Bocconea 29: 103-119
https://doi.org/10.7320/Bocc29.103
Version of Record published online on 5 August 2021

K. Gigauri, O. Abdaladze, A. Bakhia, Z. Asanidze & A. Mamedova

The first results of the 3rd cycle of Global Monitoring GLORIA Network of the Central Great Caucasus

Abstract

Gigauri, K., Abdaladze, O., Bakhia, A., Asanidze, Z. & Mamedova, A.: The first results of the 3rd cycle of Global Monitoring GLORIA Network of the Central Great Caucasus. — Bocconea 29: 103-119. 2021 — ISSN: 1120-4060 printed, 2280-3882 online.

The global climate change will affect all the ecosystems around the world, but the most rapid and sharp changes are expected in high mountain areas with one of the most sensitive biomes. Global climate is changing and this is obvious due to a wide range of observations. GLORIA is a monitoring program to determine the effect of climate global change on alpine plant communities, within the framework of which Georgia has been participating since 2001. The study sites and permanent plots in the Central Great Caucasus were chosen according to the GLORIA protocol (which is a standard for all target regions in the GLORIA network). The summits were monitored in 2001, 2008 and 2015 years. Our research presents the analysis of the data of 2008 – 2015 with the comparison to the previous period of 2002-2008. The study includes such aspects as: soil temperature, growing degree day (GDD), thermic indicator (S), thermophilization index (D). The average annual soil temperature did not increase during the monitoring period, however, there were some fluctuations in 2002-2003. GDD changed in different years, but there was no strongly increasing trend. The thermic indicator (S) decreased on all summits during monitoring period. This indicates the low degree of the thermopilization status of the monitored plots. There were no distinctive changes observed during monitoring period of 2008-2015 years, hence the Central Great Caucasus did not face strong climate change at this time.

Key words: Climate global change, GLORIA, Soil temperature, Thermic indicator, Thermophilization index, Growing degree day, Alpine vegetation.

Introduction

The Earth's biosphere is currently experiencing and will continue to experience rapid climate change (Solomon & al. 2007; Arndt & al. 2010). Temperature change scenarios in Europe for 2080 vary regionally, but show a clear trend towards warming (IPCC 2007). The average projected increase in Europe ranges from 2.1°C to 4.4°C, with considerable seasonal and regional variation of changes in precipitation (Schröter & al. 2005). It is assumed that average temperatures during the second half of the 20th century in the northern hemisphere were likely the highest in at least the past 1300 years (Spehn & al. 2010).

High mountains of the temperate zone are among the most sensitive areas in terms of environmental impacts of climate change (Körner 2002; Nagy & Grabherr 2009). Development and normal functioning of alpine ecosystems are largely determined by the low temperature conditions, frequency and intensity of wind, and the distributional character of precipitation (Larcher 2012). Changing of these limiting effects will have an impact on the diversity of the vegetation: migration of species from low altitudes to high altitudes will start and the species adapted to high altitude conditions will gradually disappear until the end of the 21st century, particularly where climate warming is combined with decreasing precipitation (Körner 1992; Nagy & Grabherr 2009). The more cold-adapted species will decline and the more warm-adapted species will increase. This process is described as thermophilization. Plants as bioclimatic indicators were used to define two composite indices (thermic vegetation indicator *S* and thermophilization indicator *D*) (Gottfried & al. 2012) for climate change effects on vegetation in mountains all over Europe.

Many observations, e.g., in the Alps (Gottfried & al. 1999; Grabherr & al. 2001; Walther & al. 2005), Scandinavian mountains (Klanderud & Birks 2003), Rocky Mountains, and the Central Great Caucasus (Nakhutsrishvili & al. 2004, 2009), have shown that climate warming leads to the changes of habitats, distribution peculiarities, and viability of some vegetation types. Vertical shifting of the treeline has been shown for several mountain systems of the world (Kullman 2007). Studies in the high mountains of the Kazbegi region (the Central Great Caucasus) revealed enhancement of seed formation process in birch forests, with individuals of *Betula litwinowii* of 6–8 years old found at the altitude of 2200–2550 m (Akhalkatsi & al. 2006; Hughes & al. 2009).

Climate change in Georgia has a mosaic character reflected in the temperature rises in East Georgia in recent decades. In West Georgia, on the contrary, the temperature is reducing. The mean air temperature during the period 1982-2003 increased by 0.8°C (Elizbarashvili & al. 2009, 2010).

The studies within the framework of GLORIA-Europe (Global Observation Research Initiative in Alpine Environments) project in the Caucasus Mountains of Georgia were initiated from 2001. First results were given in the following publications: Nakhutsrishvili & al. (2004, 2013), Dullinger & al. (2007), Erschbamer & al. (2010, 2013), Gigauri & al. (2013, 2014, 2016), Gottfried & al. (2012), Pauli & al. (2012) and Winkler & al. (2016).

This study aims to process the data, collected from the 3rd cycle (2008-2015) of the results of GLORIA's permanent monitoring plots, then to analyze it, and compare to the 2nd (2001-2008) and 1st (2001) cycles data.

Materials and Methods

Study area

The Central Great Caucasus was one of the initially selected European target regions for GLORIA studies (Pauli & al. 2004). In 2001, 2008 and 2015 field monitoring was carried out on the southern macro slope of the main watershed range of the Central Great Caucasus in the Cross Pass area of the Kazbegi region of Georgia (Fig. 1). The relief of the Kazbegi region is formed by ascending, bare, sharp ridges, isolated peaks, very steep rocky slopes, narrow gorges and caves of erosion-tectonic origin (Nakhutsrishvili & al. 2005). The vegetation survey of the Kazbegi region, climatic conditions, and main threats to the alpine species and plant communities are given in the following sources: Nakhutsrishvili & al. (2005, 2006, 2009, 2017), Nakhutsrishvili (2013), and Abdaladze & al. (2015).

Study sites

According to the GLORIA protocol vascular plant species occurrence was recorded first in 2001 at four expositions (East, North, South, West) on the four summits (CP1, CP2, CP3, and CP4) along the vertical vegetation zones (Table 2). The summit CP1 (2240 m a.s.l.) is located in the treeline ecotone with birch (*Betula litwinowii*) forest predominantly with dwarf birch trees and alpine *Rhododendron caucasicum* shrubs. The birch forest was degraded in the past centuries and only a small number of trees remained. The summit CP2 (2477 m a.s.l.) is located in the lower alpine zone and represents an area between the treeline ecotone and alpine grassland which was used as a hay meadow and currently has no impacts. The CP3 summit (2815 m a.s.l.) is covered by alpine grassland and used a cattle pasture with lower grazing impact. The highest summit CP4 (3024 m a.s.l.) is located in the subnival zone and has no human impact. CP3 and CP4 summits are located in the vicinity of the alpine ski resort Gudauri (Table 1).

