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Special Aspects of the Use of Complex Phenological Index Method

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ABSTRACT This study considered the complex phenological indicators method, which allows to study geocomplexes at the facies level and take into account all life forms of vegetation. The studies have been carried out since 2011 on the constant phenocenters along the route that crosses the central part of the low mountain strip of the Middle Urals from west to east. Data analysis led the researchers to conclude that the method could be used to study low mountains at the level of landscape areas. Based on the analyses, it could be concluded that the results obtained by the SFP method are consistent with the generative and vegetative cycles of vegetation development. According to the findings, it is concluded that we can use the SFP method for landscape-phenological studies in the poorly studied territories with a rare network of weather stations, which can help the clarification of the boundaries of geocomplexes of various ranks.

INTRODUCTION

Landscape scientists often use phenological methods for the most complete description of geocomplexes (GC). For example, Isachenko (1973) believed that the characteristic of the seasonal dynamics of landscapes is an obligatory part of the physical and geographical characteristics of landscape geocomplexes of all kinds, because major structural features of landscapes and basic interrelations of their components are disclosed more fully due to these dynamics (Isachenko 1973). Based on a fundamental and applied perspective, the onset period of the phenological phenomena in wildlife is of great importance. Basically, the weather conditions determine the onset of phenological events for many species of plants and animals.

This means that with climate change in the timing of phenological event onset, systematic changes will occur and they will shift towards earlier or later dates. Therefore, in order to analyze the effects of climate change, it is necessary to detect shifts in the timing of phenological events within the life of plants and animals and predict them in connection with the future climate changes. However, at the current level of science development, the knowledge about the onset of phenological phenomena is applied in agriculture and forestry (Thackeray et al. 2016), climate research and meteorological changes (Baoquan 1996; Grebenyuk and Kuznetsova 2012; Khasanova 2014; Thackeray et al. 2016), landscape dynamics (Oribe and Kubo 1997; Chen et al. 2005; Khasanova 2014; Martínez-Lüscher et al. 2015; Yantser and Skok 2016; Liu et al. 2016), and plant biology and ecology (Bratkov et al. 2005).

In this regard, a special position is occupied by the Ural phenological school, whose representatives' use the methods that differ from the classical ones applied in the specially protected natural areas. Its founder is Vladimir Alekseevich Batmanov, who revised phenological research methods and developed a number of new ones. In particular, Yantser and Skok (2016) provided a detailed critical review of the methods.

Notably, the present study used a fairly accurate method of complex phenological indicators (CFI). It was comprehensively developed and tested by Terentyeva in the eastern foothills of the Middle Urals during 1997-2000 (Terentyeva 2000), Yantser and Skok in the midlands of the Northern Urals during 2001-2005, as well as Skok and Ivanova in the Middle Urals (Terentyeva 2000; Skok et al. 2014; Ivanova et al. 2019). It should be noted that the method was developed to identify the differences in the phenological development of vegetation at the level of lower-level geocomplexes – facies.

Objectives

This study aimed at studying the possible use of the method to compare the dynamics at the level of landscape areas of the Middle Ural-mountains - the geocomplexes of a higher rank.

METHODOLOGY

When the territory of the GC is studied by CFP method, the phenological state of all types of communities is determined by evaluating its accounting unit according to the standards. Observations are conducted at constant reference sites, and their size and shape depend on the terrain, the nature of the plant community, complexity of the vegetation cover, and other conditions. However, necessary indicators of the phenological area (PA) in the studies are its placement within the same facies and representation of all types of community. For the generative and vegetative cycles of vegetation development, there is own phenostandard, which is a set of phenophases successively replacing each other. In fact, each phenophase has a digital number (Yantser and Skok 2016).

For the vegetative cycle, the phenostandard consists of eight phenophases, and for the generative one, it contains nine phenophases. Then, the results of observations are recorded in the survey form. The research methodology by this method is described in detail by the works of E.Yu. Terentyeva (Terentyeva 2000; Skok et al. 2014; Yantser and Skok 2016; Ivanova et al. 2019). Here, the researchers focus only on the basic concepts. The summarized phenological characteristic (SPC) of the community vegetation reflects the phenological state of the facies on the day of observation. Moreover, the average phenological coefficient Kf is calculated for each SPC, which is the average score of the phenological state of the phytocenosis supplemented with a mean square error of ± m. In addition, the average phenological score is a phenological characteristic that takes into account the phenological state of all plant species of phytocenosis, but expressed in each process with only one number (Ivanova et al. 2019).

