Abstract: The sword lily *Gladiolus palustris* Gaudin is protected on European level and listed in Annexes II and IV of the EC Habitat Directive 92/43/EEC. It grows in nutrient-poor, calcareous meadows in central and eastern Europe. Tree encroachment in montane meadows of the European Alps as a result of recent land use changes and the abandonment of traditional farming practices threaten the survival of this species. Conservation-driven mowing is considered a feasible conservation measure for maintaining high species diversity in abandoned semi-natural grasslands. To assess the effects of ten years of biennial mowing on a grassland community in the Dolomiti Bellunesi National Park, Italy (Site of Community Importance, Natura 2000 network), ten 25 m² plots were established whereby four plots were placed in the mowed area, four in the non-mowed area and two in a small non-mowed patch of grassland inside the mowed area. In each plot the following variables were recorded, total percentage of plant cover, percentage cover of woody species, percentage cover of herbaceous species, percentage cover and number of flowering ramets of *G. palustris* and a complete list of species and their percentage abundance. Mowed plots showed a higher species richness than non-mowed plots. The number of *G. palustris* flowering ramets and percentage cover increased manifold in mowed plots compared to non-mowed plots. The resumption of mowing for
conservation purposes undertaken by the managing authority halted the process of tree encroachment and avoided a drastic change in plant composition. Periodic mowing (every second or third year) was demonstrated to be a cost-effective conservation measure in non-productive grasslands to keep grasses at bay in favour of forbs of high conservation value.

Keywords: Conservation management; Semi-natural habitats; Habitat directive; Montane grassland; Natura 2000 network; Dolomiti Bellunesi National Park

Introduction

Traditionally, low productive grasslands in mountain areas are mowed once a year (Middleton et al. 2006). However in many places, this practice has become economically unsustainable where mechanisation is not possible for example due to difficult access and steep slopes (Török et al. 2011; Valkó et al. 2012). Conservation-driven mowing is an effective practice to maintain high species diversity in abandoned semi-natural grasslands, because it simulates traditional land management practices (Horak and Safarova 2015). It avoids the dominance of grasses and other graminoids and the often irreversible encroachment of shrubs and trees into open areas (Agnoletti 2007; Halada et al. 2011). Mowing is successfully applied in several protected areas, either on an experimental basis or as a specific conservation management tool (Balazsi 2016). However due to an impoverished soil seed bank and limited seed immigration (Stampfl and Zeiter 1999) or due to changes in soil properties (as a result of successional changes in vegetation coverage) (Swacha et al. 2018), mowing may not completely reverse the loss of plant species in those areas abandoned long ago. A timely resumption of traditional practices for conservation purposes is therefore the key in order to maintain semi-natural grasslands and species of conservation importance (target species sensu Kiehl et al. 2010) in good condition (Joyce 2014). Indeed, the impact of mowing on single plant species performance may differ across the vegetation structure, and beneficial effects might occur for some species or groups of species but might have negative effects on other species (Valkó et al. 2012). It is therefore essential to carefully assess the effects of conservation-driven mowing on target plant species and communities. Such assessments can monitor progress and eventually help adjust the used techniques for a more cost-effective management of plant species and ecosystems. In addition, the implementation of conservation practices could interest valuable entities as endemic and sub-endemic, as well as relict species, or plants occurring at the edges of their geographical ranges. In this study, we evaluated the effect of conservation-driven mowing to preserve Gladiolus palustris in a montane environment in the Italian Alps. Specifically, we assessed the conservation status of a G. palustris population and the plant diversity after ten years of mowing in a species-rich wet meadow in the Dolomiti Bellunesi National Park (N-E Italy). We asked the following three questions, 1) is plant diversity higher in mowed than in non-mowed areas? 2) does G. palustris perform better in terms of abundance and number of flowering ramets in mowed than in non-mowed areas? 3) do other relevant species (i.e. endemic and sub-endemic, species characteristic for the habitat, locally protected species) benefit from conservation-driven mowing intended to conserve G. palustris? We hypothesised a general increase in plant diversity and a higher abundance of G. palustris and other species of conservation interest in mowed areas compared to non-mowed areas. G. palustris is listed in the European ‘Habitat’ Directive 92/43/EEC (Annex II and IV). As such, it provokes the designation of Special Areas of Conservation (SACs), the application of ad hoc feasible conservation measures and periodical monitoring of its conservation status in all EU Member States (Ostermann 1998). This is why the results presented here may have relevance for the conservation management in all 146 designated SACs (Special Areas of Conservation) located in 13 EU Member States where G. palustris naturally occurs (European Environmental Agency 2019).