Field work

The sampling design of the GLORIA-Europe project (Pauli & al. 2015) (GLORIA-Field Manual see also (http// www.gloria.ac.at) was used. 64 permanent plots in 1 m × 1 m were established for monitoring plant composition and frequency across the treeline-alpine-subnival ecotone in 2001. The positions of all 1 m × 1 m quadrates were permanently marked and precisely documented by a tachymeter survey of each corner point as well as by a photo of each plot. The plots were reinvestigated in 2008 and 2015. In both years,

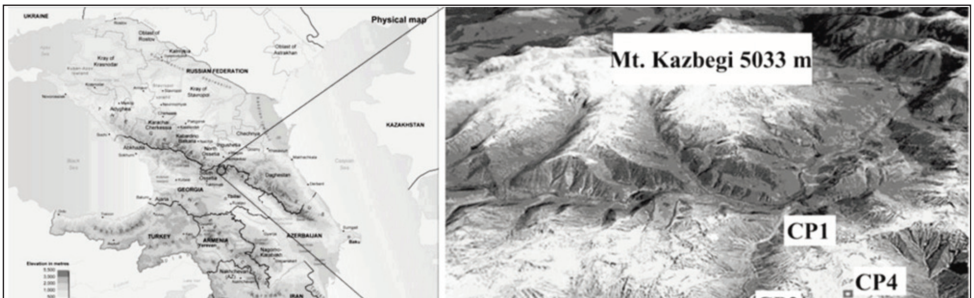

Fig. 1. The Central Great Caucasus (A) Location of the Kazbegi region (B).

Table 1. Characteristics of study sites in the Central Great Caucasus.

Study sites	Altitude (m.s.l.)	coordinates	Summit's area (m²)	Vegetation zone
CP1	2240	N44⁰29'35"; E 42⁰32'33"	1085.77	Treeline
CP2	2477	N44⁰27'33"; E 42⁰29'57"	9628.81	Lower alpine
CP3	2815	N44⁰30'04"; E 42⁰29'44"	14974.31	Upper alpine
CP4	3024	N44⁰30'36"; E 42⁰29'49"	3429.60	Subnival/nival

Table 2. The difference between summits (CP1-CP4) by average ToC 2002, 2008 – 2015 (ANOVA post hoc test. Multiple Comparison).

Year	(I) Summit		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
2002	CP1	CP2	-2.250	0.196	0.000	-2.64	-1.86
		CP3	-1.750	0.196	0.000	-2.14	-1.36
		CP4	-0.062	0.196	**0.751**	-0.45	0.33
2008	CP2	CP2	0.60312	0.35767	0.097	-0.1123	1.3186
		CP3	0.70062	0.35767	0.055	-0.0148	1.4161
		CP4	4.59312	0.35767	0.000	3.8777	5.3086
2009	CP1	CP2	.01375	.40163	.973	-.8702	.8977
		CP3	1.28250*	.40163	.009	.3985	2.1665
		CP4	1.81292*	.43382	.002	.8581	2.7677
2010	CP1	CP2	-.12650	.34413	.720	-.8839	.6309
		CP3	1.59650*	.34413	.001	.8391	2.3539
		CP4	1.45250*	.37170	.002	.6344	2.2706
2011	CP1	CP2	-.02975	.39417	.941	-.8973	.8378
		CP3	1.24425*	.39417	.009	.3767	2.1118
		CP4	2.13650*	.42576	.000	1.1994	3.0736
2012	CP1	CP2	-.02575	.38279	.948	-.8683	.8168
		CP3	.81875	.38279	.056	-.0238	1.6613
		CP4	1.96467*	.41346	.001	1.0546	2.8747
2013	CP1	CP2	.24675	.33630	.478	-.4934	.9869
		CP3	1.57375*	.33630	.001	.8336	2.3139
		CP4	2.08192*	.36324	.000	1.2824	2.8814
2014	CP1	CP2	-.14875	.38952	.710	-1.0061	.7086
		CP3	1.21725*	.38952	.010	.3599	2.0746
		CP4	1.99742*	.42073	.001	1.0714	2.9234
2015	CP1	CP2	.73300	.41026	.102	-.1700	1.6360
		CP3	1.96075*	.41026	.001	1.0578	2.8637
		CP4	2.84025*	.44313	.000	1.8649	3.8156

*. The mean difference is significant at the 0.05 level.

all vascular plant species and their percentage cover were recorded (Gigauri & al. 2013, 2014). The cover value of each vascular plant species was visually determined and was estimated on the percentage scale (e.g., an area of 10 × 10 cm equals 1%, while 1 × 1 cm equals 0.01%) (Frey & Lösch 2004). The frequency of species was determined using a frame divided into 100 subplots of all 1-m^2 permanent plots. The data were registered in electronic format with the MSAccess program (Pauli & al. 2015).

Soil temperatures in 2001-2008 were measured in the center of the 3 m × 3 m grid in 10 cm soil depth by temperature data loggers (Onset Stow Away Tidbit Model, USA, and from 2008 by *GEO-Precision, USA*) (Fig. 4). Altitudinal distribution ranges (AR) of the species were described according to Nakhutsrishvili (1999). We used vascular plant species as bio-indicator. We ranked the recorded species according to their bioclimatic position as follows: AR1: species with nival distribution centre, AR 2: alpine to nival species that do not descend to the treeline, AR 3: alpine centered species which do not descend to the montane belt, AR 4: alpine centred species that descend to the montane belt, AR 5: species centred in the treeline ecotone or indifferently distributed from the montane to the alpine belt, AR 6: species which are montane-centered or indifferently distributed from the montane belt to the treeline (Gottfried & al. 2012). We apply known optima of species vertical distribution ranges and weight these by species cover to calculate an average of the thermic vegetation indicator *S* for each plot:

$$S = \frac{\sum \mathrm{AR}\ (\mathrm{species\ i})\ \mathrm{x\ cover}\ (\mathrm{species\ i})}{\sum \mathrm{cover}\ (\mathrm{species\ i})}$$

Where: AR is –i species rank, cover (species i) - i species cover. Differences of the thermic vegetation indicator between 2002 and 2008 were used to quantify transformation of the plant communities and termed the thermophilization indicator *D*.

$$D = S_{\mathrm{present}} - S_{\mathrm{historical}}$$

Where: S_{present} is thermic vegetation indicator in 2008, and S_{historic} – in 2002.

Plant species were identified according to Sakhokia & Khutsisshvili (1975) and Flora of Georgia (1971-2013). Critical samples were compared with samples in the Herbarium of the Tbilisi Institute of Botany and with collection of Stephantsminda Alpine Ecology Institute of Ilia State University. The species nomenclature fits with the international nomenclature. We used The Plant List (www.theplantlist.org) and Pan-European Species Directories Infrastructure (www.eu-nomen.eu/portal).

