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Rapid and massive habitat change is destroying the Vauda heathland (Piedmont, Italy)

ABSTRACT - Encroachment by pioneer trees such as *Betula pendula* and *Populus tremula* is one of the main threats to the conservation of the Po Plain heathland, a vegetation type restricted to fluvio-glacial terraces of northern Italy. I report the results of 15 years of monitoring in a network of permanent plots located in the Vauda, one the largest heathlands in Italy. The data show that encroachment is progressing very fast, and that fire is not able to control the expansion of pioneer trees. Even at high frequencies (3-8 fires in 15 years) cover of pioneer trees doubled in the 15 -years time. Intermediate burning frequencies (1-2 burns in 15 years), appeared to stimulate pioneer trees. In these plots, pioneer trees expansion (400% in 15 years) was faster than in plots that were burned more frequently, and even than in plots that did not burn at all (200% expansion). Only mechanical cutting was able to effectively control woody plants. It is predicted that heathland and grassland will be completely lost from the Reserve in as little as 15 years. In turn, the loss of open habitats will cause a major biodiversity crisis in the Reserve. This work shows that the management of Northern Italian heartlands can not rely only on prescribed fire. Mechanical cutting and grazing/browsing by large herbivores need to be used in conjunction to prescribed fire in order to achieve long-term maintenance of the heathland.

KEYWORDS - Long-term monitoring, fire, mechanical cutting, conservation, management.

RIASSUNTO - *Rapidi e massicci mutamenti ambientali distruggono la brughiera della Vauda.*

L'invasione da parte di alberi pionieri come *Betula pendula* e *Populus tremula* è una delle principali minacce per la conservazione delle brughiere della Pianura Padana, un tipo di vegetazione limitato ai terrazzi fluvio-glaciali dell'Italia Setten-

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trionale. Questo lavoro presenta i risultati di 15 anni di monitoraggio in una rete di aree campione fisse nella Riserva Naturale Orientata della Vauda, uno dei frammenti di brughiera più grandi d'Italia. I dati mostrano che l'invasione degli alberi pionieri procede molto rapidamente, e che il fuoco non è in grado di controllarla. Ad alte frequenze di incendio (3-8 incendi in 15 anni) gli alberi hanno raddoppiato la loro estensione nelle aree campionate. Frequenze intermedie (1-2 incendi) apparentemente facilitano l'espansione degli alberi pionieri, in quanto in queste aree, si è osservata un espansione più rapida (circa il 400% nel periodo dello studio), sia di quella osservata in aree bruciate più spesso, che di quella osservata in aree non percorse da fuoco (incremento del 200%). Solo la falciatura meccanica si è dimostrata capace di controllare l'espansione della vegetazione arborea pioniera. I dati lasciano prevedere che le praterie erbacee e la brughiera a *Calluna* spariranno completamente dalla Riserva in meno di 15 anni. A sua volta, la scomparsa degli ambienti aperti causerà una grave perdita di biodiversità. Questo lavoro mostra che la gestione delle Brughiere della Pianura Padana non può basarsi solo sul fuoco prescritto. Lo sfalcio meccanico ed il pascolo di erbivori domestici e selvatici dovranno essere adottati insieme al fuoco per mantenere la brughiera.

INTRODUCTION

Heathlands are a typical habitat of western Europe. They are characterized by an open landscape, with high abundance of Heather *Calluna vulgaris* L. (Hull), along with groves of pioneer shrubs and trees (e.g. Birch *Betula pendula* Roth and Aspen *Populus tremula* L.). The Po Plain Heathlands are only found on fluvio-glacial terraces of Northern Italy, and are classified as a subtype of the European Dry Heaths vegetation (Devillers, Devillers-Terschuren & Ledant, 1991).