1 Material and Methods

1.1 Study species

The sword lily Gladiolus palustris Gaudin (Iridaceae) is a bulbous geophyte. Its spherical
corm reaches a diameter of 2-3 cm and is located about 10 cm deep in the soil. The species grows 30-60 cm tall. It flowers in May-June. It is endemic to Europe, occurring in Central and Eastern Europe from France to Ukraine (EURO+MED 2018) and across a wide altitudinal range. The species typically grows in grasslands, pastures and wet meadows over nutrient-poor, calcareous soils (Sburlino et al. 1995; Da Canal et al. 2013). The co-occurring vegetation represents a key aspect in assessing restorations, since as a biotic factor it may influence the realized niche of target species. Habitat characterization and monitoring are particularly relevant for montane meadows, which are considered hotspots of biodiversity, because the richness in microhabitats allows the growth of specialized species with narrow realized niches (Czortek et al. 2018). Using the classification of the EU Habitat Directive 92/43/EEC, its habitats can be classified as H6410 (Molinia meadows on calcareous, peaty or clayey-silt-laden soils; Molinia caeruleae), H62A0 (Eastern sub-Mediterranean dry grasslands; Scorzoneralatia villosae) and H6210 (Semi-natural dry grasslands and scrubland facies on calcareous substrates; Festuco-Brometalia). In the EU Red List of policy species (Bilz et al. 2011) G. palustris is assessed as Data Deficient (DD) however in several European countries, it is locally threatened: extinct (EX) in Slovakia, critically endangered (CR) in Czech Republic (Witkowski et al. 2003), endangered (EN) in Switzerland (Moser et al. 2002) and Germany (Metzing et al. 2018), near threatened (NT) in Italy (Rossi et al. 2016). Its population trend is declining over most of the historical range (Da Canal et al. 2003) and its conservation status is considered inadequate in Italy (Fenu et al. 2016). Threats affecting G. palustris (as well as other montane meadow forbs) are manifold and include, shrub and tree encroachment in montane meadows (Peter et al. 2009; Joyce 2014), intensive or heterogeneous grazing (Parolo et al. 2011; Wiesmar et al. 2017), human-mediated habitat destruction in mountain and lowland areas, and a change in precipitation regimes with increased drought at the edge of its area of distribution (e.g. Italy; Da Canal et al. 2003; Rossi et al. 2016; Buffa et al. 2016). In greater detail, the factors responsible for negative population trends of G. palustris in the study area are strictly connected to land use change and the abandonment of traditional land management regimes with grazing and mowing (Lasen et al. 2018a,b; Tallowin et al. 2005).