Data analysis

Using the data of loggers we calculated average soil temperature, minimum soil temperature and mean of daily minimum temperature during June for the period 2002-2008. June is the first month when region was free of snow. In addition, the thermal regime in early summer is considered to be more important for plant growth than in the second half of growing period (Grabherr & al. 1995). Minimum temperature was used because it is less influenced by solar radiation. Growing degree day (GDD) index was calculated using temperature data logger

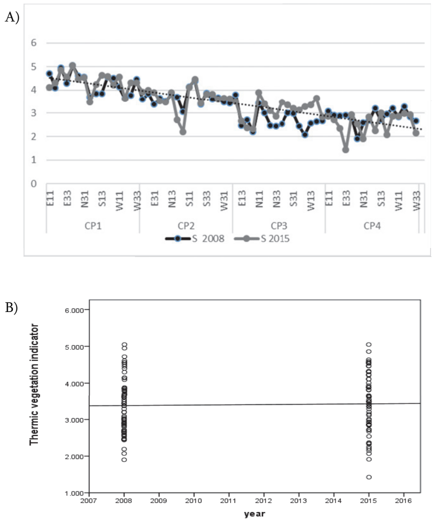

Fig. 4. The change of the thermic vegetation indicator (S) according to expositions on four summits (CP1, CP2, CP3, CP4) (A) and according to 2008 – 2015 period of time (B).

information on the number of days per year when soil upper layer mean temperatures were above 2°C (Molau & Molgaard 1996).

All the statistical analysis were performed by using statistical software SPSS 16.0 for Windows (Hammer & al. 2001). Data were first tested for normality using a Shapiro-Wilk test. As some parameters were not normally distributed, we used non-parametric Wilcoxon signed-rank test for paired samples. Mean, median, and standard error were calculated for each quantitative data set. Means were compared using one-way ANOVA ($P < 0.05$) post hoc range tests. We also used ANOVA post hoc range test to investigate whether the average soil T°C and GDD changed in the 1m × 1m quadrates from 2001 to 2015. Linear regression on the different measures of species richness with altitude and the different soil temperature-derived variables was also performed in SPSS. We used a paired test and ordination analysis to analyze the changes of the thermic vegetation indicator at the permanent plots between the two periods of time (2002/2015). Polynomial regression by cubic effect was used for each graph to fit a nonlinear relationship between the value of x (GDD) and the corresponding conditional mean of y (thermic vegetation indicator S).

Results

Average soil temperature

From 2002 to 2015 average soil temperature rising tendencies are not observed. 2002 was the warmest and 2008th – the coldest years (Fig. 2). The temperature was changing over by years and exposition; the change was significant ($R^2 = 0.109$, $F = 25.32$, $b = -2.19$, $P<0.001$).

Difference between the highest and lowest hypsometric heights as well as by the average temperature was not significant in 2002 (*P=0.751*), while new data processing showed that differences were significant in following years (Table 2).

The average soil temperature change in 2009-2015 by exposition was significant (*P*<0.001). Charts show that difference between cardinal exposition (North and South) on CP3 and CP4 is less distinctive (Fig. 3) than on lower summits.

Growing Degree Day (GDD)

The defrosting period on the lowest summit, CP1, starts in April, and the mean daily temperatures persisted for the whole spring, summer, and part of autumn, falling below 2°C in early November and thus lasting, on average, 213.25 ± 20.18 days for the monitoring period. On the highest summit, CP4, the frost-free period was shorter: 175.8 ± 11.64 days from the end of April through early October, more than 1 month less than that on the lowest summit. No radical changes were observed during GDD analyzing data (2002-2014). The trends were statistically significant for all expositions at confidence level. GDD index differs between north and south slopes. The new (current) data was compared to the previous ones, conducted in 2002 and in 2008. The change of GDD index over 2002-2014 was significant (t = 0.21, df = 13, *P<0.001*) (Table 3), though the strong growth trend was not revealed. GDD data of the last three years (2012; 2013; 2014) show significant increase per year across all slopes (R^2 = 0.065; *P=0.001*).

The thermic vegetation indicator (S); the thermophilization indicator (D)

We calculated the *S* for the present (2015) and historic (2008) dataset. *S* varied at different altitude and exposition. S increased on CP3 summit, but the growth was not significant (*P* >0.05) (Fig. 4A).

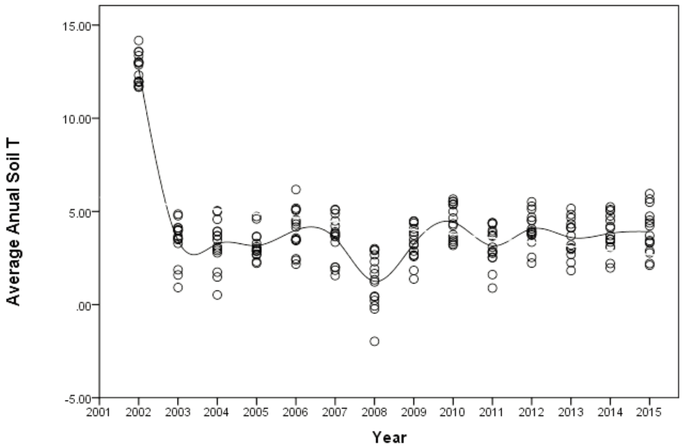

Fig. 2. Average soil temperature change in summits during 2002-2015 on CP1-CP4 (CP1 - 2240 m a.s.l., CP2 - 2477 m a.s.l., CP3 - 2815 m a.s.l., CP4 – 3024 m a.s.l.).

