

## Article

# Altitudinal Vascular Plant Richness and Climate Change in the Alpine Zone of the Lefka Ori, Crete

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**Abstract:** High mountain zones in the Mediterranean area are considered more vulnerable in comparison to lower altitudes zones. Lefka Ori massif, a global biodiversity hotspot on the island of Crete is part of the Global Observation Research Initiative in Alpine Environments (GLORIA) monitoring network. The paper examines species and vegetation changes with respect to climate and altitude over a seven-year period (2001–2008) at a range of spatial scales (10 m Summit Area Section-SAS, 5 m SAS, 1 m<sup>2</sup>) using the GLORIA protocol in a re-survey of four mountain summits (1664 m–2339 m). The absolute species loss between 2001–2008 was 4, among which were 2 endemics. At the scale of individual summits, the highest changes were recorded at the lower summits with absolute species loss 4 in both cases. Paired *t*-tests for the total species richness at 1 m<sup>2</sup> between 2001–2008, showed no significant differences. No significant differences were found at the individual summit level neither at the 5 m SAS or the 10 m SAS. Time series analysis reveals that soil mean annual temperature is increasing at all summits. Linear regressions with the climatic variables show a positive effect on species richness at the 5 m and 10 m SAS as well as species changes at the 5 m SAS. In particular, June mean temperature has the highest predictive power for species changes at the 5 m SAS. Recorded changes in species richness point more towards fluctuations within a plant community's normal range, although there seem to be more significant diversity changes in higher summits related to aspects. Our work provides additional evidence to assess the effects of climate change on plant diversity in Mediterranean mountains and particularly those of islands which remain understudied.



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**Keywords:** islands; GLORIA; Greece; mountains; re-visitation study; species turnover

## 1. Introduction

Global warming represents one of the most significant threats to biodiversity, worldwide [1] with some studies [2] tentatively forecasting the loss of 1 million living species by 2040. During the last two decades, evidence of global warming has accumulated and has been documented in the periodical IPCC reports [3,4] with the most recent report [5] suggesting a warming of 0.85 (0.65 to 1.06) °C, over the past two centuries. In alpine areas, climate drives plant species distribution [6,7] and this is the main reason why they are considered sensitive to any future climate changes [6,7] and why alpine ecosystems may serve as case studies to detect early indications of such changes [8]. Empirical studies in the Alps [7,9–11] provided already evidence that many plants have extended their altitudinal range as a result of recent climate warming. Species richness in high alpine mountains has also revealed considerable alterations [7,11–15]. According to future projections for 2100, at

low altitude mountain ranges, half of the total species might be at risk [16], with rare and endemic species being particularly vulnerable to climatic changes [17], a general concern also for subnival–nival species [7].

For the Mediterranean Basin, future warming is expected to exceed global rates by 25% [18] with regional climate models predicting a sharp decrease in precipitation coupled with increasing summer temperatures [19–21]. In the case of mountain areas, worldwide changes in temperature and precipitation are projected higher than other regions [4], with Southern European mountains being more vulnerable to climate change [22]. For Mediterranean mountains, projections of future climate, under different emission scenarios and Atmosphere-Ocean-Coupled General Circulation Models, predict warming over 1.4 °C and a reduction of precipitation over −4.8% until 2085 (which vary according to the employed scenarios) [22].

The overall picture of several global change scenarios [23] is that significant biodiversity loss is likely in the Mediterranean mountains, due to habitat tracking problems and interspecific competition. Higher temperatures in mountain regions will lead to an upward shift of biotic zones and a possible decrease in endemic species [3,24]. In Europe, there is already evidence for shifting of vegetation belts and species distribution ranges [9,25–27] which are likely to continue in the future [28,29]. European-wide mountain studies report an increase in plant species richness [30] over a 145-year period, with significant abundance changes for species in highest elevations [31]. In particular, a synthesis on plant diversity changes across European summits showed that on Mediterranean summits species gains were outstripped by losses of cryophilic species, resulting in a net species loss of on average 1.4 species over a seven-year period [32].

Evidence on how climate change affects the flora of Mediterranean is relatively limited [33–35] with few field based monitoring studies [36,37]. The largest Mediterranean islands are in their majority mountainous and considered global biodiversity hotspots [38,39], for which there is a substantial body of climatic and ecological biological evidence on the impacts of climate change (see reviews in [40,41]). On those islands, mountain massifs are very important in the context of national and international biodiversity and the Lefka Ori in Crete is such an example [42,43].

The vegetation formations of the Lefka Ori above the tree line are typical of the oro-Mediterranean and alti-Mediterranean zone [44,45] of the Mediterranean mountains and comprise either low prickly scrub formations or communities of spiny cushion-shaped dwarf shrubs [45,46]. Recognizing its ecological importance, Lefka Ori has been included in the Global Observation Research Initiative in Alpine Environments (GLORIA) network (see [www.gloria.ac.at](http://www.gloria.ac.at)). GLORIA is an international long-term observation network in alpine environments to detect impacts of climate change on mountain ecosystems. In 2001, the first field baseline data in GLORIA-Europe were collected from 18 target regions, amongst which is the Lefka Ori massif in Crete [35]. Variation among summits in species richness and measures of similarity have been recorded for GLORIA summits in Europe [11,34,35,47], in New Zealand [48] and in Australia [49]. Changes in species richness and composition, paralleling changes in temperature, have also been identified in many European mountain regions [7,11,15].