Graphically, the percentage ratio of species can be represented by a diagram, in which the sector corresponds to the percentage of species in a particular phenophase (Yantser and Skok 2016). Each development process (generative and vegetative) is characterized by its percentage ratio of species and its own diagram (Figs. 2 and 3). Kf and SPC are two necessary complementary complex phenological indicators of phytocenosis: Kf summarizes SPC and SPC “deciphers” Kf.

Actually, if a repeated survey of the geocomplex is performed the next year, then it will show the weather difference in the seasonal development of the phytocenosis on this particular day. Even such a one-time visit to the phenoarea will allow us to calculate the weather deviation of the seasonal development of the community annually that would be expressed in the points of the standard: F = Kf1 - Kf2. When you calculate F, it is possible to determine the degree of the obtained difference reliability (Yantser and Skok 2016).

Phenological observations using SPC method were carried out in the central part of the Middle Urals along the Serebryansky tract from the village of Verkhnyaya Oslyanka to the Serovsky tract. Actually, 75 km route was laid through a mountain strip from west to east, located within the Novaya Zemlya-Ural plain-mountainous country, and crossed four landscape macro-regions and 7 landscape regions in the latitudinal direction. In each of the landscape areas, PCs were identified. In fact, 2 PCs were laid in mountainous areas on the western and eastern slopes, which occupied a plateau-like position (Fig. 1). It should be mentioned climate of the research area is moderate transitional, with an average annual air temperature of +1.3 °C. The study area entirely falls into the subzone of southern taiga dark coniferous forests mainly with sod-podzolic soils.

Annual observations were carried out during the spring on the same dates, which fall on the last fourth phenological subseason of spring (IV C); that is, “blooming spring” (May 24 to June 6) according to the data obtained for the

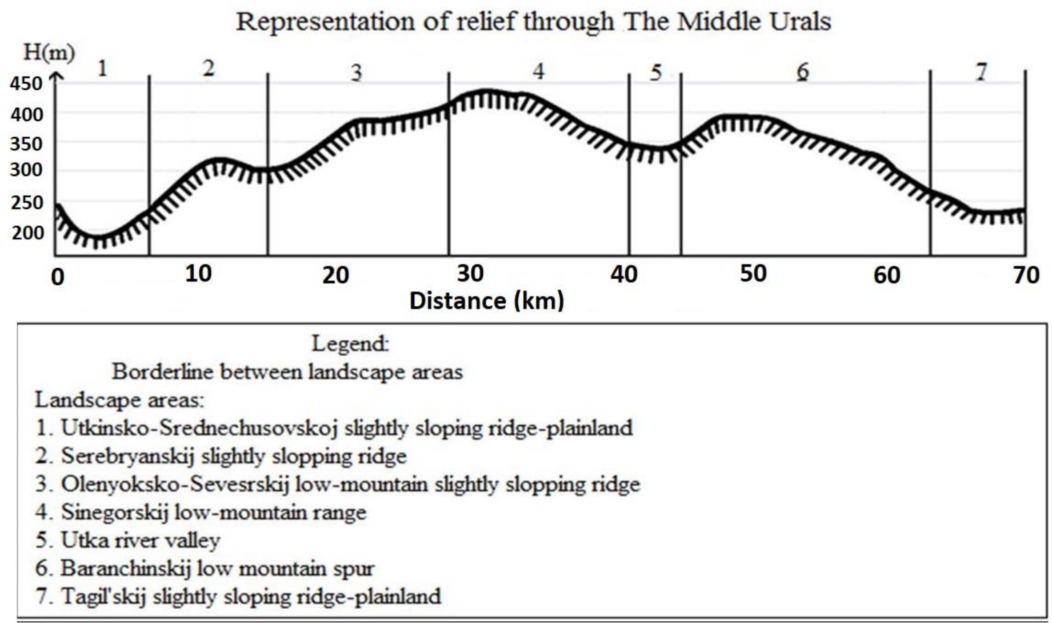

Fig. 1. The scheme of landscape areas of the studied route

environs of Yekaterinburg by Terentyeva. It lasts for about 14 days, Kfâ = 2.5 - 4.0 ± 0.5, and Kfg = 1.0 - 2.5 ± 0.5. Of course, indicators of the subseason start are the flowering of bird cherry and the spread of batfish (Terentyeva 2000).