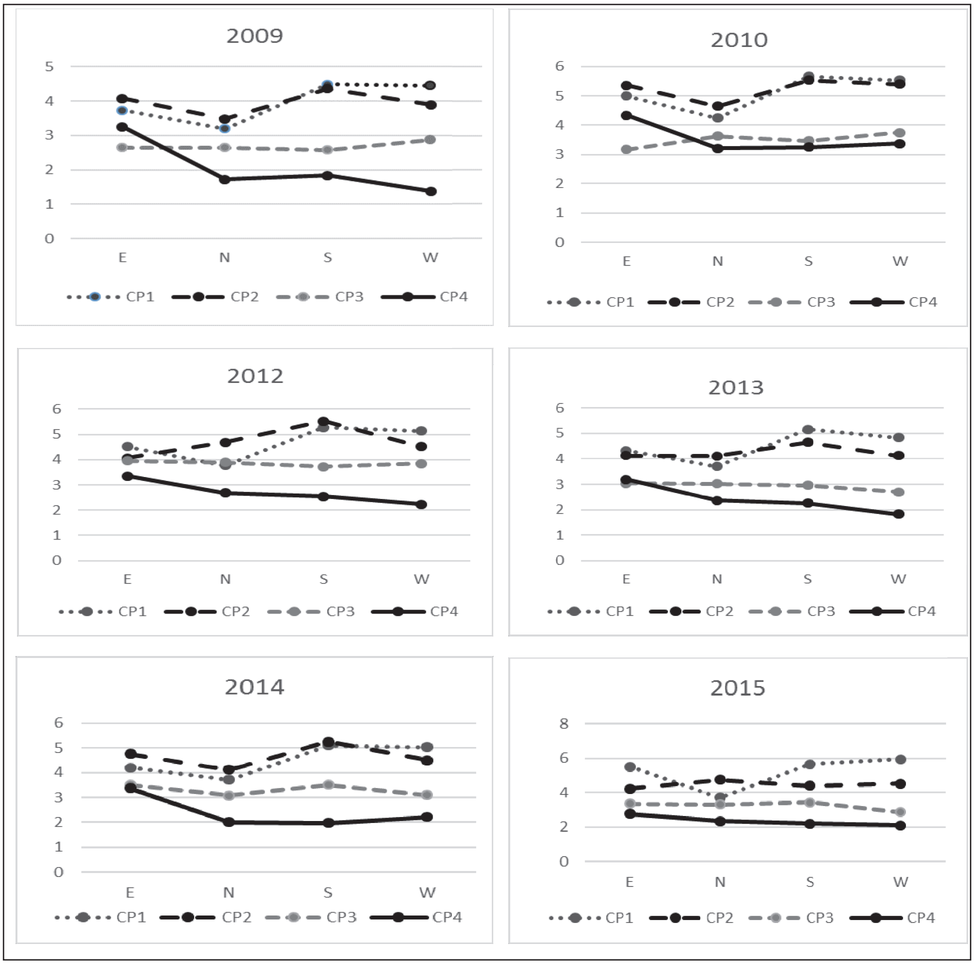

Fig. 3. Average soil temperature change at various expositions by 2009-2015 (N-North, S-South, E-East, W-West).

While calculating of *D* did not show positive feedback (Fig. 4B).The regression analysis was used to show that probability value was not significant ($R^2 = 0.0008$; $P = 0.739$). During previous monitoring process, the data revealed the same results (Gigauri & al. 2016).

The present score of *S* correlated with GDD in 2002, 2008, and 2015 (2002- r = 0.669, $P < 0.012$; 2008-r= 0.576. P<0.001; 2015-0.541, P=0.002) (Fig. 5).

Species richness

Floristic descriptions were carried out in 2001, 2008, and 2015 all over four expositions (CP1, CP2, CP3,CP4). 138 of vascular plant species were recorded, which belong to 32 fami-

Table 3. The statistical table of the changes of GDD (growing degree day) during monitoring period (2002-2014).

Years	Mean	St.Dev.	St.Error Mean	t	df	Median	95% Interval Lower	Confidence of Mean Upper	P
2002	155.62	11.913	4.208	36.9	7	155	145.67	165.57	0.001
2003	150.32	17.212	6.085	24.7	7	150	135.98	164.76	0.001
2004	147.72	18.156	6.419	22.9	7	148	132.07	162.42	<0.001
2006	148.12	14.456	5.107	29.0	7	147	136.04	160.20	0.002
2007	151.75	11.656	4.117	36.8	7	152	142.01	161.48	0.001
2009	148.06	25.092	6.478	22.9	14	149	134.17	161.96	0.001
2010	155.86	30.486	7.871	19.8	14	155	138.98	172.74	0.001
2011	143	26.731	6.902	20.71	14	148	128.19	157.81	<0.001
2012	182.73	21.265	5.491	33.28	14	180	170.95	194.51	0.002
2013	164.6	33.784	8.723	18.86	14	172	145.89	183.31	<0.001
2014	169.6	26.81	6.922	24.50	14	167	154.75	184.44	0.001

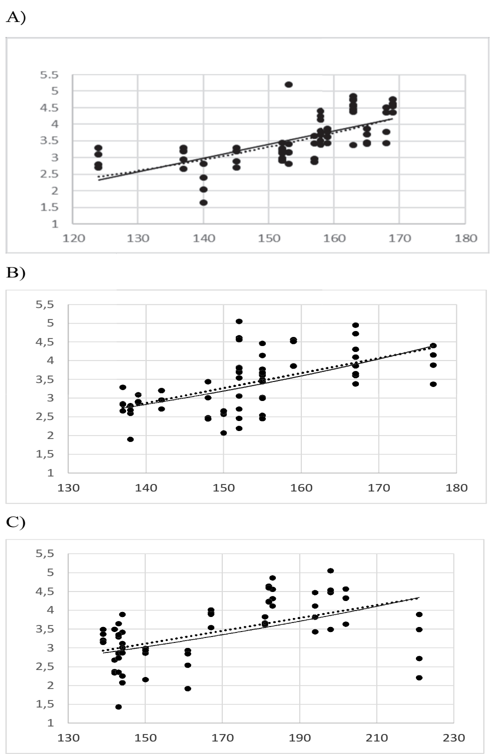

Fig. 5. Dependence of the thermic vegetation indicator (S) on Growing Degree Days (GDD) in 2002 (A), 2008 (B) and 2015 (C).

lies. The species richness is raised on three (CP1, CP3, CP4) summits in 2015. The highest score was recorded on CP1 research plot, on the lowest altitude exposition (Table 4). The richness also increased in 1m^2 plots, especially in CP4 summits. Only 3 species were not refound on CP2 (*Sedum pallidum, Lotus corniculatus, Viola odorata*) and CP4 (*Anthemis iberica, Veronica gentianoides, Jurinella subacaulis*). The cover of these species were low in 2008. The percentage of newcomer species was highest on the southern slope. The altitudinal distribution of this species was mainly of the montane-treeline-alpine classes. Species richness per 1m^2 increased during 2008-2015 period by 2.19 on the CP2 and by 2.28 on the upper CP4 summit.

Discussion

No noticeable increase of temperature observed within the time frame of 2002-2015. 2002 was the warmest and 2008 the coldest years. There was no distinctive change observed in average soil temperature from 2009 to 2015. Summer of 2002 was the hottest (Gigauri & al. 2013) one with less precipitation, however, we can't know the change of soil temperature before 2002. Although in 2002 the difference between the maximum values of average soil temperature from the lowest (CP1) to the highest (CP4) summits was very low. According ANOVA statistic the difference by this variable between the same summits was not significant in 2002. It may be a direct effect of the exceptionally warm summer in this year. However, within the following years (2009-2015) the data showed that differences were significant. The increase in global mean temperature about 1-2°C will result in short-term changes among alpine vegetation, taking into account the peculiarity of high levels of genetic diversity of highland species to adapt to new conditions. Still, the long-term change will certainly affect the high mountain ecosystem and lead to migration processes (Körner 2009; Gottfried & al. 2012). On the other hand, the great number and diversity of ecological niches are in the highlands (especially in the upper part of the alpine zone and sub nival/nival belt), which can be the so-called "life ring" to give a chance to survive for many of the taxons (Körner & al. 2005; Scherrer & Körne 2010, 2011; Scherrer & al. 2010). Such transformation, as inter-species interactions, acquiring of migratory behavior, shifting altitudinal range of many species are already happening consequently because of global climate change (Spehn & al. 2010; IPCC 2014).