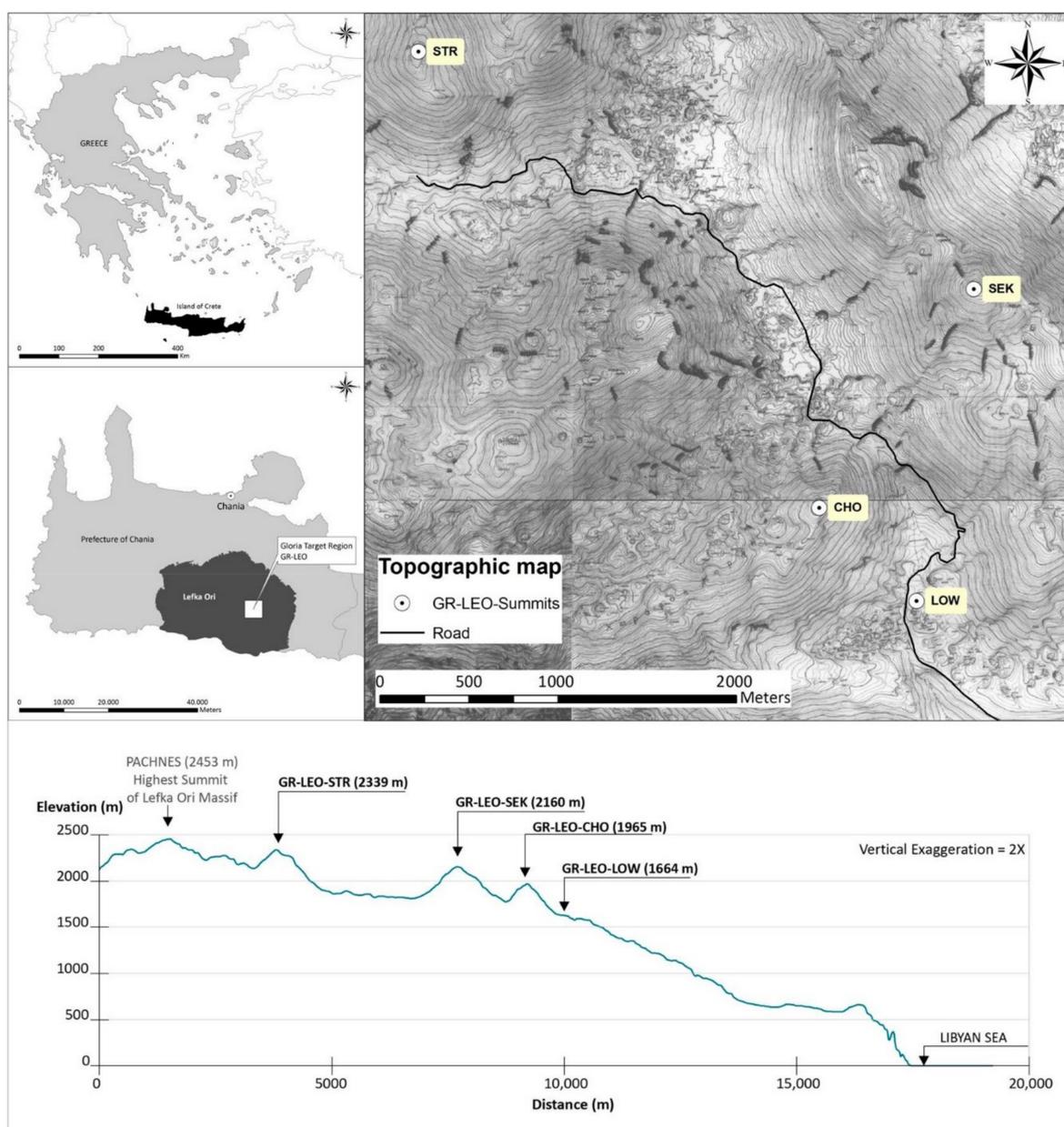
This paper is part of the GLORIA project methodological framework [8] which consists of re-visitation of summit-areas worldwide, including the Lefka Ori, every seven years. Therefore, the focus herein is on the vegetation and species patterns of four high summits on the massif. The importance of this work is twofold. This is the first consistent monitoring scheme of this kind in Greek mountains and the second in a Mediterranean island mountain. Moreover, the work provides additional evidence to the effects of climate change on plant biodiversity in Mediterranean mountains and particularly those of islands which remain understudied. The aim of this study is to detect species' and vegetation change across four summits, which were first surveyed in 2001 [35] and re-surveyed in 2008 using the same GLORIA protocol. In order to achieve this aim, the paper addresses the following questions:

- What are the changes in sub-surface temperature?
- What are the changes in species richness, species, and vegetation turnover?
- Are changes scale specific?
- Do different life forms and endemics show strong changes over time?
- What are the effects of temperature on species richness?
- Are observed changes fluctuations or signals of climate change?

## 2. Materials and Methods

### 2.1. Study Area

The study area is the Lefka Ori massif situated on the western part of Crete, Greece (Figure 1), which culminates at the Pachnes summit (2453 m).



**Figure 1.** Topographic profile of South Lefka Ori massif and the four Gloria summits (GR-LEO). LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

It is a rugged marble and dolomite massif rich in rock debris and karstic formations and the wettest place on the island with over 2000 mm mean annual precipitation [50].

