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Does intensive cutting regime maintain lowland dry heathlands habitat? The case study of Milano Malpensa airport (Northern Italy)

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ABSTRACT

Airports are anthropogenic settlements which can harbour large portions of open habitats, including grasslands, which may host high species richness. Milano Malpensa Airport is the second main Italian airfield. One of its main open habitats is lowland dry heathland, frequently mown to fulfil aircraft safety requirements. The same habitat was formerly common in the surroundings of the airport, but it is nowadays endangered by management cessation and consequent tree (mainly *Prunus serotina*) encroachment. We compared heathland structure and vegetation composition in *Calluna vulgaris* populations within Malpensa Airport and outside it, where three degradation stages (identified by increasing *P. serotina* encroachments) were studied. We performed 52 surveys (10 within the airport, 18 in the less encroached heathland, 12 in the intermediate, and 12 in the most encroached) where we visually estimated the percentage cover of all plant species and we assessed heather density and height. Heathlands inside the airport (subjected to up to two cuts per year at 5 cm above ground) were richer in plant species and with a higher rejuvenation rate, but with a relevant cover of alien species and of plants typical of more intensive and disturbed grasslands. Among the heathlands outside the airfield, the two with the highest encroachment harboured few, tall, degenerate heather individuals, and were invaded by *P. serotina* and *Molinia arundinacea*. Among all, the heathland showing the best habitat conservation status was that outside the airport with the lowest *P. serotina* encroachment. There, heather population structure assumed a typical shape of young communities, likely due to the high light availability related to the low tree species cover. Additionally, the limited presence of bare soil compared to heathland inside Malpensa likely hampered the colonization by both alien species and pioneer plants of other environments. These outcomes showed that an intensive cutting regime in lowland dry heathlands can counteract habitat loss due to tree encroachment, which has been confirmed as one of the main threats to its conservation. However, cut frequency and height should be carefully determined to hinder the expansion of plants belonging to other habitats while encouraging the typical floristic composition.

1. Introduction

Increasing anthropization is threatening many ecosystems by replacing natural habitats with human settings. Nonetheless, also areas with high degree of anthropization can have a role in biodiversity conservation (Hüse et al., 2016; Kowarik, 2011; Niemelä et al., 2010). In particular, civil and military airfields can harbour a rich species diversity inside urban ecosystems (Bespalov and Belyaev, 2018; Caccamise et al., 1996; Kutschbach-Brohl et al., 2010; Wang et al., 2010), thanks to the presence of large surfaces usually managed to maintain open habitat vegetation (such as grasslands and heathlands) around the air operation areas for several safety reasons (DeVault et al., 2012; Kutschbach-Brohl et al., 2010). The quality of such habitats and the associated species composition are strictly dependent on the persistence

Abbreviations: MA, heathland occurred within the Malpensa Airport; H1 to H3, semi-natural heathlands located outside the airfield.

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of suitable management practices. For example, Fischer et al. (2013) reported how open patches in airports may have unique characteristics such as large patch size, high connectivity, and lack of fertilisation or irrigation compared to other urban land uses, such as historic parks, which may assist the persistence of many species. Moreover, some of the surfaces included within airfields are recognised as important habitats for nature preservation (such as those belonging to Natura 2000 network), but their conservation status is still under-assessed. Nonetheless, vegetation in airports undergoes periodic alterations (e.g. mowing, with or without biomass removal) in order to keep the habitat open and prevent shrub and tree encroachment as well as to reduce feeding and resting sites for species hazardous to aviation, i.e. birds and mammals. Additionally, insects and rodents are often controlled, e.g. by means of biocides, to decrease food availability for birds and prevent spread of accidentally introduced alien species (Blackwell et al., 2013; Hamilton et al., 2007; Pennell et al., 2016).

Despite the well-known importance of airports in preserving species richness within urban environments, the harboured vegetation has been sparsely studied in Europe (Fischer et al., 2013; Keenleyside and Tucker, 2010). Additionally, little is known about their role in biodiversity conservation when airfields are surrounded by areas with high natural value, such as natural parks (Martignoni et al., 2019). This is the case of Milano Malpensa International Airport (hereafter 'Malpensa Airport'), which is set within the 'Parco Naturale Lombardo Della Valle Del Ticino' (Regional Natural Park of Ticino Valley in Lombardy, North-Western Italy; hereafter 'Ticino Natural Park'). Malpensa Airport is one of the main European airfields, being the 20th busiest airport (2nd in Italy) in terms of passengers in 2019 (Assaeroporti, 2020). It covers an area of 1'244 ha within the Po basin (Southern Alps), 45 % of which is covered by open habitats, including a large portion of lowland heathlands. These habitats are subjected to an intensive management of severe sward cutting regimes, in terms of both cutting height and frequency, to fulfil airport safety standards.

