
Sensitive Alpine Plant Communities to the Global Environmental Changes (Kazbegi Region, the Central Great Caucasus)

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Abstract: Sensitive plant communities are complexes of species particularly susceptible to global environmental changes (climate, land use, etc.). In the temperate zone alpine areas are considered as the most important “hot spots” in this respect. In the Central Great Caucasus, which is the traditional alpine vegetation monitoring site in the Caucasus, on the basis of 50-years long (1964-2014) phytosociological and ecological studies the most sensitive plant communities were distinguished: 1) Treeline ecotone communities, including: (a) Evergreen prostrate shrubbery dominated by *Rhododendron caucasicum*, (b) Dwarf semi-shrubbery dominated by *Dryas caucasica* and (c) Thermo-hygrophilous subalpine tall herbaceous vegetation dominated by *Heracleum sosnowskyi*; 2) Subalpine broad-leaved mesophilous meadows dominated by *Anemonastrum fasciculatum*, *Geranium ruprechtii*, *Betonica macrantha* and *Trollius ranunculinus*; 3) Alpine carpet-like meadows (“Alpine carpets”) consist of *Campanula biebersteiniana*, *Veronica gentianoides*, *Taraxacum porphyranthum*, *Sibbaldia semiglabra*, etc.; 4) Snow-bed vegetation (*Galanthus platyphyllus*, *Fritillaria latifolia*, etc.), and 5) Subnival/nival vegetation patches formed by 2-5(7) species (*Cerastium kasbek*, *Alopecurus dasyanthus*, *Tripleurospermum subnivale*, *Saxifraga sibirica*, *S. flagellaris*, *Delphinium caucasicum*, *Nepeta supina*, *Pseudovesicaria digitata*, *Symphyloma graveolens*, etc.). Totally habitats of these plant communities cover about 1/3 of Kazbegi region area. Temperature rise, decrease in precipitation will lead to abrupt decrease of already small areas covered by Tertiary’s relict tall herbaceous vegetation; elimination of a number of highly sensitive plant species including: relict, rare, endemic and critically endangered; disappearance of alpine snow-bed species. On account of early snow thawing or belated snowfall in autumn chionophyte plants (elfin, prostrate and dwarf shrubs and forbs in the alpine zone) sensitive to low moisture content, few and short-term snow cover and high temperature will lose. Probably sharp changes should be expected in subnival/nival zones, first of all, related to abrupt decrease in the glacier areas and subsequent increase in the distribution range of many species. According to the scenario suggested for the South Caucasus, which is based on predicted 3.9°C rise of temperature and decrease of precipitation by 9-13% during the century, it is expected that further climate warming may significantly change the vegetation and consequently the landscapes in the region. The vegetation may become similar to that of dry gorges of the Rocky Ridge of the Great Caucasus, which are situated 10-15 km to the north of the Kazbegi region.

Keywords: Caucasus, Climate Change, Sensitive Plant Communities, Alpine Plant Diversity

1. Introduction

The world climate continues steady warming. Global climate change and its ecological perspectives are the topical ecological problems of modernity [1]. The climate change effect will occur more or less in all ecosystems of the world,

but most acute and rapid changes will be expected in a highly sensitive alpine environment. The sensitivity of alpine species and plant communities are determined by low temperature conditions of alpine habitats [2-6]. Because of this, alpine environments of temperate zone are considered as the most important “hot spots” and alpine vegetation is viewed as the most noticeable bio-indicator [7-9]. Changing of low

temperatures limiting effects will have a sharp impact on the diversity of alpine vegetation. Species vertical (along the altitudinal gradient) and horizontal (along the geographic sites) migrations will be the most prominent effect due to climate change [10, 11]. As a result contemporary structure of vegetation, pattern of its spatial distribution formed during centuries will be disturbed, new plant communities will gradually develop, some species will disappear, and others will occupy new more or less suitable ecological niches. The mosaic structure of micro-relief in high mountains and hence highly heterogenous microclimate create diverse ecological niches, which will be very important for local plants to find shelters during vegetation transformation caused by climate change [12-14].

Sensitivity of alpine species is strongly dependent on plant living form, development rithm and other ecological peculiarities which determine vitality, competition, resistance, etc. [2, 9, 15-18].