Table 4. Change the species richness in 2001, 2008 and 2015 in summits and plots.

Summits	Altitude	Number of species			Number of species 1m²		
		2001	2008	2015	2001	2008	2015
CP1	2240	59	63	71	12.5 ± 2.87	15.5 ± 3.12	16.18 ± 2.2
CP2	2477	71	77	73	17.6 ± 3.29	21.06 ± 3.17	18.87 ± 1.56
CP3	2815	15	13	22	9.12 ± 1.2	10.8 ± 1.68	11.87 ± 2.39
CP4	3024	29	32	36	5.25 ± 2.5	6.65 ± 3.2	8.93 ± 3.01

The temperature inter-annual variability, shown by our data, is a normal phenomenon and plants are generally able to tolerate short-term fluctuation through phenotypic plasticity, but low value of difference of average and minimum soil T°C from the lowest to the highest summits may cause plant species to shift distribution to higher altitudes. Warming effect could be driven by two main mechanisms: filling process and moving processes, due to the immigration of thermophilic species from the lower altitude (Gottfried & al. 2012; Stanisci & al. 2014). Vertical shifting of species was recorded in the Central Great Caucasus in earlier publications (Nakhutsrishvili 2003; Akhalkatsi & al. 2006; Togonidze & Akhalkatsi 2015). Six-eight years old individuals of *Betula litwinowii* were found at 2200-2550 m a.s.l. According to Pauli & al. (2012) in other GLORIA target regions species were shifting their distribution by 2.7 m on average.

In some of the regions, involved in GLORIA project, perceptible increase of average soil temperature was observed during the monitoring period (Alps, Mediterranean region) (Reginster & al. 2005; Pauli & al. 2004, 2012) and in some cases there was little change. For example, in the Norwegian highlands, the average annual soil temperature of 2001-2008 has increased slightly, although winter temperatures showed the significant growth (Bockmühl 2008).

In 2009-2015 the average soil temperature varied according to the different expositions. It is noteworthy, that temperature difference between CP3 and CP4, extreme spots (North, South) with cardinal aspects was not conspicuous. This may be explained by the fact, that on the North exposed slope snow cover protects the soil form unnecessary cooling, in contradistinction to the lower slopes (Rixen & al. 2014).

GDD data of 2009-2015 were calculated and analyzed, then compared to the previous data of 2002-2008. Regression analysis of the 2009-2015 data revealed, that compared to 2002, GDD showed relatively growth tendency. The change of GDD index over 2002-2007 was significant, though the growth trend was not revealed. The increase of the growing season is associated with the reduction of snow cover duration, caused by increase of winter temperatures influences directly on species, whose development follows snow-melt with minimum delay (Körner 1992, 1999).

Thermic vegetation indicator varied at different altitude and exposition. Thermic vegetation indicator increased on CP3 summits, but the growth was not significant ($P > 0.05$). By means of regressive analysis of the statistical program, it was revealed, that the Thermic indicator change of 2015 in comparison to 2009, i.e. the thermophilization index (D), was not distinctly positive and significant. The high variation of D at the plot level could be ascribed to both ecological reasons, such as different age structure of plant population and to observer errors associated with the visual recording of species and percentage cover. As thermophilization indicator is based on species cover changes, the positive D may result from increased cover or immigration of higher rank species. The cover increase mostly reflects filling process of species already present at the alpine belt, rather than immigration of species. The bulk of alpine plant species are slow-growing and long-lived and only very few are annual species. Thus, it can be assumed that above-ground biomass which is related to cover does not change much from year to year (Pauli & al. 2003), but thermophilization of plants communities change in time intervals.

At the continental scale D was highly significant, but less at summit and plot levels. It was noticeable, that the D indicator was positive in 16 regions out of 17 and on 42 summits out of 60 (Gottfried & al. 2012). It is in significant correlation with amount of winter precipitation. Disputed data received throughout some regions (e.g., the D indicator was positive in Norwegian mountains and negative in the Scottish region, while it is known that the climate warming rate in the north of Europe is quite high) was explained by the change of winter precipitation. In Scotland winter precipitation notably decreased. During the last decade there were no significant reduction in winter precipitation in the Central Caucasus (mean annual precipitation – 1412.07 mm ± 112.07 mm) (http://trmm.gsfc.nasa.gov/). The less reduction of the precipitation may be the reason why our results are in contrast to the temperate European mountains. Insignificant changes of D indicator and reduction of thermic indicator on our monitoring summits gave us reason to believe, that the climate warming has not yet happened on the Central Caucasus.

GDD correlated positively and significantly with the thermic vegetation indicator S in all years and the correlation is significant. GDD often appear in the literature as key climatic factor for alpine vegetation (Körner 2002, 2003, 2009, 2011; Larcher 2012). GDD as proxy for snow free season is important for seed ripening and it is based on soil temperature and correlated with thermic vegetation indicator, so the changes this indices are very important for explaining mountain plant responses to changing climate. Prolonged growing seasons promote the expansion of species from the lower altitudes (Erschbamer & al. 2009). Although in our summits the length of growing season (GDD) did not show strongly increasing trend from 2002-2015.

Species richness has increased on 3 summits out of 4 during 2008-2015. The reason can be growth of GDD during 2008-2015. All "new species" rank was mainly the upper forest border and the alpine one and preferred the southern and eastern slopes, i.e. the directions with the higher temperature and longer growing season (Erschbamer & al. 2009). Invasion of species on the south slopes, resulting from climate warming, was predicted by a number of researchers (Stanisci & al. 2005). On the eastern and southern slopes the soil is better developed and the substrate is more stable (Nadelhoffer & al. 1996), but the northern slopes are more conservative for distribution of the vegetation. Increasing temperatures and prolonged growing season have important effects on mineralization activity (Chapin & al. 2005). At this stage of the research, taking into account, that the average annual soil temperature hasn't been increased, all these changes should be considered as some local fluctuations and not as consecutive. In high mountains, local colonization or filling processes by new species appear to be more rapid than local extirpations (Grabherr & al. 2001; Walther & al. 2005). In the upper alpine and subnival zones, the scattered vegetation provides space for new plants, and thus invasion should be easier than on the lowest summit (Holzinger & al. 2006). However, potential immigrants from lower elevations would have to cross the upper alpine grassland belt, which may act as an effective barrier to invasion due to the predominantly closed, longlived grassland communities (Pauli & al. 2007).