1.2 Study area

The study area on Mt. Grave is located in the outer Dolomites in the Dolomiti Bellunesi National Park (DBNP) in N-E Italy (Figure 1). It lies within the Site of Community Importance (SCI) IT3230083 “Dolomiti Feltrine e Bellunesi”, which forms part of the European Natura 2000 Network. Monte Grave (N 46°5′21.4″, E 11°55′27.7″; 1544 m asl.), located in the western parts of DBNP, is characterised by calcareous soils over limestone of the Maiolica Formation. The study area at an altitude between 1220 to 1280 m a.s.l. is characterised by slope angles ranging from 20 to 30°, while aspect ranges from 180° to 222° (S to SW). At lower elevations up to about 1200 m a.s.l. Fagus sylvatica woodlands (mainly Dentario-Fagetum, with patches of Aremonio-Fagion) dominate the aspect, while the higher areas up to the summit are characterised by semi-natural habitats classified as Gladiolus palustris-Molinietum arundinaceae. This vegetation type is part of H62A0 (Eastern sub-Mediterranean dry grasslands; Scorzoneralatia villosae). Some areas of Mt. Grave can be assigned to H6210 (Semi-natural dry grasslands and shrubland facies on calcareous substrates; Festuco-Brometalia). It is important to mention that H6210 is a habitat of high conservation interest for the alpine biogeographical region (Campagnaro et al. 2018). It is rich in plant species, including taxa of conservation interest such as Gladiolus palustris (Figure 2 C, 2D, 2E), and it is considered an important site for the presence of several wild orchid species such as Dactylorhiza maculata (L.) Soó subsp. fuchsii (Druce) Hyl. and Gymnadenia conopsea (L.) R.Br.. During the past centuries, meadows at higher altitudes had been managed by clear-cutting and mowing to allow sheep grazing and the production of hay. These traditional management practices were abandoned in the 1960-70 as the mountain area depopulated. This land use change resulted in the bush and tree encroachment of the montane meadows by woody species such as Betula pendula Roth, Larix decidua Mill, Corylus avellana L., Sorbus aria (L.)
Crantz and the expansion of beech woodlands (Figure 2A, 2B). The establishment of DBNP in 1993 allowed to adopt conservation management actions, including the removal of woody species and periodical mowing of species-rich meadows with the aim to restore and maintain the plant diversity. In addition, three large natural wildfires between 1975 and 2012 restricted the further expansion of woody species.

1.3 Mowing treatments and survey

Since 2009, DBNP has used mowing and cutting in an area of 21.6 ha on Mt. Grave to limit the expansion of grasses and other graminoid weeds and woody plants. In the first year, trees and shrubs were removed manually. Mowing is done every other year in late August-early September, according to the seed dispersal phenology of *G. palustris*. The vegetation is mowed at a height of 10-12 cm from ground, the cut material is not removed. No additional treatments (such as fertilization or sowing) are done. In 2018, ten 25m² plots were established on the southern and south-south-eastern slopes of Mt. Grave to assess the effect after 10 years of mowing on the local population of *G. palustris* and on the grassland community more generally. The plots were distributed as following, four in the mowed area, four in the non-mowed area and two in a small non-mowed patch of grassland inside the mowed area (Figure 1). These last two plots were established to see whether mowing had an effect on adjacent non-mowed areas. Since we do not have historical data on the situation before the start of the conservation management actions in 2009, we assume that non-mowed areas represent the conditions as pre-2009 (or at least very close to them). In each plot, the following variables were recorded, total species percentage cover, percentage cover of woody species, percentage cover of herbaceous species, percentage cover and number of flowering ramets of *G. palustris* and a complete list of species and their percentage abundance (according to Van der Maarel 2015). Species cover is the cover of each plant species independently from the cover of other species. The sum of combined species cover can exceed 100%. Using the lists of species, the species richness and the Shannon Index *H* were calculated ($H = -\sum pi \ln(pi)$, where $pi$ is the proportional abundance of the $ith$ species; Shannon 1948).

Figure 1 Study area. The shaded area in the main figure represents the mowed area on Mt. Grave (Dolomiti Bellunesi National Park), where mowed plots were established (black squares marked with the progressive M letter). The black line shows the National Park border. Non-mowed plots (white squares marked with progressive N) where established in the non-mowed areas just outside the National Park. Light blue squares represent non-mowed plots inside the mowed area.
1.4 Data analysis

The effect of mowing on *G. palustris* and grassland vegetation was tested using a Generalised Linear Model (GLM), in which mowing was treated as the fixed factor, while slope and aspect were treated as co-variates. As vegetation parameters, we employed the cover and the number of flowering ramets of *G. palustris*, the total cover of herbaceous species and the total cover of woody species. Slope and aspect were recorded as environmental factors. Elevation was not considered a variable, since all mowed plots were situated at a higher elevation than non-mowed plots. However, the altitudinal difference is very small (15.41 ± 3.2 m) and does very likely not affect the performance of *G. palustris* or any other variable. A linear distribution was employed. Moreover, two multiple linear regressions, with consideration of *G. palustris* cover and the number of ramets as response variables, and vegetation parameters and abiotic factors as predictors were performed to evaluate how parameters of co-occurring vegetation and abiotic factors influenced the performance of *G. palustris*. A Principal Component Analysis (PCA) was performed to correlate the performance of *G. palustris* with vegetation variables (total species percentage cover, percentage cover of woody species, percentage cover of herbaceous species, percentage cover and number of flowering ramets of *G. palustris*). Finally, a cluster analysis was performed to