Expected transformation of alpine vegetation threatens populations of species adapted to very specific ecological conditions; among such species are many rare, relict and endemic taxa. For this reason biodiversity degradation will become a real problem. These factors determine the importance of identification and ecological assessment of sensitive species and plant communities.

The goal of this study was to identify alpine species and plant communities sensitive to the global climate change in the Central Great Caucasus.

2. Study Area & Methods

Studies were conducted in the Kazbegi region, which is located (N 42°39'; E 44°37') on the extreme eastern, highest and geomorphologically the most complex central part of the Great Caucasus range (Fig. 1).

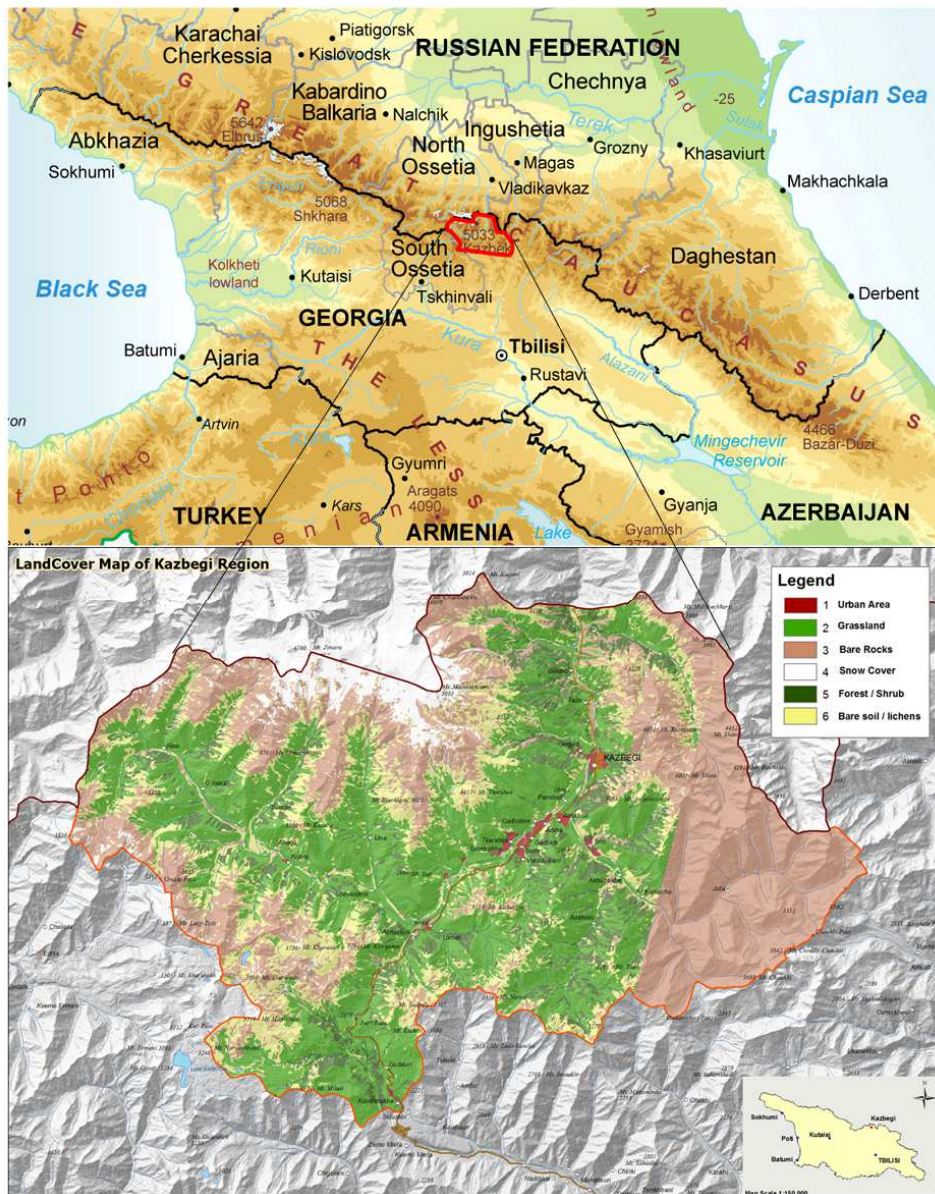


Figure 1. Location and main types of vegetation of the Kazbegi region (the Central Great Caucasus)

The study area is of volcanic origin. Topography is formed by Jurassic rocks, Paleozoic and even older granites, younger lava and moraines. Mountain massifs of the Kazbegi volcanic area are overlain by Quaternary glacial or river deposits and rock falls as well as major accumulations of calcareous tuffs and travertines. Glacial deposits occur in many places. 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. Ninety-nine big and small glaciers with different exposure and morphology are present in the region. The lowest, average and highest elevations of the region are 1210 m a.s.l., 2850 m a.s.l. and 5033 m a.s.l. (Mt. Kazbegi). Area of Kazbegi region is 1081.7 km² [19, 20]. The dominant soil types are: leptic, folic, aluminic, humic umbrisols [21].