In the permanent plots of the Central Caucasus, 51 (37%) species out of the total of 143 species were Caucasus endemics (Nakhutsrishvili & al. 2006; Solomon & al. 2013). Seven of them were recorded on the highest summit. When habitats of the endemic species are damaged by human activities or by other factors, the distribution range and population sizes of the species will be reduced. During study period, Caucasus endemics were not seriously endangered.

Thus, the results of this study confirm the hypothesis that high mountains of temperate zones are one of the most sensitive areas in terms of environmental impacts of climate change, which already has influence on the diversity of vegetation and migration of species from low to high altitudes. The observed changes in average soil T°C and thermic vegetation indicator (*S*) indicate that the Central Great Caucasus has faced no climate warming on this stage of monitoring. If the difference between average soil temperatures from the lowest to the highest summits is low in the future, this would theoretically imply that, habitats of subnival plant communities would be colonized by species of alpine grasslands. However, drastic acceleration of climate warming in Europe implies that climate change would become the major treat to biodiversity in the high mountain regions and short-term analyses of ecological indicators are necessary to improve our understanding concerning species behavior in a changing climate, so these observations should be continued in the future.

Acknowledgements

The Gloria –Europe project no.EVK2-CT-20000006 was funded by the EU 5th framework program in the Central Greater Caucasus during the years 2001-2003 and by support of Switzerland (OFES 00.0184-1). Resurvey in 2008 was supported by the Swiss MAVA Foundation for Nature Conservation and by a number of national funding agencies, analysis by the Austrian Federal Ministry of Science and Research, the Austrian Academy of Sciences and the University of Vienna. We would like to thank Georg Grabherr, Harrald Pauli, Michael Gottfried and the GLORIA co-ordination group in Vienna as well as Georgian students from the Ilia State University and technical assistants participating in the plant monitoring project GLORIA.

References

Abdaladze, O., Nakhutsrishvili, G., Batsatsashvili, K., Gigauri, Kh., Jolokhava, T. & Mikeladze, G. 2015: Sensitive Alpine Plant Communities to the Global Environmental Changes (Kazbegi Region, the Central Great Caucasus). – Amer. J. Env. Protect. **4:** 92-100. https://doi.org/10.11648/j.ajep.s.2015040301.25

Akhalkatsi, M., Abdaladze, O., Nakhutsrishvili, G. & Smith, W. K. 2006: Facilitation of Seedling microsites by *Rhododendron caucasicum* Extends the *Betula litwinowii* Alpine Treeline, Caucasus Mountains, Republic of Georgia. – Arct. Antarct. Alp. Res. **38:** 481-488.

Bockmühl, K. 2008: Comparing species-temperature relationships of arctic-alpine plants among three altitudinal transects in Svalbard. – Bergen.

Dullinger, S., Kleinbauer, I., Pauli, H., Gottfried, M., Klettner, Ch., Brooker, R., Nagy, L., Theurillat, J.-P., Holten, J. I., Abdaladze, O., Benito, J.-L., Borel, J.-L., Coldea, G., Ghosn, D., Kanka, R., Merzouki, A., Moiseev, P., Molau, U., Reiter, K., Rossi, G., Stancisi, A., Tomaselli, M., Unterlugauer, P. & Grabherr, G. 2007: Weak and variable relationships between environmental severity and small-scale co-occurrence in alpine plant communities. – J. Ecol. **95:** 1284-1295. https://doi.org/10.1111/j.1365-2745.2007.01288.x

Elizbarashvili, E. Sh., Meskhiya, R. Sh., Elizbarashvili, M. E. & Megrelidze, L. 2009: Climate Dynamics of Glaciers of the Greater Caucasus for the 20th Century. – Russ. Meteorol. Hydrol. **34:** 838-846.

—, Urushadze, T. F., Elizbarashvili, M., Elizbarashvili, Sh. E., Schaefer, M. K. 2010: Temperature Regime of Some Soil Types in Georgia. – Eur. Soil Sci. **43:** 427–435.

Erschbamer, B., Kiebache, T., Mallaun, M., Unterluggauer, P. 2009: Short-term signals of climate change along an altitudinal gradient in the South Alps. – Pl. Ecol. **202:** 79-82. https://doi.org/10.1007/s11258-008-9556-1

—, Mallaun, M., Unterluggauer, P., Abdaladze, O., Akhalkatsi, M. & Nakhutsrishvili, G. 2010: Plant Diversity Along Altitudinal Gradients in the Central Alps (South Tyrol, Italy) and in the Central Greater Caucasus (Kazbegi Region, Georgia). – Tuexenia **30:** 11-29. https://doi.org/10.1007/978-3-540-47229-2_22

—, —, —, Nakhutsrishvili, G., Akhalkatsi, M. & Abdaladze, O. 2013: Plant diversity along altitudinal gradients in the Central Alps and in the Central Caucasus: The project GLORIA in south Tyrol (Italy) and in the Kazbegi region (Georgia). – Pp 167-188 in: Pedrotti, F. (ed.) Colloques Phytosociologiques **29.** – Camerino.

Frey, W. & Lösch, R. 2004: Lehrbuch der Geobotanik. Pflanze und Vegetation in Raum und Zeit. 2 Auflage. – The Netherlands.

Gigauri, Kh., Akhalkatsi, M., Nakhutsrishvili, G. & Abdaladze, O. 2013: Monitoring of vascular plant diversity in a changing climate in the alpine zone of the Central Greater Caucasus. – Turk. J. Bot. **37(6):** 1104-1114.

—, —, — & — 2014: Vascular plant diversity and climate change in the alpine zone of the Central Greater Caucasus. – Int. J. Ecosyst. Ecol. Sci. **4(4):** 573-578.

—, —, Abdaladze, O. & Nakhutsrishvili, G. 2016: Alpine plant distribution and thermic vegetation indicator on Gloria summits in the Central Greater Gaucasus. – Pakistan J. Bot. **48(5):** 1893-1902.

Gottfried, M., Pauli, H., Reiter, K. & Grabherr, G. 1999: A fine-scaled predictive model for change in species distribution patterns of high mountain plants induced by climate warming. – Divers. Distrib. **5:** 241-251. https://doi.org/10.1046/j.1472-4642.1999.00058.x

—, —, Futschik, A., Akhalkatsi, M., Barancok, P., Benito Alonso, J. L., Coldea, G., Dick, J., Erschbamer, B., Fernandez Calzado, M. R., Kazakis, G., Krajci, J., Larsson, P., Mallaun, M., Michelsen, O., Moiseev, D., Moiseev, P., Molau, U., Merzouki, A., Nagy, L., Nakhutsrishvili, G., Pedersen, B., Pelino, G., Puscas, M., Rossi, G., Stanisci. A., Theurillat. J. P., Tomaselli, M., Villar, L., Vittoz, P., Vogiatzakis, I. & Grabherr, G. 2012: Continent-wide response of mountain vegetation to climate change. – Nat. Clim. Change **2:** 111-115.