Heathlands (i.e. grasslands dominated by heather *Calluna vulgaris* (L.) Hull) and, particularly, lowland dry heathlands (Nat-2000 '4030 - European dry heaths', 'Habitat' Directive 92/43/CEE) support a wide number of plant, invertebrate, and vertebrate species that are specialized, rare, declining, or restricted to this habitat (Parry, 2003). They also play an important role in maintaining the ecological connectivity between ecosystems, as they are interspersed and in contact with other types of natural habitats, such as grasslands, forests and wetlands (Ramil Rego et al., 2013). In recent decades, the importance of the development of dry heathland conservation plans has been stressed as this habitat is subjected to several threats: fragmentation and destruction, pollution and eutrophication, climate change, secondary succession, invasion by alien species and, above all, both management intensification and abandonment (European Environment Agency, 2015; Fagúndez, 2013; Viciani and Cerabolini, 2016). At varying intensities, all these drivers negatively affect heathlands in Southern Alps and particularly in the Po basin, where they undergo high levels of anthropogenic disturbance (Lonati et al., 2009; Parco Lombardo della Valle del Ticino, 2013; Vegini et al., 2020).

Within Ticino Natural Park lowland dry heathlands can be found in the valley of the Ticino River on recent deposits of fluvial or fluvial--glacial origin (Holocene) and older deposits of glacial origin (Pleistocene) (Cerabolini et al., 2017). In these areas, which include the one currently occupied by Malpensa Airport, heathlands were historically fostered by agro-silvo-pastoral and, in some cases, military activities (Sulli, 1985; Sulli and Zanzi Sulli, 1994), which contributed to the preservation and expansion of large patches of open landscapes to the detriment of shrubland-woodland communities. However, the abandonment of such activities in the last decades, caused a widespread and progressive decline of this habitat. This decline is represented both by the regression of their surfaces and by various stages of degradation characterised by loss of typical habitat species, increase in the proportion of *Molinia arundinacea* Schrank cover, shrub and tree (mainly the invasive alien species *Prunus serotina* Ehrh.) encroachment (Vegini et al., 2020), and a predominance of old heather individuals ('degenerate phase' *sensu* Watt, 1955). Therefore, a recurrent management practice that halts succession is needed (Olmeda et al., 2020) since natural (pre-human) disturbances that kept the heathlands open (such as natural large herbivores) are not present anymore.

Among others management practices, such as grazing and prescribed burning, sward cutting has been successfully implemented as a conservation measure for dry heathlands, promoting periodical renewal of heather and contrasting shrub and tree encroaching (Ascoli et al., 2013). Cutting regimes can broadly vary depending on conservation objectives and local environmental conditions. For instance, in Polish dry heathland Olmeda et al. (2020) suggested sward cutting every three-five years at a height of 10–20 cm. More frequent cutting regimes are generally not optimal for heathland conservation being heather a perennial woody species, with slow regeneration rates (Calvo et al., 2002). While grazing and prescribed burning are not allowed within airports, the previously reported cutting regimes are apparently in contrast with the much more intensive management exerted on heathland within Malpensa Airport, where up to two cuts per year at 5–10 cm above ground are operated.

In the present research, we compared species diversity and vegetation structure and composition of heathlands inside Malpensa Airport with outer heathlands located in an area of high natural value of Northern Italy (Ticino Natural Park). In particular, we compared sites subjected to frequent cutting inside the airport, with nearby outer abandoned sites with similar abiotic conditions, where no management took place since decades, characterised by different levels of degradation, mainly due to the alien tree *P. serotina* invasion. Our aim was to assess if, in a context of abandonment and degradation of the typical lowland dry heathlands, the intensive management applied inside the airport could play a positive role in the conservation of this habitat, by means of periodical heather renewal and reduction of *P. serotina* encroachment.

2. Methods

2.1. Study area and experimental design

The study was conducted in the Milano Malpensa airport (Airport Reference Point: 45°37'48'' N, 8°43'23'' E) and in an area about 1 km South of the airport, in the Ticino Natural Park in similar topographic, climatic, and soil conditions (Fig. 1).

Both study areas were located within the Po plain (Northern Italy), on flat surfaces at approximately 200 m a.s.l. Average annual rainfall was 1211.7 mm, well distributed in the vegetative season with two equinoctial maxima (May and October) and two minima, one in winter (January and December) and the other in summer (July), without climatic drought (according to Bagnouls and Gaussen, 1957). Annual average temperature was 11.6 °C, with the hottest month in summer (July, 22.2 °C) and the coldest in winter (January, 1.7 °C) (Società per azioni Esercizi Aeroportuali, 2019). According to Rivas-Sáenz (2010), the bioclimate was temperate continental, the thermotype mesotemperate, the ombrotype humid. Soils below the studied heathlands were homogeneous and originated over fluvial and fluvial-glacial deposits, rich in gravelly sediments mixed with siliceous sands, acid to subacid reaction, low available water capacity, fast moderate drainage, and high to moderate permeability and can be defined as Umbrisols (Società per azioni Esercizi Aeroportuali, 2010; Cerabolini et al., 2017; Vegini et al., 2020). Vegetation was composed by various opened habitats, including: i) therophytic pioneer formations characteristic of oligotrophic and dry soils (*Thero-Airion*, Nat-2000 6220*), ii) acidophilous dry grasslands (*Violon caninae*, Nat-2000 6230*), and iii) heathlands dominated by heather and *M. arundinacea* (*Genistion tinctorio-germanicae*, Nat-2000 4030). These habitats were interspersed within shrublands and woodlands mainly dominated by *Cytisus scoparius* (L.) Link, *Betula pendula* Roth, *Populus tremula* L., *Quercus robur* L., and *P. serotina*. Without