The following factors determine the climate in the region: high elevations, complex topography, and location on north-facing macro-slope of the Great Caucasus. Tab. 1 represents some main characteristics of climate of the region. The climate type characteristic to upper forest-subalpine zones is moderately dry with short and cool summer and relatively cold winter. The climate type of subalpine-alpine zones is moderately moist, with short and cool summer and relatively dry and cold winter. The climate type of alpine-subnival zones is moderately dry and characterized by severe and long winter and absence of real summer. The climate type of subnival-nival zones is moderately moist, without summer and characterized by the permanent snow cover and ice [20, 22].

The Kazbegi region is characterized by rich flora. It contains 1112 vascular plant species, which makes up 27% of the total number of plants (about 4100 species; [23]) recorded in Georgia. The study area is characterized by a high richness of Caucasus endemic species (26%) and genera (6 out of 11) [18, 24-27], as well as high diversity of plant communities [20, 28].

The altitudinal zonation of the vegetation is well pronounced. Mountain forest fragments, shrubberies, rock and scree vegetation is typical in the mountain-forest zone (up to

1800/1850 m a.s.l.). The alpine vegetation can be divided into four zones: subalpine (1800/1850–2450/2500 m a.s.l.), alpine (2450/2500–2950/3000 m a.s.l.), subnival (2950/3000–3650/3700 m a.s.l.) and nival (> 3700 m a.s.l.) [18, 20, 22].

In the subalpine zone birch forests and elfin woodland (*Betula litwinowii*), shrub communities (*Rhododendron caucasicum*), herbaceous and tragacanthic (*Astragalus denudatus*) vegetation are typical remnants of natural vegetation types. However, vast grasslands, pastures and hay meadows characterized by e.g. *Festuca ovina*, *F. varia* subsp. *woronowii*, *Hordeum violaceum*, and *Bromopsis variegata* dominate in the subalpine landscape. The alpine zone is mainly characterized by grazed grasslands, which cover mountain ridges and south-facing steep slopes (dominated by *Festuca varia* subsp. *woronowii*), while the north-facing slopes are mainly covered with shrubs (*Rhododendron caucasicum*). Carpet-like meadows (where dicots mostly dominate), rock and scree vegetation are also well pronounced in the alpine zone. In the subnival zone vegetation is present as patches of few (2-5) species. In such micro-coenoses (nanocoenoses) cushion-like, dense-tussock and rosette life forms are predominate. In the nival zone only two species (*Cerastium kasbek*, *Alopecurus dasyanthus*) are recorded and they reach 4000 m a.s.l. [18, 20, 24, 25, 28]. In the Kazbegi region alpine vegetation is under long-term human impact [17].

Plant species were identified according to the following sources [29, 30]. Critical samples were compared with samples in the Herbarium of the Tbilisi Institute of Botany and with collection of Stepantsminda Alpine Ecology Institute of Ilia State University. Botanical nomenclature follows to [23, 30]. Phytosociological surveys have been carried out according to the cover-scale method [31, 32] during 1961-2014. The altitudinal differentiation of the vegetation as well as classification and nomenclature of plant communities are given according to [18]. ArcGIS Desktop version 9.3 (ESRI Inc., Redlands, CA) was used to calculate of areas covered by sensitive plant communities.

