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ALPINE PLANT DISTRIBUTION AND THERMIC VEGETATION INDICATOR ON GLORIA SUMMITS IN THE CENTRAL GREATER CAUCASUS

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Abstract

The distribution of plant species within alpine areas is often directly related to climate or climate-influenced ecological factors. Responding to observed changes in plant species, cover and composition on the GLORIA summits in the Central Caucasus, an extensive setup of 1m x 1m permanent plots was established at the treeline-alpine zones and nival ecotone (between 2240 and 3024 m a.s.l.) on the main watershed range of the Central Greater Caucasus nearby the Cross Pass, Kazbegi region, Georgia. Recording was repeated in a representative selection of 64 quadrates in 2008. The local climatic factors - average soil T°C and growing degree days (GDD) did not show significant increasing trends. For detection of climate warming we used two indices: thermic vegetation indicator *S* and thermophilization indicator *D*. They were varying along altitudinal and exposition gradients. The thermic vegetation indicator decrease in all monitoring summits. The abundance rank of the dominant and endemic species did not change during monitoring period.

Key words: Alpine, Thermic vegetation indicator, Gloria summits, Thermophilization indicator.

Introduction

The earth's biosphere is currently experiencing and will continue to experience rapid climate change (Solomon *et al*., 2007; Arndt *et al*., 2010). Temperature change scenarios in Europe for 2080 vary regionally, but show a clear trend towards warming (Anon., 2007). The average projected increase in Europe ranges from 2.1° to 4.4°C, with considerable seasonal and regional variation of changes in precipitation (Schröter *et al*., 2005). A warming over all European regions is found, especially in last two decades, with slightly weaker amplitude than the global warming over north-western Europe, but a more intense warming (up to +3°C) in northern and eastern Europe in winter and in southern Europe in summer (Vautard *et al*., 2014). The precipitation decreases in Central/Southern Europe in summer, with changes reaching 20%.

In mountainous regions trends are even higher than in lowland (Böhm *et al*., 2001). In winter temperatures increase more than in summer (Jones & Moberg, 2003). 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 & Rudmann-Maurer, 2010).

Ecosystems of alpine life zone are considered to be particularly sensitive to warming because they are determined by low temperature conditions and they show the effects of climate change earlier and more clearly than some other ecosystems (Grabherr *et al*., 2001; Larcher, 2012). Low temperatures can affect plant growth through their influence on plant development and season length (Körner,1998b, 2005). A prolonged climate warming could not only enhance local species richness, but over the longer term is expected to reduce alpine biodiversity by driving cold-adapted species out of their distribution range (Grabherr *et al*., 1995; McCarty, 2001; Theurillat & Guisan, 2001; Pauli *et al*., 2012). 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 (Van de Ven *et al*., 2007; 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 *et al*., 2012) for climate change effects on vegetation in mountains all over Europe. These indices are assumed to represent the "thermophilic" and "cryophilic" status of vegetation. The results revealed that most of summits in Europe have positive thermophilization indicator.

In Georgia the mean air temperature during the period 1982-2003 increased by 0.8°C (Elizbarashvili *et al*., 2009). 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: Dullinger *et al*. (2007), Erschbamer *et al*. (2010, 2013), Gigauri *et al*. (2013, 2014), Gottfried *et al*. (2012), Pauli *et al*. (2012) and Nakhutsrishvili *et al*. (2013). Although the preliminary considerations on possible transformation of alpine vegetation of the Caucasus due to climate warming were already presented (Nakhutsrishvili *et al*., 1999, 2004). The aim of this study was to recognize if any species-specific change in plant distribution and variation thermic vegetation indicator reflect an effect of climate changes.

Materials and Methods

Study area: The Central Greater Caucasus was one of the initially selected European target regions for GLORIA studies (Pauli *et al*., 2004). In 2001 and 2008, field monitoring was carried out on the main watershed range of the Central Greater Caucasus in the Cross Pass area of the Kazbegi region of Georgia (Fig. 1a, b). 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 *et al*., 2005, 2006).The vegetation survey of the Kazbegi region and main threats to the alpine species and plant communities are given in the following sources: Nakhutsrishvili *et al.* (1999, 2005, 2006, 2009. 2013).

