**Effect of grassland mosaic structure and dynamism on the reproductive habitat suitability for *Alectoris graeca* in central Apennines**

**Abstract:** Over the last several decades, the Mediterranean region has been subjected to mountain abandonment and farming cessation, leading to changes in vegetation and coenological features of grasslands, contextually to the strong decline of the rock partridge (*Alectoris graeca*). Our hypothesis was that the ongoing dynamic processes leading to the compositional changes of grasslands in central Apennines affect the habitat suitability for the singer male. To investigate the interplay of the presence/absence of singer males and the composition and dynamism of the vegetation mosaics, the sampling design consisted in two phases, aimed to define the presence/absence of spring territorial singer males in different sites, and to characterize the vegetation mosaic of such sites*.*Our results emphasized the marked overlap between the general environmental conditions, which proved to define the habitat suitability for *A. graeca*, and the characteristics of the site chosen by the singer male for starting the reproductive activities. Moreover, we found that the site suitability for the singer male decreases when the vegetation recovery processes are ongoing, because of the spread of coarse tall grasses-dominated communities and/or grassland types with dense turf. Tall grass-dominated communities and thick-turf grasslands exert their negative effect decreasing the habitat suitability for the singer male starting from very low cover values.Therefore, it is conceivable that singer male’s suitable habitat will be dramatically restricted to the steepest south-facing slopes, where topographic and soil conditions do not allow the spread of grasslands with dense turf and of invasive/dominant tall grasses, increasing the threat to the species due to the effect of climate change on the vegetation features.

**Keywords:** *Brachypodium genuense*; Grazing cessation; Habitat suitability; Rock partridge; Singer male

**Introduction**

Over the last several decades, the Mediterranean region has been subjected to major changes in land use/cover (Balabanis et al. 2000; Burke and Thornes 2004; Symeonakis et al. 2007). In particular, the socio-economic changes that occurred after World War II triggered the abandonment of mountain areas (Antrop 2004; Mazzoleni et al. 2004). This process did not leave the central Apennine landscape unaffected (Geri et al. 2010; Bracchetti et al. 2012). Because of this, assessment of the effect of vegetation dynamic processes on ecosystem features and services has become a major issue throughout Europe, as well as in Mediterranean mountains (Luick 1998; Zervas 1998; Dullinger et al. 2003; Kaligarič et al. 2006; Sebastià et al. 2008; Vitasović Kosić et al. 2011; Peco et al. 2006, 2012). Nevertheless, the question of whether abandonment of mountain farming enhances or threatens biodiversity conservation remains still an open one, since the various impacts of abandonment are evaluated in different ways, through the choice of metrics, taxa to be assessed, and the aspect of conservation to receive attention (Quieroz et al. 2014).

Cessation of traditional land use induced the expansion of shrub-lands and forests (e.g., Mottet et al. 2006; De Aranzabal et al. 2008; Petanidou et al. 2008), leading to a remarkable modification of ecosystem services and mountain biodiversity. However, along the Apennine ridge, paramount changes in the grassland landscape composition are also due to the increase of turf density and cover value, especially due to the spread of graminoids such as *Festuca* sp. pl. (Giarrizzo et al. 2017) in less productive conditions (Catorci et al. 2013) and to the invasion of stress-tolerant-competitive (sensu Grime 2001), coarse tall grasses in more productive conditions (Malatesta et al. 2019). At the highest altitudes (over 1,400 m a.s.l.), an important species in this respect is *Brachypodium genuense* (DC.) Roem. et Schult, an endemic rhizomatous tall grass, which originates a dense monospecific turf, 30-60 cm tall. *B. genuense* occurs in the semi-natural grasslands of the Italian peninsula, over 1200-1400 m a.s.l. (Camiz et al. 1991). Because of its silica-rich and hairy leaves, domestic herbivores feed on it only in overstocking conditions (Catorci et al. 2014a). Contrariwise, small clumps of *Brachypodium* enclosed in a multispecies community are visited by herbivores, and consequently have a better chance (neighbor association) to be defoliated (Canals et al. 2017). Therefore, its spread is primarily fostered by the cessation or reduction of traditional management practices, such as grazing and mowing (Catorci et al. 2011 a, b).

