A study of seasonal dynamics of herbaceous plant communities in Khakassia using ground-based and satellite data

A P Shevyrnogov¹, N A Kononova¹*, A I Volkova², I Yu Botvich¹ and T I Pisman¹

¹ Institute of Biophysics, Siberian Branch, Russian Academy of Sciences, 50/50 Akademgorodok, Krasnoyarsk, 660036, Russia
² Katanov Khakass State University, 90 Lenina, Abakan, 655017, Russia

*E-mail: nata_slyusar@mail.ru

Abstract. The present study addresses the seasonal dynamics of productivity and species composition of the meadow and steppe vegetation communities in Khakassia, determined using the ground-based and satellite data of 2017. The MODIS/Terra satellite data were used to analyze the Normalized Difference Vegetation Index (NDVI) and the Land Surface Water Index (LSWI). The NDVI and LSWI were found to be related to the productivity of the meadow and steppe vegetation. The NDVI increased as the portion of the mesophyte grasses in the grass canopy became larger. The LSWI was higher in the steppe communities, which had lower projective coverage, with spots of bare soil, than in the meadow communities, with their abundant vegetation.

1. Introduction
The advantages of natural communities compared to agroecosystems are the longer growing periods and the higher water stability of the soil, which has a thicker sod layer. Being a powerful biologically active producer of organic mass and oxygen, natural vegetation stabilizes cultivated lands [1].

The contemporary state of the steppe and meadow plant communities suggests their high sustainability potential, but human-induced activities reduce the diversity of the plant kingdom. Therefore, these communities have become a focus of research on both the global and regional scales [2].

Conservation of biodiversity, sustainable use of plant resources, and optimization of the state of vegetation under climate change should be based on conserving the existing plant species and increasing the diversity of plant communities by introducing the species that are better adapted to the extreme factors caused by the changing agroclimatic conditions [2, 3].

Biological production of the ecosystem is the major resulting parameter characterizing biomass growth rate, which is based on the efficiency of solar energy conversion in photosynthesis. This is actually the parameter of formation of organic matter, which can be subsequently used as food by various organisms. Because of climate change, sustainable use of natural resources of grasslands has become a global issue [4 – 6].

Phytomass accumulation is a major ecological parameter showing the functional state of the vegetation cover. The amount of aboveground phytomass and proportions of its main components are...
largely determined by the species composition of vegetation, projective coverage of the grass canopy, and the degree of human impact.

The purpose of this research was to study seasonal dynamics of the species composition and production of the meadow and steppe vegetation in the North-Minusinsk Depression at Lake Shira (Khakassia) using ground-based and satellite data for 2017.

2. Materials and methods

The study was conducted at two permanent plots (1 and 2) located in the Shirinskiy District, in the steppe and forest-steppe zones of the Republic of Khakassia. The geobotanical subdivision performed by A.V. Kuminova [7] classified the study area as part of the Iyus-Shirinskiy (North-Khakassia) steppe geobotanical district in the Minusinsk Depression Province. The terrain is mostly rolling plain. The flat regions are separated from each other by monoclinic cuestas with distinctly asymmetric slopes and broad, flat valleys between the ridges.

Plant communities of true dry meadows and true bunchgrass steppes were studied. These communities differ considerably in their species composition, projective coverage, and production. Therefore, they are most suitable to be identified using satellite and ground-based methods.

As the study region was the grassland, each sample plot for geobotanical observations had an area of 100 m². Each sample plot was a 10×10 m square. Geobotanical observations were carried out to determine the structure of plant communities, projective coverages of the total grass canopy and of different species, and the ecological group. The projective coverage was determined visually. Latin names were found in S.K Cherepanov’s report (1995).

Dry aboveground phytomass (production) was determined for each sample plot. The amount of phytomass was measured using the plants cut from an area of 1 m² (1×1 m); four replicates were made. To measure the total mass of the dry plants, air-dry samples were prepared and weighed. All results were calculated as g/m². The data were processed using the MS Excel 2013 software. The data on phytomass were given as arithmetic means with confidence intervals.

Analysis of seasonal dynamics of vegetation using MODIS/Terra satellite data was based on eight-day data of the visible and near infrared bands at a spatial resolution of 250–500 m.

The following vegetation indices were used:

- Normalized Difference Vegetation Index (NDVI) – the index of photosynthetically active biomass. NDVI is calculated using the formula
  \[ NDVI = \frac{(NIR - Red)}{(NIR + Red)} \] (1)
  where NIR is reflection in the near infrared spectrum and RED is reflection in the red range of the spectrum [8].

