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N. Tephnadze-Hoernchen, Z. Kikvidze, G. Nakhutsrishvili & O. Abdaladze

Subalpine vegetation along the soil moisture gradient under the climate change conditions: re-visitation approach (the Central Great Caucasus)

Abstract

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Global climate change impacts the phytodiversity and plant distribution. Plant species migration to newly favourable areas is already observable in many parts of the world. Though, the effect of global climate change on plant diversity and distribution along the soil moisture gradient is little studied. Thus, we compared historical and newly collected vegetation data, and we asked: 1) have species richness and species composition of vascular plants changed over the last >30 years along the soil moisture gradient? 2) Do global climate change induces the changes in plant species certain ecological characteristics? 3) Is plant species migration observable from dry to wet plant communities? We resampled study sites in the Kazbegi region, recorded >30 years ago. The hierarchical clustering, Principal Component Analysis and Sørensen index, as well as Landolt indicator values revealed the high similarity between historical and recent relevés. The comparison of species richness showed a significant increase of species richness in a recent data for wet and dry plant communities. Species migration wasn't observed. In conclusion, the increase of species richness is most likely to be governed by land-use activities rather than by Global climate change.

Key words: Global climate change, Caucasus, Alpine plants, Cluster analysis, Landolt indicator values, Species richness.

Introduction

Global climate change driven by natural causes and human activities is considered as one of the most urgent problem of nowadays (Stern 2008; IPCC 2013). The consequences are already observable. The recent report of the Intergovernmental Panel on Climate Change (IPCC) states an average temperature rise on Earth by 0.7°C since the beginning of industrialisation (IPCC 2013). Species migration from increasingly hostile locations to newly favourable areas takes a place in many parts of the world (Gottfried & al. 1994; Grabherr & al. 1994, 1995, 1999; Pauli & al. 1996, 1997; Thuiller & al. 2005; Gigauri & al. 2011, 2013, 2014; Pauli & al. 2012; Abdaladze & al. 2015) and result in biodiversity loss, habitat degradation and landscape modifications (Körner 2003). Such changes can alter the key role of ecosystems in regulating climate, soil, water and air quality (Millennium Ecosystem Assessment 2005; Smith & al. 2012).

According to the United Nations Framework Convention on Climate Change (UNFCCC) the Earth's climate system is recognized as a shared resource. Thus, scientific attention has focused on biodiversity and associated ecosystems' functioning in relation to climate change at different spatial and temporal scales (Parmesan 2006; Bellard & al. 2012). Among them lots of studies concentrate on high mountain ecosystems because they are considered as particularly vulnerable to climate change, as montane species has narrow geographic and climatic ranges with limited dispersal opportunities (Beniston 1994; Guisan & al. 1995; Aeschimann & Guisan 1995; Beniston & al. 1996; Kienast & al. 1998; Cebon & al. 1998; Theurillat & al. 1998). In addition, the alpine environments with their topographic diversity and rapid shifts in environmental gradients provide an excellent opportunity for complex studies. For further research initiatives are required international and interdisciplinary cooperation (Becker & Bugmann 1997; Pauli & al. 1999), as well as long-term monitoring to establish an effective early warning system (Pauli & al. 2003).

Global climate change in different parts of the world reveals different character. It depends on the features of physical-geographical and landscape-climatic conditions (IPCC 1990, 1996). The Caucasus region - a Global 200 Ecoregion and biodiversity hotspot (Biodiversity assessment for Georgia 2000) already shows climate induced changes (Sylvén & al. 2008). In Georgia already has been observed increasing temperatures and decreasing annual precipitations. The largest decrease in precipitation trend is characteristic for the Great Caucasus - 9 mm per year (Elisbarashvili & al. 2017). Furthermore, it is expected an increase in temperature of 4.1°C and a decrease in precipitation of 14% by the end of the century (World Bank 2012). Many species with specialised habitat requirements will likely to decline, especially those linked to moist / very moist habitats (Sylvén & al. 2008).

In order to protect important alpine resources and key species, it is a necessary to have a clear understanding of climate change effects on the alpine community and ecosystem processes. Since climate does not change rapidly over a short period a long-term monitoring is preferable. Thus, can be effectively assessed and predicted the effects of climate change on the biodiversity of mountain habitats (Pauli & al. 2003, 2012; Stöcklin & al. 2011; Matteodo & al. 2013). Obviously, such long-term research deserves attention.