Spread of *Brachypodium* dramatically changes the coenological composition of plant communities (Catorci et al. 2011b) and the feed value of pastures (Vitasović Kosić et al. 2014), negatively affecting domestic herbivores rearing (Catorci et al. 2014a; Scocco et al. 2012, 2013, 2016). The *Brachypodium* invasion decreases also the vegetation heterogeneity from a phenological point of view since, as indicated by Corazza et al. (2016), it decreases the abundance of early and mid-flowering species and this may be a key issue in habitat suitability for wild animals. In fact, Duparcet al. (2013) found that subalpine grassland communities are heterogeneous in timing of maximum productivity and flowering phenology, creating small-scale variability in forage quality and seed production, that are basic conditions for animals living in the summit sectors of high mountains. Actually, it has been proved that *Brachypodium* encroachment reduces habitat suitability for wild herbivores like the Apennine chamois (Corazza et al. 2016).

Since also bird species have been proved to be largely affected by the vegetation dynamic processes (Rolando et al. 2014), we focused on the interplay between the grassland mosaic structure and dynamism of vegetation in the Alpine/sub-Alpine Apennine mountain belts and the habitat suitability for *Alectoris graeca* Meisner 1804. *A. graeca* is listed in the 2009/147/EC Directive and is declining in many territories (Nicolai 1986; Del Hoyo et al. 1994; Trouvilliez 1994; Bernard-Laurent and Boev 1997; Meriggi et al. 1998; Bernard Laurent and Léonard 2000). In particular, along the Apennine ridge, *A. graeca* survives in small and fragmented populations undergoing a drastic decrease in connectivity, likely as a result of a reduction in numbers and size of suitable patches, increasingly separated by unsuitable areas (Siragusa and Carelli 1979; Bologna et al. 1983; Angelici and Luiselli 2001). This is a constraint for the species conservation, since it seems to have low dispersive ability. In fact, radio-tracking studies performed in the Sibillini National Park (Renzini et al. 2001) highlighted that the autumn and winter trips are shorter than 2 kilometers, and the spring ones do not exceed distances of 3-4 kilometers. This species prefers rocky, dry, particularly steep slopes (Bocca 1990), with low herbaceous cover and scattered bushes (Cramp and Simmons 1980; Spanò et al. 1998; Amici et al. 2004). Its diet is composed of numerous plants and arthropods; *Coleoptera*, *Chrysomelidae*, and *Orthoptera* are the most represented groups among eaten insects (De Sanctis et al. 2000). From a reproductive viewpoint, dominant males choose the most suitable site around the second half of April, and then they start singing to attract females and to send information of their presence to other males (Wiley and Richards 1978).

It was largely argued that land use changes may strongly reduce the habitat suitability for *A. graeca* (Rippa et al. 2011), but few data are available on how vegetation dynamic processes affect these conditions, with particular regard to the reproductive sites.

Improving our knowledge on the effects of vegetation dynamism on reproductive habitat requirements of *Alectoris graeca* is, therefore, a major goal in refining the management direction devoted to its conservation and in better understanding the causes of its decline.

Because of this, we performed a study aimed at understanding the effect of grassland mosaic structure and dynamic processes at the medium scale (one hectare), and the threshold values of the plant landscape composition in determining the habitat suitability for the singer male. In particular, we hypothesized that grassland mosaic modification, especially tall herbs encroachment and increase in turf density due to grazing cessation and the activation of vegetation recovery processes, led to the decrease of habitat suitability for the singer male of *A. graeca*, even if the landscape features remain substantially unchanged from a physiognomic point of view (i.e. herbaceous vegetation).

