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A contribution to the knowledge of *Linaria tonzigii* Lona, a steno-endemic species of the Orobie Bergamasche Regional Park (Italian Alps)

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Keywords: Linaria tonzigii, *endemic species, CSR strategy, ecological indices, alpine plant, Orobie Bergamasche, Lombardy*

Abstract

Linaria tonzigii is a rare steno-endemic species of Community interest that grows on some limestone screes in the Orobie Bergamasche Regional Park (Italian Alps). Information is scarce regarding its ecology (and especially synecology) and its Grime's CSR functional strategy. For this reason, this research, as well as analysing the floristic composition and ecology of the *L. tonzigii* community by means of traditional methods, also evaluated the Grime's CSR strategy of this endemic species using the latest methods and tools. Analysis of the phytosociological relevés conducted in five different areas revealed that the species constitutes a single plant community (the *Linaria tonzigii-Hornungia alpina* community) consisting of basophile and xerophile species mostly typical of limestone screes. The analysis of the CSR strategy revealed that the mean strategy of *L. tonzigii* is R/CSR, although the species presents slightly different strategies in the different sampling areas. This article reports the first ever data regarding inter-population variation in plant functional strategies in nature and suggests that the functional variability of the species is much wider than had been thought. The analysis of plant height of *L. tonzigii* also showed that the population isolated at the northern limit of the species' distribution range has significantly taller and less stress-tolerant individuals than those in other areas, suggesting that it may be a different ecotype. This article aims to stimulate researchers to study little-known endemic species in order to protect and valorize the biodiversity of protected areas.

Profile

Protected area

Orobie Bergamasche Regional Park

Mountain range

Alps

Country

Italy

Introduction

The conservation of biodiversity is currently an issue of great importance and the subject of debate and action both locally and globally, as the extinction of species (animals and plants) can alter the functions of ecosystems and their services which are essential for human well-being (Fedele et al. 2017). In recent decades, many steps have been taken to protect rare and/or threatened species, from both legislative and applicative points of view. One example is the strategic plan for biodiversity of the Convention of Biological Diversity (Rio Earth Summit 1992), another the Habitat Directive (92/43/EEC), which is the most important strategy for nature conservation in Europe aimed at halting biodiversity loss. There are also many activities undertaken at various levels for the protection of species of conservation interest, such as the creation of Red Lists, ecological networks, protected areas or restocking plans.

In order to maximize the success of actions to protect rare and / or threatened species, a thorough knowledge of the different aspects of the species concerned is essential, including biological and ecological issues, which are particularly important for the correct implementation of conservation activities. Despite the progress of scientific research, there is still much work to be done to understand the ecology of countless species on Earth. In particular, it is essential to encourage ecological studies of rare and / or threatened plants that are widespread only within a limited habitat (endemic species), or that are even extremely localized (steno-endemic species). Such species contribute to enriching and enhancing the prestige of the biological heritage of a given territory, and hence that of the whole planet.

One such example is *Linaria tonzigii* Lona (Plantaginaceae), a very rare plant which is steno-endemic to the Orobie Bergamasche Regional Park (Orobic Alps, Lombardy, Italy) (Pignatti 1982; Calegari et al. 1995; Aeschimann et al. 2004; Conti et al. 2005; Martini et al. 2012; Peruzzi et al. 2014; Andreis et al. 2017). This plant has so far been little studied, even though it was discovered over sixty years ago (Lona 1949). Currently, its presence is certain in just a few sites of the Orobic pre-Alps, many of which were refuge zones during the glaciations of the Quaternary Age: Mt. Arera / Mt. Corna Quadra group (locus classicus), Mt. Menna, Mt. Secco, Mt. Ferrante / Mt. Presolana group and Mt. Cavallo / Mt. Pegherolo group (Valoti 1996; Bendotti 1996; Pignatti 1982; Brissoni 1983; Crescini et al. 1985; Tagliaferri 1992; Martini et al. 2012; Giupponi & Giorgi 2017). In such areas, *L. tonzigii* consists of fragmented populations in the subalpine and alpine belt (at around 2 000 m altitude), always on limestone screes of Calcare di Esino formation (Upper Anisian – Ladinian). The characteristics of this species, in particular its rarity and its limited range, meant that