*Figure 2* Mt Grave - comparison of the situation as shown on a postcard of 1963 and in 2018. The yellow line marks the woodland upper limit (A-B). Conservation-driven mowing performed by the staff of Dolomiti Bellunesi National Park (C). A mowed plot during the 2018 survey (D). *G. palustris* flowering ramets in the study area (E-F).
highlight similarities among plots based on the recorded species and their abundances. The Bray-Curtis Index was used as compositional dissimilarity index. PCA and cluster analysis were performed in PAST v3.20 (Hammer et al. 2001), while GLM and linear regressions were performed in SPSS v21.

2 Results

*G. palustris* is present on Mt. Grave with a flourishing population estimated to have more than 74,000 flowering ramets. The GLM analysis revealed a significant effect of mowing on species richness and Shannon Index, with mowed plots being richer and more diverse than non-mowed plots (Table 1; Figure 3). The effects of slope and aspect were never statistically significant, except when considering the percentage cover of the woody species and the Shannon Index. Independent of mowing treatment, woody species on Mt. Grave were mainly present on the south-south-eastern slope and almost absent on the southern slope, resulting in a stronger shrub encroachment on the former slope. Effect of mowing can also be seen from the PCA analysis, in which the first two axes account for more than 80% of the total variance (Figure 4). Mowed plots are distributed along an increasing gradient of species richness and Shannon Index, and according to the PCA, performance of *G. palustris* is negatively correlated with the percentage vegetation cover with both components, herbs and trees. The multiple regressions highlighted a significant positive relationship between the percentage cover of *G. palustris*, the cover of woody species and the mowing treatment, while a negative relationship was found with slope (Table 2). None of the abiotic and biotic variables were related to the number of flowering ramets of *G. palustris*. The cluster analysis clearly identified two groups corresponding to mowed and non-mowed plots (Figure 5), although two non-mowed plots (N5 and N6) clustered in the mowed group.

3 Discussion

Semi-natural habitats such as montane grasslands depend on traditional agricultural

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**Table 1** Results from the GLMs on the effects of mowing on different grassland characteristics and the performance of *Gladiolus palustris*. Statistically significant effects are shown in bold. Degree of freedom is 1 in all cases.

|                        | Average values ± (st.dev.) | GLM Statistics |
|------------------------|---------------------------|----------------|
|                        | Mowed                     | Non-mowed      | Wald $\chi^2$ | $P$     |
| *G. palustris* flowering ramets | 27.75 ± (32.54)         | 3.00 ± (7.35)   | 6.273          | 0.012   |
| *G. palustris* cover (%)  | 4.00 ± (2.00)            | 0.83 ± (2.04)   | 8.208          | 0.004   |
| Total cover (%)         | 166.50 ± (37.86)         | 183.0 ± (27.31) | 2.208          | 0.137   |
| Herbs cover (%)         | 149.50 ± (37.00)         | 162.7 ± (19.13) | 0.937          | 0.333   |
| Woody species cover (%) | 17.00 ± (3.16)           | 20.33 ± (18.97) | 3.459          | 0.063   |
| Species richness        | 45.00 ± (3.16)           | 30.83 ± (7.93)  | 14.408         | <0.001  |
| Shannon index           | 3.377 ± (0.14)           | 2.503 ± (0.57)  | 15.351         | <0.001  |

