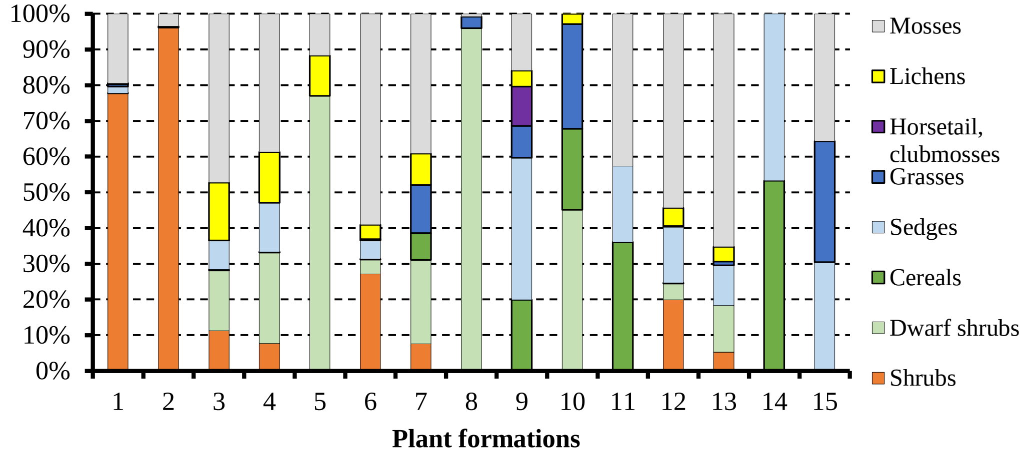

Fig. 8. Proportion of phytomass of various fractions in the formations of the typical tundra subzone.

The coastal-water vegetation is represented by the lowest number of fractions. In the formation of pendant grass the entire phytomass consists equally of cereals and sedges, in the fraction of purple marshlocks it consists of sedges, grasses and mosses.

Therefore, in the typical tundra the largest phytomass stocks are registered in the group of shrub tundra formations within the communities of willow and alder formations; while in dwarf shrub tundra the highest stock is found in the dwarf birch and willow tundra. High phytomass indices are also found in the group of cotton grass-sedge tundra formations and bogs in cotton grass and sedge-cotton grass formations, where an excess of mortmass indices over living phytomass was also registered, especially in the water-sedge communities (exceeding more than 10 times). An insignificant excess of mortmass was also noted in willow dwarf shrub tundra and mixed grass-cereal meadow communities. The smallest stocks are common for the tundra meadows and coastal-water meadows. In the fractional phytomass structure the proportion of shrubs and dwarf shrubs is significantly higher in comparison with the arctic tundra, while the share of mosses remains rather high.

Southern Tundra

The southern shrub tundra subzone includes 20 plant formations, divided into 6 groups.

Dwarf shrub tundra is the most widespread group (42% of the territory; fig. 9) in tundra zone. The large areas are occupied by grass (sedge and cotton grass) tundra and bogs (28.9%) and shrub communities (19.4%). Despite the fact that shrub communities are smaller than both shrub tundra and sedge and cotton grass tundra and bogs, they are the one to determine the appearance of the subzone vegetation.

Shrub communities of the southern tundra grow in the habitats of flat interfluves, and are very coenotically diverse, with relatively high shrubs stability in the subzone communities. Mesophytic and hygrophytic meadows are less widespread (3.6% and 5.2%); psammophytes communities and groups occupy less than 0.05% of the territory. Generally, the ratio between the areas with different groups of formations in the southern and typical tundra subzones is similar.

We analyzed the aboveground phytomass stock for 17 plant formations, grouped in 5 classes. The values of total phytomass in the shrub and dwarf shrub communities of the southern tundra are maximal (fig. 10). In most of the studied formations these values are about 300-2000 g/m^2, however, in some formations of the shrub and dwarf shrub tundra they are close to 4000 g/m^2. Those are formations of willow (*Salix lanata, S. phylicifolia, S. glauca*) with 4634 g/m^2, alder with 5583 g/m^2, and bog bilberry with 3960 g/m^2.