Above the tree line, the vegetation is dominated by low prickly scrub formations or spiny cushion-shaped dwarf shrubs (such as *Berberis cretica* L., *Euphorbia acanthothamnos* Heldr. & Sart. ex Boiss., *Juniperus oxycedrus* L. subsp. *oxycedrus* *Acantholimon androcaceum* (Jaub. & Spach) Boiss., and *Astragalus angustifolius* Lam) [51]. Grazing, by far the major human impact on Lefka Ori, decreases in intensity along altitude. The four selected summits were Low summit (1664 m), Chorafas (1965 m), South-East Kakovoli (2160 m), and Sternes (2339 m), reported hereafter as LOW, CHO, SEK, and STR, respectively.

## 2.2. Vegetation Sampling

In May–June 2008, we revisited four mountain summits of the Lefka Ori massif (GR-LEO study site) which were sampled in 2001. Summit selection and sampling were based on the GLORIA project multi-summit approach [8] (Figure S1). Two Summit Area Sections referred to herein as SAS were defined per summit within which floristic survey took place. The first SAS in each summit was defined as a polygon with four corners at each cardinal direction at 10 m lower from the summit top (referred to as 10 m SAS) where a complete list of plants was compiled. Within each 10 m SAS, a smaller SAS was defined (referred to as 5 m SAS) in a similar manner at 5 m lower from the summit top in order to evaluate the quantitative floristic composition for each principal exposure (N-E-S-W). On each summit, the four corner 1 m × 1 m quadrats of a 3 m × 3 m grid were established as permanent plots in each cardinal direction (i.e., east, south, west, north) 5 m below the highest summit point. In each of the 1 m × 1 m quadrats, we recorded all vascular plant species and the percent cover of each species was visually estimated following [8]. The position of every plot was recorded using a GPS receiver, accompanied by photo documentation.

For species identification, the Flora Europaea [52] and Mountain Flora of Greece [53] were used. Nomenclature of the plant taxa given in this paper is according to Turland, Chilton and Press [54]; Chilton and Turland [55]. For the nomenclature on chorotypes and life forms, we refer to Jahn and Schönfelder [56]; while bioclimatic zonation is according to Quézel [45].

## 2.3. Climatic Variation

In the center of each 3 m × 3 m grid, a data logger (StowAway Tidbit v2; Onset Corporation, Bourne, MA, USA) recorded the soil temperature 10 cm below the surface at hourly intervals continuously from June 2001 to July 2008. During this time period, temperature data were used to calculate annual values of absolute minimum soil temperature, annual daily mean soil temperature, absolute maximum soil temperature, temperature sums, growing degree days, and length of the growing season across the sampled years. The assumption made herein is that the defrosting period starts when the mean daily temperature is constantly above 0 °C while the freezing period starts in the autumn when the mean daily temperatures are constantly below 0 °C [35].

## 2.4. Data Analysis

### 2.4.1. Climate

We used the `lm` function in R [57] to build up a linear regression time series model for each data set. The explanatory variables were “Time  $t$ ”, which refers to the number of days elapsed since the origin ( $t = 1$ , day one), the average temperature of each month, as a dummy variable and the cyclical effect. We modeled the daily changes on the average daily temperature (based on four measurements). In order to measure the monthly seasonal effect, we calculated the regression coefficient for each month, which could be interpreted as the average increase in the temperature due to specified month, which is constant over the years. All the monthly effects were statistically significant. The shape of the seasonal trend is taken into account with the cosine element, which is dependent on time  $t$ , i.e., how far away from the origin we are. In this way, we managed to explain about 95% of the variability of the daily average temperature.

### 2.4.2. Species Richness

We have compiled species richness data at the 1 m<sup>2</sup> quadrats, on each aspect of the SAS at the 5 and 10 m contour line and took the means at the 5 m and 10 m SAS and at the ‘whole of summit’ species (5 + 10 m SAS) (Table 1 to provide a summit overview. We used paired t-tests, following a Shapiro-Wilk test for normality, to assess changes in total species richness at the 1 m<sup>2</sup> quadrats and at the 5 m SAS and 10 m SAS for all summits, and linear regression models to assess temperature effects on species richness at various scales as well as changes in species richness. Prior to employing regression, we checked that all assumptions were met (including continuous variables, linear relationship of variables independence of observations, homoscedacity, outliers, and residuals). These statistical analyses were performed with PAST software version 4.03 [58].

**Table 1.** Summary information for the four summits: Location, altitude, and size of the SAS \*, mean species richness in 2001 and the mean difference between 2008 and 2001.

Location	LOW **		CHO		SEK		STR	
	E24.0873 N35.2686		E24.0813 N35.2734		E24.0892 N35.2819		E24.0549 N35.2940	
Altitude (m a.s.l.)	1664		1965		2160		2339	
<b>Mean species richness per area</b>	2001	2008	2001	2008	2001	2008	2001	2008
1 m <sup>2</sup> quadrats mean ± 1 SE	11.87 ± 0.87	+0.06	3.75 ± 0.59	−0.06	1.50 ± 0.22	−0.12	1.44 ± 0.44	+0.44
5 m SAS (mean of aspects)	42.00 ± 1.47	−2.25	16.50 ± 0.86	−2.00	8.75 ± 0.75	+0.50	6.50 ± 1.32	+0.75
10 m SAS (mean of aspects)	39.25 ± 0.62	−4.00	17.00 ± 0.70	+1.00	10.00 ± 1.29	+0.25	8.50 ± 1.19	+2.75
5 + 10 m SAS (mean of aspects)	46.75 ± 0.47	−2.25	20.50 ± 0.64	−1.00	12.75 ± 0.47	−0.75	9.50 ± 1.50	+1.75

\* SAS: Summit Area Section, \*\* LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

### 2.4.3. Species Diversity and Turnover

We use Shannon diversity index (Shannon H' Log Base 10) to measure diversity at every cardinal direction per summit as well as the overall diversity per summit. We used two indices to assess turnover at the summit level for all scales as follows [59]:

- Species turnover based on individual species frequency:

$$T_{sp} = (A + D)/(A + D + U),$$

where A is the frequency of quadrats where the species appeared in 2008; D is the frequency of quadrats where the species disappeared; U is the frequency of quadrats where the species' frequency was unchanged.