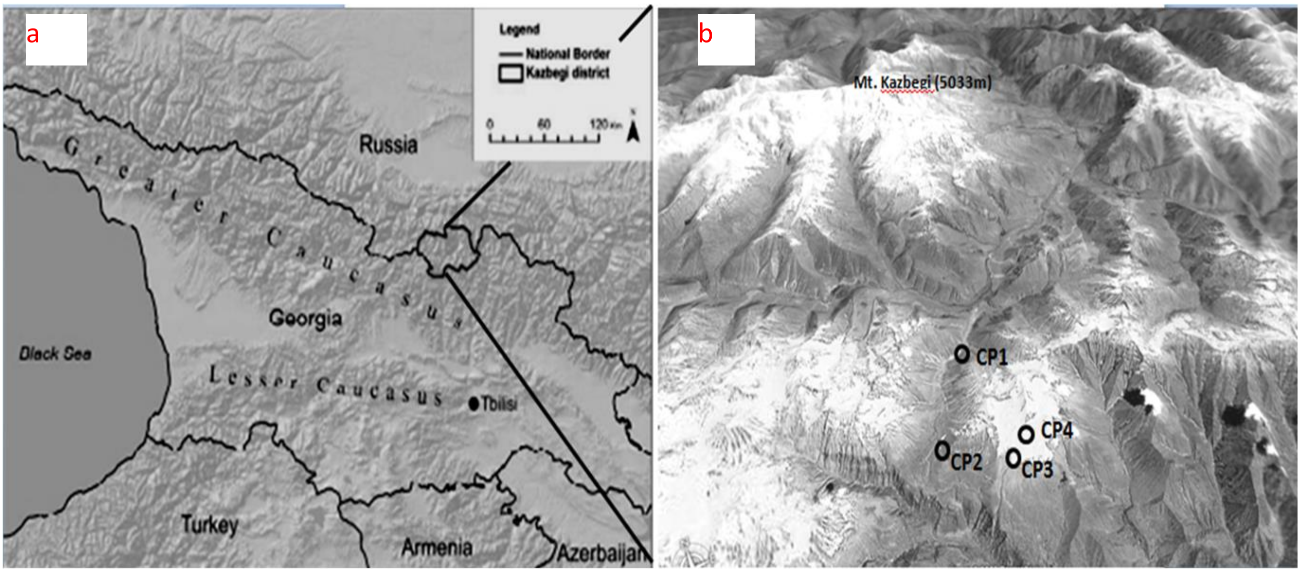

Fig. 1a. Location of the investigated high mountain GLORIA sites (Kazbegi region in the Central Greater Caucasus). b- Study summits in cross pass on the main watershed range of the Central Greater Caucasus: CP1 - 2240 m a.s.l.; CP2 - 2477 m a.s.l.; CP3 - 2815 m a.s.l.; CP4 - 3024 m a.s.l.

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 1). 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 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 (2815m 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.

Field measurements: The sampling design of the GLORIA-Europe project (Pauli *et al*., 2003) (Gloria-manual see also (http// www.gloria .ac. at) was used. 64 permanent plots in 1 m x 1 m were established for monitoring plant composition and frequency across the treeline-alpine-subnival ecotone in 2001.The positions of all 1 m x 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. In both years, all vascular plant species and their percentage covers were recorded (Gigauri *et al*., 2013, 2014).

In 2008, the reinvestigation involved two steps: (1) repeating the survey was conducted in 2001; (2) using the 2001 species data and the photo for comparison. In all cases where the species were readily visible on the photograph, we noted the cover difference, discernable by the plot/photo comparison, in a separate column. The cover values resulting from the second recording step documented the change in percentage cover of the species.

Soil temperatures were measured in 2002, 2005 and 2008 in the centre of the 3 m x 3 m grid in 10 cm soil depth by temperature data loggers (Onset Stow Away Tidbit – 20 to + 50 Model, USA). 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 *et al*., 1980). Minimum temperature was used because it is less influenced by solar radiation. Growing degree day (GDD) index was calculated using temperature data logger information on the number of days per year when soil upper layer mean temperatures were above 2°C (Molau & Molgaard, 1996). Altitudinal distribution ranges (AR) of the species were described according to Nakhutsrishvili *et al*. (2005, 2006).

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 *et 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:

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

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* hereafter ($D=S_{2008}-S_{2002}$) (Gottfried *et al*., 2012). We also calculated *Sørensen* coefficient for summits in 2001 and 2008 years using this formula - 2a/2a+b+c (where a - number of species common to both summit; b - number of species in one summit; c - number of species in other summit).

Species nomenclature is given according to Sakhokia and Khutsishvili (1975). 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).

Statistical analysis: All the statistical analysis were performed by using statistical software SPSS 16.0 for Windows (Hammer *et al*., 2001) and PCORD. 5. 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. We used ANOVA ($p<0.05$) post hoc range test to investigate whether the average soil T°C, minimum soil T°C, June minimum T°C and GDD changed in the 1m x 1m quadrates from 2001 to 2008. Mean, median, standard error, minimum and maximum were calculated for each quantitative data set.

We used a paired test (Sokal & Rohlf, 1981) and ordination analysis to analyze the changes of the thermic vegetation indicator at the permanent plots between the two periods of time (2002/2008). Polynomial regression by cubic effect was used for each graph to fit a nonlinear relationship between the value of x (GDD and June mean of daily minimum temperature) and the corresponding conditional mean of y (thermic vegetation indicator S).

We used Canonical Component Analysis (CCA) of the species cover in 1m x 1m permanent plots and Dominance Curves test of PCORD.5 statistic program in order to test the species composition and determine dominant species on each summits. The species are ranked by cover and abundance. According the Dominance test the most abundant species are given rank 1, less abundant species- rank 2 and so on (McCune & Mefford, 1999).

Results

Average soil temperature and GDD (growing degree day): The average soil temperature at the area varied highly significant between the monitoring years, with highest temperature in 2002 on all summits (Table 2a). Although according ANOVA post hoc test the difference between the maximum value of average soil temperature from lowest (CP1) to highest (CP4) summits was only 0.01 in 2002 years and 0.06 in 2008 (Table 2b).

At each summit significant GDD differences were detected with the highest divergences between south (154±3.48) and north (146±2.78). The statistical table show that GDD did not increase during monitoring years (Table 3).

Altitudinal distribution range (AR), t**he thermic vegetation indicator *S* and the thermophilization indicator *D*:** We calculated the thermic vegetation indicator *S* for the present (2008) and historic (2001) dataset. *S* varied at different altitude and exposition. Thermic vegetation indicator decreased significantly in all summits ($z=3.211$, $P=0.001$), especially on CP3 summit (Fig. 2).

D varied significantly at the plot level ($t = 3.2$, $df = 61$, $P = 0.032$) but the statistical significance is not high. The regression analysis was used to show that the difference of the thermic vegetation indicator *S* in the given period of time (2002/2008) was negative ($R^2= 0.015$, $F = 1.877$, $b1 = -0.030$, $P = 0.073$) but less significant. The present score of the thermic vegetation indicator *S* correlated with two climatic factors: June mean of daily minimum T °C ($r = 0.748$, $P = 0.031$) and GDD ($r = 0.576$, $p<0.012$) (Fig. 3 a, b).

In 2008 year only the frequency of montane-treeline species (AR 5) increased significantly (AR 5: $z =2.561$, $P=0.012$) (Table 4).