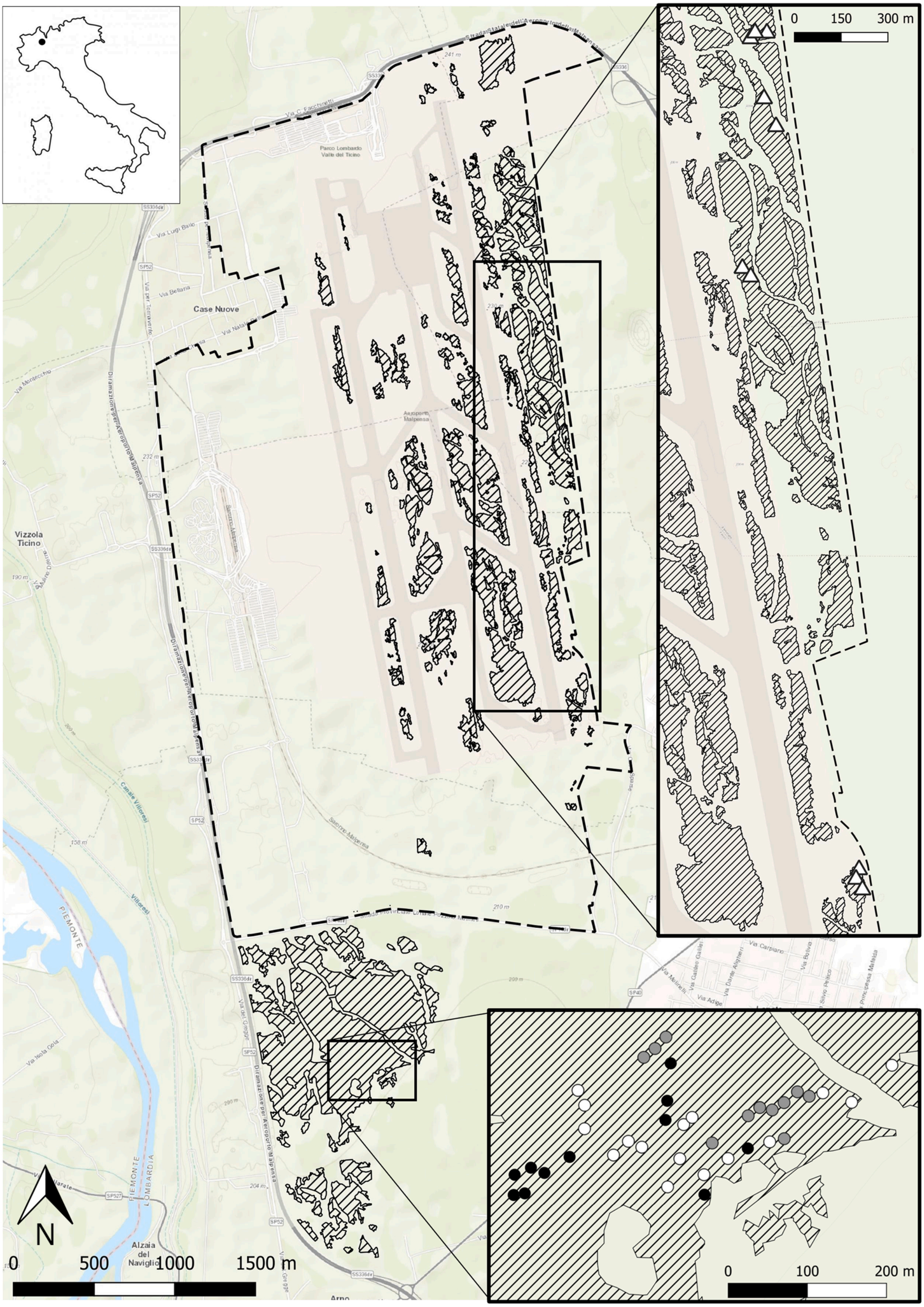

Fig. 1. Map of the study areas. The dashed line contours Milano Malpensa airport area, while striped polygons indicate heathland vegetation communities. Different symbols correspond to the different surveyed heathlands: triangles, intensively managed heathlands inside Malpensa Airport; white, grey, and black circles, heathlands outside the airfield encroached by *Prunus serotina* with < 5 %, 5–50 %, and > 50 % coverages, respectively.

disturbance the vegetation is supposed to develop into a deciduous plain oak forest (pedunculate and/or sessile oakwood) (Società per azioni Esercizi Aeroportuali, 2010).

In the present research, we compared four heathlands, differing from each other for management intensity and habitat degradation to which they are subjected. The first heathland (MA) occurred within the Malpensa Airport and was subjected to high intensity continuous management; sward height is maintained under 20 cm by means of mowers operating up to two cuts per year at 5 cm above ground, without clipping removal. This site was compared with semi-natural heathlands (H) located outside the airfield, where no management has been practiced in the last 50–70 years (while before they represented a resource for the subsistence economy of the local farms with grazing livestock; Brusa et al., 2019). In this unmanaged area we selected three different heathlands according to an increasing level of habitat degradation due to *P. serotina* encroachment: H1, with *P. serotina* coverage < 5 %; H2, with *P. serotina* coverage 5-50 %; and H3, with *P. serotina* coverage > 50 %.