- Vegetation turnover index at different spatial scales and life forms (at summit level):

$$T_{veg} = (A + D)/(A + D + B)$$

where A is the number of new species in 2008; D is the number of disappearing species; B is the number of species present in both years of comparison.

For both indices, low turnover values are close to 0.01 and complete turnover is 1.0.

## 3. Results

### 3.1. Climate

In all four models (Table 2), there is a constant increase on the average temperature per year. More specifically, it increases by 0.118 degrees per year (LOW), 0.035 degrees per year (CHO), 0.047 degrees per year (SEK), and 0.041 degrees per year (STR). The highest average temperature usually occurs in July and August. However, the average temperature between years remains constant without any significant change on its variability.

**Table 2.** Time series regression for the temperatures in the four summits.

Explanatory Variable	LOW *	CHO	SEK	STR
Time t	0.00032	0.000096	0.00013	0.000112
January	10.51	8.222	7.705	6.266
February	10.51	7.995	7.684	6.553
March	11.39	8.585	6.972	5.964
April	11.25	8.300	5.720	5.422
May	12.11	9.598	7.802	7.351
June	12.05	9.537	8.514	7.504
July	12.56	10.03	8.716	8.117
August	12.69	10.05	8.833	7.863
September	11.41	8.769	7.481	6.205
October	10.82	7.940	6.758	5.488
November	9.309	6.531	5.329	4.193
December	9.588	7.006	6.350	5.427
$\sin((2/365)*\pi*t)$	-4.976	-4.030	-4.099	-3.848
$\cos((2/365)*\pi*t)$	8.371	7.475	7.370	7.339

\* LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

### 3.2. General Patterns

Overall, at the study area level (GR-LEO-4 summits), 66 species were recorded (Table S1), 18 of which were endemics. The absolute species loss was 4 (8 species were lost and 4 new gained) among which were 2 endemics (3 lost, 1 new gained) (Table 2). At the scale of individual summits, the highest changes were recorded at the lower summits (LOW, CHO) with absolute species loss 4 in both cases (Table 3).

**Table 3.** Number of species in GR-LEO (total) and per summit.

GR-LEO	2001	2008	Trend *	Lost	New
Total species	70	66		8	4
Endemics	20	18		3	1
Summits					
LOW **	59	55		6	2
CHO	32	28		7	3
SEK	18	18	-	2	2
STR	14	15		0	1

\* red arrow indicates decreasing trend while green arrow increasing trend, \*\* LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

Mean species richness at the 5 + 10 m SAS was highest at the lower summit (LOW) and lowest at the highest summit (demonstrate a trend in decreasing richness with altitude). This pattern was also observed at the 10 m SAS, 5 m SAS, and the 1 m<sup>2</sup> level (Table 1).

A two tailed *t*-test comparing the total species richness at 1 m<sup>2</sup> (64 quadrats) between 2001–2008, revealed no significant differences at the 0.05 level (*t*-value = 0.03541, *p*-value = 0.971807). No significant differences were found at the individual summit level neither at the 5 m SAS or the 10 m SAS between 2001 and 2008 (Table 4).