Table 1. Climate characteristics of the Kazbegi region (according to: Nakhutsrishvili, 2003; Nakhutsrishvili et al., 2005)

Vegetation zone/ Altitude (m a.s.l.)	Temperature of warm (July- August) months (°C)		Temperature of cold (January- February) months (°C)		Duration of snow cover (month)	Max. depth of snow cover (cm)	Average annual precipitation (mm)	Other information
	Ave.	Max.	Min.	Ave.				
Upper forest; Subalpine/ 1500-1900 m	14-18	33	-28	-5	3-5	≤ 80	780-800	In summer air humidity two times higher than in winter; in August number of clear, cloudless and hot days are 70%; Drought is often
Subalpine; Alpine/ 1900-2600 m	10-14	33	-30	-11	5-7	115-120	1000-1500	Number of foggy days: 135/yr; Winds are often
Alpine; Subnival/ 2600-3400 m	10	31	-30	-12	7-8	≤ 200	800-1000	In summer morning frosts and winds are often; Weather is strongly change during a day
Subnival; Nival/ > 3400 m	2.2	15	-33	-14	12	> 200	1000-1200	Number of windstorms: 12/month; Number of snowy days: 170/year

3. Results & Discussions

In the alpine landscape of temperate mountains upper timberline is the most noticeable and well marked phenomenon. The treeline ecotone has various important ecological functions, such as: protection against avalanches, landslides, mud-flows, debris-flows and soil erosion; regulation of water balance in lowlands; creation of natural reservoir of clean water; maintenance high species diversity, etc. [33, 34]. The treeline plant communities of the Kazbegi region are distinguished by exceptional diversity, which is expressed in the contrasting species composition and caused by various ecological conditions [22, 35]. High degree of species richness is mainly due to peculiar structural properties of plant communities, rather than ecological and human factors [28]. In the treeline ecotone of the Kazbegi region the following ecosystems should be referred to as highly sensitive: a) Evergreen prostrate shrubbery dominated by *Rhododendron caucasicum*; b) Dwarf semi-shrub community dominated by *Dryas caucasica*; c) Thermo-hygrophilous subalpine tall herbaceous vegetation (Megaphorbia); d) Subalpine broad-leaved meadows dominated by *Anemonastrum fasciculatum*, *Trollius ranunculinus*, *Geranium ruprechtii* and *Betonica macrantha*.

The sensitivity of above mentioned plant communities is caused by: high slope degree (35-750), not well-formed and mobile soil cover, frequent solifluction, insignificant and/or short-term snow cover, etc. In Georgia droughts, high air and soil temperatures of the recent years [36] have particularly affected chionophils (*Daphne glomerata*, *Rhododendron caucasicum*, *Vaccinium myrtillus*, *V. vitis-idaea*, *Empetrum caucasicum*) widely presented on north-facing slopes in evergreen *Rhododendron* shrubbery. Withering of *Rh. caucasicum* leaves and noticeable decline of *Daphne glomerata* are observed in the treeline ecotone. Some other factors also invoke the significant suppression of *Rh. caucasicum* vitality. For example, after snowless winter in spring insufficient snow thaw rapidly at the edges of *Rhododendron* thickets and high solar radiation and warm air provoke photoinhibition and “winter drought” phenomena (Fig. 2; [16]). Mass withering of *Rh. caucasicum* will have strong negative impact on elfin shrubs and rare stenotopic herbs, which grow within the dense thickets in very specific ecological conditions. It will also break important facilitation relationships with main forest forming species in the region (*Betula litwinowii*). Dense thickets of *Rh. caucasicum* promotes establishment of birch seedlings in the treeline ecotone [37, 38].

The area occupied by dwarf semi-shrub *Dryas caucasica* is not large and covers skeletal and stony calcareous soils on steep (20-500) slopes with North and North-West aspects between 2000-2600 m a.s.l.. Normally it grows on slopes with dense snow cover, often in the avalanche places. At present its area is significantly reduced. In the lower boundary of its distribution (2000-2200 m a.s.l.) only single and suppressed individuals can be found.