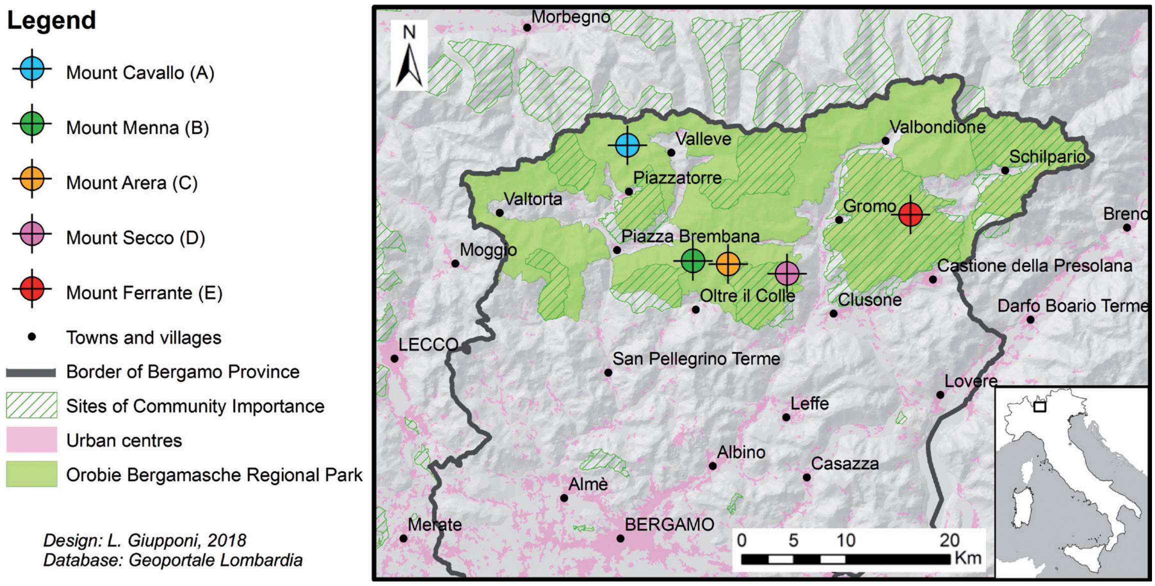

Figure 1 – Location of the five sampling areas: Mt. Cavallo (A); Mt. Menna (B); Mt. Arera (C); Mt. Secco (D); Mt. Ferrante (E). Latitude: 45°65'N; Longitude: 9°48'E.

it was chosen as a symbol of the *Flora Alpina Bergamasca* (FAB) group. According to the IUCN Red List of threatened species, *L. tonzigii* belongs to the category *Endangered D* (Mangili & Rinaldi 2011) and it is therefore subject to strict protection in Lombardy under law LR10/2008. It is also a species of Community interest, included in Annex II of the Habitat Directive (92/43/EEC). Nevertheless, the populations of *L. tonzigii* are only partially included in Sites of Community Importance (SCIs).

In the past, ski runs were created near areas where *L. tonzigii* was found, and plans for the creation of pistes right on the screes where the species was present were put forward. Fortunately, these new runs were never created. Today, due to the lack of snow during the winter months, many of the ski runs have been closed and plans to create new ones no longer pose a threat to the species and its habitat.

Although the danger of anthropic disruption would seem to have been averted, other threats to the survival of the species, such as global warming, which can affect even alpine ecosystems, may loom (Körner 2003; Klanderud 2005; Rixen et al. 2014). It is therefore necessary to clarify the ecology of *L. tonzigii* and to define the functional strategies that the species has adopted in response to the environmental factors of the areas in which it lives. As regards the latter, Grime (1974, 1977, 2001) proposed the categorization of plants according to three strategies – competitors (C), stress tolerators (S) and ruderals (R) (CSR theory). This CSR classification has been applied to thousands of species in many different environments (including Alpine areas) (see e.g. Caccianiga et al. 2006; Pierce et al. 2007a,b, 2012, 2013, 2017; Simonová & Lososová 2008; Massant et al. 2009; Cerabolini et al. 2010a, b; Kilinç et al. 2010; Navas et al. 2010; Yildirimet al. 2012; Mangili 2016; May et al. 2017). Although information is now available regarding the CSR strategies of many species that are widespread in the Alps (Cerabolini et al. 2010a; Pierce et al. 2017), the strategy of *L. tonzigii* is not present in these databases. Indeed, although Landolt et al. (2010) empirically attributed an *rss* (stress-tolerant ruderals) strategy to this species, no analyses based on precise measurements have ever been carried out.

In addition to analysing the floristic composition and ecology of the plant community of *L. tonzigii*, this study aims to evaluate the CSR strategy of this steno-endemic species using the recent method and CSR calculator tool of Pierce et al. (2017). The CSR strategy of *L. tonzigii* and its plant height were evaluated by considering the different populations found in various sites of the Orobie Bergamasche Regional Park (where the species is reported) in order to high-

Table 1 – Temperature (T), precipitation (P) and potential evapotranspiration (PE) from Mt. Arera weather station (2009–2017); data source: Centro Meteo Lombardo. PE was calculated using the online diagnosis tool developed by Rivas-Sáenz (Rivas-Martínez & Rivas-Sáenz 2009).