To test this hypothesis, we addressed the following questions: i) do sites where the singer male occurs, differ in landform and land cover features at the plant community scale, from those where it does not occur and, if so, what are their distinctive characteristics? ii) what are the landform / land cover features that decrease the suitability of sites for the singer male and do they reflect vegetation recovery stages?

**1 Material and Methods**

***1.1 Study area***

The study area encompasses the Monti Sibillini National Park (central Italy; central coordinates 42° 49’ 26” N 13° 16’ 32” E, coordinate system UTM-WGS84), and ranges from 1,250 to 2,400 m a.s.l. (Fig. 1). This area, of about 1,315 hectares, is characterized by limestone bedrock. The vegetation consists of beech forests and a very rich mosaic of herb communities, composed of scree vegetation, included in *Thlaspietea rotundifolii* Br.-Bl. 1948, *Drypidetea spinosae* Quézel 1964 and *Asplenietea trichomanis* (Br.-Bl. in Meier et Br.-Bl. 1934) Oberd. 1977 classes, and grasslands of *Nardetea strictae* Rivas Goday et Borja Carbonell in Rivas Goday et Mayor López 1966, *Festuco hystricis-Ononidetea striatae* Rivas-Mart. et al. 2002, *Festuco-Brometea* Br.-Bl. et Tx. ex Soó 1947and *Elyno-Seslerietea* Br.-Bl. 1948classes. The human-shaped upper timberline runs at 1,400–1,600 m a.s.l. (Catorci et al. 2011a).

The study area lies in the Temperate region, near the border of the Mediterranean one and is characterized by an alternation of winter cold stress and summer drought stress, with different intensities, depending on the elevation gradient and landform factors (Rivas-Martínez and Rivas-Saenz 2016). Annual average temperature ranges from 3.5 to 7.0 °C. Average annual precipitation ranges from 1,300 to 1,600 mm, with two seasonal peaks in late spring and autumn and a rainfall decrease in summer.

A very high grazing pressure characterized the pastoral landscape for centuries, but the last decades have seen a marked trend of grazing cessation and mountain farming abandonment, and thus several sectors of the National Park are currently abandoned and undergoing vegetation recovery and dynamic processes. In particular, Malatesta et. al. (2019) observed a decrease of areas covered by communities with open turf and an increase of pastures with thick and closed sward, primarily with a dominance of *Brachypodium genuense*. Moreover, a marked dynamism of the grassland mosaic was detected, involving high patch turnover and leading to homogenization of the landscape structure, especially on south-facing slopes.

**Figure 1.** Location of the study area (indicated with a black rectangle in the upper right corner) and distribution range of *Alectoris graeca* (black areas) in the Monti Sibillini National Park.



***1.2 Data collection***

To investigate the interplay of the presence/absence of singer males and the composition and dynamism of vegetation mosaics, the sampling design consisted in two phases, aimed to define the presence/absence of spring territorial singer males in different sites, and to characterize the vegetation mosaic of such sites*.*

*1.2.1 Spring census of singer males*

On the basis of previous research, performed in the last fifteen years in the Monti Sibillini National Park (Pandolfi et al. 2001; Renzini et al. 2001; Sorace et al. 2013), we selected seven sites where *A. graeca* was constantly observed, even if with different densities. Within these sites, in 2015 we laid 15 transects for a total of 44 km-long walking routes with an average length of ca. 3000 m per transect, and 74 playback stations (one station every 400 m of transect length). For each site, the number of transects was proportional to its extension. Transects starting points were set randomly. To increase the chances of sighting, each transect was covered from lower to higher altitudes.

Census of rock partridge was made by spring census of singer males in the period of maximum territorial males (May-June). Indeed, the presence of singer males is a key factor in the reproductive biology of *A. graeca*, particularly as far as nesting activities are concerned. Playback was conducted from 5:00 to 11:00 a.m., using a recorded track with the typical call of species, reproduced in the field using an amplified recorder. For each station, we repeated the call three times, oriented in three directions, maintaining a minimum angle of 90° between two consecutive repetitions. Each repetition lasted 20s, waiting 120s for the rock partridge response. For each station we noted the geographic coordinates (UTM, WGS84).