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**Figure 3** Comparison between mowed and non-mowed plots. Error bars represent double standard errors. Clockwise: *G. palustris* flowering ramets, *G. palustris* percentage cover, Shannon index and species richness.
practices including mowing or extensive grazing. In Italy, many of these ecologically valuable mountain meadows are in private ownership, often abandoned and without any management strategy for habitat conservation. Under this scenario, competitive grasses such as *Molinia arundinacea* Shranck and other graminoid species are favoured due to their large seed production, vegetative propagation and leaf cover. Local plant communities need to be supported by using traditional land management regimes, to avoid the loss of habitats and species of conservation interest (e.g. those listed in the EC Habitat Directive 93/43/EEC like *G. palustris* (McDonald et al. 2000; Luoto et al. 2003) or other congeneric species like *G. imbricatus* (Kostrakiewicz-Gieralt 2014). In the specific case presented here, the population of *G. palustris* on Mt. Grave is maintained through regular mowing of semi-natural grasslands by the Dolomiti Bellunesi National Park (DBNP) authority. These land management activities are part of the DBNP's conservation plan. Similar management plans with regular mowing aimed towards the conservation of *G. palustris* populations exist in other European countries, too (e.g. for a large population at the German border of Lake Constance, Peintinger 2000).

In our study site, the abandonment of traditional ovine grazing and regular mowing of montane grasslands led to a change in plant species composition and to a progressive encroachment of woody species. Even if the linear regression enlightened a positive correlation between *G. palustris* cover and woody species cover, we feel this result is due to the presence of young plants of *Sorbus aria* (L.)
Cranz. and Amelanchier ovalis Medik. in the eastern mowed plots. In early stages of their life cycle, individuals of woody species do not seem to affect the performance of G. palustris, but if the mowing practice is suspended for a long period it is plausible that the consequent habitat change would undermine the survival of G. palustris in the area. The resumption of mowing for conservation purposes in our study area undertaken by the DBNP authority has halted the encroachment of woody species and has avoided a drastic change in plant composition. The population size of G. palustris is remarkable in terms of flowering ramets compared to literature data (see for example the populations studied in France and Switzerland by Daco et al. 2019). The mowed area shows a larger occurrence and higher density of G. palustris in terms of flowering ramets (as shown by GLM) and percentage cover (as shown by GLM and linear regression) than the non-mowed area just outside the park border. The missing consistency of correlation between mowing and number of flowering ramets in the linear regression could be due to the limited number of replicates. Conservation management of G. palustris in this type of grassland is correlated with population dynamics of many co-occurring species, and it has benefitted several other plant species of conservation interests. For instance, the study area is rich in locally protected species co-occurring with G. palustris like Asphodelus fistulosus L., Iris graminea L., Lilium bulbiferum L., Rhaponticum scariosum Lam. (protected in Veneto region) and species characterising policy habitats like Hippocrepis comosa L. subsp. comosa, Thymus pulegioides L., Koeleria pyramidata (Lam.) P.Beauv. but also orchids such as Dactylorhiza maculata (L.) Soó subsp. fuchsi (Druce) Hyl., which is characteristic of semi-natural dry grasslands. This result is consistent with results from nature reserves at the northern edge of the European Alps (Peintinger 1990; Quinger 2003). In addition, other locally valuable and restricted forbs were, Cirsium pannonicum (L.f.) Link, Danthonia decumbens (L.) DC., Geranium sanguineum L., Inula hirta L., Potentilla alba L., Serratula macrocephala Bertol., and Trifolium medium L. As shown by the cluster analysis, the two plots situated inside the mowed area (plots N5 and N6) show intermediate characteristics between mowed and non-mowed plots in terms of species richness and percentage cover of species. It is to speculate that the seed production of forbs in mowed areas had an influence on these two unmowed plots, by enriching the soil seed bank of forbs even if grasses and graminoids dominate the plant cover. G. palustris and many other forbs of montane grasslands show a transient behaviour in terms of seed longevity (Cerabolini et al. 2003), presenting also physiological dormancy. This fact highlights the role of the soil seed bank on the vegetation dynamics in such habitats. Considering the concept of “extinction debt”, for which the extinction of a particular species is delayed after habitat fragmentation or degradation (Tillman et al. 1994), we may hypothesize that bulbs and the soil seed bank of