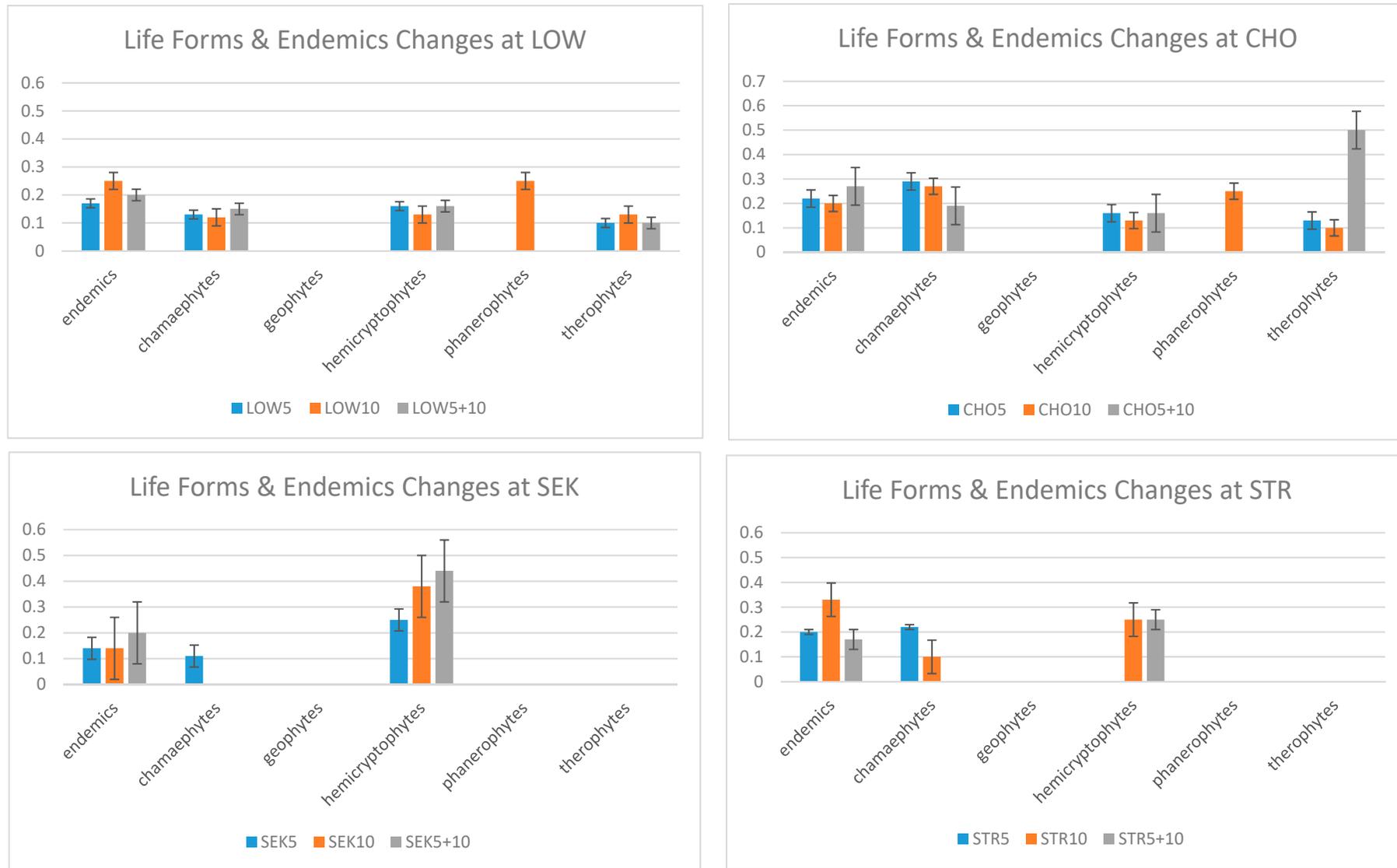
**Table 4.** Statistical tests on species richness data comparing 2001 and 2008 temperature.

Site/Sampling Scale	Model	t-Value	p-Value
LOW 5 m SAS *	Pair t-test	1.0944	0.133
LOW 10 m SAS	Pair t-test	3.7033	0.003 *
CHO 5 m SAS	Pair t-test	2.8284	0.0633
CHO 10 m SAS	Pair t-test	0.5624	0.6134
SEK 10 m SAS	Pair t-test	1.7321	0.1817
SEK 10 m SAS	Pair t-test	0.2641	0.8089
STR 5 m SAS	Pair t-test	1.5667	0.2151
STR 10 m SAS	Pair t-test	1.9612	0.1447
Site/Sampling Scale	Model	R <sup>2</sup>	sig.level
SAS 5–All sites	Linear regression against temp. means	0.78	0.001
SAS 5–All sites	Linear regression against min temp. means	0.85	0.001
SAS 5–All sites	Linear regression against max temp. means	0.63	0.001
SAS 10–All sites	Linear regression against temp. means	0.86	0.001
SAS 10–All sites	Linear regression against min temp. means	0.9	0.001
SAS 10–All sites	Linear regression against max temp. means	0.76	0.001
SAS–5 SR changes–all sites	Linear regression against temp. means	0.34	0.05
SAS–5 SR changes–all sites	Linear regression against min temp. means	0.36	0.05
SAS–5 SR changes–all sites	Linear regression against max temp. means	0.27	0.05
SAS–5 SR changes–all sites	Linear regression against June temp. means	0.46	0.05
SAS–10 SR changes–all sites	Linear regression against temp. means	0.11	n.s
SAS–10 SR changes–all sites	Linear regression against min temp. means	0.16	n.s
SAS–10 SR changes–all sites	Linear regression against max temp. means	0.13	n.s
SAS–10 SR changes–all sites	Linear regression against June temp. means	0.14	n.s

\* SAS: Summit Area Section.

### 3.3. Species and Vegetation Turnover

Mean Tsp was higher at CHO summit ( $0.46 \pm 0.12$  SE) and lower at the SEK summit ( $0.18 \pm 0.05$  SE). Endemic species turnover was between 0.17 (at LOW 5 m SAS) to 0.33 (at STR 10 m SAS) (Figure 2 but also Table S2). At the site level, chamaephytes turnover was between 0 to 0.29 and hemicryptophytes turnover was between 0.16 to 0.44, with the exception of *Euphorbia acanthothamnus* Boiss., which at the site level had a turnover of 0.5 (Table S2). The other major cushion-shaped plants recorded such as *Astragalus angustifolius* (Willd.) Hayek subsp. *angustifolius* and *Prunus prostrata* Labill. had very low or no turnover at all. Phanerophytes recorded behave similarly, with *Berberis cretica* L. having the highest turnover 0.5; whereas *Rhamnus lycioides* subsp. *oleoides* (L.) Jahand. & Maire and *Acer sempervirens* L. show no changes at the site level. Vegetation turnover (Tveg) across the four summits, within the 5 m SAS, were between 0.11 and 0.32; whereas within the 10 m SAS (not including the 5 m SAS), Tveg values were between 0.12 and 0.31 (Table S3). Overall vegetation turnover ranged from 0.06 to 0.28. At the 1 m<sup>2</sup> scale, turnover values range from no change to 0.25 at CHO summit.