*1.2.2 Vegetation survey*

Using a GIS software (QGIS desktop 3.4.2), wesurrounded the transects used for the spring census of singer males with a buffer of 400 m (200 m on each side of the transect line), and overlapped it to a grid composed of 400 x 400 m cells, so that they were divided by the transect line in two equal parts. The total number of cells was 74. Each cell was overlaid with a grid of 16 plots (100 x 100 m).We randomly selected one plot per cell. Plots falling partly inside woods or in particularly steep and hazardous sites were discarded. In each selected plot (59 in all),we collected the following data:elevation (m a.s.l.), aspect angle (azimuth degrees) and slope angle (vertical degrees), calculated using a GIS software; percentage of the plot (visually estimated) covered by rocky outcrops and debris, trees and shrubs, *Brachypodium genuense-*dominated community, herbaceous communities not dominated by *B. genuense* but with dense turf (bare soil cover lower than 10%) or with discontinuous turf (bare soil cover ranging from 10 to 40%). Surveyors did not know presence/absence data of the singer males along the transect. Afterwards, for each plot the presence/absence of the singer male of *A. graeca* in the respective 400 x 400 m cell, was annotated.

***1.3 Data analysis***

Prior to statistical elaborations, aspect angles measured in the field were converted to a scale ranging from 0 (north-north-east) to 180° (south-south-west), that is from the coldest to the warmest conditions, so that angles symmetrical with respect to the north-north-east / south-south-west axis had the same values (e.g. east-south-east and west-north-west correspond to 90°).

We performed a principal component analysis (PCA) on a correlation matrix of variables collected during the vegetation survey (elevation, aspect and slope angles, rocky outcrop and debris cover, tree and shrub cover, open-turf, dense-turf and *B. genuense* communities cover), to understand the main axes of variation of sites and the relations among variables. Prior to PCA, all the variables were standardized (Sokal and Rohlf 1981). We performed PCA using R, version 3.4.1 (R Core Team 2017) and the rda function of the *vegan* R-package (version 2.4-3, Oksanen et al. 2017).

We used generalized linear mixed-effect modelling (GLMM) to understand the single effects of the explanatory variables (fixed effects) on presence/absence of the singer male. We accounted for the sampling design using transect nested within site (1|site/transect) as random intercept. *P* values were adjusted for multiple testing, using the p.adjust function (method = holm) of the *stats* R-package (version 3.4.1, R Core Team 2017). Using the same random structure, we generated a global model using all the variables, and performed an AIC-based model selection using the dredge function of the *MuMIn* R-package (version 1.40.0, Barton 2017). We generated models using the binomial error distribution by means of the glmer function (family = binomial, link function = logit) of the *lme4* R-package (version 1.1-13, Bates et al. 2017); response variables were square-root transformed, if needed (Faraway 2006). To assess model significance, we compared the model with the respective null model, using the anova function of the *stats* R-package.

**2 Results**

Principal Component Analysis identified two main groups of plots (Fig. 2), distinguishing fairly well the sites with presence of singer male (reproductive sites) from those without singer male (non-reproductive sites). The first two PCA components explained the 37.7% and the 19.6% of the total variance, respectively. The plots in reproductive sites were characterized by higher values of slope angle, debris/outcropping rock, and dominance of grasslands with open sward; instead, high cover values of *Brachypodium genuense*-dominated community and of dense grasslands, characterized the non-reproductive sites (Fig. 2). In particular, in the reproductive sites, the slope angle was mostly higher than 38°, while in non-reproductive sites, its value was mainly lower than 35°; debris/outcropping rock cover was mostly higher than 47.5% in reproductive sites, while, generally, it did not exceed 12.8% in non-reproductive sites (Table 1). We observed the same trend as regards discontinuous vegetation cover (generally higher than 13.5% in reproductive sites and lower than 10% in the non-reproductive ones). We detected the opposite trend as far as dense vegetation communities are concerned. In reproductive sites, the cover of dense grassland vegetation usually was not higher than 15%, and the *B. genuense*-dominated community was absent; in non-reproductive sites, these variables had mean values of 55.3% and 22.3%, respectively (Table 1). Significant differences between the two groups of plots were found with regard to slope angle, debris and outcropping rock cover, and *B. genuense*-dominated community cover (Table 1). The best model, selected using the AIC-based procedure applied to all the considered topographic and vegetation variables, included elevation, slope angle, aspect angle, tree/shrub cover, cover of continuous vegetation and of the *B. genuense*-dominated community (*p* = 7.29 10-8).