Month	T [°C]	P [mm]	PE [mm]
January	−3.0	17.7	0.0
February	−2.6	32.7	0.0
March	0.3	38.2	4.6
April	3.0	71.6	29.4
May	5.2	219.2	50.9
June	9.9	268.5	83.7
July	12.3	229.5	100.2
August	12.2	230.2	92.0
September	9.1	203.0	62.8
October	4.9	177.2	35.5
November	2.2	254.3	16.2
December	−0.8	47.6	0.0
Year	4.4	1789.6	475.3

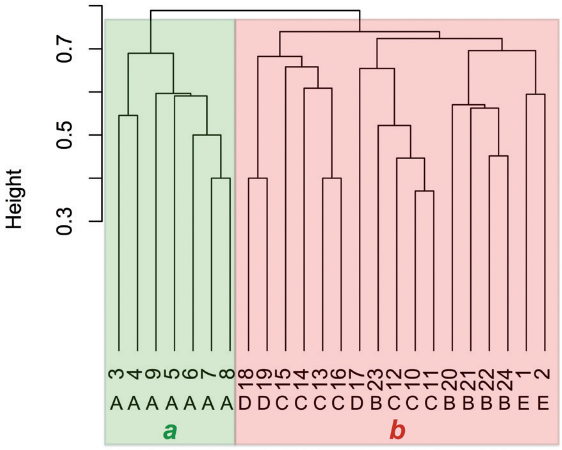

Figure 2 – Dendrogram of relevés. The numbers indicate the relevé code; the capital letters indicate the area where the relevé was performed (A – Mt. Cavallo; B – Mt. Menna; C – Mt. Arera; D – Mt. Secco; E – Mt. Ferrante); the two clusters (a and b) are shown.

light any inter-population variations which could allow different ecotypes to be defined. In order to gain as complete a picture as possible of the adaptations of *L. tonzigii* (and its plant community) to the environment in which it lives, the functional strategy of *L. tonzigii* was also compared to that of other species that make up the plant community to which it belongs.

Materials and methods

Study areas and floristic-vegetational analysis

Data for the plant communities in which *L. tonzigii* is present were collected by performing several phytosociological relevés in five study areas of the pre-Alps of Bergamo province in which the species has been recorded (Valoti 1996; Bendotti 1996; Tagliaferri 1992; Martini et al. 2012; Giupponi & Giorgi 2017): Mt. Cavallo (A), Mt. Menna (B), Mt. Arera (C), Mt. Secco (D) and Mt. Ferrante (E) (Figure 1). These areas are within the territory of the Orobie Bergamasche Regional Park, but not all are in Sites of Community Importance (SCIs). Their geological substrate is limestone rocks of Calcare di Esino formation. Table 1 shows data from the Mt. Arera weather station, which is located at 1 950 m a.s.l. near a scree where *L. tonzigii* grows. This area lies in the orotemperate ultrahyperhumid bioclimatic belt of the temperate oceanic bioclimate (Rivas-Martínez & Rivas-Sáenz 2009).

The phytosociological relevés were performed during the month of July 2017 using Braun-Blanquet's (1964) method over an area of 9 m^2. Pignatti's (1982) dichotomous keys were used to identify species and to extrapolate information regarding their chorological type. The relevés were analysed statistically by means of cluster analysis (using the Jaccard index and the Unweighted Pair Group Method with Arithmetic Mean (UPGMA)) in order to evaluate the floristic similarity. The ecological analysis of the plant community

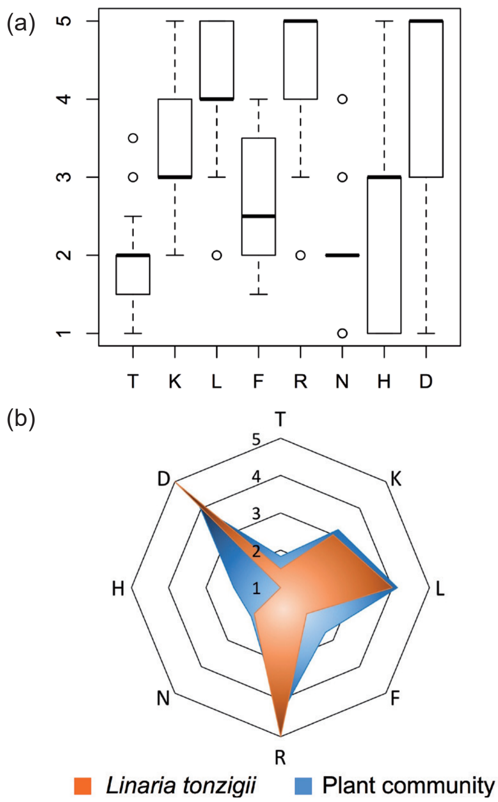

Figure 3 – (a) Boxplot of ecological indices of the Linaria tonzigii-Hornungia alpina *community; (b) radar graph of ecological features of* Linaria tonzigii *and that of its plant community. Key: T – temperature; K – continentality; L – light; F – soil moisture; R – reaction; N – nutrients; H – humus; D – aeration (Landolt et al. 2010).*

(synecology) of *L. tonzigii* was performed by applying the ecological indices of Landolt et al. (2010). In each study area, the height of the stems of *L. tonzigii* bearing the inflorescences (racemes) was also measured in order to test for inter-population morphological differences. These data were analysed using an ANOVA test followed by Tukey's Honestly Significant Difference (HSD) test. Statistical analyses were performed using R 3.3.2 (R Core Team 2015) software. The scientific names of the species are in accordance with Martini et al. (2012).