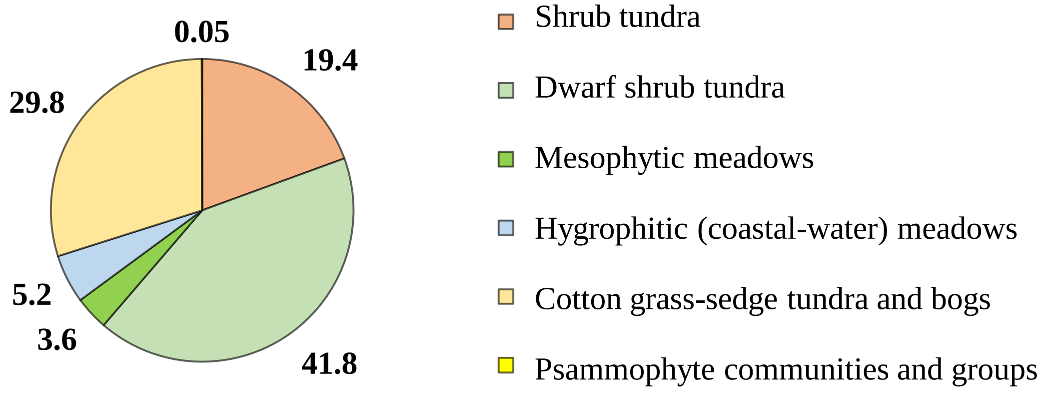

Fig. 9. The ratio between the areas occupied by different types of tundra vegetation in the southern tundra subzone (%).

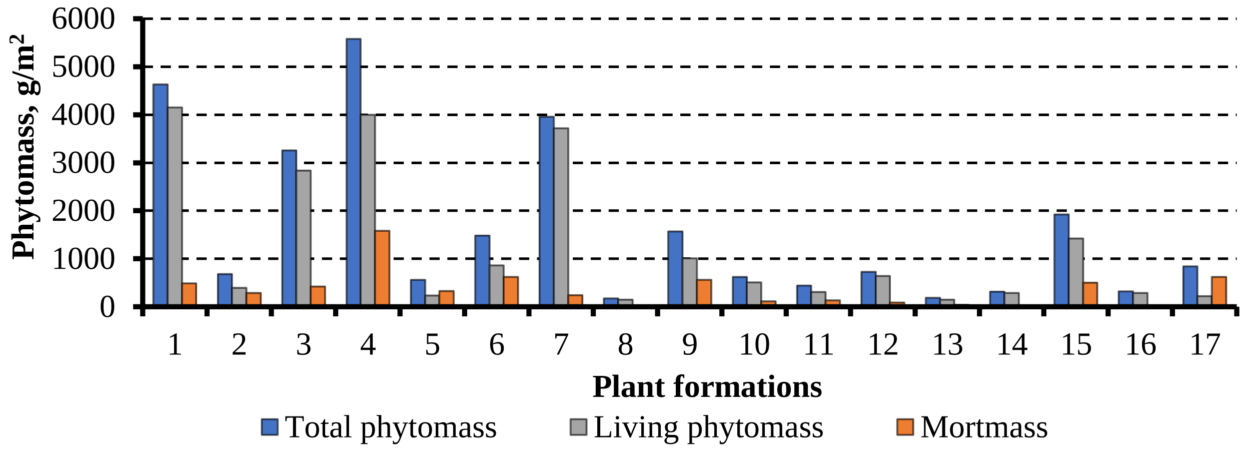

Fig. 10. Values of the total phytomass, living phytomass and mortmass for the formations of the southern tundra subzone (dry weight, g/m^2). *Legend for Fig. 10-11.* Plant formations. Shrub tundra: 1 − *Salix lanata* L., *S. phylicifolia* L., *S. glauca* L., 2 − *Salix lapponum* L., *S. glauca* L., *S. phylicifolia* L., 3 − *Betula nana* L., 4 − *Alnus viridis* (Ehrh.) Pouzar. Dwarf shrub tundra: 5 − *Arctous alpina* (L.) Nieden., 6 − *Ledum palustre* ssp. *decumbens* (Ait.), 7 − *Vaccinium uliginosum* ssp. *microphyllum* Lange, 8 − *Salix nummularia* Anderss., *S. polaris* Wahlenb., 9 − *Betula nana* L., 10 − *Empetrum nigrum* L. Mesophytic meadows: 11 − *Festuca* spp., *Poa* spp., 12 − *Hedysarum hedysaroides* (B. Fedtsch.) P. W. Ball, *Astragalus* spp., 13 − *Juncus trifidus* L., 14 − *Equisetum arvense* ssp. *boreale* (Bong.) Tolm. Cotton-grass and sedge tundra and bogs: 15 − *Carex* spp., *Eriophorum* spp. Hygrophytic (coastal-water) meadows: 16 − *Carex aquatilis* Wahlenb., *C. concolor* R. Br., 17 − *Arctophila fulva* (Trin.) Anderss.