**Figure 2.** Principal component analysis (PCA) biplot. Vectors indicate the variables considered: elevation (Elev.); aspect angle (Asp.); slope angle (Slope); rocky outcrop and debris cover (Deb./rock); tree and shrub cover (Tree/shrub), discontinuous herbaceous community cover (Disc. herb.), continuous herbaceous community cover (Con. herb.); and *Brachypodium genuense* community cover (*Bra gen*). White dots indicate reproductive sites of *Alectoris graeca*; black dots, non-reproductive sites.



**Table 1**Descriptive statistics of the environmental and vegetation variables in reproductive (1) and non-reproductive (2) sites and in all the sites, and results of the generalized mixed-effect models explaining the effect of each explanatory variable (fixed effect) on presence/absence of the singer male of *Alectoris graeca*, with transect nested inside site as random intercept. Intercept, slope estimate and its significance value (*p*) are indicated. *p* values are adjusted for multiple testing using the Holm correction.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | *n* | Mean | SD | Median | 1st quartile | 3rd quartile | Intercept | Slope | *p* |
| +Elevation(ma.s.l.) | 1 | 19 | 1771 | 117.8 | 1721 | 1681 | 1926 |  |  |  |
| 2 | 40 | 1680 | 183.2 | 1700.5 | 1567.75 | 1787 | -14.065 | 0.083 | 1.000 |
| Total | 59 | 1710 | 169.5 | 1701 | 1633 | 1797.5 |  |  |  |
| +Aspect angle (azimuth degrees) | 1 | 19 | 152.2 | 26.32 | 154.5 | 140.0 | 173.0 |  |  |  |
| 2  | 40 | 137.1 | 30.05 | 139.0 | 112.5 | 163.75 | -5.000 | -0.534 | 1.000 |
| Total | 59 | 142.0 | 29.54 | 149.5 | 120.5 | 166.5 |  |  |  |
| Slope angle (vertical degrees) | 1 | 19 | 39.6 | 4.60 | 40.0 | 38.0 | 43.0 |  |  |  |
| 2 | 40 | 28.3 | 9.05 | 27.0 | 23.75 | 35.0 | -65.909 | 1.372 | 3.61 10-3 |
| Total | 59 | 31.9 | 9.49 | 35.0 | 25.0 | 40.0 |  |  |  |
| +Debris and outcropping rock (%) | 1 | 19 | 62.5 | 18.00 | 67.0 | 47.5 | 80.0 |  |  |  |
| 2 | 40 | 11.1 | 19.33 | 3.0 | 0.5 | 12.8 | -126.124 | 21.803 | 3.14 10-5 |
| Total | 59 | 27.6 | 30.64 | 12.0 | 1.75 | 50.0 |  |  |  |
| Trees and shrub (%) | 1 | 19 | 3.7 | 5.84 | 1.0 | 0.6 | 4.5 |  |  |  |
| 2 | 40 | 6.2 | 8.51 | 2.0 | 0.0 | 9.3 | -10.811 | 0.013 | 1.000 |
| Total | 59 | 5.4 | 7.80 | 2.0 | 0.1 | 6.5 |  |  |  |
| *Brachypodiumgenuense* community (%) | 1 | 19 | 0.0 | 0.00 | 0.0 | 0.0 | 0.0 |  |  |  |
| 2 | 40 | 22.3 | 26.19 | 10.0 | 0.0 | 44.3 | -11.48 | -4142.38 | 1.33 10-3 |
| Total | 59 | 15.1 | 23.91 | 0.0 | 0.0 | 22.5 |  |  |  |
| +Discontinuousherbaceous vegetation (%) | 1 | 19 | 22.9 | 14.21 | 20.0 | 13.5 | 28.3 |  |  |  |
| 2 | 40 | 5.4 | 9.32 | 0.0 | 0.0 | 10.0 | -16.750 | 1.442 | 0.092 |
| Total | 59 | 11.0 | 13.77 | 5.0 | 0.0 | 20.0 |  |  |  |
| +Continuous herbaceous vegetation (%) | 1 | 19 | 12.1 | 19.03 | 0.0 | 0.0 | 15.0 |  |  |  |
| 2 | 40 | 55.3 | 32.07 | 61.0 | 33.6 | 83.6 | -9.824 | -0.889 | 0.090 |
| Total | 59 | 41.4 | 34.89 | 36.9 | 0.0 | 74.5 |  |  |  |