CSR analysis

The CSR strategy of *L. tonzigii* was analysed according to the methods developed by Pierce et al. (2017). In each of the five areas where phytosociological relevés were performed (Figure 1), we collected 10 fully expanded leaves, if possible taken from different individuals. The plant material was wrapped in moist tissue paper and stored overnight in the laboratory, in the dark, at 4°C. Leaf fresh weight (LFW) was determined from these saturated samples using analytical balance (Precisa XB 220A), and the leaf area (LA) was measured using a digital scanner and ImageJ 1.50i software. Leaf dry weight (LDW) was measured after oven-drying at 105°C for 24 h. CSR ternary coordi-

Table 2 – Floristic composition of the Linaria tonzigii-Hornungia alpina *community and presence of each species in the relevés (Pres. (%)).*

No.	Species	Chorotype	Pres. (%)
1	*Linaria tonzigii* Lona	Endem.	100
2	*Hornungia alpina* (L.) Appel	Centro-Europ.	100
3	*Sesleria caerulea* (L.) Ard.	SE-Europ.	83
4	*Carex firma* Host	Orof. S-Europ.	79
5	*Cerastium latifolium* L.	Alpic-W-Carpatic	75
6	*Poa minor* Gaudin	Orof. S-Europ.	58
7	*Crepis jacquinii* subsp. *kerneri* (Rech. f.) Merxm.	Orof. SE-Europ.	54
8	*Adenostyles glabra* (Mill.) DC.	Orof. S-Europ.	50
9	*Poa alpina* L.	Circumbor.	50
10	*Acinos alpinus* (L.) Moench	Orof. S-Europ.	46
11	*Biscutella laevigata* L.	Orof. S-Europ.	46
12	*Festuca quadriflora* Honck.	Orof. S-Europ.	46
13	*Thlaspi rotundifolium* (L.) Gaudin subsp. *rotundifolium*	Endem. Alp.	46
14	*Doronicum grandiflorum* Lam.	Orof. SW-Europ.	42
15	*Minuartia austriaca* (Jacq.) Hayek	Endem. Alp.	42
16	*Campanula cochleariifolia* Lam.	Orof. S-Europ.	38
17	*Viola dubyana* Burnat ex Gremli	Endem.	38
18	*Achillea clavennae* L.	E-Alp. – Dinaric	33
19	*Dryopteris villarii* (Bellardi) Woyn. ex Schinz & Thell subsp. *villarii*	Orof. S-Europ.	33
20	*Saxifraga aizoides* L.	Circumbor.	33
21	*Carduus defloratus* subsp. *tridentinus* (Evers.) Ladurner	Endem. Alp.	29
22	*Cystopteris alpina* (Lam.) Desv.	Cosmopol.	29
23	*Galium baldense* Spreng.	Endem.	29
24	*Athamanta cretensis* L.	Orof. S-Europ.	25
25	*Hieracium bifidum* Kit. ex Hornem.	Orof. S-Europ.	25
26	*Horminum pyrenaicum* L.	Orof. SW-Europ.	25
27	*Juncus monanthos* Jacq.	Artic-Alp. (Euro-Amer.)	25
28	*Rumex scutatus* L.	S-Europ.-Sudsib.	25
29	*Saxifraga hostii* subsp. *rhaetica* (A. Kern.) Braun-Blanq.	Endem.	25
30	*Arabis bellidifolia* subsp. *stellulata* (Bertol.) Greuter & Burdet	Medit.-Mont.	21
31	*Asplenium viride* Huds.	Circumbor.	21
32	*Campanula raineri* Perp.	Endem.	21
33	*Dryas octopetala* L.	(Circum) Artic-Alp.	21
34	*Pedicularis tuberosa* L.	Orof. SW-Europ.	21
35	*Salix retusa* L.	Orof. Europ.	21
36	*Silene vulgaris* subsp. *glareosa* (Jord.) Marsden-Jones & Turrill	Orof. S-Europ.	21
37	*Veronica aphylla* L.	Orof. S-Europ.	21
38	*Viola biflora* L.	Circumbor.	21
39	*Aquilegia einseleana* F.W. Schultz	Endem. Alp.	17
40	*Galium montis-arerae* Merxm. & Ehrend.	Endem.	17
41	*Persicaria vivipara* (L.) Ronse Decr.	(Circum) Artic-Alp.	17
42	*Rhododendron hirsutum* L.	Endem. Alp.	17
43	*Salix glabra* Scop.	NE-Medit.-Mont.	17
44	*Saxifraga exarata* subsp. *moschata* (Wulf.) Cavill.	Euro-Asiat.	17
45	*Trisetum distichophyllum* subsp. *brevifolium* (Host) Pign.	Orof. S-Europ.	17
46	*Valeriana montana* L.	Orof. S-Europ.	17
47	*Anthyllis vulneraria* L. subsp. *baldensis* (A. Kern.) Becker	Endem.	13
48	*Doronicum columnae* Ten.	Orof. SE-Europ.	13
49	*Papaver alpinum* subsp. *rhaeticum* (Leresche ex Gremli)	Endem. Alp.	13
50	*Primula glaucescens* Moretti	Endem.	13
51	*Saxifraga sedoides* L.	Orof. SW-Europ.	13
52	*Scrophularia juratensis* Schleich.	Orof. S-Europ.	13
53	*Trisetum alpestre* (Host) P. Beauv.	Orof. SE-Europ.	13
54	*Alchemilla nitida* Buser	Orof. S-Europ.	8
55	*Asperula cynanchica* L.	Euri-Medit.	8
56	*Bellidiastrum michelii* Cass.	Orof. SE-Europ.	8
57	*Daphne striata* Tratt.	Endem. Alp.	8
58	*Pedicularis rostratocapitata* Crantz	E-Alp.-Carpat.	8
59	*Thymus praecox* subsp. *polytrichus* (A. Kern. Ex Borbás) Ronniger	Orof. S-Europ.	8
60	*Allium insubricum* Boiss. & Reuter	Endem.	4
61	*Arabis alpina* L. subsp. *alpina*	Circum-Artic-Alp.	4
62	*Carex austroalpina* Bech.	Endem.	4
63	*Festuca alpestris* Roem. & Schult.	Endem.	4
64	*Galium anisophyllum* Vill.	Orof. S-Europ.	4
65	*Gypsophila repens* L.	Orof. S-Europ.	4
66	*Hieracium villosum* Jacq.	Orof. SE-Europ.	4
67	*Homogyne alpina* (L.) Cass.	Orof. Centro-Europ.	4
68	*Leontopodium alpinum* Cass.	Orof. Euro-Asiat.	4
69	*Moehringia concarenae* F. Fen. & F. Martini	Endem.	4