- Land Surface Water Index (LSWI) uses the shortwave infrared (SWIR) and the NIR regions of the electromagnetic spectrum. There is strong light absorption by water in the SWIR. Therefore, LSWI is sensitive to the total amount of water in vegetation and its soil background [9].

3. Results

The accurate interpretation of aerospace data should be based on a large amount of data on the monitored environmental components, including the field study findings. Contemporary data suggest that the properties of electromagnetic radiation reflected (or reradiated) from vegetation are determined by the optical properties of foliage and other components of the plants that change during the growing season and that are considerably affected by the environmental factors. In addition, these properties are influenced by the structure of the vegetation cover (plant stand density, projective coverage, leaf surface area, predominant leaf orientation, etc.), which is a species specific and time-varying factor.

Results of the ground-based study of the species composition and projective coverage of the forbs-grass meadow (Plot 1) and the forbs-grass–wormwood steppe are shown in table 1.
Table 1. Species composition and dynamics of the projective coverages of the meadow and steppe plant communities.

| Name of community (dominant species) | Projective coverage, % |
|-------------------------------------|------------------------|
|                                     | June | July | August |
| **Plot 1** Forbs-grass community (meadow)** |
| Festuca pratensis Huds.              | 4    | 5    | 6      |
| Phleum phleoides (L.) Karst          | 6    | 8    | 8      |
| Carex pediformis C.A. Mey.           | 4    | 2    | 2      |
| Ranunculus polyanthemos L.           | 6    | 4    | 3      |
| Carum carvi L.                       | 3    | 4    | 5      |
| Veratrum nigrum L.                   | 3    | 3    | 1      |
| Geranium pratense L.                 | 1    | 3    | 5      |
| Filipendula stepposa Juz.            | 4    | 4    | 6      |
| Iris ruthenica Ker-Gawl.             | 3    | 4    | 2      |
| Sanguisorba officinalis L.           | 3    | 4    | 5      |
| **Plot 2** Forbs-grass–wormwood community (steppe)** |
| Koeleria cristata (L.) Pers          | 8    | 6    | 4      |
| Festuca valesiaca Gaudin            | 4    | 3    | 2      |
| Stipa capillata L.                   | 2    | 2    | 3      |
| Festuca pseudovina Hack. Ex Wiesb.   | 4    | 2    | 1      |
| Artemisia frigida Willd.             | 4    | 6    | 10     |
| Carex duriuscula (C.A. Mey.)         | 2    | 1    | 2      |
| Carex pediformis C.A. Mey.           | Un.  | 4    | 5      |
| Cleistogenes squarrosa (Trin.) Keng  | 1    | 2    | 4      |
| Potentilla bifurca L.                | Un.  | 1    | 2      |
| Potentilla acaulis L.                | 1    | 3    | 2      |

Plot 1. A true dry mixed-grass meadow (54.519835N, 89.737342E). In the study area, meadows are formed at the upper reaches of arroyos, valleys, clearings, and edges of the birch-larch and larch forests. The total projective coverage of the forbs-grass community is 80–100%. The species composition and density of the grass canopy is chiefly uniform, with rare patches abounding in *Sanguisorba officinalis* L., *Geranium pratense* L., and *Filipendula ulmaria* (L.) Maxim, where the grass canopy is taller and denser. The height of the grass canopy, taking into account the reproductive shoots of large grasses, reaches 120 cm, but the phytomass is mainly concentrated in a layer of 55–60 cm. The community consists of 4 layers.

Plot 2. True bunchgrass steppe (54.705344N, 90.535291E). The forbs-grass-wormwood community is located on the lower third of the south-facing slope of the Gora Razluki district near the village of Vorota. The total projective coverage is 30–55%. There are 14–16 species per m². The grass canopy has a mixed structure: the plots with dominating grasses (*Koeleria cristata* (L.) Pers., *Festuca valesiaca* Gaudin, *Festuca pseudovina* Hack. Ex Wiesb.) alternate with the plots where *Artemisia frigida* Willd. and *Carex duriuscula* (C.A. Mey.) are the major species. There are 2 distinct layers. The upper 24–26-cm layer mainly consists of the reproductive shoots of grasses and wormwood. The greater portion of the grass is located in the other layer; it mainly consists of the vegetative shoots of grasses, wormwood, and sedge. *Potentilla acaulis* L., *Veronica incana* L., and *Potentilla bifurca* L. are minor species.