2.2. Data collection

In 2018, heathland vegetation was studied by performing a total of 52 surveys, also on the basis of the monitoring manual for habitats in Italy (Angelini et al., 2016; Gigante et al., 2016): 10 surveys in MA, 18 in H1, and 12 in H2 and H3, respectively (Fig. 1). Each survey consisted of i) a plot of 5 × 5 m to describe plant species composition and ii) a subplot of 1 × 1 m located at the centre of each plot to describe heather population structure. Within each 25 m^2 plot the percentage cover of gravel (i.e. showing coarse fragments > 0.5 cm), of bare ground, of sward (under 1.5 m height) and woody (over 1.5 m height) layers, and of all occurring plant species was visually estimated. A minimum value of 0.3 % was attributed to species accounting for a percentage cover lower than 1 % (Martelletti et al., 2019; Tasser and Tappeiner, 2005). Species nomenclature followed Bartolucci et al. (2018) and Galasso et al. (2018). Additionally, average and maximum height of heather were estimated in each plot. In the 1 m^2 subplot the number of all heather leading shoots were counted and their height (measured within five height classes, i.e. < 5, 5–15, 15–30, 30–50, and > 50 cm) was recorded.

Heather counts and heights were used to calculate the relative density (number of individuals m^{-2}) and the height Shannon diversity index and evenness (Lexerød and Eid, 2006). Plant species diversity was assessed in terms of both species richness and effective number of species (Jost, 2006). Moreover, the total number and cover of typical species (as defined by Bonari et al., 2021) of 'European dry heaths' habitat (as reported in Biondi and Blasi, 2015) and of alien species (listed by Galasso et al., 2018) were computed for every plot. All other plant species were associated to their phytosociological *optimum* at class level (according to Aeschimann et al., 2004) and further grouped into four functional species pools (as reported in Appendix A), namely: i) woodland species (i.e. species belonging to *Carpino-Fagetea, Crataego-Prunetea, Quercetea robori-sessiliflorae,* and *Pyrolo-Pinetea* classes); ii) meso-eutrophic grassland species (*Molinio-Arrhenatheretea* classes); iii) dry grassland species (*Festuco-Brometea* class); and iv) therophitic pioneer species (*Koelerio-Corynephoretea* and *Thero-Brachypodietea* classes). Total species number and cover accounting for each functional species pool was calculated for every plot, while species belonging to other classes (accounting for a negligible cover) were not further considered.

2.3. Statistical analyses

To test for differences among the four heathlands in terms of soil cover (i.e. bare ground, sward layer, and woody layer covers), sward layer structure (i.e. heather and *M. arudinacea* covers and heather density, average and maximum height, and height Shannon diversity index and evenness), plant diversity (i.e. species richness and effective number of species), and functional species pools (i.e. number and cover of European dry heath, alien, woodland, meso-eutrophic grassland, dry grassland, and therophytic pioneer species) generalised linear models (GLM) were performed. Continuous variables were modeled with both Gaussian and gamma functions, while count variables were modeled with both Poisson and negative-binomial functions. Between the two models run for each variable, the one with the lowest Akaike's Information Criterion (AIC) value was considered as the best fitting model and retained (Zuur et al., 2009). The data distribution chosen for each response variable is indicated in Table 1. Percentage cover variables were rescaled to 0–1 interval and modeled with beta distribution. Since this distribution does not accept 0 and 1 values the transformation proposed by Smithson and Verkuilen (2006) was previously applied. When significant differences were found, Tukey's *post-hoc* tests were carried out.

Additionally, to compare heather population structure among heathlands, the number of leading shoots recorded in each of the five height classes were analysed through a PERMANOVA with 9999 permutations. The Euclidean distance was set as dissimilarity index and pairwise comparisons with FDR correction were performed.

Statistical analyses were carried out using the v. 3.6.2 of R environment (R Core Team, 2019) with the 'EcolUtils' (Salazar, 2020), 'emmeans' (Lenth, 2018), 'glmmTMB' (Brooks et al., 2017), and 'multcomp' (Hothorn et al., 2016) packages.

3. Results

A total of 58 plant species, belonging to 21 families, was found in the heathlands during the study (see Appendix A) and 784 heather leading shoots were counted and measured. The vegetation of the four heathlands significantly differed among each other in terms of the studied variables, as reported in Table 1 and Fig. 2.

In terms of soil cover, the heathland managed within the Malpensa airport (MA) and H1 were characterised by a higher proportion of bare ground and lower sward and woody layer covers than H2 and H3. The sward layer cover was similar between H2 and H3, while the highest value of woody layer cover (lacking in MA and H1) was found in H3 (about 60 %). Gravel abundance did not differ among heathlands.

Within the sward layer, heather cover was lower in MA and H3, while *M. arundinacea* cover significantly increased from MA and H1 to H2 and to H3. Heather density decreased from MA (almost 30 leading shoots m^{-2}) to H3 (less than three leading shoots m^{-2}). In MA heathers were shorter (about one third), in terms of both average and maximum height, than in the other three heathlands. Heather heights were more heterogeneous in MA and H1 than in the other heathlands, according to both Shannon index and evenness.