The difference between summits, Dominant species and coefficient of similarity: According ANOVA post hoc range test the difference between summits in 2002 and 2008 years was mostly significant ($p<0.001$). But in 2002 years the difference between CP1 and CP4 summits by average soil T°C and minimum soil T°C was not significant. In 2008 the difference by average soil temperature was significant, but the difference by minimum soil T°C is less significant. The difference between the same summits by June minimum T°C was significant in both years (Table 5a, b).

Using the Dominance Curve test of PCORD statistical program we determined the dominant species on each summit. In the table 6 we show only the species with high abundance rank from1 to 5. On the lower summits (CP1 and CP2) the dominant species were mostly grasses. One of them is Caucasus endemic (*Bromus variegatus*). On the higher summits (CP3 and CP4) only two species of grasses had high abundance rank: *Nardus stricta* (RankAbun-3) on CP3 and *Festuca varia* (RankAbun-1) on CP4. *Carex tristis* had high abundance rank on all summits, but on the lower summits the rank was higher than on the higher summits (Table 6). The abundance rank of less abundance species changed insignificantly in 2008 years. On CP1 summit the abundance rank of *Hieracium pannoniciforme* changed from 50 to 52 and *Cicerbrita racemosa*-from 49 to 51. On CP2 summit the abundance rank of *Luzula multiflora* changed from 66 to 63, *Rumex alpinus* - from 66 to 59 and *Primula algida* - from 50 to 52. On CP3 and CP4 summits the abundance rank of less abundant species did not change. The abundance rank of some endemic species (*Veronica telephiifolia, Draba hispida, Rhododendron caucasicum, Dryas caucasica)* did not decrease importantly during monitoring period. The coefficient of similarity (S_s- *Sørensen* coefficient) of the summits in 2001 and 2008 years was high (for CP1- 0.492; CP2- 0.489; CP3- 0.625; CP4- 0.487), especially for the CP3 summit.

Table 1. The characteristics of the study sites. Four summits at the cross pass (CP) of the main range of the Central Greater Caucasus.

Study summits	Elevation	Coordinates	Summit area (m^2)	Vegetation zone
CP1	2240	N44°29'35"; E 42°32'22"	1085.77	Treelineecotone
CP2	2477	N44°27'23";E 42°29'57"	9628.81	Lower alpine
CP3	2815	N44°30'04";E 42°29'44"	14974.31	Upper alpine
CP4	3024	N44°30'36";E 42°29'49"	3429.60	Subnival

Table 2. The changes of annual average soil temperature in 2002-2008 years (a) and on four summits (b) (CP1 - 2240 m a.s.l.; CP2 - 2477 m a.s.l.; CP3 - 2815 m a.s.l.; CP4 - 3024 m a.s.l;).

a)

Monitoring years	Minimum T°C	Maximum T°C	Mean	Std. Dev.	Std. Error mean
2002	10.9	14.7	12.43	1.118	0.395
2003	-0.38	4.86	2.99	1.639	0.579
2004	-0.93	5	2.79	1.771	0.626
2005	-0.52	3.64	2.54	1.313	0.464
2006	1.98	6.18	3.79	1.376	0.486
2007	0.82	5.07	3.14	1.426	0.504
2008	-4.75	3.32	0.95	2.695	0.952

b)

Summit	2002				
	Mean	St. Dev.	Std. Error mean	Minimum	Maximum
CP1	-0.884	0.2072	0.0518	-1.00	-0.54
CP2	0.705	0.2945	0.0736	0.42	0.99
CP3	0.420	0.0041	0.0004	0.42	0.42
CP4	0.625	0.1859	0.0882	-1.00	-0.53
			2008		
CP1	0.624	0.2679	0.0669	0.23	0.94
CP2	0.783	0.3479	0.8698	0.20	1.00
CP3	0.783	0.3250	0.0812	0.24	0.99
CP4	-0.232	0.8186	0.2047	-0.94	1.00

Table 3.The statistical table of the changes of GDD (growing degree day) during monitoring period (2002-2007).

	Mean	St. Dev.	St. Error mean	t	df	Mean difference	95% Interval lower	Confidence of mean upper	P
2002	1.556E2	11.913	4.208	36.9	7	155.62	145.67	165.57	0.001
2003	1.503E2	17.212	6.085	24.7	7	150.37	135.98	164.76	0.001
2004	1.147E2	18.156	6.419	22.9	7	147.25	132.07	162.42	<0.001
2006	1.148E2	14.456	5.107	29.0	7	148.12	136.04	160.20	0.002
2007	1.151E2	11.656	4.117	36.8	7	151.75	142.01	161.48	0.001

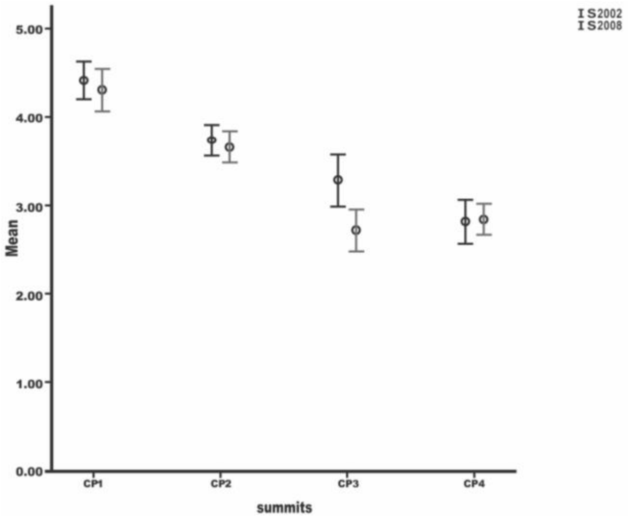

Fig. 2. The difference of the thermic vegetation indicator *S* in the given period of time (2002/2008) on four summits (CP1, CP2, CP3, CP4) in 2002 (black) and 2008 years (grey). (CP1 - 2240 m a.s.l.; CP2 - 2477 m a.s.l.; CP3 - 2815 m a.s.l.; CP4 - 3024 m a.s.l;)