The dynamics of the productivities of the meadow and steppe plant communities during the growing season are shown in figure 1. The communities differed significantly in dry mass production. The meadow communities showed the highest productivity in July, when the dominant mesophytes were in the flowering stage. The projective coverage of the community reached 90%. In August, the meadow plant productivity dropped dramatically because of mowing. On the steppe plot, productivity dynamics corresponded to the natural cycles of bunchgrass and wormwood. There was no expected production.
peak in July because of the regular moderate grazing pressure. In August, aboveground phytomass increased as *A. frigida* plants produced seeds.

**Figure 1.** Dynamics of productivities (dry mass, g/m²) of meadow and steppe plant communities during the growing season.

The conditions on Plot 1, with meadow vegetation, vary considerably because of the diverse terrain features and the presence of buttresses. The area is a natural farmland, and the grass is used to produce hay. The grass canopy boasts high species diversity and a large total projective coverage. The average phytomass production over the season is 207.8 g/m². The grass canopy has a complex structure, including almost all commercial–botanical groups. Plot 2, with the steppe bunchgrasses, is located at the foot of the mountain and on the mid-slope. The plant community is a degraded version of the bunchgrass steppe, with the seasonal average production of 70.6 g/m². The grass canopy is low, with the characteristic overgrazed plots. The phytomass has a complex structure, including all commercial–botanical groups.

**Figure 2.** Dynamics of the NDVI (A) and LSWI (B) of the meadow and steppe vegetation in the 2017 growing season.

Then, results of the ground-based study were used to verify the remote sensing data (figure 2). Figure 2 demonstrates seasonal dynamics of the NDVI (figure 2 A) and LSWI (figure 2 B) of the meadow and steppe plots, which differ in the dominant plant species and productivity. The NDVI of the meadow vegetation was higher than the NDVI of the steppe vegetation. It is well-known that the higher NDVI values correspond to the larger phytomass amounts. That was confirmed by the results of the geobotanical study. The productivity of meadow vegetation was higher than the productivity of the steppe plants. Other factors affecting the NDVI were the species composition of vegetation, plant density, vegetation state, and slope exposure. Moreover, the frequency of the available satellite images was sufficient to determine the date when the meadow grasses were mowed. Between August 5 and 13, NDVI values decreased dramatically because of the human interference.

LSWI can be used to monitor the increase in the liquid water in soil and vegetation, especially at the start of the season [10]. Analysis of the LSWI seasonal dynamics showed that the LSWI of the steppe
vegetation was higher than the LSWI of the meadow vegetation (figure 2 B). At the beginning of summer, after spring showers, the LSWI values were similar to each other, but in mid-July, water content on the steppe plot increased noticeably while water content on the meadow plot decreased at the same rate. Those trends could be associated with the differences in the horizontal structures of the communities. Because of the high projective coverage of the meadow species, the soil was almost completely covered by the canopy, and, thus, the LSWI showed water content of the plants, which was significantly affected by the amount of precipitation. The projective coverage on the steppe plot was no more than 55%, and, thus, the LSWI was largely determined by the water contained in the soil. It is well-known that water can be retained in the soil for a long time.

4. Conclusion
The modern approaches based on using satellite data have a number of considerable advantages over the ground-based methods. They can be used to study various aspects of vegetation. In order to create accurate vegetation maps, it is important to find out what level of detail is achievable in interpreting satellite images of vegetation and what approaches should be employed to make full use of the satellite data for vegetation mapping. The data on vegetation can be retrieved from the satellite image by analyzing the relationship between the biological/ecological parameters of plant communities and the spectral data. Based on the analysis of proportions of different spectral bands, spectral indices can be used to determine various morphological and ecological parameters of the vegetation cover over vast areas, and selective ground-based geobotanical observations provide a necessary basis for verifying satellite data.

The present study showed the relationship between vegetation parameters (species composition, projective coverage, aboveground phytomass) of the meadow and steppe communities studied using ground-based methods and the spectral indices, NDVI and LSWI, determined using MODIS data. The NDVI was higher for the meadow communities compared to the steppe ones. LSWI determined water contents of plants and soil, and, thus, the LSWI was higher for the steppe communities, which had low projective coverage and spots of bare soil.

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