When considering plant diversity, MA showed the highest species richness, while a moderate but significant difference was found between H1 and the other two heathlands, with H1 hosting the lowest number of species. Effective number of species, instead, was highest in MA and H3, followed by H2 and then by H1.

The analysed functional species pools differed among heathlands as well. A total of six typical species of European dry heaths was found, namely *C. vulgaris, C. scoparius, Genista tinctoria* L., *G. germanica* L., *M. arundinacea,* and *Potentilla erecta* (L.) Raeusch. Their average number did not significantly differ among heathlands, being around three in each of them. A relevant number of alien, both woody (*P. serotina, Ailanthus altissima* (Mill.) Swingle, *Quercus rubra* L., and *Robinia pseudoacacia* L.) and herbaceous (*Ambrosia artemisiifolia* L., *Erigeron annuus* (L.) Desf., *Solidago gigantea* Aiton, and *Dichanthelium acuminatum* (Sw.) Gould & C.A.Clark) species was detected in the four heathlands. Higher values of alien (even if slight) and meso-eutrophic grassland species were observed in MA, followed by H2 and H3 and, then, by H1. Additionally, a higher number of dry grassland and therophitic pioneer species were found in MA, while no differences were detected in terms of number of woodland species. On the other hand, the lowest cover of

Table 1
Differences (average ± standard deviation) in soil cover, sward layer structure, plant diversity, and functional species pools among heathlands: MA, intensively managed heathlands inside Malpensa Airport; H1, H2, H3, heathlands outside the airfield encroached by *Prunus serotina* with ≤ 5%, 5-50%, and > 50% coverages, respectively. Superscript numbers after variable names indicate the data distribution family specified in the retained model. Different letters within a row indicate significant differences (P < 0.05) among the heathlands according to *post-hoc* tests.

Variables	Heathland								
	MA		H1		H2		H3		p-values
Soil cover									
Gravel [a]	1.7 ± 3.30		2.6 ± 5.20		0.0 ± 0.00		0.0 ± 0.00		0.143
Bare ground (%) [a]	27.8 ± 12.40	c	16.4 ± 12.34	b	2.8 ± 4.27	a	4.8 ± 7.12	a	<0.001
Sward layer - H ≤ 1.5 m (%) [a]	70.5 ± 12.57	a	81.0 ± 14.86	b	97.3 ± 4.27	c	95.3 ± 7.12	c	<0.001
Woody layer - H > 1.5 m (%) [a]	0.0 ± 0.00	a	0.0 ± 0.00	a	19.0 ± 9.92	b	59.2 ± 16.49	c	<0.001
Sward layer structure									
Heather cover (%) [a]	58.0 ± 10.59	a	79.7 ± 14.60	b	86.1 ± 10.02	b	53.8 ± 17.98	a	<0.001
Molinia arundinacea cover (%) [a]	0.1 ± 0.32	a	1.2 ± 1.52	a	9.6 ± 9.12	b	39.8 ± 19.17	c	<0.001
Heather density (individuals m^{-b}) [b]	28.7 ± 6.48	c	22.8 ± 16.95	b	4.4 ± 2.23	a	2.8 ± 1.48	a	<0.001
Heather average height (cm) [c]	18.5 ± 0.07	a	53.1 ± 0.09	b	52.9 ± 0.08	b	52.9 ± 0.09	b	<0.001
Heather maximum height (cm) [d]	27.0 ± 0.09	a	97.2 ± 0.14	b	95.8 ± 0.14	b	89.2 ± 0.19	b	<0.001
Heather height Shannon diversity index [c]	1.5 ± 0.38	b	1.6 ± 0.47	b	0.7 ± 0.46	a	0.3 ± 0.53	a	<0.001
Heather height evenness [c]	0.6 ± 0.16	b	0.7 ± 0.20	b	0.3 ± 0.20	a	0.1 ± 0.23	a	<0.001
Plant diversity									
Species richness (n) [b]	22.0 ± 7.76	c	3.7 ± 1.53	a	5.8 ± 0.94	ab	6.2 ± 1.03	b	<0.001
Effective number of species [d]	3.7 ± 2.17	c	1.2 ± 0.15	a	2.4 ± 0.54	b	3.6 ± 0.36	c	<0.001
Functional species pools									
Number of typical species of European dry heaths [b]	3.2 ± 1.23		2.2 ± 0.65		3.0 ± 0.60		2.8 ± 0.72		0.415
Number of alien species [b]	1.7 ± 0.67	b	0.4 ± 0.62	a	1.1 ± 0.29	ab	1.1 ± 0.29	ab	0.020
Number of woodland species [b]	0.0 ± 0.00		0.5 ± 0.71		0.5 ± 0.67		0.8 ± 0.72		0.667
Number of meso-eutrophic grassland species [b]	4.4 ± 2.01	c	0.2 ± 0.43	a	1.2 ± 0.58	b	1.2 ± 0.58	b	<0.001
Number of dry grassland species [b]	2.8 ± 1.69	b	0.1 ± 0.24	a	0.0 ± 0.00	ab	0.0 ± 0.00	ab	0.002
Number of therophitic pioneer species [b]	6.6 ± 1.78	b	0.1 ± 0.47	a	0.0 ± 0.00	ab	0.0 ± 0.00	ab	<0.001
Cover of typical species of European dry heaths (%) [a]	60.9 ± 10.15	a	82.5 ± 15.69	b	97.9 ± 7.62	c	97.2 ± 10.46	c	<0.001
Cover of alien species (%) [a]	1.1 ± 1.21	a	0.1 ± 0.18	a	22.3 ± 10.65	b	61.7 ± 13.37	c	<0.001
Cover of woodland species (%) [a]	0.0 ± 0.00	a	1.0 ± 3.51	a	0.4 ± 0.67	a	5.9 ± 8.96	b	0.024
Cover of meso-eutrophic grassland species (%) [a]	3.5 ± 2.70	b	0.1 ± 0.13	a	1.7 ± 1.68	b	2.8 ± 2.81	b	<0.001
Cover of dry grassland species (%) [a]	4.6 ± 3.97	b	0.0 ± 0.07	a	0.0 ± 0.00	a	0.0 ± 0.00	a	<0.001
Cover of therophitic pioneer species (%) [a]	5.1 ± 4.32	b	0.0 ± 0.14	a	0.0 ± 0.00	a	0.0 ± 0.00	a	<0.001