In shrub tundra the communities of *Alnus viridis* (8% of the territory, or almost half of the entire shrub communities) formation are the most widespread. The values of its total phytomass stock are the highest among the formations of the southern tundra (5583 g/m^2). They cover large areas and have a significant input into production of organic matter.

Alder communities occupy the edges of watersheds and ridges, watershed slopes, floodplains of large rivers, and are unevenly spread in the south of Yamal and Gydan, as well as on the Taz Peninsula. The dominant communities are represented with plant litter (if the shrub layer is very dense), moss (*Calliergon* spp.) and mixed grasses (*Petasites frigidus, Equisetum arvense, Chamerion angustifolium*). Their shrub layer is very developed (alder forms an almost impenetrable canopy up to 2-2.5 m), while the projective cover of other shrubs and dwarf shrubs remains low.

Aside from the communities where *A. viridis* is an absolute dominant, there can be also found alder-birch communities (*A. viridis, B. nana*). The projective cover of alder in these communities is relatively low and about 30-35%, the average height of shrub layer 1.5-2 m, the dwarf shrub layer with its project cover of 50%, and the average height about 0.5-1 m, is formed mostly with *B. nana* and *Ledum palustre*, and sometimes with another shrubs and dwarf shrubs. The grass cover is dominated by sedges (*Carex vaginata, C. bigelowii*). The moss layer is developed unevenly (its projective cover is 10-85%), while its species composition is quite diverse (*Aulacomnium* spp., *Calliergon* spp.); the lichens are rare.

Communities of *willow formation* (*Salix lanata, S. phylicifolia, S. glauca*) cover 5% of the territory and mostly concentrated in the northern part of the subzone, mostly on the Yamal Peninsula, and are less spread in Gydan and Taz, usually growing in the river floodplains, lake depressions and on the gentle slopes of river valleys. They divide into formations of moss (*Polytrichum* spp., *Sphagnum* spp., *Tomentypnum nitens, Calliergon* spp., *Aulacomnium* spp., *Hylocomiums plendens*) and mixed grass-sedge (*Carex aquatilis, C. rariflora, C. rotundata, Alopecurus pratensis, Veratrum album, Equisetum pratensis*).

The *mixed grass-sedge willow* formations have a high projective cover of grass layer (about 50%, including 15% of grasses aside from graminoids), the grass, shrub and dwarf shrub species are abundant. These communities usually form in the river floodplains and creeks valleys, on the lower parts of slopes of river valleys. Their total phytomass is not very high (680 g/m^2).

The *moss willow* formations has a high projective cover (100%), the moss cover is dense as well (90-100%), the cover of the shrub layer is 30-60%, the grass layer is dominated by graminoids, with its cover up to 40%, the average height of the community is up to 50 cm. These communities form in the damp watershed hollows, on the slopes and bottoms of gullies, and in the floodplains. They have high phytomass stocks (4635 g/m^2), which makes them the 2nd largest producer of the total phytomass in the southern tundra formations.

The high values of the total phytomass are also common for the *large-birch tundra* (3260 g/m^2). These communities are widespread in the territory (6.6%), mostly occupying the northern part of the subzone, Yamal and Gydan, and are less common for the Taz Peninsula (photo 10). They are common for the ridges, slopes of thermokarst depressions, sides of river valleys and above-floodplain terraces, and can also be found on the flat interfluves. Aside from *Betula nana*, the shrub layer is represented by *Salix phylicifolia, S. glauca*; the dwarf shrub layer is formed by *Vaccinium uliginosum* ssp. *microphyllum, V. vitis-idaea* ssp. *minus, Ledum palustre* ssp. *decumbens*. While the total projective cover is 90-100%, the average cover of the shrub layer is 60%. Among the plants of the grass layer the main one is *Rubus chamaemorus*. Usually, the moss-lichen layer is well-developed, with its projective cover about 85-90%. The dominants of the layer are various species of mosses and lichens, such as *Dicranum* spp., *Pleurozium schreberi, Hylocomium splendens, Cetraria islandica, C. islandica*, etc.

The dwarf shrub tundra is the most widespread type of tundra vegetation in the subzone of the southern tundra and is divided into 9 formations. The highest phytomass stocks are found in the *Vaccinium uliginosum* ssp. *microphyllum* formation (3960 g/m^2).

The bog bilberry communities form on the watershed slopes, lake terraces and gentle ridges.