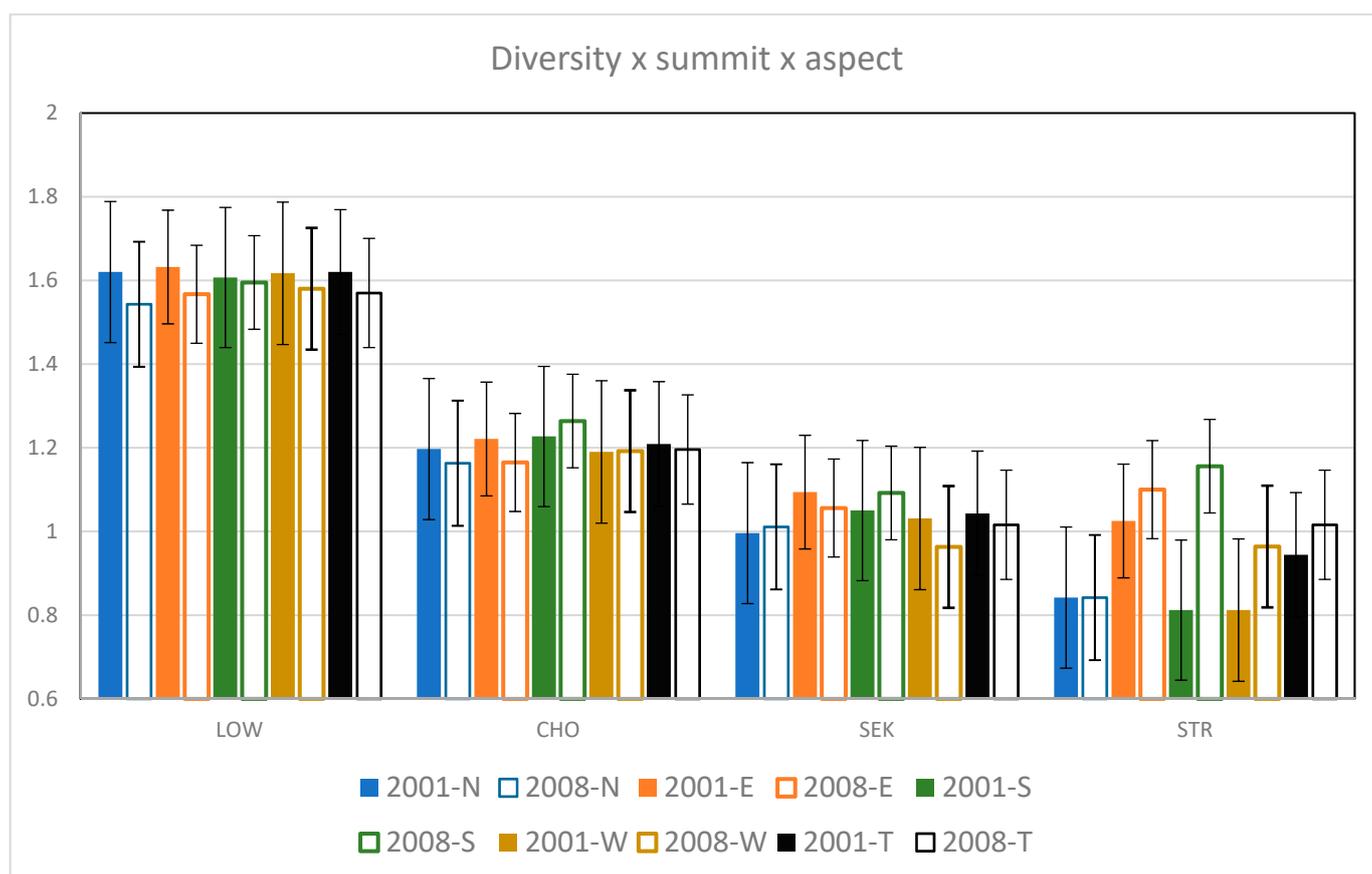
**Figure 2.** Vegetation turnover over the two monitoring periods. LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

### 3.4. Species Richness and Climate

Linear regressions with the climatic variables used can explain both species richness at the 5 and 10 m SAS as well as species changes at the 5 m SAS. They all have moderate to high predictive power (27 to 90%). Temperature has a positive effect on species richness at 5 SAS and 10 SAS with high predictive power (over 70%) and a positive effect on changes at 5 SAS but with moderate predictive power. June mean temperature, in particular, has the highest predictive power for species changes at the 5 m SAS. Linear regressions with the climatic variables used had no explanatory power for changes observed at the 10 m SAS (Table 4).

### 3.5. Species Diversity

Species diversity decreases with altitude for all summits and years with the exception of the highest summit (STR: see Figure 3). STR summit shows the highest variation in species diversity when different aspects and years are examined, while the lowest summit LOW shows the lowest. The highest species diversity is consistently observed in the East slopes for the 2001 data and in the South slopes for 2008 data.



**Figure 3.** Species diversity per summit per aspect for the two monitoring periods. (N: North, S: South, E: East, W: West, T: Total Summit). LOW: low summit, CHO: Chorafas, SEK: South East Kakovoli, STR: Sternes.