During observation within the framework of the accounting PP (Purchase Processing), the phenological state of each type of community is determined by evaluating its accounting units according to the standard. The accounting unit of a species is usually an individual, or something that can replace it when observed: something indivisible, isolated, possessing all species attributes, but more easily observed. For example, batfish or ramets of clover creeping (Terentyeva 2000). If there are many leaves (flowers) on the accounting unit, then it is considered to have entered the next phase provided that at least a quarter of the accounting units have phase characteristics. Often, there are cases when the leaves (flowers) on the accounting unit are in three or more phenophases simultaneously. Therefore, some difficulties arise when they determine the phenophase of accounting units.

The researchers recorded the vegetation of the above plants from the first to the fifth phenophase in the first group of leaves. Here, the difficulty in isolation of fern and horsetail plant phenophases in accordance with the points of the standard should be noted. For *Pteridium aquilinum* (L.) Kuhn, *Athyrium filix-femina* (L.), *Matteuccia struthiopteris* (L.), *Dryopteris filix-mas* (L.), and *Gymnocarpium dryopteris* (L.) Newman, the researchers accepted the appearance of the "snail" leaf, the beginning of the "snail" deployment, the beginning of leaf unfolding, significant unfolding, and complete unfolding of the twisted leaf as the phenophases corresponding to 1-5 points of vegetative development standard. For the vegetation of *Equisetum sylvaticum* L. and *Equisetum arvense* L., the appearance of a pale brownish stalk with a spore-bearing spikelet is accepted for phenophase 2, and 5 for the complete formation of a green plant. However, for the generative development cycle, the researchers adopted the following ratio: for fern-shaped, the appearance, and mass appearance of sporangia on the lower part of the leaf correspond to the phenophase 3 and 4, 8 - maturation of spores (their falling off when the leaf is shaken, its browning or yellowing). In addition, Phenophase 2 of *Equisetum sylvaticum* L. and *Equisetum arvense* L. were noted by "dusting" (dispersion of spores). The standard 4 score for *Equisetum sylvaticum* L. is represented by the death of a stem with a spore-bearing spikelet after dispersion of spores, and for *Equisetum arvense* L., the appearance of green branches on a spore-bearing stem, while a score 7 for *Equisetum sylvaticum* L., is represented by the appearance of a green branched stem (Beydeman 1974).

Upon the determination of the phenological state of individual accounting units, the phenological state of the species is determined as a whole. At the time of observation, accounting units of the same type can be in different phenophases. However, of all the phenophases noted, it is necessary to choose the main one, which is the characteristic of the whole species. It is notable that there are different opinions about the period of introduction of a particular phase for a species among various researchers. In fact, the appearance of the first accounting units entering the phenophase can greatly accelerate the onset of this phenophase in the entire species as a whole.

In addition, the term of entry into the phenophase of the first accounting units in a cenopopulation is dependent on the total number of the accounting units for this cenopopulation. Actually, the process of the introduction of the species accounting unit into the phenological phase is subject to the law of normal distribution and is characterized by a cumulative curve, the interquartile region of which (25-75%) is the most informative part. Therefore, during observation, the researchers take the threshold of twenty-five percent as the beginning of the phase and consider the species to have entered the phenophase if a quarter or more of its accounting units have the phase characteristics.

This moment characterizes the beginning of the mass development of phenophase, and to a certain extent causes the avoidance of the influence of individual variability on the observation results. Thus, if PP of *Vaccinium vitis-idaea* L. is noted for individuals during the phases of bud swelling and nibbling, then the nibbling phase of the buds will be considered the main one, provided that twenty-five percent or more of the buds have already opened. In this case, at the time of observation, *Vaccinium vitis-idaea* L. is considered to have entered the phase of bud opening. Otherwise, lingonberry is still in the phase of bud swelling, and thus this phase should be regarded as the main one.

RESULTS AND DISCUSSION

Based on the data obtained from the field studies in 2011-2017, the researchers calculated the mean long-term Kfg and Kfb supplemented by the standard error (± m) and SFP diagrams were developed (Table 1, Figs. 2, 3).