G. palustris make this species more resilient to habitat degradation. Consequently, conservation actions like in this case mowing, could restore the population even with a limited plant cover. Moreover, the persistence of plant species through soil seed bank or other dormant dispersal units is also connected to the so-called “dark diversity” (Pärtel et al. 2011), the presence of a given species is sometimes only potential, and its survival is related to the effectiveness of the adopted restoration measures. Looking at the effectiveness of mowing, a recent study showed that positive effect of mowing on biodiversity (on both flora and fauna) is not related to mowing frequency (Talle et al. 2018). In non-productive grasslands, positive effects on the number of species and their percentage cover could be obtained through mowing every second or third year, while mowing once (or more often) per year did not produce sizeable advantages considering the higher operational costs. Therefore, the increase of competitive species (e.g. Molinia arundinacea Schrank, Sesleria caerulea (L.) Ard. subsp. caerulea) may be limited by non-frequent periodic mowing (Hájková et al. 2009). Late summer mowing in mountain meadows is currently perceived as economically disadvantageous by land owners, due to difficult access for mechanic devices and low hay quality and productivity. Nevertheless, the establishment of nature reserves, in the presented case of a Site of Community Importance, gives managing authorities the possibility to obtain additional funds for the management of nature conservation.
Such funds might be provided by the European Agricultural Fund for Rural Development (EAFRD) as part of the EC’s Common Agricultural Policy (CAP). In the specific case of Italy, grants might be provided by the regional authorities for agriculture (e.g. Veneto Agricoltura in Veneto, ERSAF in Lombardy) as part of the Rural Development Plan or by national authorities as funds for biodiversity conservation. Besides conservation-driven mowing, other conservation actions can be effectively used to restore or reduce the loss of plant diversity in semi-natural grasslands. As suggested by Muller (2002), moderate sheep grazing may be an alternative conservation measure. On the other hand, even if grazing limits the growth of graminoids, oligotrophic species of montane meadows could be disadvantaged by an increased nitrogen intake. Reintroduction of ovine grazing were tried in the DBNP, but led to dramatic changes in habitat composition and to the establishment of species-poor Nardus stricta L. prairies, especially in areas of livestock stationing (C. Lasen personal observation). Moora et al. (2007) showed similar results for the congenere Gladiolus imbricatus L. in coastal meadows of Estonia, both cattle and sheep grazing led to higher damage of generative and vegetative plants compared to juveniles, which prevented an increase of population size and density. Grazing therefore seems a suitable tool for maintaining plant population dynamics (e.g. the ratio between mature/juvenile plants), but it should be applied once and alternated with mowing. Mowing or mixed grazing-mowing practices are also prescribed for other plant species protected at European level, such as Arnica montana L. in the Carpathians (Michler et al. 2004). Palatability of plant species for herbivores may play a role in conservation grazing practices as the target species should not be eaten by livestock (Rotar et al. 2011). Concerning the Italian policy species, other montane species reported by ISPRA (2016) deserve a more detailed examination of the effects of mowing on their conservation status, such as Lilium rubrum Lam. & DC., Peonia officinalis subsp. banatica (Rochel) Soò, Crambe tataria Sebeok, Serratula lycopifolia (Vill.) A.Kern and Euphrasia marchesettii Wettst. ex Marches.

4 Conclusions

Managed areas showed a more complex vegetation structure and presence of species which are typical of EU policy habitats. At the same time, G. palustris benefitted from periodical mowing, showing higher number of flowering ramets and percentage cover in mowed areas than in non-mowed areas. Although the extent of the study area was limited to one nature reserve, the results obtained are particularly relevant taking into account that the conservation status of G. palustris in Italy is currently considered inadequate. We could show that multiple mowing per year was not necessary, while mowing every other year is recommended to maintain montane grasslands where traditional grazing and agricultural practices had been abandoned. Areas outside of the control of the Park authorities or in general outside SACs rarely benefit from adequate funds for conservation, and abandonment of traditional practices often result in loss of biodiversity. Ad hoc economic incentives for farmers and land owners (e.g. Rural Development Plan funds provided by the EC Common Agriculture Policy) may represent a further incentive for maintaining biodiversity-rich semi-natural habitats outside protected areas.

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