## 4. Discussion

### 4.1. Species Richness and Climatic Parameters

The GLORIA initiative responds to the need for a consistent long-term monitoring, an activity timely and essential for detecting and predicting mountain species' responses to local climate change [8]. The value of experimental field sites for climate change studies is promoted in conservation biology, particularly for tracing/documenting aberrant re-

sponses [60], and to document the effects of elevational gradients on species richness often contested in biogeography [61–63]. Compared to the changes reported by similar studies emerging from Europe [15,36,37], changes from Lefka Ori seem to be variable. The increase in species number on individual summit level was very small compared to what has been reported elsewhere (max three species). A comparison between and within summits for the two monitoring years (2001 and 2008) did not reveal any significant changes in species richness (Tables 1 and 3) throughout sampling scales but evident changes in different cardinal directions were recorded (Figure 3). Temperature explains species richness at the spatial scales examined (5 SAS, 10 SAS) (Table 4), showing a positive effect. This is consistent with the other similar studies from GLORIA network [59] alluding to an increase of warm-adapted species as temperature increases continues [64]. Temperature also explains changes at the 5 m SAS and in particular June mean temperature has the highest predictive power (Table 4). At the coarser spatial scale (10 m SAS), temperature had no effect on recorded changes. This is possibly due to the highest contribution/presence of larger perennial shrubs at that scale suggesting that changes are perhaps related more to biotic interactions than temperature changes [65].

In this study, the sub-surface soil temperature data over a seven-year period for the GR-LEO study site showed that there is a constant increase in the average temperature per year ranging from 0.047 (SEK) to 0.118 degree (LOW) (Table 2). Based on observed data for the periods 1970–2000 in Crete, Tsanis et al. [66] give a monthly temperature increase of 0.5 degree per decade and a monthly average precipitation decrease of 26 mm per decade. Recent research for Crete suggests that the known trends for the eastern Mediterranean will be mirrored on the island's climate with the optimistic estimates of 12% lower temperature and 2 degrees' temperature increase until 2040 further aggravating, following the same trend in the decades to come [66].

#### 4.2. Changes in Species Composition and Abundance

Overall, there are less pronounced species changes at the smallest sampling scales while it seems that changes are more evident in middle altitudes, particularly the increase of therophytes and the highest turnover at the CHO summit (Figure 2). Similar trends were also reported during the first survey of the area [35], while high species turnover in middle altitudes is also suggested by modeling studies for Mediterranean mountains [25].

There is a higher turnover in chamaephytes–hemicryptophytes compared to other life forms across summits and sampling scales. Increase in chamaephytes has also been reported for other Mediterranean mountains [36,37]. Since chamaephytes and hemicryptophytes constitute the majority of the flora in the study area [51], this result is expected. These changes of course may indicate changes in biotic relations between life forms i.e., a competitive advantage of some life forms at the expense of others. Although not a pronounced change, a moderate increase was recorded in therophytes in the middle summit CHO, which has also the highest species turnover (Figure 2).

As evidence on the responses of mountain ecosystems on climate change are mounting, it becomes clearer that there are many aspects which need to be taken into consideration in order to draw reliable conclusions (see review in [67]). For example, plants' response will be too slow to keep pace with the speed of climate change [68] or that invasions of non-native plants on mountainous areas cannot be excluded [69]. In fact, a summit's response will be 'individualist' since vegetation composition particularly between the lowest and the highest summits in studies similar [36,37] to this one usually differs. Therefore, the traits of the constituent species in every summit will determine their ability to compete, disperse, and adapt. Alexander et al. [70] also highlight the importance of community dynamics in determining mountain species responses. This can be either related to new composition but also to facilitation of existing plants. For example, the role of cushion plants in facilitating range expansion has been demonstrated for mountain environments [65,71]. Mediterranean mountains in general and Lefka Ori in particular have a high number of cushion plants such as *Astragalus angustifolius* Lam., *Acantholimon androcaecum* (Jaub. & Spach) Boiss., but

also shrubs such as *Berberis cretica* L. which act as ‘eco-engineers’ in a harsh environment. Their persistence and role in the future may be critical for the survival of other mountain plants. This study did not record any significant changes of the major cushion-shaped plants across summits.

Although species diversity decreases with altitude and across years for three out of four summits, there is an increase in overall species diversity from 2001–2008 in the highest summit (STR) (Table 3). In addition, STR summit shows the highest variation in species diversity when different aspects between the two years were surveyed. Differences in species numbers among cardinal directions in European mountain summits have been recently documented [72]. This study suggests that species richness on Mediterranean summits tend to be highest on the West facing and lowest on the East and North facing summit slopes, although no significant differences were recorded. What is emerging from the GR-LEO summit data is that species diversity is higher in the East slopes for the 2001 data and the South slopes for the 2008 data, compared to the other two directions. This might point towards a more individualistic response per site and the effect of summer drought, which may limit species numbers on the warmer slopes of Mediterranean mountains.