Grabherr, G., Gottfried, M. & Pauli, H. 2001: Long-term monitoring of mountain peaks in the Alps. – In: Burga, C. A. & Kratochwill, A. (eds): Biomonitoring: General and applied aspects on regional and global scales, **35.** – Dordrecht.

—, —, Gruber, A. & Pauli, H. 1995: Patterns and Current Changes in Alpine Plant Diversity, in Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences. – Pp. 167-181 in: Chapin III, F. S. & Körner, C. (eds): Ecological Studies. – Berlin.

Holzinger, B., Hulber, K., Camenish, M. & Grabherr, G. 2006: Change in plant species richness over the last century in the eastern Swiss Alps: elevation gradient, bedrock effects and migration rates. – Pl. Ecol. **195:** 179-196. https://doi.org/10.1007/s11258-007-9314-9

Hughes, M. N., Johnson, D., Akhalkatsi, M. & Abdaladze, O. 2009: Characterizing *Betula litwinowii* Seedling Microsites at the Alpine-Treeline Ecotone, Central Greater Caucasus Mountains, Georgia. – Arct. Antarct. Alp. Res. **41(1):** 112-118.

IPCC, Intergovernmental Panel on Climate Change 1991: Report of the sixth session of the intergovernmental panel on climate change. – Geneva: Chapter 3, mitigation – introduction 1.1.

— 2014: Mitigation of Climate Change, Summary for Policymakers and Technical Summary. – Shanghai, China.

Klanderud, K. & Birks, H. J. B. 2003: Recent increases in species richness and shifts in altitudinal distributions of Norwegian mountain plants. – Holocene **13:** 1-6. https://doi.org/10.1191/0959683603hl589ft

Kikvidze, Z., Pugnaire, F. I., Brooker, R. W., Choler, P., Lotrie, C. J., Michalet, R. & Callaway, R. M. 2005: Linking patterns and processes in alpine plant communities: a global study. – Ecology **86:** 1395-1400.

Körner, Ch. 1992: Response of alpine vegetation to global climate change. – CATENA Suppl **22:** 85-96.

— 1999: Alpine Plant Life. – Berlin.

— 2002: Mountain biodiversity, its causes and function: an overview. – Pp 3-10 in: Körner, Ch. & Spehn, E. M. (eds): Mountain biodiversity: a global assessment. – London.

— 2003: Alpine plants life: functional plant ecology of high mountain ecosistems. 2nd ed. – Berlin.

— 2009: Mountain vegetation under environmental change. – Pp. 25-30 in: Jandl, R., Borsdorf, A., Van Meigroet, H., Lackner, R. & Psenner, R. (eds): Global change and sustainable development in mountain regions. – Innsbruck.

— 2011: Coldest places on earth with angiosperm plant life. – Alpine Bot. **121:** 11-22. https://doi.org/10.1007/s00035-011-0089-1

—, Ohsawa, M., Sphen, E., Berge, E., Bugmann, H., Groombridge, B., Hamilton, L., Hofer, T., Ives, J., Jodha, N., Messerli, B., Pratt, J., Price, M., Reasoner, M., Rodgers, A., Thonell, J., Yashina, M., Baron, J., Barry, R., Blasis, J., Bradley, R., Hofstede, R., Kapos, V., Leavitt, P., Monson, R., Nagy, L., Schindler, D., Vinebrooke, D. & Watanabe, T. 2005: Mountain systems. – Pp. 881-716 in: Hassan, R. & Scholes, R. N. (eds): Ecosystems and human well-being: Current state and trends, eds. Ash, **1.** – Washington.

Kullman, L. & Oberg, L. 2009: Post-Little Ice Age tree line rise and climate warming in the Swedish Scandes: a landscape ecological perspective. – J. Ecol. **97(3):** 415-429. https://doi.org/10.1111/j.1365-2745.2009.01488.x

Larcher, W. 2012: Bioclimatic Temperatures in the High Alps. – In: Lütz, C. (ed.): Plants in Alpine Regions. – Vienna.

Molau, U. & Mølgaard, P. 1996: ITEX manual, 2nd ed. – Copenhagen.

Nagy, L. & Grabherr, G. 2009: The Biology of Alpine Habitats. – Oxford.

Nadelhoffer, K., Shaver, G., Fry, B., Giblin, A., Johnson, L. & McKane, R. 1996: ^{15}N natural abundances and N use by tundra plants. – Oecologia **107:** 386-394. https://doi.org/10.1007/bf00328456

Nakhutsrishvili, G. 1999: The vegetation of Georgia (Caucasus). – Braunn-Blanquetia **15:** 5-74.

— 2003: High mountain vegetation of the Caucasus Region. – Pp. 93-103 in: Nagu, L., Grabherr, G., Körner, C. & Thompson, D. B. A. (eds): Alpine Biodiversity in Europe, Ecological Studies. – Berlin, New York.

— 2013: The vegetation of Georgia (South Caucasus). – Heidelberg-London.

— & Gagnidze, R. 1999: Die Subnival und nival Hochgebirgsvegetation des Kaukasus. – Phytocoenosis **11:** 173-183.

—, Abdaladze, O. & Akhalkatsi, M. 2004: Global warming and Treeline. – Proc. Acad. Sci. Biol., Ser B., **2(3-4):** 87-90.

—, — & — 2006: Biotope types of the treeline of Central Greater Caucasus. – Pp. 211-225 in: Gafta, D. & Akeroyd, I. (eds): Nature Conservation (Concepts and Practice). – Berlin, Heiderberg.

—, — & Kikodze, A. 2005: Khevi, kazbegi Region. – Tbilisi.

—, Akhalkatsi, M. & Abdaladze, O. 2009: Main Treats to the Mountain Biodiversity in Georgia (the Caucasus). – Mount. Forum Bull. **9(2):** 18-20.

—, — & — 2013: First signs of transformation of alpine vegetation in the Caucasus as a result of climate warming (on the example of Kazbegi region). – Pp. 405-414 in: Pedrotti, F. (ed.): Colloques Phytosociologiques, **29.** – Camerino.

Pauli, H., Gottfried, M., Dirnböck, T., Dullingerm, S. & Grabherr, G. 2003: Assessing the long-term dynamics of endemic plants at summit habitats. – Pp. 196-207 in: Nagy, L., Grabherr, G., Körner, C. & Thompson, D. B. A. (eds): Alpine biodiversity in Europe - a Europe-wide assessment of biological richness and change, **167.** – Berlin, Heidelberg.