The main dominants of the dwarf shrub layer are *Vaccinium uliginosum* ssp. *microphyllum* and *Betula nana* (the projective cover of bilberry can be up to 45%, while the total cover is 90-100%, and the average height is 15-20 cm). In the *Cetraria* (*Cetraria islandica, Cetrariella delisei*) and moss (*Sphagnum* spp., *Polytrichum* spp.) communities, where the cover of the moss-lichen layer is about 60-80%, the bog bilberry is dominant in the dwarf shrub layer, while in some communities the dominants are another species of dwarf shrubs, such as *Ledum palustre* ssp. *decumbens, V. vitis-idaeae, Empetrum nigrum*.

The average phytomass value of *Ledum palustre* communities is 1480 g/m^2. They (*Ledum palustre* ssp. *decumbens*) are the most common formations of dwarf shrub group in the southern tundra (18.2% of the territory). They evenly occupy vast areas in the south and of Yamal, Gydan and Taz. They grow on the bogged territories of watersheds and floodplains, on the turf hillocks, thermokarst ridges and small ridges (photo 11). *Ledum palustre* ssp. *decumbens* is their main dominant with its projective cover of 35%, the dwarf shrub layer also includes *Betula nana,* while *Vaccinium uliginosum* ssp. *microphyllum*, *V. vitis-idaea* ssp. *minus*, *Empetrum nigrum* are scarce (1-5%). A distinctive feature of this formation is its high abundance of *Rubus chamaemorus* and cotton grass species, especially of *Eriophorum vaginatum*. Its moss-lichen layer is well-developed, with the projective cover of 85-90% (*Sphagnum* spp., *Dicranum* spp., *Polytrichum* spp., *Flavocetraria cucullata*, *Cladonia stygia*). The total cover is usually about 100%.

Photo 10. Dwarf birch (*Betula nana* L.) formation in the southern tundra of the Taz Peninsula (photo by D.A. Sorochinskaya).

The lowest phytomass stocks in the dwarf shrub tundra are common for the bearberry (559 g/m^2), willow (175 g/m^2) and crowberry (618 g/m^2) communities. They occupy small areas in the southern tundra territories (0.1-3%).

The total phytomass stocks of <u>meadow communities</u> mostly vary from 200 to 400 g/m^2, the highest stock is common for the *mixed grass-legume formation* (727 g/m^2). Communities of this formation (*Hedysarum hedysaroides, Astragalus* spp.) occupy steep and warm slopes with light substrate. This formation has a high projective cover of legume (*Hedysarum hedysaroides, Astragalus* spp.). The grass layer also includes *Campanula rotundifolia, Equisetum arvense, Festuca rubra, Tanacetum bipinnatum*; the dwarf shrub layer includes *Salix nummularia*, the projective cover of which is about 10-15%.

Meadows with mixed grass-legume, rushes and horsetail occupy small territories (0.1-0.5%), while the largest areas are usually occupied with cereal-mixed grass communities of mostly anthropogenic origin (2.7%). Natural tundra meadows are common for the floodplain habitats and slopes; anthropogenic meadows can be also found on the flat interfluves.

Photo 11. *Ledum palustre* ssp. *decumbens* (Ait.) formation in the southern tundra by the Baidarata River (photo by D.A. Sorochinskaya).

Formation group of sedges and cotton grass tundra and bogs consists of one *sedge-cotton grass formation* only. Its total phytomass stock is up to 1925 g/m^2, exceeding mortmass values almost 3 times (1424 and 500 g/m^2 respectively), in comparison to the typical tundra. The input of this tundra into phytmass production within the subzone is significant, because its communities with *Carex* spp. and *Eriophorum* spp. occupy almost 30% of the southern tundra territories. They are especially spread on the Yamal Peninsula and occupy smaller areas of the Gydan and Taz Peninsulas. Sedge-cotton grass communities form in the well-humidified, waterlogged and bogged habitats. They are usually found in the damp floodplains, thermokarst and lake depressions, in the areas with stagnant water, on the gentle slopes of ridges and on the watersheds. Sedges and cotton grasses (*Carex chordorrhiza, C. concolor, C. aquatilis, Eriophorum scheuchzeri, E. russeolum*) form dense layer, the projective cover of which is 65-90% (the total cover is 90-100%), and its average height is 20-30 cm. Shrubs and dwarf shrubs are sporadic and do not form a thick. Moss layer is mostly formed with sphagnum, feather mosses and *Aulacomnium* species, its projective cover can be up to 100%. Lichens are sparse but can be found almost everywhere, but their share in the projective cover is insignificant.