*n* – number of sites; SD - standard deviation. +The variable was square root-transformed to build the generalized mixed-effect model.

**3 Discussion**

Our results confirm the preference of *A. graeca* for medium/high altitudes (Salvini and Colombi 1983; Spanò et al. 1998). Moreover, we found that the site conditions chosen by singer males (high slope angle, open areas with high debris/outcropping rock cover and absence of tall grass communities) overlap with the site characteristics considered favourable to increase the habitat suitability for the species(see Fella et al. 1994; Renzini and Ragni 1998; Cattadori et al. 1999; Pompilio et al. 2003; Scalisi and Guglielmi 2004; Viterbi et al. 2006). This may depend on a complex set of factors; one of the most important is likely that, as indicated by Bernard-Laurent et al. (2017), at the beginning of the mating period, males pick the site taking into account the nesting, and consequently the parental care (Parmelee and Payne 1973; Hilden 1975). In fact, to promote the nest survival, firstly the soil should be characterized by an excellent drainage, because the hatching is performed at ground level (Casas et al. 2009), conditions that could be ensured, in accordance with our results, by the rather high slope angle, with high debris/outcropping rock cover and on south-facing slopes. In addition, the nest is generally placed in the shelter of a shrub or under a protruding rock, dug into the ground and covered with feathers and not inside tall vegetation (Amici et al. 2004). Moreover, an area with open vegetation is a favourable site for the chick’s diet, composed primarily by animal proteins (e.g. *Coleoptera*, *Chrysomelidae* and *Orthoptera*, De Sanctis et al. 2000). Indeed, chicks tend to feed in areas predominantly characterized by low and sparse grasses, and use to follow an adult during the first weeks after the hatching (Thaler 1987; Bernard-Laurent et al. 2017). Essentially, the above-mentioned conditions emerged to significantly discriminate the sites with occurrence of singer males.

A new key finding of the present study is the importance of the spread of *B. genuense*-dominated communities. This is rather interesting, since our results indicated that the loss of habitat suitability for the singer male occurred when the land cover variations were not still dramatic and the landscape substantially remained a grassland ecosystem. This is a paramount question, since *B .genuense* is able to sustain dominance in a wide range of environmental conditions, modulating the coordination strategies of resource acquisition and use and, thanks to its clonal integration strategy, quickly spreads on mountain slopes (Tardella et al. 2017; Malatesta et al. 2019). The spread of *B. genuense* also reduces plant diversity at the community scale, because of competitive exclusion exerted on small and early flowering species (Catorci et al. 2012). Moreover, the presence of litter and old tussocks hamper the normal cycle of seasonal vegetation re-growth, lowering the availability of new buds and leaves to *A. graeca*.