In this work, we performed a re-visitation study using historical and newly collected vegetation data to find out how the biodiversity changed in relation with global climate change during the last >30 years.

The main aim of this paper is to analyse species diversity and distribution in the Central Great Caucasus along the soil moisture gradient from very moist to dry plant communities, and thus, to find similarity/dissimilarity between the historical and current data.

We addressed the following questions: 1) how species richness and species composition of vascular plants have changed over the last >30 years along the soil moisture gradient? 2) Do plant certain ecological characteristics (Landolt indicator values, Landolt 1977; Landolt & al. 2010) experience changes induced via the global climate change? 3) Have plant species migrated from dry to wet plant communities?

Materials and methods

Kazbegi region is located in the valley of the river Tergi. The valley belongs to the north part of the main watershed of the Central Great Caucasus Mountains. It is characterised by a complex geomorphology and the harsh climate changes along the elevational gradient from 1210 to 5033 m a.s.l. In the subalpine zone (1700-2400 m a.s.l.) the mean annual air temperature is 4.7°C and the mean annual precipitation is 765.2 mm. The snow cover of 20-40 cm depth persists for 3-5 months (Nakhutsrishvili & al. 2005; Abdaladze & al. 2015). The vegetation of subalpine zone is most complex among all altitudinal zones of the Kazbegi region (Nakhutsrishvili & al. 2005, 2006; Gigauri & al. 2013; Nakhutsrishvili & Abdaladze 2017a).

Our study was conducted between 1740-2000 m a.s.l. From historical (1986) data were available the following six plant communities sampled by Nakhutsrishvili G. along the soil moisture gradient:

Deschampsietum (1800 m a.s.l.): - belongs to a well moistened (27.6 ±2.3%) habitats dominated by: *Deschampsia caespitsa*, *Equisetum palustre* and *Phragmites australis* (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b). This site is not disturbed by any human activities;

Hordeetum (1850 m): is located a bit higher than the previous study site. In this plant community soil water content is 21.9±3.7%. Here the dominant species are: *Hordeum violaceum*, *Festuca pratensis*, *Ranunculus elegans*, *Trifolium repens* (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b). Hordeetum is located in the fenced area and represents a typical hay meadow (ones per year);

Festucetum NW (1950 m): located at North-West exposed slope belongs to moist habitats. The soil water availability (21±3.5%) is almost the same as Hordeetum. This plant community is characterised by a large bunches of *Festuca varia*. Other dominant species are: *Carex meinshauseniana*, *Polygonum carneum* and *Ranunculus oreophilus* (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b). This site is also used for hay-making (ones per year);

Festucetum SW (1940 m): almost the same location as Festucetum NW, but the slope is exposed to SW. This site is dryer (18.8±2.1 %). Such species as *Bromopsis variegata*, *Alchemilla sericata,* and *Polygonum carneum* are dominants together with *Festuca varia*. Festucetum SW is grazed mainly by horses, but very rarely (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b);

Pulsatilletum (2002 m): occupies Northern slopes with soil moisture of 15.3±4 % and dominated by *Pulsatilla violacea*, *Festuca ovina*, *Ranunculus oreophilus*, etc. These communities are intensively grazed by cattle (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b);

Astragaletum (1740 m a.s.l.): occupies the driest (8.5±3.2 %) slopes exposed to South-East. This thorn tragacanthic community is dominated by *Astragalus denudatus*, *A. captiosus*, *A. kasbeki*, *Antenaria caucasica*, and *Festuca valesiaca* (Nakhutsrishvili 2013; Nakhutsrishvili & Abdaladze 2017b). No human activities are observed during the past 40 years.

In July 2016 we resampled the same sites (25m^2 each relevé) with the same phytosociological approach using the Braun-Blanquet cover scale (Braun-Blanquet 1964). For taxonomic reference were used Sakhokia and Khutsishvili (1975). In the field were measured the following environmental variables: slope inclination in degrees (using a compass clinometer

- Recta DP 6, Switzerland), altitude (m a.s.l.), geographical coordinates and exposition were measured with a *Garmin GPS* device. Soil moisture logger (Fieldscout TDR 100, Spectrum Technologies, Inc., USA) were used under the dry weather conditions (no rain 4 days before) to measure soil moisture values (%, Table 1).