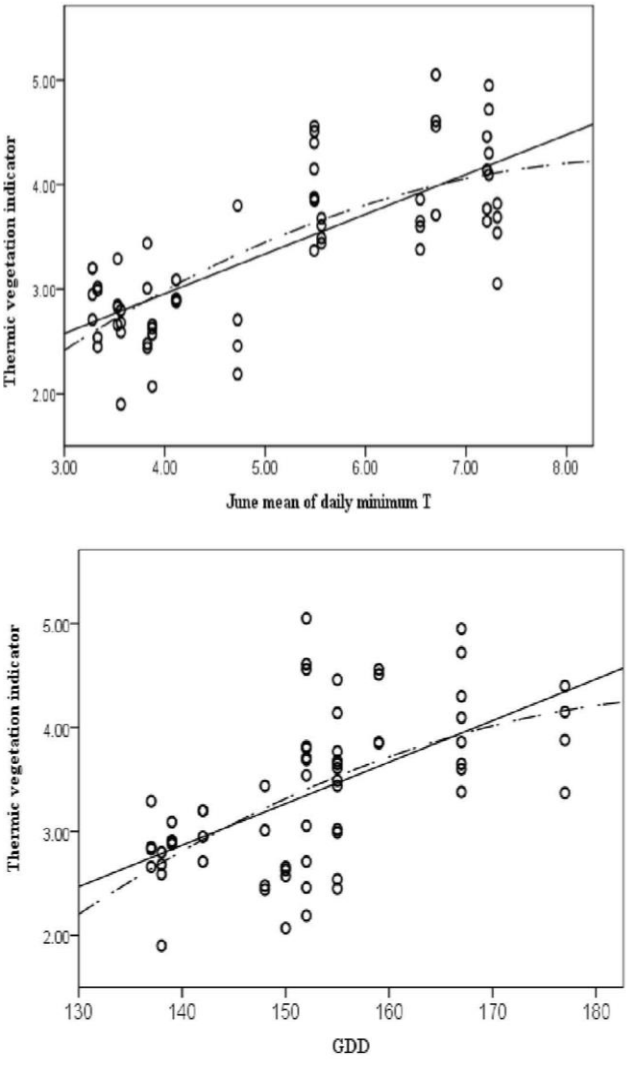

Fig. 3. Dependence of the present score (thermic vegetation indicator - 2008 year) on local climate. A- dependence on growing degree days (GDD). B –dependence on June mean of daily minimum temperature.

Table 4. Changes in AR frequencies between 2001-2008 years in the Central Greater Caucasus (significant $p<0.05$; ↑-increase, ↓-decrease).

AR (Altitudinal distribution range)	Trend	z	*P*
1	↓	0.899	0.217
2	↑	0.574	0.542
3	↑	0.167	0.753
4	↑	1.892	0.058
5	↑	2.561	**0.012**
6	↑	1.732	0.162

Discussion

The change in the thermic vegetation indicator exceeds the mean European summits increment and this is due to the expansion of thermophilic species (Stanisci *et al.*, 2014). Thermophilization of mountains plants communities and increase of warm-adapted species are the result of recent warming (Gottfried *et al.*, 2012). According to Pauli *et al.*, (2012) vascular plant species number increased on 45 GLORIA target regions (especially in the boreal temperate mountains) and decreased on 10 summits (mainly in Mediterranean region). Such alternation in Mediterranean areas is a result of warmer conditions the combination of rising temperatures and stable-to-decreasing precipitation sum such as was recently documented for the southern Europe for the past decades (Mariotti *et al.*, 2008; Del Rio *et al.*, 2011). This process is different in the Central Caucasus in contrast to the other boreal and temperate regions. During monitoring period (2001-2008) average annual soil temperature did not increase. Although in 2002 year 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. The segregation between CP1 and CP4 summits by minimum soil T°C also was not significant in 2002. It may be a direct effect of the exceptionally warm summer in this year. June mean of daily minimum temperature also was high in 2002, but decreased in the following years (Gigauri *et al.*, 2013).

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 *et al.*, 2012, Stanisci *et al.*, 2014). Vertical shifting of species was recorded in the Central Greater Caucasus in earlier publications (Nathutsrishvili, 2003; Akhalkatsi *et 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 *et al.* (2012) in other GLORIA target regions species were shifting their distribution by 2.7m on average.

Table 5. The results of ANOVA post hoc test. Multiple Comparisons between summits by variables in 2002 (a) and 2008 (b) years (CP1 - 2240 m a.s.l.; CP2 - 2477 m a.s.l.; CP3 - 2815 m a.s.l.; CP4 - 3024 m a.s.l.)

a)

Variables	Summit		Mean difference	St. Error mean	Sig.	95% Confidence Lower bound	Interval Upper bound
					2002		
Average T°C	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
	CP2	CP1	2.250	0.196	0.000	1.86	2.64
		CP3	0.500	0.196	0.013	0.11	0.89
		CP4	2.188	0.196	0.000	1.80	2.58
June min T°C	CP1	CP2	-0.01750	0.06629	0.793	-.1501	.1151
		CP3	0.10250	0.06629	0.127	-.0301	.2351
		CP4	-0.24750	0.06629	0.000	-.3801	-.1149
	CP2	CP1	0.01750	0.06629	0.793	-.1151	.1501
		CP3	0.12000	0.06629	0.075	-.0126	.2526
		CP4	-0.23000	0.06629	0.001	-.3626	-.0974
Minimum T°C	CP1	CP2	-8.000	0.946	0.000	-9.89	-6.11
		CP3	-10.250	0.946	0.000	-12.14	-8.36
		CP4	-0.250	0.946	**0.793**	-2.14	1.64
	CP2	CP1	8.000	0.946	0.000	6.11	9.89
		CP3	-2.250	0.946	0.021	-4.14	-0.36
		CP4	7.750	0.946	0.000	5.86	9.64

b)