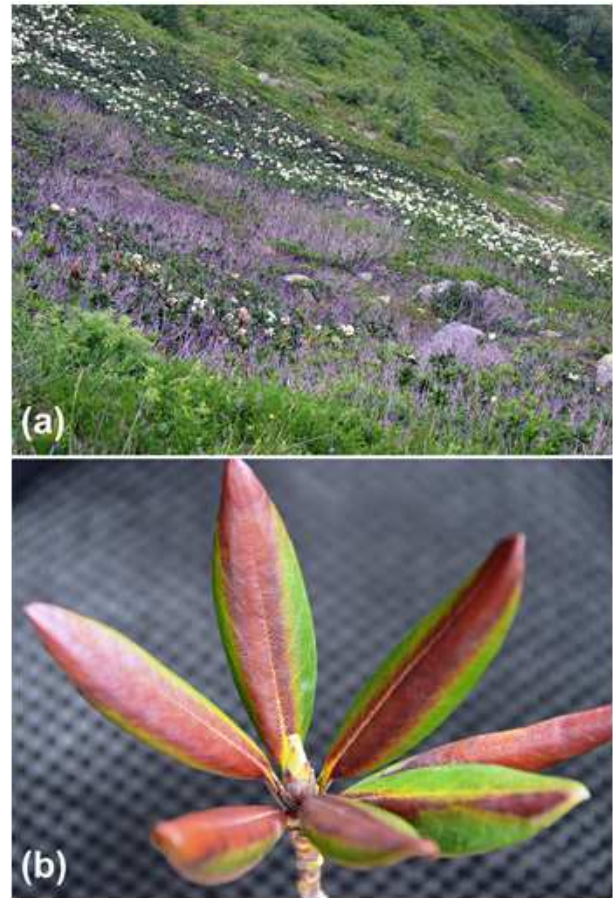


Figure 2. Damaged *Rhododendron caucasicum* thickets due to winter drought (a) and damaged leaves due to high insolation (b) in the treeline ecotone of the Kazbegi region

Our studies have shown, that the habitat of special natural phenomenon represented by stenotopic Tertiary relict thermo-hygrophilous subalpine tall herbaceous vegetation has a specific character: a) variable slope angle (between 1-20 and 600) and all available exposures; b) optimal air (15-21°C) and soil (10-14°C) temperatures without strong daily fluctuations; c) high level of soil moisture (33-62%) and air humidity (58-89%), including frequent horizontal precipitation (fog); d) low or moderate illumination (800-1300 $\mu\text{mol photons}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$); e) rich soils usually with near neutral pH (5-7), etc. This type of vegetation is composed of tall (1.8-2.5 m, rarely >3 m) forbs (chiefly dicots) and grasses. They are characterized by rosetteless shoots, short top roots and rhizomes. Stratification is not observed in the canopy. Species richness of an individual community is not high (from 13 up to 33). Soil pH measurements revealed that tall herbaceous vegetation is confined to weak acid soils. It is known that in such type of soils humus horizon is well developed and mineralization is rather high [39]. It is also mentioned that the weak acid reaction of the soil helps to increase respiration of root system [40]. Soil temperature and moisture also influence CO₂ output, although effect of these factors depends on vegetation type [41, 42]. Temperature increase may dry out

soil upper layer, change soil pH and after certain time decrease mineralization rate. At the same time, if pool of nutrients will not correspond to excess CO₂, flower and fruit development will decrease [16]. These processes may create some threats to tall herbaceous vegetation, which is strongly adapted to the certain environmental conditions. Tall herbaceous vegetation is one of the main bio-indicators for climate warming. It is very sensitive to the fluctuations of temperature and humidity. Recent droughts have had negative influence on the development of such species as: *Senecio rhombifolius*, *S. propinquus*, *S. othonnae*, *Aconitum nasutum*, *A. orientale*, *Swertia iberica*, *Gadalia lactiflora*, *Dolychorhiza renifolia*, *Heracleum sosnowskyi*, *H. roseum*, *Cicerbita racemosa*, *Polemonium caucasicum*, *Delphinium flexuosum*, *Aquilegia caucasica*, *Asyneuma campanuloides*, *Doronicum macrophyllum*, *Inula helenium*, *I. magnifica*, *Lilium monadelphum* subsp. *georgicum*, *Valeriana tiliifolia*, *Cephalaria gigantea*, *Calamagrostis arundinacea*, etc. Totally 85 tall herbaceous species are mentioned in the Central Caucasus [18]. In particular, plants will not grow properly; undeveloped inflorescence will be observed; flowers will be open permanently; early senescence and even complete wilting of leaves will occur [20, 28].

Current climate warming will induce drastic changes in subalpine mesophilous broad-leaved meadows. Some of these meadows are associated with cool habitats above timberline, and some of them – with secondary meadows in the forest zone, on gentle or slightly sloping hillsides ($\leq 10^\circ$) of both subalpine and alpine zones. Species composition in the plant communities will change due to soil drying, and populations of such species as: *Anemonastrum fasciculatum*, *Trollius ranunculinus*, *Geranium ruprechtii* and *Betonica macrantha* will decline, or even some taxa will disappear.

