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INFLUENCE OF LANDSCAPE DIVERSITY ON TEMPORAL VARIABILITY OF ECOSYSTEM FUNCTIONING IN THE SOUTH OF WESTERN SIBERIA

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Abstract

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Biodiversity increases the stability of ecosystem functioning. This is the most frequent pattern in the field of ecosystem functioning, which has been evaluated generally at the community scale. However, most management decisions are made at the landscape scale, which requires the need to confirm these relationships at this level. In the study, we analyzed the relationship between temporal variability of ecosystem functioning and two landscape diversity indices (Shannon and Pielou). We used snow water equivalent and soil moisture content as the indicators of functioning, which are closely related to the runoff formation function. The field data were collected in a small plain basin of the Kasmala river during the period from 2011 to 2017. Within four spatial scales, we have not identified significant linear relationships between the indicators of functioning and diversity indices. These results indicated the strong influence on the total variability by variation in the most widespread ecosystem types (also called idiosyncratic response). It is one of the consequences of landscape structure homogenization within the study area.

Key words: landscape scale, diversity, ecosystem functioning, water, Siberia.

Introduction

It is found today that biodiversity enhances the stability of ecosystem functioning and the provision of ecosystem services (Cardinale et al., 2012; Isbell et al., 2011; McCallum, 2015). Therefore, the loss of diversity is one of the most important environmental problems on a global scale (Butchart et al., 2010; Oliver et al., 2015; Waldron et al., 2017). Biodiversity may influence the response of ecosystem functioning to external agents of variability and, as a result, it may confer stability, that is, the relative constancy of ecosystem properties after the variation of external agents (Cottingham et al., 2001; Hooper et al., 2005; Ives, Carpenter, 2007; Marcinkonis et al., 2015; McCann, 2000; Tilman et al., 2014; Turnbull et al., 2016).

Most of the studies have considered diversity at the level of communities; therefore, the number of species is often used as an indicator of diversity (Bukvareva, 2018; Noss, 1990). However, most management decisions are made at the landscape level and verification of diversity–stability relationship on the landscape scale has become extremely important (Walz, Syrbe, 2018). Consequently, scaling these patterns and searching for appropriate indicators are significant research problems (Loreau et al., 2001; Wang, Loreau, 2016). In their study, Aragón et al. (2011) found that fundamentally similar mechanisms in the diversity–stability system can act on the landscape scale. These are insurance hypothesis, statistical averaging, and idiosyncratic response. However, the intensity of each mechanism varies depending on the landscape properties.

Stability is measured as the opposite of temporal variability of ecosystem functioning. Productivity indicators (biomass, greenness, Normalized Difference Vegetation Index, etc.) are most often used as indicators of functioning, which are strongly related to seasonal variation of environmental fluctuations (Knapp, Smith, 2001; Paruelo, Lauenroth, 1998; Pennington, Collins, 2007; Wen et al., 2017; Yang et al., 2008). However, ecosystems are multifunctional systems (Hector, Bagchi, 2007; Pasari et al., 2013). The behavior of many ecosystem functions in the context of the "diversity–stability" pattern remains insufficiently studied.

In this study, we analyzed the relationship between diversity and temporal variability of ecosystem functioning indicators at the landscape level. As the indicators characterizing the ecosystem's functioning, we used two variables that are closely related to the runoff formation function – snow water equivalent (SWE) and soil moisture content (SM). These indicators are closely connected with environmental fluctuations, highly variable at the landscape scale, and are available for field observations. We also used the Shannon diversity (H) and Pielou evenness (J) indices as indicators of landscape diversity.