In total were analysed the data matrix of 176 species X 6 relevés from the 2016 year data and of the historical data – 144 species X 6 relevés. Prior to the statistical analysis, we transformed original Braun-Blanquet cover scale to ordinal values (van der Maarel 1979), and species with less than two occurrences across all plots were excluded to avoid statistical noise (McCune & Mefford 1999).

In a first step, we performed hierarchical clustering with a group average linkage method and Sorensen (Bray-Curtis) distance measure to detect groups of closely related plant communities. To analyse the effects of environmental variables on species composition were performed Principal Component Analysis (PCA). The Sørensen index (Eq. 1) was used to reveal the similarity between the historical and the recent data in terms of species composition.

$$S_S = 2a / (2a + b + c) \qquad (1)$$

Where:
Ss = the Sørensen similarity coefficient,
a = number of species common to both plots,
b = number of species unique to the first plot, and
c = number of species unique to the second plot

In addition, we calculated averages of Landolt indicator values to measure ecological features for each site and the given years. Such an approach has been shown by many authors (Schwabe & al. 2007; Thimonier & al. 2011; Evangelista & al. 2016; Matteodo & al. 2016). We have used the following indicator values: F – Moisture, R – Reaction, N – Nitrogen, L – Light, T – Temperature. Each of these Landolt indices is expressed as a range of values from 1 to 5 (Landolt 1977; Landolt & al. 2010). Plant species as bio-indicators of the environment (Diekmann 2003) can show how the ecological conditions vary along the spatial (the given

Table 1. Characteristics of the selected phytosociological relevés in the Central Great Caucasus, Kazbegi region, Georgia.

	Altitude m a.s.l.	Aspect	Slope°	Soil moisture (%, 2016)	Species richness (1986 & 2016)
Deschampsietum	1800	SW	2	27.6 ± 2.3	46
Hordeetum	1850	W	8	21.9 ± 3.7	43
Festucetum NW	1950	NW	12	21 ± 3.5	48
Festucetum SW	1940	SW	34	18.8 ± 2.1	24
Pulsatilletum	2002	SW	34	15.3 ± 4	31
Astragaletum	1740	SE	35	8.5 ± 3.2	33

six plant communities) and temporal (1986 and 2016 years) gradients. All Statistical analyses were performed with PcOrd 5.33 (McCune & Mefford 2006).

Results

Species composition, richness and similarity index

The hierarchical clustering in both cases (data of 1986 and 2016) results in three groups. It merges the similar plant communities in terms of soil moisture. In the first one were grouped most wet plant communities: Deschampsietum and Hordeetum. Moderately wet and dry communities like Festucetum NW, Festucetum SW, and Pulsatilletum are grouped together. The driest community - Astragaletum belongs to the third group (Fig. 1).

The PCA revealed differences in the floristic composition of the given plant communities at a spatial scale. The relevés are ordered on axis 1 following the soil moisture gradient from Deschampsietum to Hordeetum, followed by Festucetum NW, Festucetum SW and Pulsatilletum to Astragaletum. The first two axes of PCA explain 53% of the total variance (Axis1: 29%, Axis2: 24%, Fig. 2). Slope inclination is significantly correlated to the first axis, while altitude is significantly correlated to the second axis. The PCA also shows that historical and recent relevés are quite similar in terms of species composition (Fig. 2).

The analysis of the Sørensen index proves the results of hierarchical clustering and PCA. It reveals the high similarity between historical and recent relevés of six plant communities. The most similar are Deschampsietum (82%), Hordeetum (86%), Festucetum NW (87%), and Astragaletum (81%). While Festucetum SW and Pulsatilletum are less similar (68% and 64%, respectively; Fig. 3).

The average species richness in the historical plots was 38, ranging from 24 to 48 species per 25 m². In the recent data, the average number of species was 52, ranging from 41 to 58 species.

The comparison of species richness between the historical and recent plant communities grouped along the soil moisture gradient shows a significant increase of species richness in 2016 for wet (Deschampsietum and Hordeetum) and dry plant communities (Pulsatilletum and Astragaletum, Fig. 4). Although there was not observed plant species migration from dry to wet communities.

Landolt indicator values

The comparison of average Landolt indicator values shows that the ecological features of the given plant communities in 1986 and 2016 are almost identical to each other. Thus the significant temporal change was not detected. The average moisture indicator values show that these plant communities become significantly dry from Deschampsietum to Astragaletum (Fig. 5). The reaction indicator value changes from acid to moderately acid. The soil fertility (N) is very poor at all sites. The light indicator values increase from wet to dry communities. While the average temperature indicator value varies among the plant communities indicating about the presence of montane – subalpine plants (Fig. 5).