Table 1: The average seven-year values of phenological coefficient for landscape areas

Landscape area	$Kf_{(v)}$ *±m*	$Kf_{(g)}$ *±m*
Utkinsko-Srednechusovskoj	2.4±0.2	1.7±0.4
Serebryanskij	2.7±0.2	1.8±0.4
Olenyoksko-Sevesrskij	2.6±0.2	1.7±0.4
Sinegorskij	2.9±0.1	1.7±0.3
Utka river valley	2.5±0.2	1.7±0.3
Baranchinskij	2.8±0.1	1.8±0.3
Tagil'skij	3.0±0.2	2.4±0.4
Average value	2.7±0.2	1.8±0.4

According to the analysis of the average seven-year coefficients of the generative development cycle, Kfcp = 1.8 ± 0.4 points. As seen, with significant advances, vegetation develops takes place in the Tagil bumpy-plain region (Kf = 2.4 ± 0.4). Therefore, by considering the significant standard errors and close to or equal to the average for the Kf profile, the researchers could not compare the generative development of vegetation based on Kf only.

Utkinsky-Srednechusovskoy, Oleneksko-Seversky, and the Utkin depression regions have the same Kf (1.7 ± 0.4); however, their SPC ratio has significant differences. In the Oleneksko-Seversky landscape region, more than half of the species are in the resting phase, and in the Utkin depression region, with the smallest proportion of the same phenophase, the species in the phase of "distribution of fruits and seeds" are completely absent. However, the largest percentage of the species in the budding phases was noted in the Utkin-Srednechusovsky landscape region (23%), in the flowering phases

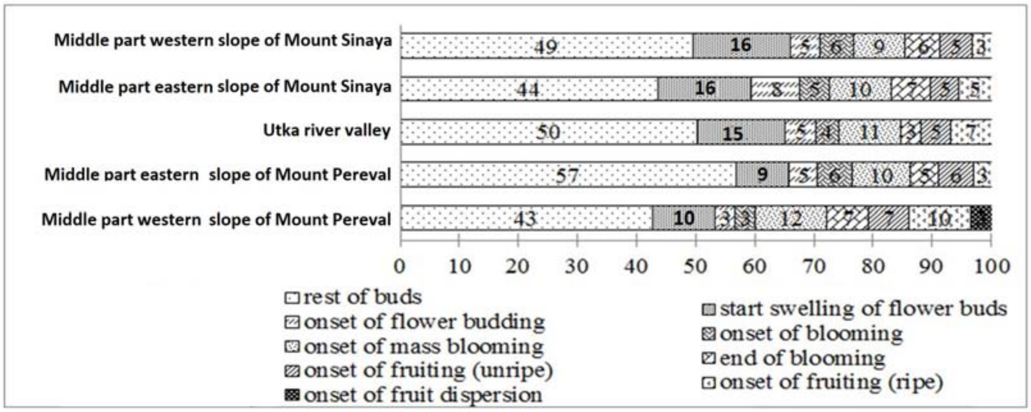

Fig. 2. The long-term averages of CPI of vegetation process in landscape areas

(22%), and in the region of the Utkin depression. Moreover, Serebryansky and Baranchinsky districts with Kfã = Kfñð have a different percentage of phonophobes (Ivanova et al. 2019).

The CPP diagram allows indirect judgment of the physical and geographical characteristics and species composition of the landscape areas (Kühne 2018). Of course, the percentage of the species found in earlier phenophases of the generative development decreases when moving from the central part of the mountain strip to the foothills (Fig. 2). In addition, the CPP diagram visualizes the differences in the development of vegetation in mountainous regions on the slopes of the western and eastern expositions and in intermountain depression (Fig. 3).

Based on the ratios of the slope phenophases of both Siney and Pereval cities, it could be concluded that the western windward slopes are significantly delayed relative to the warmer eastern ones. However, the coefficient of the Utkinskaya depression region is somewhat overestimated due to the peculiarities of the species composition of vegetation on PP, including proportion of the primroses, early flowering spring plants, and high shallow grass, which is ex-