Besides above mentioned sensitive treeline ecotone habitats there are some other ones as well. These are: a) Snow-bed patchy vegetation; b) “Alpine carpets” and c) Subnival plant communities. The snow-bed vegetation mostly occupies shady and wet cirques and small relief depressions with long-term snow cover and cool microclimate. These communities strongly depend on snowmelt water. Especially stress-dominated situations are observed in early spring flowering species (*Galanthus platyphyllus*, *Fritillaria latifolia*, *F. lutea*, *Ficaria calthifolia*, *P. auriculata*). For example, in the habitats of early spring geophyte (*G. platyphyllus*) the highest level of temperature and moisture stress probability was observed in the areas completely clear from snow cover, where plants are in the phase of fruiting. Individuals which start their flowering phase at the edges of snow-beds were in somewhat better hydro-thermal conditions than individuals in the snow cover.

Snow cover reduction caused by climate warming and early snowmelt will drastically change the ecological situation. Because of this the snow-bed plant communities could be considered as highly sensitive, as well as carpet-like alpine meadows (“Alpine carpets”) occurring in the upper part of the alpine zone. These small plant communities are found among large stones and moraines. They are predominantly composed

of *Campanula biebersteiniana*, *Veronica gentianoides*, *Taraxacum porphyranthum*, *Gnaphalium supinum*, *Sibbaldia semiglabra*, *Poa alpina*, *Pedicularis crassirostris*. “Alpine carpets” which occur around the permanent snow spots and at the edges of glaciers contain the following species: *Ranunculus oreophilus* var. *pumilus*, *R. baidarae*, *Primula algida*, *Gentiana djimilensis* (= *G. pyrenaica*), *G. angulosa*, *G. nivalis*, *Corydalis emanueli*, *Minuartia aizoides*, *Cerastium cerastoides*, etc. “Alpine carpets” differ from true alpine meadows by their floristic composition and ecological peculiarities. Due to the lasting snow cover, they are characterized by short vegetative period. Herb cover does not exceed 3-4 cm, and 80% of aboveground phytomass is accumulated near the soil surface. Besides the climax “alpine carpets”, secondary ones, enriched mainly by *Alchemilla* species, are present widely. Their development is caused by overgrazing. They occupy the most exploited alpine pastures [18, 22, 28].

At the edge of alpine and subnival zone climatic and edaphic conditions become more severe and only few species are adapted to them [1, 4, 6, 15]. In the Central Great Caucasus in the subnival zone vegetation is represented by individuals, or by small patches, which consist of 2-5(7) species. These are mostly cushion, trellis-like, tussock and rosette living form plants [26]. These plant ultra-microgroupings or micro-coenoses are determined as nanocoenoses [22]. The “hosting plants” of these nanocoenoses create microclimate, which use some other species [43, 44] among which are many rare, relict and endemic plants [18, 25, 27]. The majority of subnival/nival species are chionophytes: they need deep and long-term snow cover for successful wintering. Probably sharp climatic changes in subnival/nival zones enforce plants to change habitats: move upwards, or even change slope aspect. During these processes a number of species might lose their habitats and completely disappear, populations of some others will be depressed and decreased, and vegetation patches will change their composition and areas.

A number of studies in the worldwide (GLORIA Project first monitoring cycle – 2001-2008) has shown that area of some alpine species, distribution character and vitality were changed due to of climate change [45]. According to these study vascular plant species number increased on 45 GLORIA target regions (especially in the boreal-to temperate mountains) and decreased on 10 summits. Such alteration is a result of warmer conditions; the combination of rising summer temperatures and stable to decreasing precipitation, which was recently documented for southern Europe for the past decades [46, 47]. In the Central Great Caucasus GLORIA studies have shown insignificant increase in the abundance of resistant species individuals. This was recorded in parallel with an insignificant decrease in abundance of sensitive species. In subnival zone the changes are more visible, as a number of alpine species can be found at unusually high altitudes. In spite of this species migration processes from lower altitudes was not observed yet. Therefore, all of these changes must be considered as local fluctuations, and not as a succession phenomenon [48-52].