[a] Beta;
[b] Poisson;
[c] Gaussian;
[d] Gamma

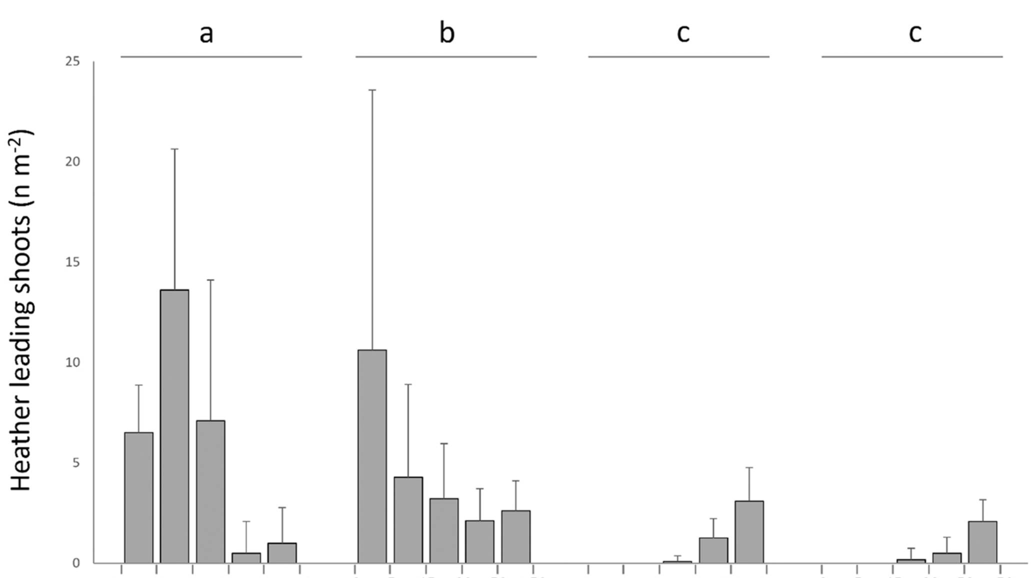

Fig. 2. Average number of heather leading shoots per height class by heathland. The ranges of every class (in cm) are provided below the histograms, while error bars represent the standard deviations of the averages. Letters above histograms indicate significant differences (P < 0.05) among heathlands, according to PERMANOVA pairwise comparisons. Heathlands: MA, intensively managed heathlands inside Malpensa Airport; H1, H2, H3, heathlands outside the airfield encroached by *Prunus serotina* with < 5 %, 5–50 %, and > 50 % coverages, respectively.

typical species of European dry heaths was found in MA, followed by H1 and, then, by H2 and H3. Alien species cover differed among each heathland, being the highest in H3, then H2 and, finally, H1 and MA. Woodland species cover was in negligible in MA, H1, and H2 while H3 showed the highest value. H1 was characterised by the highest cover of meso-eutrophic grassland species, while higher covers of dry grassland species and therophitic pioneer species were found in MA, compared to the other heathlands.

The four heathlands significantly differed in terms of heather population structure ($F = 15.61$, $p < 0.001$), based on the distribution of the five height classes (Fig. 2). Particularly, H2 and H3 showed similar structures, with a predominant number of leading shoots in the last height classes (h=30–50 cm, h>50 cm). On the other hand, MA had a complementary distribution of height classes, with a very limited number of leading shoots with h> 30 cm, while H1 showed an intermediate structure, with a large number of small heather leading shoots.