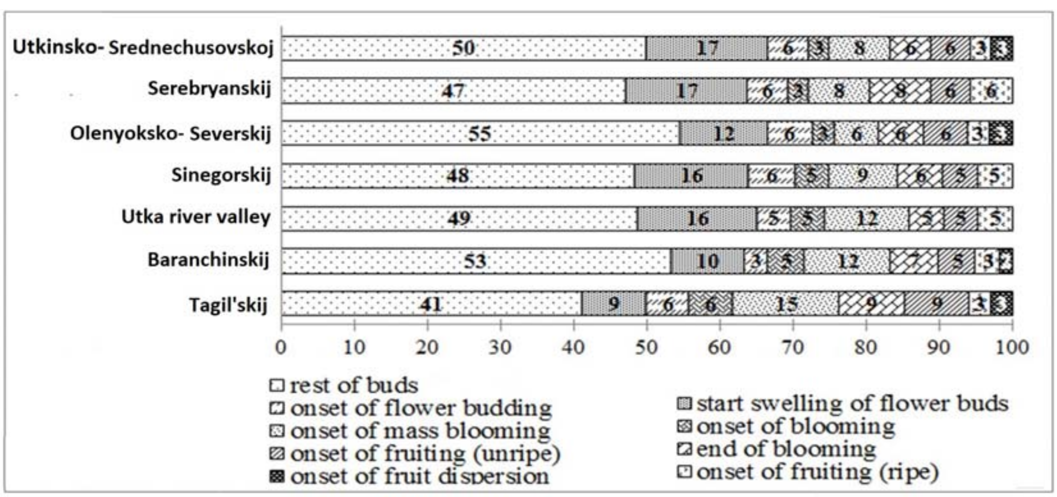

Fig. 3. The long-term averages of CPI of generation process in landscape areas

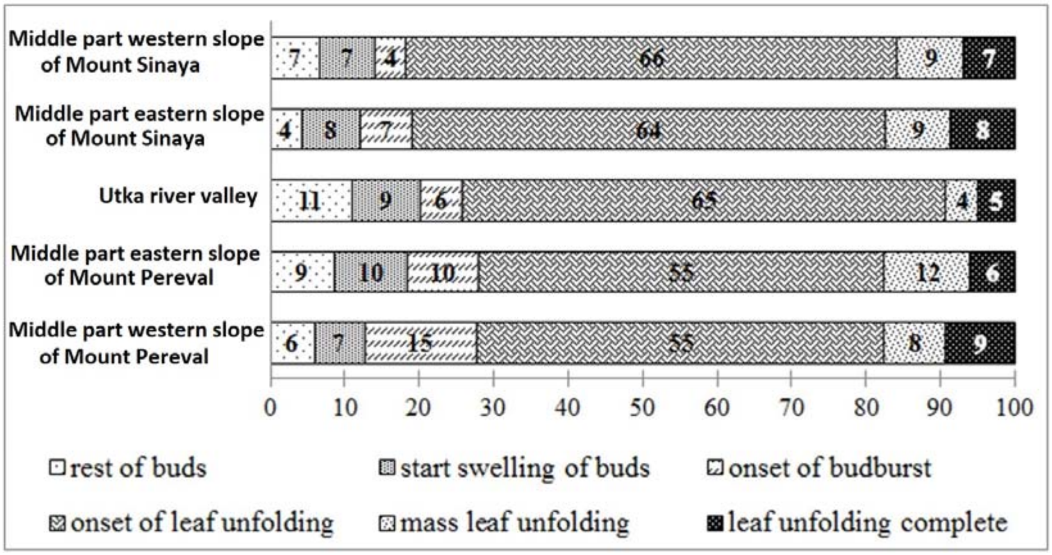

Fig. 4. The long-term averages of CPI of vegetation process in landscape areas

pressed as a significant percentage of species that are in the phase of setting, ripening, and distributing fruits and seeds (Herbertsson et al. 2018).

The vegetative cycle of the vegetation development on the studied area is characterized by Kfcp = 2.7 ± 0.1 points, which corresponds to the "leaf growth" phenophase. According to the CPI diagram (Fig. 4), the plant assimilation apparatus develops with the greatest advancement in the extreme eastern Tagil bump-plain region (Kfâ = 3.0 ± 0.2). Moreover, the Sinegorsky low-mountain range region is slightly ahead of the average value for the profile. In addition, the maximum delays of the vegetative development are noted in Chusovskaya and Utkinskaya depression, Kfâ = 2.4 ± 0.2 and Kfâ = 2.5 ± 0.2, respectively.