Table 2 – continued

No.	Species	Chorotype	Pres. (%)
70	*Polystichum lonchitis* (L.) Roth	Circumbor.	4
71	*Potentilla nitida* L.	Subendem.	4
72	*Primula auricula* L.	Orof. S-Europ.	4
73	*Ranunculus alpestris* L.	Orof. S-Europ.	4
74	*Ranunculus thora* L.	Orof. S-Europ.	4
75	*Rosa pendulina* L.	S-Europ.-Sudsib.	4
76	*Saxifraga caesia* L.	Orof. S-Europ.	4

nates (and CSR strategy) were determined using the *StrateFy* tool (Pierce et al. 2017) and were projected in the CSR ternary graph using the *ggplot2* package of the software R 3.3.2 (R Development Core Team 2015). The CSR strategy of *L. tonzigii* was compared with the known strategies of other species of the relevés (Pierce et al. 2017).

Results

Twenty-four phytosociological relevés were performed in the five study areas (seven on Mt. Cavallo, five on Mt. Menna, seven on Mt. Arera, three on Mt. Secco and two on Mt. Ferrante) at altitudes ranging from 1 850 m a.s.l. (Mt. Secco) to 2 270 m a.s.l. (Mt. Ferrante). Table 2 lists the 76 species identified and their percentage presence in the relevés. Seven species are present in more than half of the relevés: *L. tonzigii*, *Hornungia alpina*, *Sesleria caerulea*, *Carex firma*, *Cerastium latifolium*, *Poa minor* and *Crepis jacquinii* subsp. *kerneri*. Most of the species identified are orophytes which are quite frequent in the Alps, but several endemic species are also present (in addition to *L. tonzigii*): *Viola dubyana*, *Allium insubricum*, *Galium montis-arerae*, *Campanula raineri*, *Galium baldense* and *Moehringia concarenae*. The dendrogram provided by cluster analysis (Figure 2) shows the level of floristic dissimilarity between the relevés and their subdivision into two clusters (*a* and *b*). Cluster *a* groups all the relevés performed in the screes of Mt. Cavallo (A) which are differentiated from the others by the constant presence of *Doronicum grandiflorum* and *Poa alpina*; the relevés performed in the other four areas are all included in cluster *b* since they present some species which are not present in the relevés of area A (*Crepis jacquinii* subsp. *kerneri*, *Adenostyles glabra*, *Thlaspi rotundifolium*, *Acinos alpinus*, *Biscutella laevigata* and *Viola dubyana*). Considering the slight floristic differences, the two clusters would seem to describe two variants of the same plant community, defined as *Linaria tonzigii-Hornungia alpina*, differentiated by the presence or absence of *C. jacquinii* subsp. *kerneri*, *Adenostyles glabra*, *Thlaspi rotundifolium*, *Acinos alpinus*, *Biscutella laevigata* and *V. dubyana*.