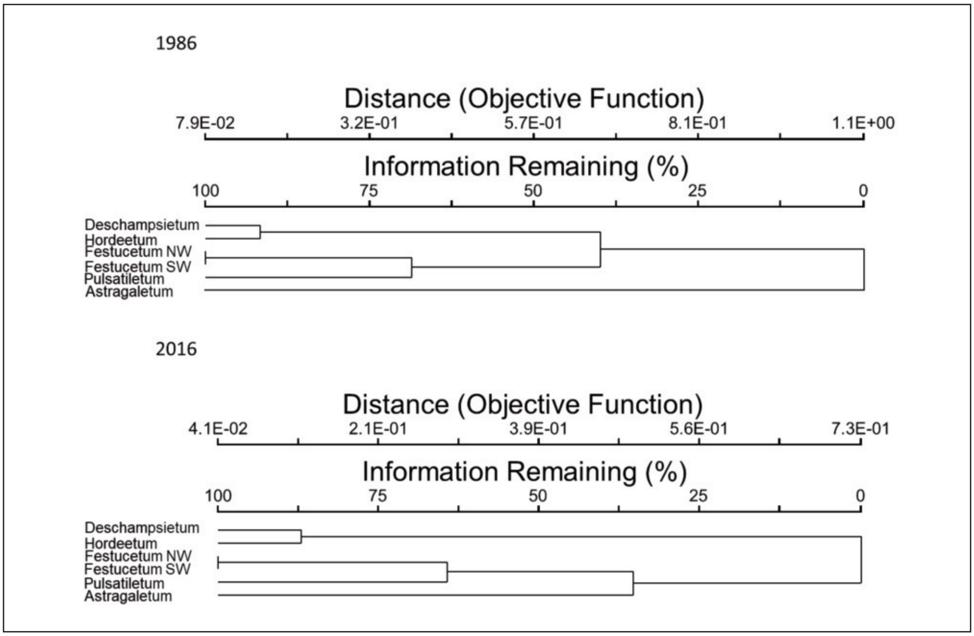

Fig. 1. The hierarchical clustering of six plant communities.

Discussion

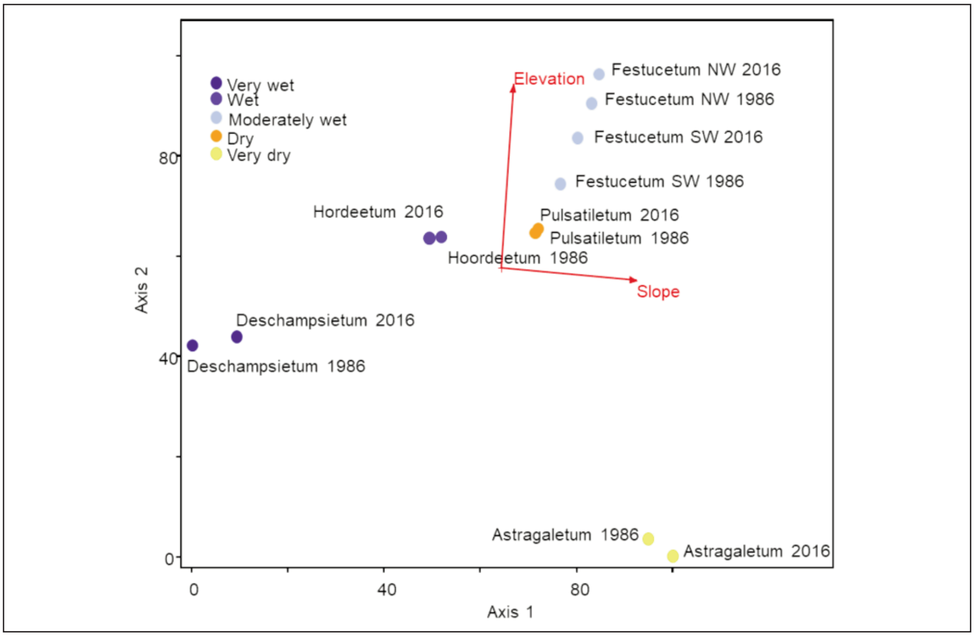

Fig. 2. Principal component Analysis of 12 habitat types based on species composition and cover. The Axis 1 explains 29% of the variance and the Axis 2 explains 24%.