4. Discussion

The comparison among the four heathlands provided significant and relevant results concerning the effects of an intensive management (within Malpensa Airport) and of abandonment (outside the airport) on population structure, biodiversity, and conservation of lowland dry heathlands. Indeed, while livestock grazing and sod-cutting has been widely experienced in dry heathlands as a proficient management tool for habitat conservation (Dostálek and Frantík, 2015; Gallet and Roze, 2001; Pakeman et al., 2003), the present work provides novel results on sward cutting practices, which have been little implemented since now in such environments. Moreover, it highlights the opportunities of biodiversity conservation in intensively disturbed anthropogenic area (i.e. an airport), suggesting that the exerted cutting frequency could represent a starting point to find an optimum strategy able to combine two management goals: safety (cutting often) and biodiversity conservation (cutting less frequently). Heathlands cover about 250 ha within the Ticino Natural Park, 113.5 (46 %) of which are located inside the airport. Therefore, the potential of heathland management in the airport in counteracting *P. serotina* encroachment and enhancing habitat conservation is remarkable when compared to the surroundings, where all heathlands are currently unmanaged.

The intensive cutting regime operated inside Malpensa Airport was effective in limiting the threat of afforestation, since the woody species cover, particularly the alien *P. serotina*, was outcompeted. Mowing operation was also able to promote a noteworthy rejuvenation rate of heather, thanks to the creation of a high percentage of bare ground (Henning et al., 2015, 2017). The frequent and intensive cuts determined a reduced heather average height, favouring the lowest height classes with few tall plants (i.e. those eluding mowers). As for plant diversity, species richness was four- to six-folds higher in MA than in the sites outside the airport. Similar results were obtained by Sedláková and Chytrý (1999), reporting an increase in species richness and abundances in semi-natural heathlands after cutting vegetation at 3–5 cm above the ground.

Even if species diversity is commonly considered a positive outcome, the general result of the Malpensa Airport intensive management was an alteration of the typical plant species composition of lowland dry heathlands. On the one hand, 33 species (13 % average cover in each survey) recorded in MA were typical of other vegetation communities (e.g. *Agrostis stolonifera* L. for meso-eutrophic grasslands, *Thymus oenipontanus* Heinr.Braun ex Borbás for dry grasslands, and the therophitic pioneer *Aira caryophyllea* L.). The reduced competition with dominant species (i.e. heather) and the high proportion of bare ground created by the periodic mowing probably determined these entries (Henning et al., 2017; Lonati et al., 2009), as well as for the alien *Ambrosia artemisiifolia* L., *D. acuminatum, and Erigeron annuus* L. (Desf.), even if with very low covers (i.e. about 1 % on total). However, in the specific site conditions of Malpensa Airport, despite the strong non-native propagule pressure one to two cuts per year appear enough to keep the presence of such invasive species under control, which usually forms dense populations (e.g. Essl et al., 2015). On the other hand, the contribution of European dry heath typical species was reduced (more than −20 % cover compared to degraded heathlands outside the airfield) while the presence of species typical of other environments was remarkable. Among them, some species, mainly belonging to therophytic and succulent plant communities (i.e. *Koelerio-Corynephoretea* class) and considered of high natural value were found: *A. caryophyllea*, *Euphrasia cisalpina* Pugsley, *Logfia minima* (Sm.) Dumort., *Jasione montana* L., and the rare species (according to Pignatti et al. 2017–2019) *Anarrhinum bellidifolium* (L.) Desf., and *Teesdalia nudicaulis* (L.) R. Br, which were almost exclusively found in MA sites (apart from *L. minima* and *T. nudicaulis* which were also found in H1, but less frequently). All of them, except for *A. bellidifolium*, have been also reported by Cerabolini et al. (2017) as characteristic species of the association *Jasiono montanae–Callunetum vulgaris*, which depict at local scale the dry heathlands on gravelly deposits mixed with sands typical of Ticino valley. Heathlands inside the airport, even if intensively managed, apparently have the potential to serve as a refugium for open habitat plant species (as already shown for other taxa such as arthropods; Kutschbach-Brohl et al., 2010), destined to disappear in outer landscapes threatened by tree encroachment. They can also act as a reservoir of seeds for restoration actions of degraded heathland surfaces, where soil seed-bank may be depauperated (Henning et al., 2017), despite heathlands species often have a long lived seed-bank (Thompson and Band, 1997). Nonetheless, the presence of these species and of those belonging to meso-eutrophic grasslands suggested a partial shift from the typical vegetation community of European dry heaths to more disturbed and intensively managed ones, which can be find in the environment surrounding Malpensa airport interspersed with the typical heathland communities (Società per azioni Esercizi Aeroportuali, 2010; Società per azioni Esercizi Aeroportuali, 2019).

In light of this, a more ‘environment-friendly’ management of green surfaces inside the airport, promoting a balance between the conservation of heathland communities and airport security is advisable. Likely, less frequent cuts would have a rejuvenation effect on the heathland (Zavagno and D’Auria, 2020) but alien species would not find enough favourable micro-sites for an unconstrained increase. However, a specific monitoring on alien species to survey their development and spread and, if needed, to address focused management options (e.g. to prevent seed set) appears advisable. The development of site-specific management plans targeted to vegetation conservation could not obviously forget safety needs.