Variables	Summit		Mean difference	St. Error mean	Sig.	95% Confidence Lower bound	Interval Upper bound
					2008		
Average T°C	CP1	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
	CP2	CP1	-0.60312	0.35767	0.097	-1.3186	0.1123
		CP3	0.09750	0.35767	0.786	-0.6179	0.8129
		CP4	3.99000	0.35767	0.000	3.2746	4.7054
June min T°C	CP1	CP2	0.43075	0.21659	0.051	-0.0025	0.8640
		CP3	2.71600	0.21659	0.000	2.2828	3.1492
		CP4	3.03400	0.21659	0.000	2.6008	3.4672
	CP2	CP1	-0.43075	0.21659	0.051	-0.8640	0.0025
		CP3	2.28525	0.21659	0.000	1.8520	2.7185
		CP4	2.60325	0.21659	0.000	2.1700	3.0365
Minimum T°C	CP1	CP2	-0.16250	1.70494	0.924	-3.5729	3.2479
		CP3	-6.04000	1.70494	0.001	-9.4504	-2.6296
		CP4	3.25000	1.70494	0.061	-0.1604	6.6604
	CP2	CP1	0.16250	1.70494	0.924	-3.2479	3.5729
		CP3	-5.87750	1.70494	0.001	-9.2879	-2.4671
		CP4	3.41250	1.70494	0.050	0.0021	6.8229

The thermic vegetation indicator *S* decreased significantly in all monitoring summits. An increment of S value could be expected when the frequency of species with high AR value increase or the frequency of species with low AR value decline. On summits of the Central Caucasus only species with AR5 increased their frequency significantly. The observed increase in monitoring plots mostly reflects a filling process of species that were already present in the alpine ecotone, rather than colonization of species immigrating from lower altitude (Gigauri. *et al*., 2013, Abdaladze *et al*., 2015). The same results were reported by Petriccione (2005) and Di Pietro *et al.* (2008). In the southwestern Apls species with AR 5 (e.g. *Festuca varia*) showed a consistence increased. In the Central Caucasus alpine grassland communities have strengthened their presence too. We used Dominance Curve test to determine dominant species on each summits (CP1, CP2, CP3, CP4) and to analyze how the annual local climate oscillations have influenced on the dominant species abundance. On the lower summits dominant species with high abundance were especially grasses. They are “key species” with high competitiveness and can inhibit newcomers by not leaving enough gaps for germination and establishment (Grabherr, 1989). When the abundance of “key species” decrease or they are removed, the result will be dramatic for plants communities. Experimental related to climate change in the tundra region showed that the grasses are more stable against local climate oscillation (Walker *et al*., 2006). The abundance of *Catex tristis* also was high on all four summits in 2001 and 2008. It is very important dominant plant of alpine grasslands. Sedges contributed to reduction of soil erosion (they generally form dense clumps or rhizomatous mats) and some sedges are tolerated of environmental stresses (Ratliff, 1983). Although according Alatalo *et al*. (2014) grasses and sedges respond differently to temperature and nutrient perturbation. During monitoring years *Carex tristis* was stable against local climate oscillation. During monitoring period the abundance of other dominant species did not change. The high value of the Sørensen coefficient of summits in 2001 and 2008 years clearly show that the composition of plots did not change noticeably. If the frequency of thermophilic species increases more in the future, cold-adapted species would be declined.

Table 6. The results of Dominance Test. Rank abundance and other statistical dates of the dominant species on each summit (CP1, CP2, CP3, CP4) in 2001 and 2008 years.

Species	Rank Abund 2001	Rank Abund 2008	Rank Freq.	Frequency	Mean	St. Dev.
CP1						
Carex tristis	1	1	1	13	9.906	8.948
Empetrum nigrum	2	2	6	4	5.187	11.956
Festuca airoides	3	3	5	9	4.094	6.563
Bromus variegatus	4	4	6	7	3.968	5.368
Agrostis capillaris	5	5	12	5	3.937	6.276
CP2						
Festuca varia	1	1	7	10	20.125	19.449
Carex tristis	2	2	2	14	12.200	3.228
Poa alpina	3	3	3	13	9.000	7.659
Anthoxantum odoratum	4	4	13	7	4.437	7.966
Festuca airoides	5	5	8	8	3.343	4.791
CP3						
Sibbaldia procumbens	1	1	1	16	23.750	8.690
Carex tristis	2	2	2	14	8.937	6.647
Nardus stricta	3	3	4	13	5.000	6.186
Plantago atrata	4	4	5	13	4.062	3.492
Carum Caucasicum	5	5	3	13	4.000	3.983
CP4						
Festuca varia	1	1	3	8	7.062	11.636
Alchemilla chlorosericea	2	2	1	12	4.562	3.794
Carex tristis	3	3	2	10	3.937	4.654
Anthemis iberica	4	4	6	6	1.312	2.750
Alchemilla retinervis	5	5	7	4	1.218	2.750

The regression analysis show that the thermophilization indicator *D* was negative, but the significance was low. 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. At the continental scale *D* was highly significant, but less at summit and plot levels (Gottfried *et al*., 2012). 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 (Nagy *et al*., 2002). Thus, it can be assumed that above-ground biomass which is related to cover does not change much from year to year (Pauli *et al*., 2003), but thermophilization of plants communities change in time intervals. According to Gottfried *et al*. (2012) the thermophilization indicator *D* was highly significantly positive on the 16 of the 17 GLORIA regions and 42 of the 60 summits and significantly correlated with June minimum T°C. *D* index also highly and positively correlated with winter precipitation. Due to this fact above mentioned authors explained why *D* was negative in Norwegians target region and positive in Scottish Cairngorms. The last one faced a dramatic reduction in winter precipitation with very much warming in June. In the Central Greater Caucasus precipitation have not reduce significantly during last decade (mean annual precipitation – 1412.07±112.07) (http://trmm.gsfc.nasa.gov/).We suppose that the less reduction of the precipitation may be the reason why our results are in contrast to the temperate European mountains. The decrease of thermic vegetation indicator in all summits has shown that the Central Caucasus faced no warming with high variation of June minimum T°C in 2002-2008 years.