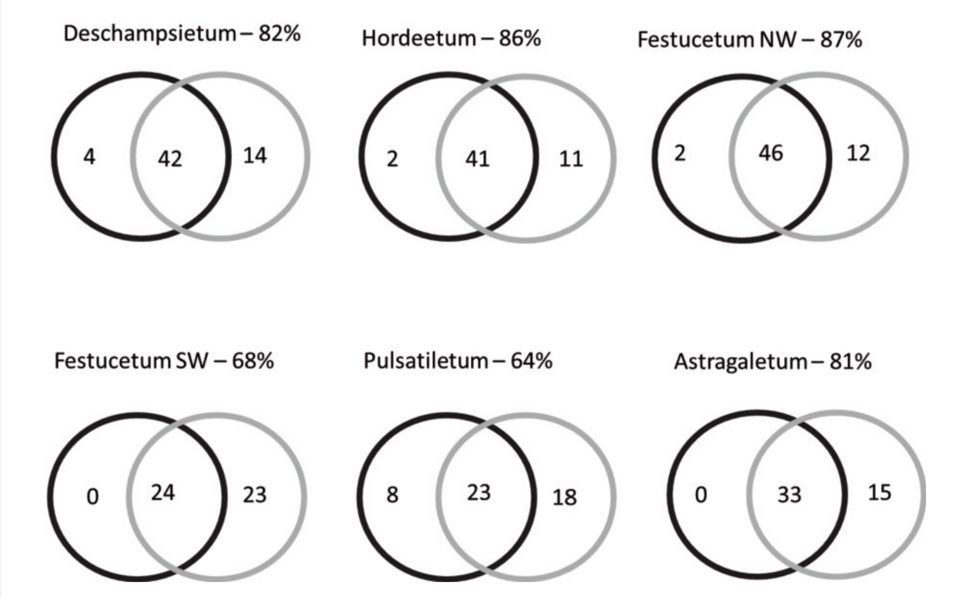

Fig. 3. The Venn diagram of six plant communities displaying the number of unique and common species of historical (black circles) and recent (grey circles) relevés. The Sørensen indices are given in percentages.

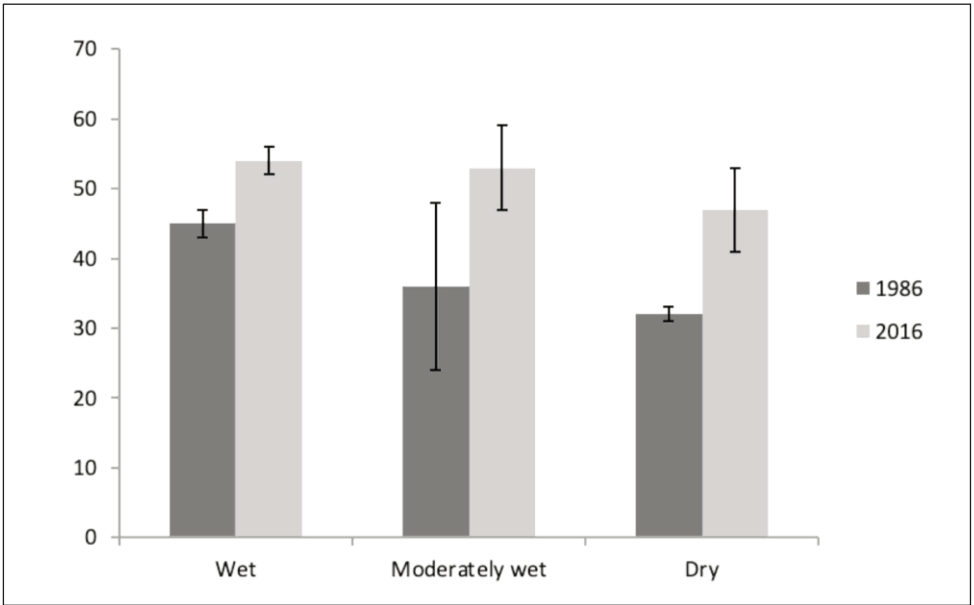

Fig. 4. The species richness of historical and recent plant communities. Abbreviations: **Wet** – Deschampsietum, Hordeetum, **Moderately wet** – Festucetum NW, Festucetum SW, **Dry** – Pulsatilletum, Astragaletum.