#### 4.3. Changes in Endemic Species

Mountain areas with high endemism level have received much attention in the literature owing to the vulnerability of endemic species [8,73,74]. The flora of the Cretan mountains comprises relict species, many of which are endemic derivatives of lowland species and species that also occur in the continental Greek mountains such as *Scutellaria hirta* Boiss. from *Scutellaria sieberi* Benth and *Bellis longifolia* Boiss. & Heldr. from *Bellis sylvestris* Cirillo [75]. According to [42], regional and local endemism in Greece increase in a southerly direction, culminating in the Lefka Ori, which displays one of the highest rates of narrow endemism in the Mediterranean area. Narrow endemics seem to be highly threatened on the low mountain summits of the north-eastern Alps [17,73] and this was also reported for the Lefka Ori in Crete [35], compared to endemics with wider distributions [76]. Our results show that endemics’ turnover was very small across summits and overall in the area where a small decrease was recorded in absolute numbers. Still the highest turnover was recorded at the middle altitude (CHO) but also at the highest summit (STR). The first finding is consistent with the overall turnover vegetation pattern recorded herein. In the case of STR, a high value is due to the fact that contribution of the endemics to the overall flora of the Lefka Ori increases with altitude (i.e., endemics richness along an elevation gradient) [51]. In similar fashion, a small decrease in endemics is reported also for the Apennines [36] while in Sierra Nevada it seems that endemics were more affected [77]. These findings might support the view of the mountains’ resilience at least as endemic flora is concerned although findings should be interpreted with caution [78].

Mediterranean mountains acted as refugia in the Mediterranean Basin during the Pleistocene cycles preventing species extinctions and likely supporting speciation processes [22,79]. Medail and Diadema [80] identified 18 out of 52 of these refugia in mountains, among which are the Pyrenees, South Apennines, Middle and High Atlas, Taurus and the mountains of Crete. In addition to differences in biogeography, glaciation pattern seems to be very different in the Apennines and the Sierra Nevada compared to Crete with evidence still contested for the Lefka Ori (see [81]).

Lefka Ori still host important populations of tertiary elements [51]. As in the case of several other Mediterranean mountains, some of these elements are in isolated occurrences i.e., linked to specific azonal habitats resulting from geomorphological and hydrological processes [82]. Micro-habitat diversity influences species distribution at small scales [83] with some micro-habitats reported to have lower than soil surface temperatures [84] acting as a potential buffer to climate change [83].

Even if endemics persist, there might be other consequences for them including changes in their phenology, reported already in other mountain regions of the world [85], and disproportionate range losses [23,73]. Range boundaries of many narrow endemics

in mountain environments are associated with localized environments (geology, geomorphology). Since these species already exhibit realized climatic niches much more restricted compared to their potential climatic niche, their distributions might not be immediately affected by climate change [86] nor influenced by other species' altitudinal shift due to biotic interactions [35]. Out of the 18 endemics recorded in this study, the ones with the highest turnover rate included *Crepis sibthorpiana* Boiss. & Heldr., *Centaurea idea* Boiss. & Heldr. and *Alyssum fragillimum* (Bald.) Rech. f. These three species are locally quite common i.e., widely distributed along the massif over 1500 m and are not restricted to a single specialized habitat. Although turnover might be due to interannual fluctuations, it might imply that widely distributed species will be more affected by changes in climate, compared to narrow endemics associated with localized habitats. In addition, a recent study in Sierra Nevada showed that interspecific hybridization between narrowly endemic alpine plants and widely distributed lowland plants is an overlooked consequence of altitudinal shift of the latter [87]. Therefore, studying endemic plants population viabilities and extinction probabilities under interspecific competition have been suggested [11].

## 5. Conclusions

Recorded changes in species richness in Lefka Ori point more towards fluctuations within a plant community's normal range, although there seem to be more significant diversity changes in higher summits related to aspects. Empirical studies like this one may serve as a validation and refinement of climate species modeling related techniques in an attempt to draw meaningful conclusion on the effects of climate change on biodiversity [88]. For example, a recent synthesis [89] predicted small extinction risks in Europe and the Mediterranean area compared to other geographical areas of the world. Subsequent re-surveys will determine whether the trends and patterns recorded herein will hold. In addition, this study did not find any evidence showing that endemics have been influenced by changes in climate parameters, although the pace of current global warming and its interactions with other drivers of change has no precedent [90]. Mediterranean mountains might continue to hold as biodiversity refugia for the years to come under the current climate change projections.

**Supplementary Materials:** The following are available online at <https://www.mdpi.com/1424-2818/13/1/22/s1>, Figure S1: Scheme of the Multi-Summit sampling design (from Pauli, H.; Gottfried, M.; Lamprecht, A.; Niessner, S.; Rumpf, S.; Winkler, M.; Steinbauer, K. and Grabherr, G., coordinating authors and editors (2015). The GLORIA field manual—standard Multi-Summit approach, supplementary methods and extra approaches. 5th edition. GLORIA-Coordination, Austrian Academy of Sciences & University of Natural Resources and Life Sciences, Vienna). Table S1: List of species present across the GR-LEO summits (LOW, CHO, SEK and STR) during the 2001 and 2008 surveys, their families, life forms (P = Phanerophyte, Ch = Chamaephyte, H = Hemicryptophyte, G = Geophyte, T = Therophyte) and their endemism to Cretan flora. Table S2: Species turnover ( $T_{sp}$ ) for species recorded in the 1 m<sup>2</sup> quadrats for each summit (LOW, CHO, SEK AND STR) and for the four summits combined (GR-LEO); A = Number of quadrats the species appeared in 2008, D = Number of quadrats the species disappeared in 2008, U = Number of quadrats the species unchanged. Table S3: The species richness in 2001 and 2008, the number of new and lost species and also the number of species found in both surveys; used for calculating the vegetation turnover ( $T_{veg}$ ) between 2001 and 2008 in summit area sections and for different groups of species and life forms.

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