GDD and June mean of daily minimum T°C correlated positively and significantly with the thermic vegetation indicator *S*, but the correlation between S index and GDD is more significant. S index is related also to June minimum T°C in all GlORIA regions with different slopes and strengths of correlation (Gottfried *et al*., 2002, 2012). These two factors often appear in the literature as key climatic factors for alpine vegetation (Körner, 2002, 2003, 2009, 2011; Larcher, 2012). GDD as proxy for snowfree season is important for seed ripening. June (i.e. early growing season) mean of daily minimum is important for cell growth. It is the temperature in the first part of the growing period which is the most decisive for plant growth. Both temperature indices are based on soil temperature and correlated with thermic vegetation indicator, so the changes these indices are very important for explaining mountain plant responses to changing climate. The increase of temperature and prolonged growing seasons promote the expansion of species from the lower altitudes (Erschbamer *et al.*, 2009). Although in our summits the average annual T°C and the length of growing season (GDD) did not show increasing trend.

The Central Greater Caucasus has high proportion of endemic plants (Nakhutsrishvili *et al*., 2006). When habitats of endemic species are damaged by human activity or other factors, the distribution range and population sizes of the species will be reduced. During study period on the GLORIA summits endemic species and cold-adapted plants were not endangered, their abundance rank did not change.

Conclusion

Thus, high mountain ecosystems are considered to react sensitively to the climate warming. A sustained change in climate is expected to cause changes in the composition of species and shift in plant distribution. The observed changes in average soil T°C and thermic vegetation indicator *S* indicate that the Central Greater Caucasus has faced no climate warming on this stage of monitoring. The abundance rank of the dominant species did not change. 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.

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References

Abdaladze, O., G. Nakhutsrishvili, K. Batsatsashvili, Kh. Gigauri, T. Jolokava and G. Mikeladze. 2015. Sensetive Alpine plant Communities to the Global Environmental Changes (Kazbegi region, the Central Great Caucasus). *Amer. J. Envi. Prote*., 4: 93-100.

Akhaikatsi, M., O. Abdaladze, G. Nakhutsrishvili and W.K. Smith. 2006. Facilitation of seedling microsites by *Rhododendron caucasicum* extend the *Betula litwinowii* alpine treeline, Caucasus Mountains, Republic of Georgia. *Arct. Antract. Alp. Res*., 38: 481-488.

Alatalo, J.M., Ch.J. Little, A.K. Jägerbrand and U. Molau. 2014. Dominance hierarchies, diversity and species richness of vascular plants in an alpine meadow: contrasting short and medium term responses to simulated global change. *Peer J*., 2: 2-18.

Arndt, D. S., M. O. Baringer and M. R. Johnson. 2010. State of the Climate in 2009. *B. Am. Meteorol. Soc*., 91: S1-S.

Böhm, R., I. Auer, M. Brunetti, M. Mauger, T. Nanni and W. Schöner. 2001. Regional temperature variability in the European Alps: 1760–1998 from homogenized instrumental time series. *Int. J. Climatol*., 21: 1779-1801.

Del Rio, S., L. Herrero, R. Fraile and A. Penas. 2011. Spatial distribution of recent rainfall trends in Spain (1961-2006). *Int. J. Climatol*., 31: 656-667.

Di Pietro, R., G. Pelino, A. Stanisci and C. Blasi. 2008. Phytosocological' Features of Adonis distorta and Trifolium Noricum subsp.praetutianum, two endemics of the Apennines (Penin-sular Italy). *Acta Bot.Croat*., 67(2): 175-200.

Dullinger, S., I. Kleinbauer , H. Pauli , M. Gottfried , Ch. Klettner, R. Brooker, L. Nagy, J-P. Theurillat, J. I. Holten, O. Abdaladze, J.L. Benito, J.L. Borel, G. Coldea, D.Ghosn, R.Kanka, A. Merzouki, C. Klettner, P. Moiseev, U. Molau, K.Reiter, G. Rossi, A. Stanisci, M.Tomaselli, P.Unterluggauer, P. Vittoz and G. Grabherr. 2007. Weak and variable relationships between environmental severity and small-scale co-occurrence in alpine plant communities. *J. Ecol*., 95: 1284-1295.

Elizbarashvili, E. Sh., R. Sh. Meskhiya, M.E. Elizbarashvili and L.D. Megrelidze. 2009. Climate Dynamics of Glaciers of the Greater Caucasus for the 20th Century. *Russ. Meteorol. Hydrol*., 34: 838-842.

Erschbamer, B., T. Kiebache, M. Mallaun and P. Unterluggauer. 2009. Short-term signals of climate change along an altitudinal gradient in the South Alps. *Plant Ecol*., 202:79-89.

Erschbamer, B., M. Mallaun, P. Unterluggauer, O. Abdaladze, M. Akhalkatsi and G. Nakhutsrishvili. 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.

Erschbamer, B., M. Mallaun, P. Unterlugauer, G. Nakhutsrishvili, M. Akhalkatsi and O. Abdaladze. 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). In: *Colloques Phytosociologiques*. (Ed.): F. Pedrotti, Camerino, pp. 167-188.