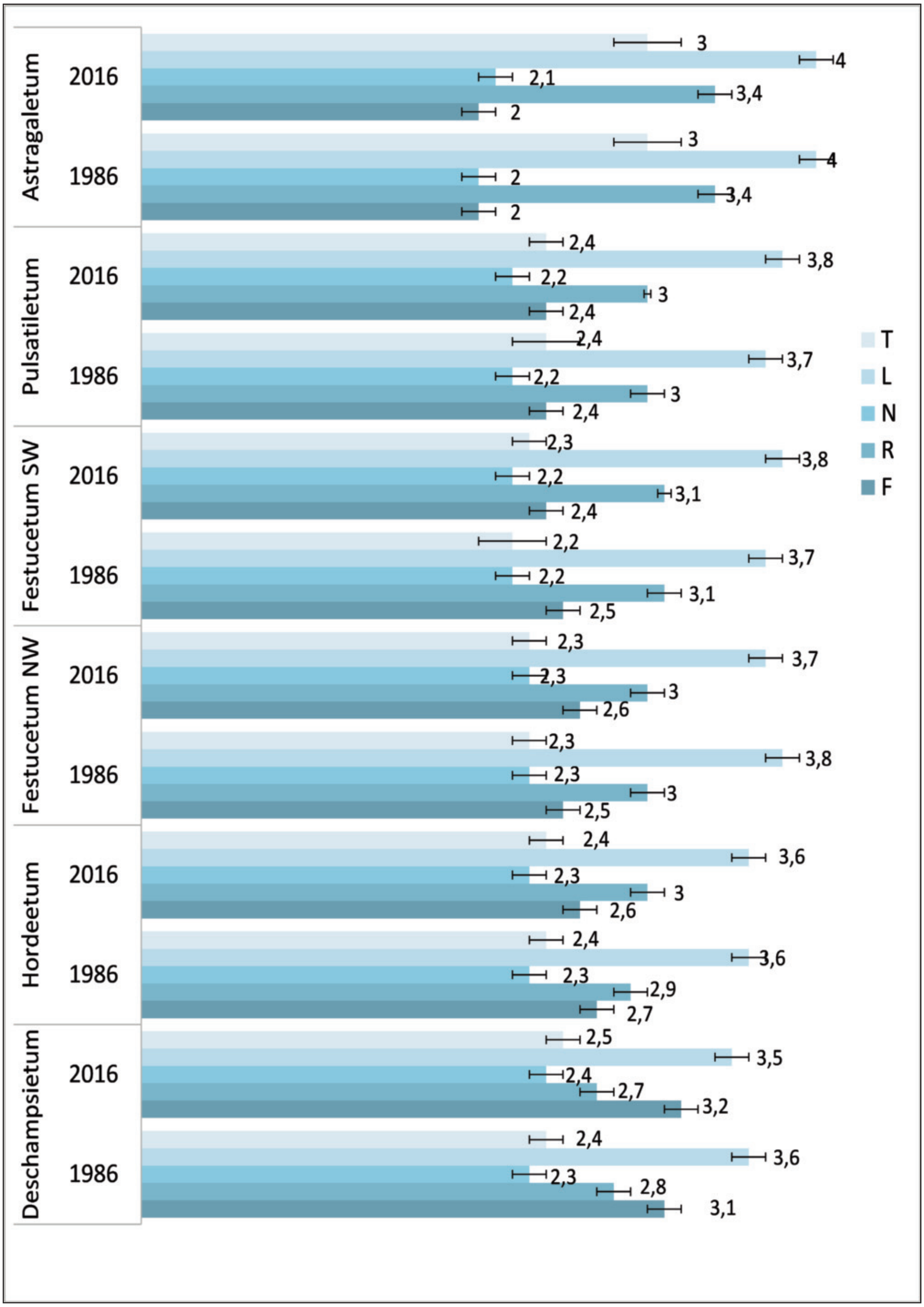

Fig. 5. Temporal and spatial changes in the averages of Landolt indicator values. Abbreviations: F – Moisture, R – Reaction, N – Nitrogen, L – Light, T – Temperature.

The results of the current study clearly demonstrate that species composition and diversity slightly changed over the past >30 years in the subalpine belt of the Central Great Caucasus. Although there was not observed significant changes in ecological features, as well as patterns of species migration from dry to wet plant communities.