—, —, Hohenwallner, D., Reiter, K., Casale, R. & Grabherr, G. 2004: The GLORIA field manual Multi-summit approach. European Commission DC Research, European Commission. – Luxemburg.

—, —, Dullinger, S., Abdaladze, O., Akhalkatsi, M., Benito Alonso, J. L., Coldea, G., Dick, J., Erschbamer, B., Calzado, R. F., Ghosn, D., Holten, J. I., Kanka, R., Kazakis, G., Kollár, J., Larsson, P., Moiseev, P., Moiseev, D., Molau, U., Mesa, J. M., Nagy, L., Pelino, G., Puşcaş, M., Rossi, G., Stanisci, A., Syverhuset, A. O., Theurillat, J.-P., Tomaselli, M., Unterluggauer, P., Villar, L., Vittoz, P. & Grabherr, G. 2012: Recent plant diversity changes on Europe's mountain summits. – Science **336(6070):** 353-355. https://doi.org/10.1126/science.1219033

—, —, Lamprecht, A., Niessner, S., Rumpf, S., Winkler, M., Steinbauer, K. & Grabherr, G. 2015: GLORIA Field manual, standart multi-summit approach. Supplementary methods and extra approaches, 5th ed. – Vienna.

Reginster, I., Rounsevell, M. & Spangenberg, J. 2005: Development, Promision and Application of the ALARM project. – RTD Framework Programme 6 of the European Commission.

Rixen, T., Baum, A., Gaye, B. & Nagel, B. 2014: Seasonal and interannual variation in the nitrogen cycle in the Arabian Sea. – Biogeosciences **11:** 5733-5747. https://doi.org/10.5194/bg-11-5733-2014

Sakhokia, M. & Khutsishvili, E. 1975: Conspectus florae plantarum vascularium Chewii. – Tbilisi.

Scherrer, D. & Körner, Ch. 2010: Infra-red thermometry of alpine landscapes challenges climatic warming projections. – Global Change Biol. **16:** 2602-2613. https://doi.org/10.1111/j.1365-2486.2009.02122.x

— & — 2011: Topographically controlled thermal-habitat differentiation buffers alpine plant diversity against climate warming. – J. Biogeogr. **38:** 406-416. https://doi.org/10.1111/j.1365-2699.2010.02407.x

—, Schmid, S. & Körner, Ch. 2010: Elevational species shifts in a warmer climate are overestimated when based on weather station data. – Int. J. Biometeorol. **55:** 645-654. https://doi.org/10.1007/s00484-010-0364-7

Schröter, D., Cramer, W., Leemans, R., Prentice, I. C., Araújo, M. B., Arnell, N. W., Bondeau, A., Bugmann, H., Carter, T. R., Garcia, C. A., de la Vega-Leinert, A. C., Erhard, M., Ewert, F., Glendining, M., House, J. I., Kankaanpaa, S., Klein, R. J. T., Lavorel, S., Lindner, M., Metzger, M., Meyer, J., Mitchell, T. D., Reginster, I., Rounsevell, M., Sabate, S., Sitch, S., Smith, B., Smith, J., Smith, P., Sykes, M. T., Thonicke, K., Thuiller, W., Tuck, G., Zaehle, S., Zierl, B. 2005: Ecosystem service supply and vulnerability to global change in Europe. – Science **310:** 1333-1334. https://doi.org/10.1007/s10021-007-9028-9

Solomon, J., Shulkina, T. & Schatz, G. 2013: Red list of endemic plants of the Caucasus: Armenia, Azerbajan, Georgia, Iran, Russia, Turkey. – Monographs in Systematic Botany from the Missouri Botanical Garden (MSB), **125.** – Saint Louis.

—, Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. & Miller, H. L. 2007: Climate Change 2007 - The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. – Cambridge.

Spehn, E. & Rudmann-Maurer, K. 2010: Impact of climate change on mountain biodiversity in Europe. – Convention on the conservation of European wildlife and natural habitats. Strasburg.

Stanisci, A., Pelino, G. & Blasi, C. 2005: Vascular plant diversity and climate change in the alpine belt of the central Apennines (Italy). – Biodivers. Conserv. **14:** 1301-1318. https://doi.org/10.1007/s10531-004-9674-6

—, Frate, L., Morra Di Cella, U., Pelino, G., Petey, M., Siniscalco, C. & Carranza, M. L. 2014: Short-term signals of climate change in Italian vegetation: observations at two GLORIA sites. – Pl. Biosyst. **10:** 2-10. https://doi.org/10.1080/11263504.2014.968232

Togonidze, N. & Akhalkatsi, M. 2015: Variability of plant species diversity during the natural restoration of the subalpine birch forest in the Central Great Caucasus. – Turk. J. Bot. **39(3):** 458-471. https://doi.org/10.3906/bot-1404-19

Walther, G.-R., Beiβner, S. & Pott, R. (2005) Climate change and high mountain vegetation shifts. – In: Broll, G. & Keplin, B (eds): Mountain Ecosystem Studies in Treeline Ecology. – Berlin, Heidelberg.

Winkler, M., Lamprech, A., Steinbauer, K., Hülber, K., Treurillat, J.-P., Breiner, F., Choler, P., Ertl, S., Giron, G. A, Rossi, G., Vittoz, P., Akhalkatsi, M., Bay, Ch., Alonso, J. L., Bergström, T., Carranza, M. L., Corcket, E., Dick, J., Ershbamer, B., Calzado, R. F., Forsaa, A. M. R., Gavilan, G., Chosn, D., Gigauri, Kh., Huber, D., Kanka, R., Kazakiz, G., Klipp, M., Kollar, J., Kudernatsch, T., Lersso, P., Mallaun, M., Michelsen, O., Moiseev, P., Moiseev, D., Mollau, U., Mesa, J. M., di Cella, U. M., Nagy, L., Petey, M., Puscas, M., Rixen, Ch., Stanisci, A., Suen, M., Syverhuset, A. O., Tomaselli, M., Unterluggauer, P., Ursu, T., Villar, L., Gottfried, M. & Pauli, H. 2016: The rich sides of mountain summits - a pan-European view on aspect preferences of alpine plants. – J. Biogeog. **43:** 2261-2273.

Addresses of the authors:
Khatuna Gigauri[1], Otar Abdaladze[2], Arsen Bakhia[2], Zezva Asanidze[2] & Albina Mamedova[2],
[1]Georgian Institute of Public Affairs, 9 Ietim Gurji st., 0105, Tbilisi, Georgia.
[2]Alpine Ecosystems Research Program, Institute of Ecology, Ilia State University; 5 Cholokashvili Ave, 0162, Tbilisi, Georgia.