According to the scenario suggested for the South Caucasus and particularly the Central Great Caucasus which is based on predicted 3.9°C rise of temperature and precipitation decrease by 9-13% during a century [53], it is expected that further climate warming may significantly change the vegetation and consequently the landscapes in the region. Vegetation change models based on these data predict subalpine zone rise by 400-500 m. Subnival/nival zones will also rise by 500-600 m. This will be problematic to species occurring on plane areas at high elevation. These species are adapted to wintering under deep and long-term snow cover. It is doubtful that they can survive on steep slopes of the peaks. At the same time low competitiveness of subnival/nival plants may cause their suppression by expansion of subalpine and alpine plants. The worst predictions are plausible for such rare endemic species of monotypic genera as *Symphyloma graveolens* and *Pseudovesicaria digitata*. The vegetation of Kazbegi region will resemble to that of dry gorges of the Rocky Ridge of the Great Caucasus, which are situated 10-15 km north of the Kazbegi region, in Russian Federation.

All above mentioned types of alpine vegetation are rather sensitive not only to the climate change, but also to damage by grazing, trampling and other human impacts [17, 18, 20]. Besides, they are characterized by low ability for natural recovery. The total area covered with habitats of sensitive plant communities is rather significant and reaches about 1/3 of the Kazbegi region area (Fig. 3).

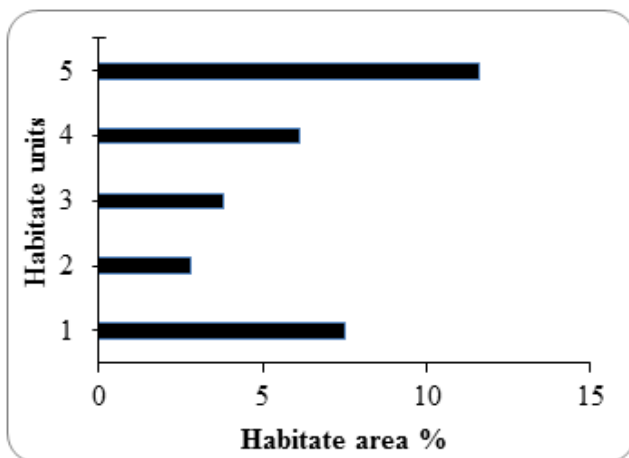


Figure 3. Proportion of sensitive plant community habitats from the total area of the Kazbegi region (1 – *Rhododendretum caucasicum* and *Betuletum litwinowii* together; 2 - *Dryetum caucasicum*; 3 - Broadleaf mesophilous meadows; 4 – Tall herbaceous vegetation and snowbed vegetation together; 5 – Subnival/Nival vegetation patches

Transformation of sensitive alpine vegetation due to of climate global warming will drastically change phytolandscapes in the Central Great Caucasus.

4. Conclusions

In the Kazbegi region (the Central Great Caucasus) on the basis of long-term phytosociological and ecological studies the most sensitive plant communities were distinguished: 1)

Alpine treeline ecotone communities: (a) Prostrate evergreen shrubbery dominated by *Rhododendron caucasicum*, (b) dwarf-shrub community dominated by *Dryas caucasicum*; (c) Tertiary's relict thermo-hygrophilous subalpine tall herbaceous vegetation dominated by *Heracleum sosnowskyi*, *Aconitum nasutum*, *Senecio rhombifolius*, etc.; 2) Subalpine broad-leaved mesophilous meadows dominated by *Anemonastrum fasciculatum*, *Trollius ranunculinus*, *Geranium ruprechtii* and *Betonica macrantha*; 3) Alpine carpet-like meadows ("Alpine carpets") represented by *Campanula biebersteiniana*, *Veronica gentianoides*, *Corydalis emanueli*, *Taraxacum porphyranthum*, *Sibbaldia semiglabra*, *Poa alpina*, etc.; 4) Snow-bed vegetation (*Galanthus platyphyllus*, *Fritillaria latifolia*, *Primula auriculata*); 5) Subnival/nival vegetation patches consist of few (2-5) species: *Delphinium caucasicum*, *Cerastium kasbek*, *Saxifraga flagellaris*, *S. Sibirica*, *Alopecurus glacialis*, *A. Dasyanthus*, *Nepeta supina*, *Tripleurospermum subnivale*, *Pseudovesicaria digitata*, *Symphyloma graveolens*.

Further climate warming may significantly change the vegetation and consequently the phytolandscapes in the Central Great Caucasus.

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