Gigauri, Kh, M. Akhalkatsi, G. Nakhutsrishvili and O. Abdaladze. 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.

Gigauri, Kh, M. Akhalkatsi, G. Nakhutsrishvili and O. Abdaladze. 2014. Vascular plant diversity and climate change in the alpine zone of the Central Greater Caucasus. *Int. J. Ecosys. & Ecol. Sci.,* 4(4): 573-578.

Gottfried, M. H., Paul, K. Reiter and G. Grabherr. 2002. Potential effects of climate change on alpine and nival plants in the Alps. In: (Eds.): Körner Ch. and E.M. Spehn. *Mountain Biodiversity-A Global Assessment*. Parthenon Publishing, London, New York, pp. 213-223.

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

Grabherr, G. 1989. On community structure in high alpine grasslands. *Vegetatio*, 83: 223-227.

Grabherr, G., W. Brzoska and H. Hofer. 1980. Energiebindung und Wirkungsgrad der Nettoprimärproduktion in einem Krummseggenrasen (*Caricetum Curvulae*) der Ötztaler Alpen, Tirol. *Acta Oecologia, Oecologia Plant*, 1 (15): 307-316.

Grabherr, G., M. Gottfried, A. Gruber and H. Pauli. 1995. Patterns and current changes in alpine plant diversity. In: *Arctic and alpine biodiversity: patterns, causes and ecosystem consequences.* (Eds.): Capin, F.S. III. and C. Körner. Ecological Studies 113. Springer, Berlin. pp. 167-181.

Grabherr, G., M. Gottfried and H. Pauli, 2001. Long-term monitoring of mountain peaks in the Alps. In:, *Biomonitoring: General and applied aspects on regional and global scales*. (Eds.): Burga, C.A. and A. Kratochwill. Vol 35. Tasks for Vegetation Science. Kluwer, Dordrecht, pp. 253-177.

Hammer, Ø., D. Harper and P.D. Ryan. 2001. PAST: Paleontological statistics software package for education and date analysis. *Paleontologia Electronica*, 4: 1-9.

Anonymous. 2007. Intergovernmental Panel of Climate Change. Climate change 2007: the physical science basis. Summary for policymakers. IPCC Secret, Geneva.

Jones, P.D. and A. Moberg. 2003. Hemispheric and large-scale surface air temperature variation: An extensive revision and an update to 2001. *J. Climate*, 16: 206-223.

Körner, Ch. 1998b. Alpine Plants: Stressed or adapted? In: *Physiological plant ecology*. (Eds.): M.C. Press, J.D. Scholes and M.G. Barker, Blackwell Science, Oxford. pp. 297-311.

Körner, Ch. 2002. Mountain biodiversity, its causes and function: an overview, In: *Mountain biodiversity: a global assessment*. (Eds.): Ch. Körner and EM. Spehn, Parthenon Publishing, London. pp. 3-20.

Körner, Ch. 2003. Alpine plant life: function plant ecology of high mountain ecosystems. Springer. Berlin-Heidelberg.

Körner, Ch. 2005. The green cover of mountains in a changing environment. In: *Global change and mountain regions. An overview of current Knowledge*. (Eds.): Huber, U.H., H. Bugmann and M. Reasoner, Springer, Berlin, pp. 367-375.

Körner, Ch. 2009. Mountain vegetation under environmental change. In: *Global change and sustainable development in mountain regions*. (Eds.): R. Jandl, A. Borsdorf, H. Van Meigroet, R. Lackner and R. Psenner, Innsbruck University Press, Innsbruck, pp. 25-30.

Körner, Ch. 2011. Coldest places on earth with angiosperm plant life. *Alpine Bot.*, 121: 11-22.

Larcher, W. 2012. Bioclimatic Temperatures in the High Alps. In: Lütz C. (Ed.), *Plants in Alpine Regions.* Springer, Vienna, pp. 21-27.

Mariotti, A., N. Zenge, J.H.Yoon, V. Artale, A. Navara and P. Apert. 2008. Mediterranean water cycle changes: transition to drier 21 st century condition in observation and CMIP3 simulation. *Envir. Res. Lett*., 3: 223-234.

McCarty, J.P. 2001. Ecological consequences of recent climate change. *Conserv. Biol*., 15: 320-331.

McCune, B. and M.J. Mefford. 1999. PC-ORD. Multivariate analysis of ecological data, Version 4, MjM Software Design, Gleneden Beach.

Molau, U. and P. Mølgaard. 1996. ITEX manual, 2nd ed. Danish Polar Center, Copenhagen.

Nagy, L. and G. Grabherr. 2009. The Biology of Alpine Habitats. Oxford University Press, Oxford.

Nagy, L., J. Nagy, C.J. Legg, D.I. Sales and D. Horsfield. 2002. Monitoring vegetation change caused by trampling: a study from the Cairngorms, Scotland. *Bot. J. Scotland*, 54(19): 191-207.

Nakhutsrishvili, G. 2003. High mountain vegetation of the Caucasus region. In: *Alpine Biodiversity in Europe – A Europe-wide Assessment of Biological Richness and Change*. (Eds.): Nagy, L., G. Grabherrb, C. Körner and D.B.A. Thomson. Ecological Studies, Vol. 167, Springer Berlin, Heidelberg, pp. 93-103.

Nakhutsrishvili, G., O. Abdaladze, N. Zazanashvili, T. Gamkrelidze and M. Chiboshvili. 1999. Excepted transformation of high-mountain vegetation of the Caucasus in connection with possible global climate change. In: *Georgia's Initial National Communication under the UN framework Convention on Climate Change*, (Eds.): Gzirishvili, T. and B. Beritashvili, Tbilisi. pp. 77-88.