Coastal-water vegetation is represented by pendant grass (*Arctophila fulva*) and water-sedge (*Carex aquatilis*, *C. concolor*) formations.

Phytomass of *pendant grass* communities is rather low (319 g/m^2). This formation occupies small territories, and is mostly found on the Yamal Peninsula, on the river and lake shores is almost absent (with rare small patches of sphagnum and feather moss), as well as shrubs and dwarf shrubs. *Arctophila fulva* is the only dominant, its projective cover varies from 15 to 90%, and its average height is 50 cm. The areas with open water are common for this formation; some communities include *Eriophorum scheuchzeri*. Litter is almost absent there, and the mortmass is 29.4 g/m^2.

Communities of *water-sedge formation* has slightly higher phytomass values (844 g/m^2), however the values of their mortmass are 3 times higher than those of living phytomass (620 and 223 g/m^2 respectively).

Communities of *Carex aquatilis* and *C. concolor* can be found near the bodies of water and in the waterlogged floodplains, on the bottoms of damp hollows, gullies and thermokrast hollows with sand and turf-sandy substrate. The moss layer is formed with sphagnum and feather mosses, its projective cover varies from almost zero to 100%, the lichens are very rare, the single shrubs of *Salix* spp. and *Betula nana* cannot form a dense layer. Sedges mostly form mono-dominant communities (their projective cover is 70%, the average height is 40-50 cm) with a few species of cotton grass and cereals, and sometimes with *Comarum palustre*.

Analysis of fraction composition of living phytomass in the southern tundra communities. In the faction composition of the southern tundra shrubs are the leading phytomass producers (fig. 11). In the group of shrub tundra formations the share of the woody species is 55-98%, the share of mosses is low.

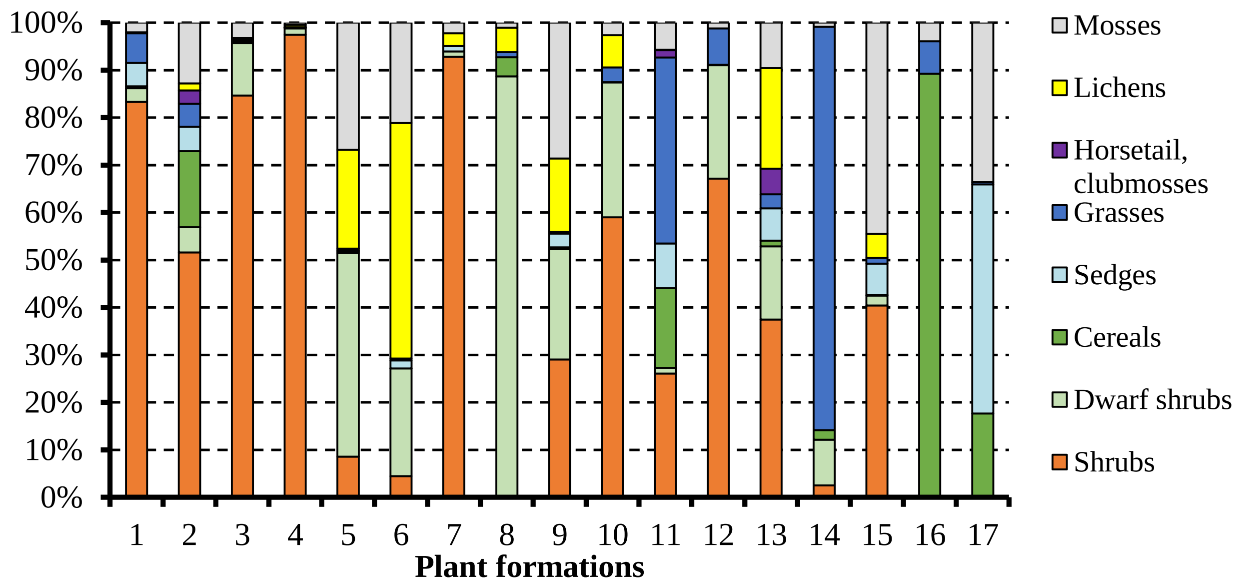

Fig. 11. Proportion of phytomass of various fractions in the formations of the southern tundra.

In the dwarf shrub tundra the share of shrubs and dwarf shrubs varies from 87 to 93% in the formations of bog bilberry, willow and crowberry.