As for the heathlands outside Malpensa Airport, differences were highlighted both with MA sites and among the encroached sites themselves. The sites with the highest *P. serotina* invasion (i.e. H2 and H3) appeared strongly degraded, with a predominance of few tall and old heather individuals, and a reduced presence of young shoot renewal. This was related to the increased canopy shading, which is a restricting factor for heather persistence (Henning et al., 2015). Species composition was dramatically altered as well, being mainly composed by heather and by the woody alien *P. serotina*, together with a remarkable cover of *M. arundinacea*. The latter, even if reported as typical species of 4030 European dry heaths by Biondi and Blasi (2015), is less light-demanding than heather (Pignatti, 2005; Vegini et al., 2020) and proficiently took advantage of the increased woody layer cover in these sites. The antagonist behaviour of *M. arundinacea* towards heather may have also been boosted by the allelopathic effect of *P. serotina* (Csiszàr et al., 2012; Starfinger, 1990, 2010) which can hamper the incidence of heather. However, further research on this species-specific interaction is advisable. The strong negative influence of the invasive alien *P. serotina* on heathland habitat was thus confirmed: heather renewal was hindered, while the remaining heaths became oversized and senescent. Particularly, where the largest encroachment was found (H3), heather population represented the last active stage of lowland dry heathlands, while slightly lower degradation (in terms of woody species, alien species, and *M. arundinacea* covers) occurred in the intermediate H2. In these sites, among other restoration actions, tree removal is essential to counteract their expansion and re-establish the open area character typical of heathlands (Henning et al., 2017). Additionally, Calvo et al. (2005) reported a reduced capacity of heathland communities in the mature phase to regenerate after an intensive cutting. According to these authors, a drastic impact, such as cutting, may determine an increase in herbaceous species cover rather than an enhancement of heather re-growth.

In the present study, the heathland showing the best habitat conservation status was H1, i.e. the portion of lowland dry heathland with the lowest *P. serotina* invasion rate (less than 5 %). Likely due to the limited presence of this invasive species, heather population structure assumed a typical shape of young communities, with remarkable presence of small individuals and limited number of high leading shoots (similarly to the 'building' phase described by Watt, 1955), contrasting to H2 and H3. On the other hand, species diversity was the lowest among the studied sites. The high light availability compared to H2 and H3, encroached by woody species, together with the lack of disturbance, such as cutting operated within the airport, favoured the competition ability of heather, in terms of both cover and height, while reducing the possibility of colonization by both alien and therophitic pioneer plants of other environments (Henning et al., 2017). Similar results were obtained in a management experiment carried out in a Northern-Italian heathland, where the presence of the alien herbaceous species *D. acuminatum* was counteracted by the lowest disturbance treatment in terms of limited phytomass removal (Lonati et al., 2009). As suggested by Henning et al. (2017) and Seifert et al. (2015), operating one-time rejuvenation cuts integrated with periodic lenient management practices (such as grazing), may increase proportion of bare ground and, as a consequence, species richness, being potentially beneficial for lowland dry heathland conservation. Certainly, specific trials in habitat characterised by *P. serotina* encroachment should be addressed, to explore management practices able to both prevent invasion by alien species and enhance availability of suitable patches for heather rejuvenation and heathland species establishment.

5. Conclusions

Given the high conservation value of relict lowland dry heathlands, management practices carried out in these environments should consider the implications on habitat characteristics and vegetation community dynamics. Presence of bare ground and reduction of interspecific competition have been demonstrated to be fundamental for the persistence of heather and species typical of heathlands (Henning et al., 2017), as well as the prevention of tree encroachment, especially aliens characterized by high invasiveness (Ascoli et al., 2013; Lonati et al., 2009).

Our results showed how the intensive cutting regime carried out within Malpensa Airport was able to counteract habitat loss due to the alien tree *P. serotina* encroachment, while the unmanaged heathlands in the surroundings were threatened by the invasiveness of the alien tree and at increasing degradation stages. Nonetheless, the frequency and height of cuts should be carefully determined to hinder the expansion of plants belonging to other habitats (i.e. alien, meso-eutrophic grassland, and therophitic pioneer species) while encouraging the typical floristic composition and regeneration of heather. If carefully planned, the cutting regime has the potential to be successfully applied to preserve heathlands, especially in those situations where grazing and prescribed burning could not be used (e.g. inside and nearby airports). Moreover, compatibly with safety, conservation value of heathlands inside airfields may be enhanced through the maintenance of a mosaic of patches of different heathland development phases. Indeed, open habitats inside the airport, even if intensively managed, apparently served as a refugium for species of conservation interest (and their seeds) destined to disappear in the outer abandoned landscapes threatened by tree encroachment.

This aim could be accomplished by implementing a rotational cutting strategy, based on various cutting heights and frequencies. Future research should also include specific in-depth studies of plant management intensity effects on animal assemblages (including insects and other taxa) in lowland dry heathlands as well.

CRediT authorship contribution statement

Emanuele Vegini: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing - review & editing. **Elisa Cardarelli**: Supervision, Visualization, Writing – original draft, Writing - review & editing. **Marco Martignoni**: Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Writing – original draft, Writing – review & editing. **Michele Lonati**: Conceptualization, Formal analysis, Methodology, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Simone Ravetto Enri:** Data curation, Formal analysis, Methodology, Software, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2022.127687.

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