Material and methods

We conducted the research in the 1768.7 km^2 Kasmala river basin, Altai Krai. The study area belongs to the West Siberian forest steppe ecoregion (Dinerstein et al., 2017). There are two main landscape types: slight slopes of the ouvals (flat ridges with 1°–3° slopes) and the bottom of the ancient flow gully. The ouval slopes are occupied by arable land. Long stripes of pine forests (*Pinus sylvestris*) dominate in the ancient flow gully (in Russian – *lentochnye bory*). The complexity of the landscape structure makes this area very difficult to study and manage. There are many divergent trends in recent land use and land cover changes (Chernykh et al., 2018).

We conducted field observations in 2011–2014 and 2017. These years were very different in precipitation (302–509 mm). The 3-month standardized precipitation index (SPI) varied from –2.8 to 2.1. Snow cover observations were carried out in March before the melting period. We made about 600 snow depth measurements with a 20-m interval and Global Positioning System (GPS) referencing. We measured snow density at 100–200 m intervals and then quantified SWE values. SM data were collected at 24 plots (20×20 m) in July, with reference to the ecosystem type. A gravimetric sampling was made from 1-m pits. Observations in July, before August drought, helped to identify interannual variability and the impact of different landscape properties on soil moisture variability (Lookingbill, Urban, 2004). As an inverse indicator of stability, we quantified the interannual coefficient of SWE and SM variation (CV) for each of our observation points.

The landscape diversity indices were calculated using the land cover map, based on LANDSAT images classification (Biryukov, 2013). We used *r. diversity* algorithm proposed for GRASS GIS (Bacaro et al., 2012). This method uses the moving window technique to calculate the index value. We calculated the values for 3, –5, –7, and 9-grain sizes. In our opinion, the limit of 9 pixels or 270 m (taking into account the resolution of LANDSAT images) is optimal, having regard to the scale of data collection.

With the current knowledge of diversity–stability relationship, the searched patterns were expected to be linear. At the first stage, we tested our data for normality. In the case of significant deviations from normality, we used Spearman's rank correlation to detect probable relationships. If the data allowed us to apply the linear methods, we expected to use linear regression to assess the relationship between CV and the landscape diversity indices. The analyses were carried out with Statistics 10.

Results

While the distribution of SM and SWE CVs was close to a theoretical normal distribution (Kolmogorov–Smirnov and Shapiro–Wilk tests), the distribution of landscape diversity indices was very asymmetrical, with gaps in frequencies. The major part of the observed points with small cell size (3×3 and 5×5 pixels) had zero values of H and J indices (Figs 1, 2). Otherwise, they were in a completely homogeneous neighborhood. Such distribution of data did not allow us to use the parametric methods to the full extent.

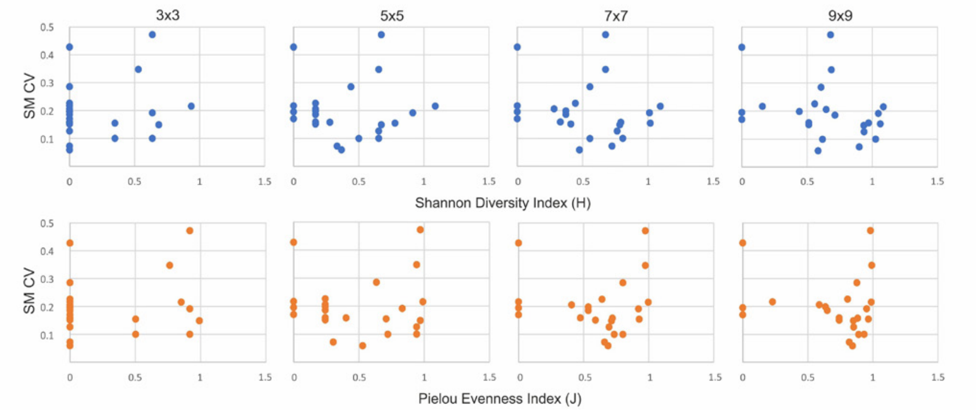

Fig. 1. Relationship between the temporal variability of SM (SM CV) and Shannon Diversity (H)/Pielou Evenness (J) indices. Notes: CV – coefficient of variation; SM – soil moisture content.