In addition to the negative effect related to the expansion of *B. genuense*, we found that the suitable sites for singer males had also low cover values of the thick-turf vegetation. High values of thick-turf community may be related to the site condition that allows for the development of quite productive grasslands (flat areas, north-facing slopes, concave drainage line landforms). However, it should be considered also that, where dynamic processes are underway, a general increase of turf density and height of plant communities is ongoing (Catorci et al. 2011a) and that Malatesta et al. (2019) proved that on south-facing slopes a noteworthy increase of the turf density occurred in the last decades.

Since the spread of tall grasses and the increase of the turf density on the least productive conditions are linked to the vegetation dynamic processes (Catorci et al. 2011b; Biondi et al. 2016), which, in turn, are related to the cessation or the strong decrease of grazing activities (Catorci et al. 2013), it is possible to confirm that the vegetation dynamic processes triggered by the cessation of the traditional pastoralism, negatively affect the suitability of sites for the singer male and, thus, for the following nesting and chicken’s parental care activities. Therefore, the loss of suitability could be found in all the complex processes of vegetation recovery after grazing cessation, highlighting how this factor is a key driver in determining the availability of suitable reproductive sites for *A. graeca*.

**4 Management directions**

Based on our results, we can argue that livestock grazing cessation might be detrimental, not only for the conservation of wild herbivores (e.g. the Apennine chamois), and plant, insect and bird diversity, as widely demonstrated elsewhere (Corazza et al. 2016; Moreira and Russo 2007), but also for *A. graeca*. Thus, actions devoted to manage changes due to dynamic processes and aimed to recover a higher degree of landscape heterogeneity are urgently needed. In particular, a modern system of shepherding in the summit sectors of the study area should be promoted, also aimed at the restoration of connectivity among the different patches. In fact, it was argued (Saura and Rubio 2010) that the spread of tall herbs-dominated patches leads to the fragmentation of the reproductive areas, and consequently to isolation of the different populations of *A. graeca*. Instead, debris, outcropping rock, and a discontinuous vegetation allow the dispersal to other habitat patches and function as stepping stones which, even when they are not the final destination, facilitate dispersal between patches (Saura and Rubio 2010). Grazing activities should envisage grassland recovery by localized and pulsing intense grazing pressure on south-facing slopes, as well as the identification of low intensity grazing areas that could be alternated with different intensity along the main environmental gradients. In fact, orienting corridor linkages along environmental gradients may assist species in tracking climatic suitability in the future (Pearson and Dawson 2005), maximizing their potential to persist in the face of rapid global climate change (Jewitt et al. 2017). Avoiding the litter and dry matter accumulation linked to *B. genuense* invasion (see Catorci et al. 2011a) could be useful also in order to prevent threats to biodiversity and anthropic settlements due to fires and avalanches.

**5 Conclusions**

Our results emphasized the marked overlap between the general environmental condition, which proved to define the general habitat suitability for *A. graeca*, and the characteristics of the site chosen by the singer male for starting the reproductive activities. Moreover, we found that the site suitability for singer male quickly decreases when the vegetation recovery processes are ongoing, because of the spread of coarse tall grasses and/or of grasslands types with dense turf. This likely decreased the connectivity among suitable sites, emphasizing the role of traditional grazing activities in maintaining wide surfaces suitable for reproduction of *A. graeca*. Without semi-extensive livestock breeding the suitable sites would be restricted to the steepest south-facing slopes, where topographic and soil conditions do not allow for the spread of thick vegetation and the invasive/dominant tall grass expansion. This might be understood as a process in which the *A. graeca* distribution reverts to ancient, non-anthropogenic conditions, in equilibrium with the local landforms and climatic features. However, this can also be considered a problematic processleading to a high risk of local extinction, because the effect of climate change will increase the negative effects of grazing cessation by modifying the vegetation characteristics; for instance, by the decrease of small-statured cryophilic species and the increase of caespitose hemicryptophytes and dwarf shrubs.

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