Nakhutsrishvili, G., O. Abdaladze and M. Akhalkatsi. 2004. Global warming and Treeline. *Proceeding of the Georgian Academy of Science* 2: 87-90. (article in Georgian with an abstract in English)

Nakhutsrishvili, G., O. Abdaladze and A. Kikodze .2005. Khevi, Kazbegi Region. Institute of Botany, Tbilisi.

Nakhutsrishvili, G., M. Akhalkatsi and O. Abdaladze. 2006. Biotope type of the treeline of the Central Greater Caucasus. In: *Nature Conservation (Concepts and Practice*). (Eds.): D. Gafta and J. Akeroyd, Spinger Berline, Heidelberg, pp. 211-225.

Nakhutsrishvili, G., M. Akhalkati and O. Abdaladze. 2009. Main Treats to the Mountain Biodiversity in Georgia (the Caucasus). Mountain Forum Bulletin, 9(2): 18-19.

Nakhutsrishvili, G., M. Akhalkatsi and O. Abdaladze. 2013. First signs of transformation of alpine vegetation in the Caucasus as a result of climate warming (on the example of Kazbegi region). In: *Colloques Phytosociologiques,* (Eds.): F. Pedrotti, XXIX. Camerino, pp. 405-414.

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

Pauli, H., M. Gottfried, D. Hohenwallner, K. Reiter, R. Casale and G. Grabherr. 2004. The GLORIA field manual Multi-summit approach. European Commission DC Research, European Commissiom. Luxemburg, Office for official Publications of the European Communities.

Pauli, H., M. Gottfried, S. Dullinger, O. Abdaladze, M. Akhalkatsi, J.L. Benito Alonso, G. Coldea, J. Dick, B. Ershbamer, R. Fernandez Calzado, D. Ghosn, J. Holten, R. Kanka, G. Kazakis, J. Kollar, P. Larsson, P. Moiseev, D. Moiseev, U. Molau, J. Molero Mesa, L. Nagy, G. Pelino, M. Puscas, G. Rossi, A. Stanisci, A.O. Syverhuset, J.P. Theurillat, M. Tamaselli, P. Unterluggauer, L. Villar, P. Vittoz and G. Grabherr. 2012. Recent plant diversity changes on Europe's Mountain Summits. *Science* 20: 336-353.

Petriccione, B. 2005. Short-term changes in key plant communities of Central Apennines (Italy). *Acta Bot. Gallica*, 152: 545-561.

Ratliff, R.D. 1983. Nebraska Sedge observation of shoot history and management. *J. Range. Manage*., 36: 429-430.

Sakhokia, M. and E. Khutsishvili. 1975. Conspectus Florea PlantarumVasculanum, Chewii. Tbilisi, Metsniereba (article in Ruusian with an abstract in English).

Schröter, D., W. Cramer, R. Leemans, I.C. Prentice, M.B. Araujo, N.W. Arnell, A. Bondeau, H. Bugmann, T.R. Carter, C.A. Gracia. A.C. De la Vegas-Leinert, M. Erhard, F. Ewert, M. Glendining, J.I. House, S. Kankaanpää, R.J. Klein, S. Lavorel, M. Lindner, M.J. Metzger, J. Meyer, T.D. Mitchell, I. Reginster, M. Rounsevell, S. Sabate, S. Smith, B. Smith, J. Smith, P. Smith, M.T. Sykes, K. Thonicke, W. Thuiller, G. Tuck, S. Zaehle and B. Zierl. 2005. Ecosystem servise supply and vulnerability to global change in Europe. *Science*, 310: 1333-1341.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry: The principles and practice of statistics in biological research. San Francisco, Freeman Press.

Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H.L. Miller. 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 University Press, New York.

Spehn, E. and K. Rudmann-Maurer. 2010. Impact of climate change on mountain biodiversity in Europe. Convention on the conservation of European wildlife and natural habitats. Strasburg, pp. 1-23.

Stanisci, A., L. Frate, U. Morra Di Cella, G. Peleno, M. Petey, C. Siniscalco and M.L. Carranza. 2014. Short-term signals of climate change in Italian summit vegetation: Observations at two GLORIA sites. *Plant Biosyst.* DOI: 10.1080/11263504.2014.968232.

Theurillat, J.P. and A. Guisan. 2001. Potential impact of climate change on vegetation in the European Alps: a review. *Climatic Change*, 50: 77-109.

Togonidze, N. and M. Akhalkatsi. 2015. Variability of plant species diversity during the natural restorasion of the subalpine birch forest in the Central Great Caucasus. *Turk. J. Bot.*, 39 (3): 458-471.

Van de Ven, C.M., S.B. Weiss and W.G. Ernst. 2007. Plant species distributions under present conditions and forecasted for warmer climates in an arid mountain range. *Earth Interact*., 11: 1-3.

Vautard, R., A. Gobiet, S. Sobolowski, E. Kjellström, A. Stegehuis, P. Watkiss, T. Mendlik, O. Landgren, G. Nikulin, C. Teichmann and D. Jacob. 2014. The European climate under a 2°C global warming. *Environ. Res. Letter.*, 9: 2-11.

Walker, M.D., C.H. Wahren, R.D. Hollister, G.H.R. Henry, L.E. Ahlquist, J.M. Alatalo, M.S. Bret-Harte, M.P. Calef, T.V. Callaghan, A.B. Carroll, H.E. Epstein, I.S. Jonsdottir, J.A. Klein, B. Magnusson, U. Molau, S.F. Oberbauer, S.P. Rewa, C.H. Robinson, G.R. Shaver, K.N. Suding, C.C. Thomson, A. Tolvanen, O. Totland, P.L. Turner, C.E. Tweedie, P.J. Webber and P.A. Wookey. 2006. Plant community responses to experimental warming across the tundra biome. *P. Natl. Acad. Sci. USA.*, 103: 1342-1346.

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