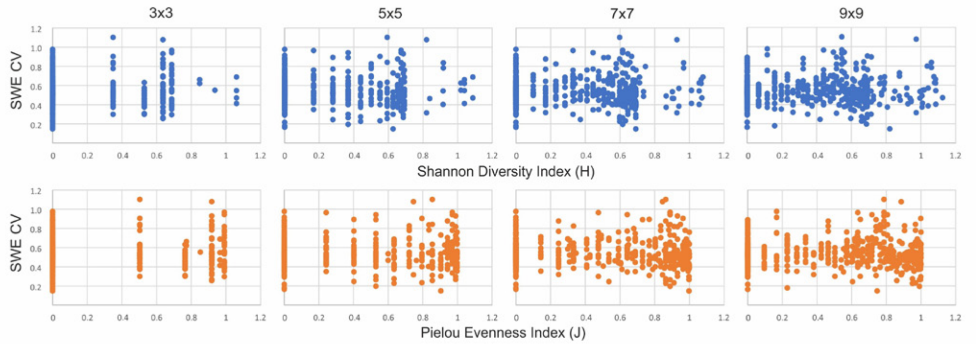

Fig. 2. Relationship between the temporal variability of SWE (SWE CV) and Shannon Diversity (H)/Pielou Evenness (J) indices. Notes: CV – coefficient of variation; SWE – snow water equivalent.

The larger grain size points had more non-zero values; however, the distribution was rather nonuniform at all scale levels and for both indicators. At some scales, we could notice the areas where the concentration of values was similar to linear patterns (Fig. 2). But, in our opinion, this was not systematic. The differences in data distribution between H and J indices were visible mainly for SM variability. At a higher scale, J values were more concentrated. However, high J values corresponded to both large and small SM CV values.

The distribution of SWE CV is primarily similar for all scale levels and for both diversity indicators. The values at large scales were concentrated at certain values of H and J, which reflected the specific characteristics of boundaries between the patches. At higher scale levels (7×7/9×9), the distribution became more equable and diffused across the entire plane (Fig. 2). Also, there were a lot of points concentrated near zero diversity value.

In general, we did not find any statistically significant linear relationships between variability indicators and diversity indices. The data structure gave clear representation of such a result. Testing the relationships between functioning variability and landscape diversity with Spearman's rank correlation also showed no statistically significant relationships.

Dividing the data set into variability by individual land cover types showed that the values could be distributed over a very wide range of diversity index values. We did not have enough