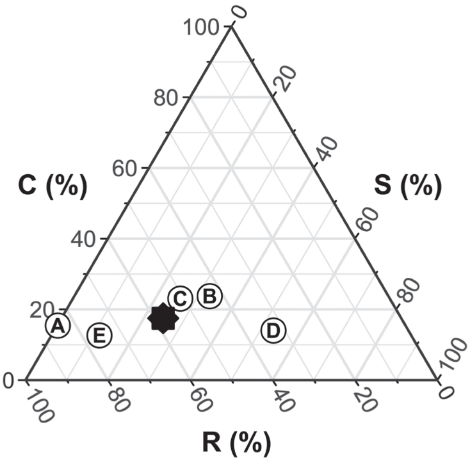

Figure 4 – CSR classification of Linaria tonzigii*, showing CSR strategies of the plants of the five areas (A – Mt. Cavallo; B – Mt. Menna; C – Mt. Arera; D – Mt. Secco; E – Mt. Ferrante) and mean strategy (black-filled star) of* L. tonzigii.

Figure 3 shows the ecological spectrum of the *Linaria tonzigii-Hornungia alpina* community with the relative average values of Landolt et al.'s (2010) indices and those referring to *L. tonzigii*. The plant community is made up of high-altitude heliophilous plants that live on coarse-grained, moderately dry soils which are highly basic and poor in nutrients. The radar graph (Figure 3b) shows that the ecology of the community (synecology) is very similar to that of *L. tonzigii* which, however, has lower values of H (humus) and F (soil moisture) but higher values of R (reaction) and D (aeration). This is due to the fact that the plant community includes some species that stabilize the screes (such as *C. firma* and *Dryas octopetala*) and favour the formation of discontinuous clods of soil (protorendzina), where less basophile species which require larger amounts of organic matter and humidity are found.

As regards the CSR strategy, the ternary graph in Figure 4 shows that the mean strategy of *L. tonzigii* is R / CSR (C:S:R = 17.5 : 25.0 : 57.5), although there are some differences for the various populations (Table 3 and Figure 4) that highlight the species' ecological plasticity. In fact, the CSR strategy is R for the samples collected on Mt. Cavallo, SR / CSR for those on Mt. Menna, R / CSR for those on Mt. Arera, S / CSR for those on Mt. Secco, and R / CR for those on Mt. Ferrante. The graph in Figure 5 shows the known CSR strategies of the species of the *Linaria tonzigii-Hornungia alpina* community, and the mean CSR strategy of this plant community (SR / CSR). The CSR values of the community (C:S:R = 24.0 : 35.8 : 40.2) are slightly different from those of *L. tonzigii* due to the presence of several stress-tolerator species, such as *T. rotundifolium*, *Saxifraga exarata* subsp. *moschata*, *Saxifraga caesia*, *Rhododendron hirsutum*, *C. firma* and *D. octopetala*.

The boxplots in Figure 6 show that, in the Mt. Cavallo area (A), *L. tonzigii* presents stems that are taller than those measured in the other four areas. This observation is supported by the results of the ANOVA (which show that the five populations are significantly (p-value $< 10^{-4}$) different for plant height) and by the results of Tukey's HSD test, which shows, in particular, that the height of the Mt. Cavallo population samples is significantly (p-value < 0.001) different from that of all the other populations (Table 4).

Discussions and conclusion

Analyses provided interesting information regarding the plant community, ecology and CSR strategy of *L. tonzigii*. In particular, they showed that the same plant community (the *Linaria tonzigii-Hornungia alpina* community) is present in the various areas where the relevés were performed, but that the community has two variants due to the presence of certain species. As well as species which are geographically widespread and mostly of *Thlaspion rotundifolii* (which live on dry screes that are basic and poor in nutrients), the *Linaria tonzigii-Hornungia alpina* community also presents a fair number of steno-endemic species that characterize its floristic composition and pinpoint it to a precise geographic context – namely the limestone pre-Alps of Bergamo. The pre-Alpine district of Lombardy, where endemic species make up 15% of the flora, is the second most important centre of endemism in the alpine chain (Pawlowski 1970). This richness in endemic species is due to the fact that many pockets in the region were glacial refuges during the Quaternary Age (Giacomini & Fenaroli 1958; Reisigl 1995; Andreis et al. 2017; Smyčka et al. 2017).

A step towards understanding the responses of *L. tonzigii* to its environment was achieved by evaluating its CSR strategy. According to the results of this research, *L. tonzigii* has a R / CSR strategy which is slightly different from the *rss* (stress-tolerant ruderals) attributed by Landolt et al. (2010), so this species must have developed morpho-physiological adaptations that allow it to withstand disturbance phenomena. In this case, the disturbance would be the movement of rocks and debris that make up the unstable screes where this endemic plant (and its plant community) lives and which, indeed, it requires. Although the mean strategy of *L. tonzigii* is R / CSR, the species presents slightly different adaptations/strategies in the different sampling areas (Figure 4 and Table 3). In particular, it would seem that the plants on Mt. Cavallo and those on Mt. Ferrante have a clear predominance of the ruderal component (R) and low values of the stress-tolerator (S) (which is zero for the Mt. Cavallo samples) and competitive (C) components, while the plants collected in the remaining areas, especially those of Mt. Secco, have developed greater adaptations to stress. This may be because in the southernmost areas (Mt. Menna, Mt. Arera and Mt. Secco; Figure 1), where the species also grows at lower altitudes, *L. tonzigii* populations have developed greater adaptations to stress, which, in this case, could be the high summer temperatures. Indeed, according to Grime (2001), sub-optimal temperature is one phenomenon that can restrict photosynthetic production (which represents a stress factor for the