Species diversity

The PCA result demonstrated altitude and slope as important determinants of the species composition, which confirmed the similar results of Moser & al. (2005), Marini & al. (2007) and Tephnadze & al. (2014).

In the current study, we have observed a significant increase in species number of wet and dry plant communities. Still, the similarity was very high. Although, species richness of moderately wet plant communities (Festucetum NW and Festucetum SW) have insignificantly increased. However, there was not observed species migration from dry to wet plant communities as well as a significant change in soil moisture gradient and other ecological characteristics. Thus the increase in species richness cannot be linked to the global climate change. Another studies from the Great Caucasus show also that changes in species richness along the elevational gradient is most likely to be governed by the land-use activities rather than by the Global climate change (Nakhutsrishvili & al. 2004; Erschbamaer & al. 2010; Gigauri & al. 2013, 2014, 2016).

Such results can be explained by several reasons such as 1) the inaccurate location of the plots in 2016, 2) the recent inventories of the plots in 2016 were more precise, or mismatch in time periods of inventarisation, and 3) new species arrived since the historical time. We can exclude the first option as it cannot be a reason for the increased number of species in the majority of plant communities. The second option also can be partly excluded as the moderately wet plant communities do not show the significant increase in species richness. Although, this could be explained by the growing form of the dominant specimen *Festuca varia*. This grass forms tussocks and thus could be a limitation of the species number. Pokarzhevskaya (1998) also reported that dominant *Festuca varia* tussocks limited species number in alpine grasslands of the Northwestern Caucasus, Russia. Therefore we assume that the third option can be an explanation of the increase in species richness. The arrival of new species is most likely connected to the land management of the study region. Nowadays the low land-use intensity is observed, while 30 (and more) years ago overgrazing took place (Tephnadze & al. 2014). Tephnadze & al. (2014) also reported that high plant diversity of the subalpine belt depends on the overall low land-use intensity in the Kazbegi region. Several studies confirm as well management as an important determinant for species richness (Marini & al. 2007; Kampmann & al. 2008) and links between land-use intensification and low species richness (Alard & al. 1994; Tasser & Tappeiner 2002; Klimek & al. 2007; Fischer & al. 2008; Homburger & Hofer 2012). Furthermore, Stöckli & al. (2012) and Wipf & al. (2013) also reported increase in plant species richness since the historical time.

Ecological characteristics

The historical and recent data were similarly characterised by the Landolt indicator values and are in accordance with the literature description of the plant communities (Nakhutsrishvili 2013) or with the field measurements. Several studies proved as well that results obtained by indicator values are in accordance with the expert knowledge and field measurements (Sherrer & Körner 2011; Schwabe & al. 2007).

As it was expected (based on the expert knowledge) the average Landolt indicator values proved the decrease of soil humidity from wet Deschampsietum to dry Astragaletum. The same trend was shown by field measurements of soil humidity in 2016, too (see chapter 2). The average reaction values showed the acidity of soils. Tephnadze & al. (2014) also showed that soils in the subalpine zone of the Kazbegi region are acid. Acid soils itself are an indication of low fertility (Egli & Poulenard 2017). According to the nitrogen indicator values, all plots were characterised as fertile-poor sites. Finally, light and temperature values indicated on the presence of semi-shade/light indicator plants of montane-subalpine zones.

In spite of the smaller dataset Landolt indicator values characterised studied sites very objectively. Therefore we could obtain significant results and thus answer the research questions.

Conclusions

This publication is a pilot study to assess the temporal change of biodiversity of the subalpine zone along the soil moisture gradient. We conclude that species richness increased over the last 30 years, though it is not governed by the global climate change. We assume that declined land-use intensity leads to an increase in species richness.

However, climate induced changes of vegetation patterns take some decades and thus require long term monitoring. Therefore, we hope that in the nearest future will be done next monitoring at a larger scale. From this perspective, our observation can play an important role in further investigations in the frames of re-visitation approach.

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Addresses of the authors:

Nato Tephnadze-Hoernchen[1*], Zaal Kikvidze[2], Gia Nakhutsrishvili[3] & Otar Abdaladze[4],

[1] Botanical Institute, AG Linstädter, University of Cologne, Germany.

[2] 4D Research Institute, Ilia State University, Tbilisi, Georgia.

[3] Institute of Botany, Ilia State University, Tbilisi, Georgia.

[4] Institute of Ecology, Ilia State University, Tbilisi, Georgia.

*Correspondig author: ntephnad@smail.uni-koeln.de