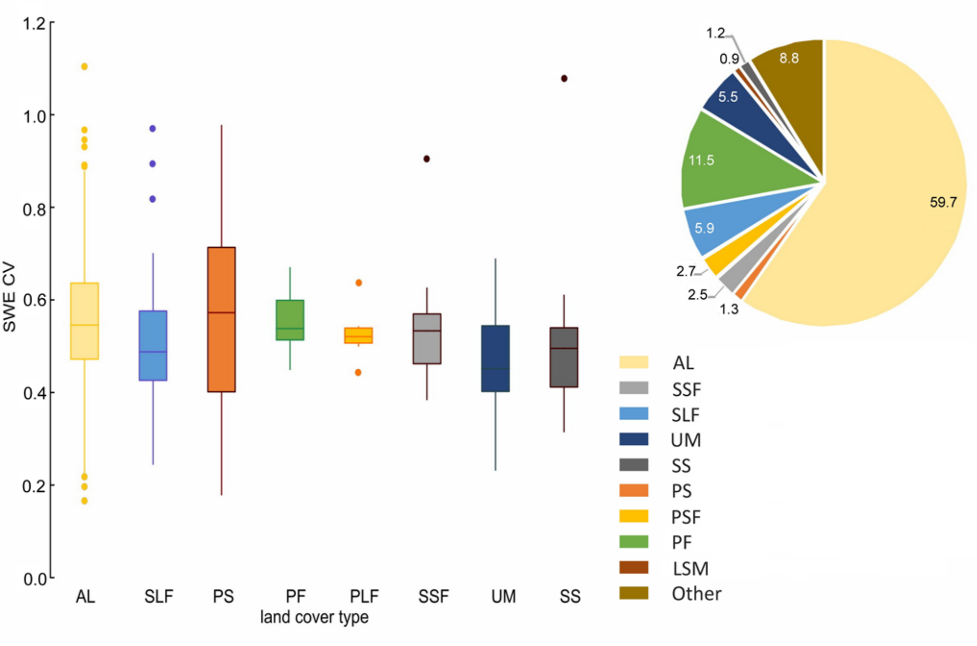

Fig. 3. Temporal variability of SWE (SWE CV, left) within land cover types and percentage of the study area (right). Notes: AL – agricultural land; CV – coefficient of variation; LSM – lowland swamp meadow; PF – pine forest; PS – psammophytic steppe and meadow; PSF – pine-small-leaved forest; SLF – small-leaved forest; SS – solonetz–solonchak; SSF – swamp small-leaved forest; SWE – small-leaved forests; UM – upland meadow.

data to assess the contribution of various types of land cover to the variability of SM, but it was possible for SWE. The most widespread land cover type, agricultural land (almost 60% of the area), made the largest contribution to SWE variability (Fig. 3). Small-leaved forests, psammophytic steppes and meadows, occupying more than 7% in total, also had very high average values of CV. Pine forests, occupying 11.5%, on the contrary, had very low average variability and could potentially play a stabilizing role due to statistical averaging effect. Pine forests were spatially combined with psammophytic steppes, where variability was very high.

Discussion

The results did not allow us to find a statistically significant relationship between ecosystem functioning indicators and landscape diversity indices. However, in this study, we explored only linear relationships. In our opinion, the response of ecosystems to environmental fluctuations in any case is associated with the existing mechanisms in the diversity–stability system.

Several studies have shown that the idiosyncratic response (dominating influence of the strongest factor) may also have a negative effect on the stability of ecosystem functioning (Aragón et al., 2011; Scherer-Lorenzen et al., 2003). In our case, the primary influence on SWE variability is formed by the agricultural lands (dominant type). Homogenization is expected to be one of the most dangerous factors affecting sustainable ecosystem functioning and landscape multifunctionality, requiring decisions on a landscape scale (Gámez-Virués et al., 2015). Taking into consideration that agricultural land is substantially homogenized, it may threaten the stability of territory functioning. We cannot uniquely identify the idiosyncratic effect in case of SM variability due to the lack of data. However, our previous studies (Chernykh et al., 2014) showed that SM variability within agricultural lands and small-leaf forests was sufficiently low (CV 0.06–0.22). Thus, the idiosyncratic factor may potentially affect various ecosystem processes in different ways.

Another significant aspect is the influence of local factors. We used the field observation data, which significantly depended on the influence of local topography, soil properties, and so on. SWE variability was greatly influenced by artificial wood lines separating croplands. Potentially, they should have a stabilizing effect, protecting snow from wind drift. However, in particular observations, it might become an additional variability factor, which we tried to exclude when choosing the surveys. At the same time, wood lines were a local factor of landscape structure heterogeneity, which could not be estimated using LANDSAT images.

Conclusion

Diversity is considered as a factor contributing to the stability of ecosystem functioning. However, we have not identified significant linear relationship between the interannual variability of SWE, SM, and particular landscape diversity indices. We have not observed such a pattern at four scales. We assumed that the lack of simple linear relationship was due to the strong influence of the most widespread ecosystem types on the total variability (also called idiosyncratic response). Besides, these ecosystems are quite homogeneous in their structure.

Taking into account that the analysis used primary field data, the influence of local topography factors could also affect the functioning indicators' variability.

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