Since the phenological coefficient is not an independent characteristic of phytocenosis development, it is necessary to analyze the ratio of SFP for each PP. For example, Tagil bump-plain region, which is characterized by the highest Kfâ value, has only three percent of the species during winter dormancy, most species are in phase 3, and the largest proportion of the species with the score of 4 accounts for twelve percent (Martínez-Lüscher et al. 2015). Depressions, along with minimal Kfâ, are characterized by the highest percentage of species at rest. For a more accurate understanding of the causes accelerating the average Kfâ and SFPs of the Sinegorsky and Baranchinsky districts, it is crucial to depict a CPI diagram for all PPs in the central part of the mountain band (Fig. 5).

The same tendencies are found for the SFP vegetation and generative cycle on the western slopes. It was found that the proportion of species in the phases of "dormancy", "beginning of fruiting", and "ripening of fruit" is greater than on the eastern ones (Yantser and Skok 2016). However, the eastern slopes, in turn, have a higher percentage of species during the "summer vegetation" phase.

CONCLUSION

Based on the analyses, it could be concluded that the results obtained by the SFP method are consistent with the generative and vegetative cycles of vegetation development. In fact, the generative cycle is characterized by a large scale and higher values of dispersion, standard deviation, and standard error as compared with the SFP of the vegetative cycle. In this regard, the indicators of the generative cycle further re-

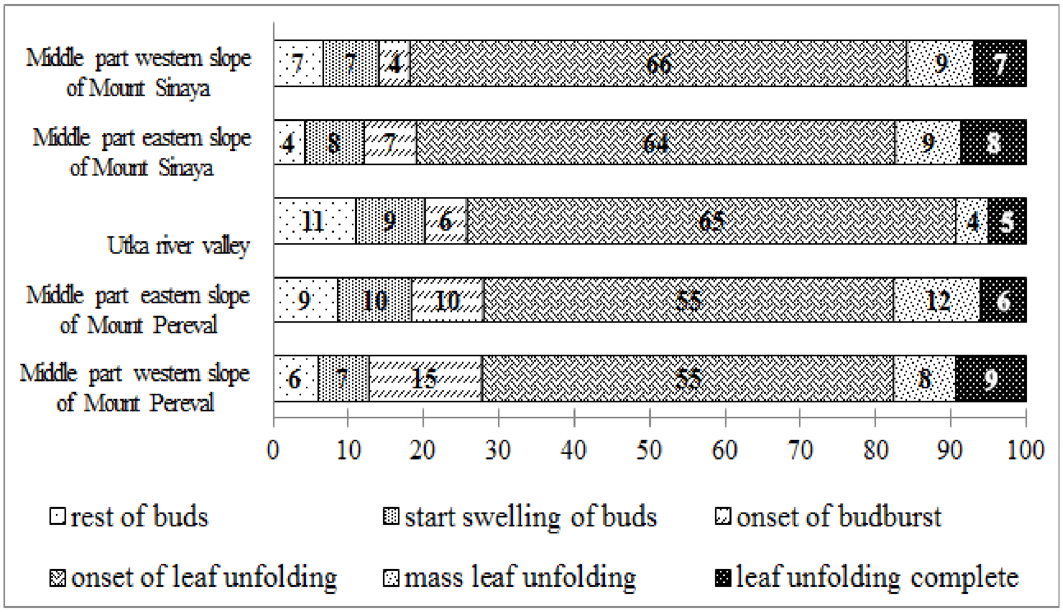

Fig. 5. The long-term averages of CPI of vegetation process in landscape areas of mountain reach

flect differences in the species composition of the vegetation than vegetative cycle, which demonstrate differences in the physical and geographical characteristics of the studied landscape areas more clearly.

According to the findings, it is concluded that we can use the SFP method for landscape-phenological studies in the poorly studied territories with a rare network of weather stations, which can help the clarification of the boundaries of geocomplexes of various ranks. The method, which has been previously tested in the midlands of the Northern Urals, exhibited its efficiency in the low mountains of the Middle Urals. Actually, its features make it possible to express a large data set in a compressed digital form and reduce the frequency of observations, up to one-time visits, which is extremely important for remote areas. Finally, the indisputable advantage of the method is that it allows us to characterize the phenological state of all plant life forms at any time convenient for the researcher.

RECOMMENDATIONS

In the light of this issue and its comprehensiveness, it is recommended that future studies address this issue with respect to the high mountains and all mountains in Russia.

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