Table 3 – Means and standard errors of C, S and R percentages of Linaria tonzigii *in each study area (A – Mt. Cavallo; B – Mt. Menna; C – Mt. Arera; D – Mt. Secco; E – Mt. Ferrante).*

Study area	C (%)	S (%)	R (%)
A (n=10)	15.29	0.00	84.71
	18.22	0.00	81.78
	23.02	0.00	76.98
	16.72	0.00	83.28
	25.04	0.00	74.96
	14.39	0.00	85.61
	11.73	0.00	88.27
	10.08	0.00	89.92
	11.08	0.00	88.92
	8.41	0.00	91.59
Mean	15.40	0.00	84.60
±SD	5.49	0.00	5.49
B (n=10)	35.70	44.62	19.68
	40.12	12.17	47.71
	33.14	45.90	20.96
	9.53	0.00	90.47
	16.95	56.95	26.10
	18.01	24.52	57.47
	17.41	55.62	26.97
	8.09	0.00	91.91
	7.61	62.50	29.90
	44.23	32.14	23.64
Mean	23.08	33.44	43.48
±SD	13.91	23.43	27.88
C (n=10)	25.79	0.00	74.21
	34.64	28.82	36.54
	1.95	93.30	4.74
	49.75	0.00	50.25
	19.67	41.68	38.64
	15.68	47.65	36.67
	17.41	0.00	82.59
	16.68	53.61	29.71
	22.95	0.00	77.05
	19.24	0.00	80.76
Mean	22.38	26.51	51.12
±SD	12.68	32.30	26.38
D (n=10)	1.95	92.97	5.08
	1.81	93.23	4.96
	23.34	0.00	76.66
	18.25	72.14	9.61
	23.40	71.39	5.21
	6.14	47.79	46.07
	15.78	64.57	19.65
	21.70	49.86	28.44
	10.84	27.36	61.80
	16.11	13.38	70.51
Mean	13.93	53.27	32.80
±SD	8.34	31.84	28.67
E (n=10)	23.63	0.00	76.37
	27.12	0.00	72.88
	13.33	0.00	86.67
	14.26	0.00	85.74
	7.63	0.00	92.37
	13.44	24.55	62.01
	14.19	0.71	85.09
	8.38	0.00	91.62
	1.93	63.92	34.15
	2.70	29.68	67.62
Mean	12.66	11.89	75.45
±SD	8.12	21.49	17.72
Total (n=50)	**C (%)**	**S (%)**	**R (%)**
Mean	17.49	25.02	57.49
±SD	10.72	30.07	29.55

Table 4 – p-values returned by Tukey's HSD test for the plant height of the samples of each study area (A – Mt. Cavallo; B – Mt. Menna; C – Mt. Arera; D – Mt. Secco; E – Mt. Ferrante). Sample sizes: A = 35; B = 53; C = 130; D = 22; E = 9. p-values < 0.001 are highlighted in bold.

Sampling area	A	B	C	D	E
A	-	0.00000	0.00000	0.00007	0.00099
B		-	**0.67074**	**0.63225**	**0.99657**
C			-	**0.97636**	**0.99901**
D				-	**0.97933**
E					-

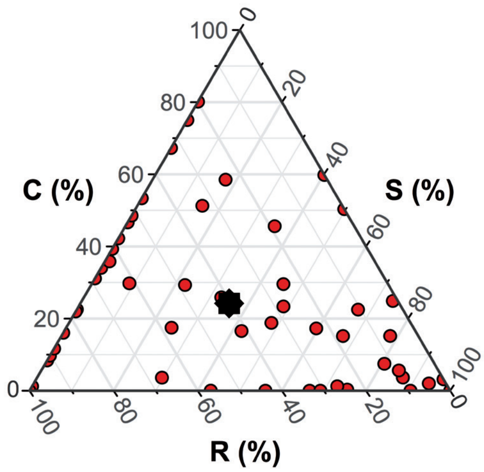

Figure 5 – CSR strategies of the species of the Linaria tonzigii-Hornungia alpina *community (red dots) and mean strategy of the community (black-filled star).*

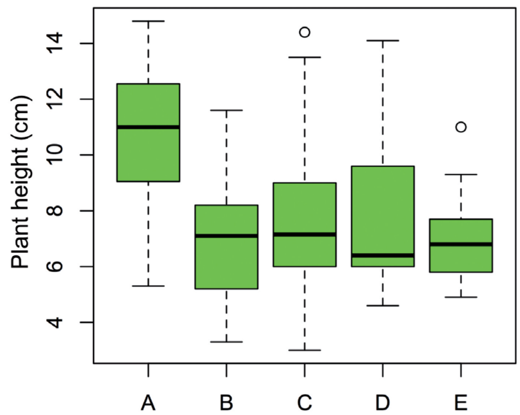

Figure 6 – Boxplots of plant height of individuals of Linaria tonzigii *in the five study areas (A – Mt. Cavallo; B – Mt. Menna; C – Mt. Arera; D – Mt. Secco; E – Mt. Ferrante). Number of samples per area: A = 35; B = 53; C = 130; D = 22; E = 9.*

plants). Moreover, May et al. (2017) demonstrated that intra-specific variation in plant functional strategies may be due to climate adaptation. In particular, they observed an intra-specific variation between *Arabidopsis thaliana* accessions (grown under controlled environmental conditions) along the S-R axis, similar to that observed in our research on *L. tonzigii* plants growing in nature, in which the greatest variation was indeed for the components R and S (Table 3).