The share of dwarf shrubs is slightly lower in the bearberry, *Ledum palustre* and small-bush formations (28-50%), while the role of lichens (up to 50% in *Ledum palustre* tundra) and mosses (20-25%) is high.

In meadow communities, the fractional composition is dominated by grasses (up to 90% in horsetail meadows), the share of shrubs and dwarf shrubs is large (from 10 to 50%), and the fraction of mosses produces 10% of the total phytomass.

In the sedge-cotton grass tundra the mosses (45%) and shrubs (38%) are dominant, the share of cotton grass and sedges is about 10%, the *Arctophila* formation is represented by cereals (90% of the phytomass), the water-sedge tundra is represented by sedges (45%), and the amount of mosses is high as well (33%).

Therefore, it is obviously a tendency of an increasing total phytomass stock, going from the arctic tundra to the southern one. The stocks of the southern tundra subzone reach 4600-5600 g/m^2 in shrub communities, although in most formations they vary from 300 to 2000 g/m^2. Among the studied formations of the subzone, the alder communities are the absolute leader in terms of phytomass, followed by willow, large-birch and bog bilberry formations. The lowest phytomass indices, just like in the typical tundra, are common for meadow and coastal-water communities. On the contrary, in the arctic tundra the phytomass of these communities is higher than in some dwarf shrub tundra because phytomass indices do not vary too much within different formations. The excess of mortmass values over living phytomass is significant only in the water-sedge formation (3:1). Generally, the stocks of living phytomass are 5-9 times higher than those of mortmass in the studied formations, which corresponds to the data obtained by N.I. Bazilevich (1993).

Shrubs are the absolute dominants in the fractional composition of the phytomass, the role of dwarf shrubs is smaller, while the amount of mosses is insignificant, however, their share in some sedge and dwarf shrub communities can be up to 20-40%.

Conclusions

The results of this study allow us to draw some conclusions about the ecological and geographical features of the aboveground phytomass structure of the studied tundra communities, and its distribution throughout the territory.

The total phytomass stock of plant communities in the tundra zone of Western Siberia depends on their geographic location, it increases while moving from north to south, from the subzone of the arctic tundra to the subzone of the southern tundra.

The accumulation of phytomass in tundra communities within one subzone differs significantly depending on the nature of their vegetation. The analysis of the aboveground phytomass distribution in communities of various formations showed the maximum indices for dwarf willows (1800 g/m^2) and sedge-cotton grass (2070 g/m^2) in the *arctic tundra*. In the *typical tundra* the highest values were in the groups of shrub formations (3080 g/m^2 for willows, 2413 g/m^2 for alder), and in dwarf birch tundra (2480 g/m^2). In the *southern tundra* communities the maximum phytomass stocks were recorded for the shrub alder (5580 g/m^2), willow (4630 g/m^2), large-birch (3258 g/m^2) and dwarf blueberry (3960 g/m^2) communities. The composition of plant communities and, respectively, the phytomass structure depend on the geological and geomorphological, climatic and soil conditions.

The analysis of the fractional composition of living phytomass within the subzones showed that in the *arctic tundra* the fraction of mosses (up to 90%) was prevalent, in the *typical tundra* it was shrubs and dwarf shrubs (30-80%) with a high share of mosses (20-40%), in the *southern tundra* the absolute dominant was shrubs (60-90%), and dwarf shrubs to a lesser extent (20-30%), while the role of mosses remained insignificant.

We determined the ratios between mortmass and living phytomass in communities of various formations within subzones, which is an important index of carbon deposition in the tundra zone. In the formations of dwarf birch, willow, horsetail and water-sedge of the *arctic tundra* the values of mortmass exceed the ones of living phytomass. In the *typical tundra* the mortmass prevails over the phytomass stocks only in the waterlogged habitats (such as cotton grass-sedge tundra and bogs). In the *southern tundra* the opposite tendency can be seen, meaning that the living phytomass stocks are 5-9 times higher than the mortmass values almost in all formations.

These results can be used to compile a map of stocks and structure of phytomass of the tundra communities of West Siberia to assess the reindeer capacity of pastures and carbon deposits in the vast and poorly explored territories.

Acknowledgements. The authors want to thank K.A. Yermokhina, the senior researcher of the A.N. Severtsov Institute of Ecology and Evolution of the Russian Academy of Sciences, for the opportunity to join the expedition, for the help with data processing and for the provided materials; and O.V. Khitun, the senior researcher of the V.L. Komarov Botanical Institute, for the aid with tundra flora identification; as well as the researchers of the Russian Center for Arctic Development for their great support of the filed works.

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