In order to understand whether the temperatures of the sampling areas really are different, it would be appropriate to conduct further field measurements and analyse the data, which might highlight the new threat to *L. tonzigii* populations (at least for those on the southernmost slopes) posed by climate warming. It would also be interesting to measure the accumulation of snow in the various areas where *L. tonzigii* is present, as well as to evaluate the speed at which the snow on the screes melts and the period during which this happens in order to understand whether particularly rapid and / or early melting can cause water stress to the plant during the summer months. In fact, according to Leuschner & Ellenberg (2017), the scree plants of alpine and subalpine environments should have good availability of water (below the dry, stony material) during the summer period from the melting of the snow cover. The absence of this source of water during the summer (due to little accumulation of snow during the winter or the fact that the snow melted too early) could represent a further stress for *L. tonzigii* (closely linked to the rise in temperatures and exposure) that could explain the different CSR strategy of the plants in the various sampling areas. Similarly, a greater adaptation to stress could also be due to a greater lack of nutrients in the substrate. Indeed, according to Zöttl (1952) and Leuschner & Ellenberg (2017) the dust contained in the snow provides a significant contribution of nutrients to the plants of the limestone scree.

The assessment of the mean CSR strategy of the *Linaria tonzigii-Hornungia alpina* community (Figure 5) has provided an overall picture of the strategies of the species (or the *CSR fingerprint* of the community), even though the functional strategy of some species (25 out of 76) is not known. This analysis shows that the CSR values of *L. tonzigii* are very different from those of other herbaceous alpine species typical of screes (which very often grow together), such as *Hornungia alpina* (C:S:R = 1.2 : 0.0 : 98.8), *Thlaspi rotundifolium* (C:S:R = 3.2 : 96.8 : 0.0), *Campanula cochleariifolia* (C:S:R = 3.6 : 29.7 : 66.7), *Saxifraga aizoides* (C:S:R = 0.0 : 66.6 : 33.4), *Carex firma* (C:S:R = 3.7 : 86.9 : 9.4), *Cerastium latifolium* (C:S:R = 16.1 : 0.0 : 83.9), and *L. alpina* (C:S:R = 0.4 : 9.6 : 90.0; original data). This may be due to the fact that plants with different growing strategies live together in the screes (scree wanderers, scree creepers, scree stabilizers, scree coverers, scree accumulators; Schröter 1926; Jenny-Lips 1930). These scree-living plants can be organized into three main groups: 1) passive scree wanderers; 2) scree creepers and coverers; 3) scree accumulators and stabilizers (Leuschner & Ellenberg 2017). Therefore, scree plants with different growing strategies could have different CSR strategies, even though they are present in the same environments. This requires confirmation from further studies, which would further enhance knowledge of the peculiarities of the plant communities of the scree. It would also be worth considering whether, in addition to *L. tonzigii*, other scree plants (or plants in other environments) have a wider range of variability in CSR strategies. Our study highlights (as does that of May et al. (2017)) that some species may have different CSR strategies based on the different sites in which they grow, hence suggesting that the functional variability of a species is much wider than has so far been apparent. In future, it would therefore be advisable to evaluate the functional variability (and mean strategy) of each plant species, in particular those of which the

CSR strategy was evaluated starting from plant material collected only at a single site and taken from a few individuals (as was the case for almost all the species of which the CSR strategy was already known).

From an overall analysis of the results of this work, it is also apparent that, in the Mt. Cavallo area, *L. tonzigii* presents morphological characteristics (plant height) and a functional strategy that, along with the floristic composition of the plant community to which it belongs, differentiate it from the populations of other areas. This would lead us to conclude that the Mt. Cavallo population could be a different ecotype. Indeed, the Mt. Cavallo population is very isolated from the others and located at the northern limit of the *L. tonzigii* distribution range. These conditions, together with the probably harsher temperatures, may have favoured the differentiation of this ecotype, a hypothesis which should, however, be verified by further studies.

In conclusion, this research, as well as stimulating a more in-depth study of variability in the CSR strategies of plants, enriches knowledge regarding *L. tonzigii* and its community. We hope that, in the next few years, similar research can be carried out for other little-known endemic and / or rare and / or threatened species so as to enrich knowledge of their ecology and of their communities, an essential step when planning conservation measures for such species and their environment, and to protect the biodiversity of the protected areas, and hence that of the planet.

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