Once widespread along the southern edge of the Alps, Po Plain Heathlands have decreased dramatically over the last century (Sindaco *et al.*, 2003). Large tracts were ploughed and converted to agriculture, and only small remnants persist inside protected areas. Unfortunately, formal protection is not enough to warrant long-term heathland conservation, because successional change towards more dense, arboreal vegetation, occurs rapidly (Borghesio, 2009). All European heathlands are cultural landscapes, which have been maintained for long times by human activities, such as grazing of domestic animals (Sheep *Ovis aries* L. and Cattle *Bos taurus* L.), cutting of straw and firewood, and fires. These activities together cause ecological disturbance (Pickett & White, 1985), namely the destruction of woody vegetation, which counters the encroachment of pioneer shrubs. However, in the last decades, human activities have changed

greatly. Pastoralism, straw mowing and firewood cutting decreased significantly, while fires now occur at greatly changed frequency, either too frequent or too spaced in time (Borghesio, 2009). Moreover, due to atmospheric pollution, nitrogen depositions have significantly increased, and, in NW Italy, they exceed the critical eutrophication loads for heathland habitats (European Environment Agency, 2010). Under natural conditions, heathlands are nitrogen-limited, therefore they can be severely impacted by nitrogen eutrophication (Bobbink & Roelofs, 1995). The demise of traditional human activities, changed burning frequencies and pollution pose a compound threat to heathland ecosystems. In particular, these factors might stimulate the growth of pioneer woody plants, such as Birch and Aspen. Encroachment by pioneer woods, with concomitant loss of species diversity, is a problem over most of Europe (Price, 2002), but it might be particularly severe in Southern Europe, where plant growth is faster due to more benign climate and longer growth seasons (Bartolome *et al.*, 2005; Borghesio, 2009).

Heathland conservation requires active management. In northern Europe, heathlands are now actively managed by combinations of grazing and browsing, mechanical vegetation cutting and prescribed fire, but experience is poorly developed in Italy, especially on prescribed fire (Ascoli & Bovio, 2013). Fire is usually considered a useful tool for heathland conservation, and burning frequencies of one in 10-25 years can contrast the expansion of woody vegetation in northern Europe (Alonso *et al.*, 2003). However, due to faster tree encroachment, these burning rates are not sufficient in southern European heathlands (Borghesio, 2009). On the other hand, frequent burns are also undesirable, because they will impact plant and animal species richness (Gimingham, 1992). Moreover, fire can also stimulate the expansion of clonal woody plants, such as Aspen, which has an extensive root system and high suckering potential (Ascoli & Bovio, 2010). Paradoxically, frequent fires might contribute rather than contrast the encroachment of pioneer trees. Unfortunately, these issues have been studied very incompletely in Italy.

The Vauda, in North-Western Italy, is one of the largest patches of heathland in Italy, and is almost entirely protected inside a Nature Reserve (Borghesio, 2004). Rapid degradation has been observed in the Vauda in recent years, and much of it has been related to widespread encroachment by pioneer trees and shrubs (Cattaneo & Biddau, 2000; Borghesio, 2004). This paper analyses a 15-years long time series recorded in a network of fixed sample plots in the Vauda Nature Reserve. The plots are subdivided in groups representing a range of potential management actions, including

mechanical mowing and different fire frequencies. Results show that habitat change is occurring very fast. Without active management, the Vauda heathland is bound to disappear in little more than a decade. The same will also occur in all other remaining heathland fragments in Northern Italy.

MATERIALS AND METHODS

Study area

The Vauda Nature Reserve (45°15'N 7°39'E) was created in 1993 to preserve a fragment of the "Po basin heathland", a habitat unique to northern Italy, located at the extreme southern edge of the range of European heathlands (CORINE code 31.229, (Devillers *et al.,* 1991)). The heathland in the Reserve has an area of 1,003 ha (fig. 1).

The Reserve is located on a fluvio-glacial terrace datable to the Mindel glaciation (c. 400,000 years ago). Soils are ancient and leached, with fairly low pH (4.8 ± 0.1, n = 14, L. Borghesio, unpublished data) and high clay content. Elevation ranges between 250 and 470 m. The climate is Prealpine, with marked yearly temperature excursions (>20°C difference between the hottest and the coldest month), and relatively well-spread rainfall, with no arid months (Sestini, 1957). Rainfall averages 1100 mm/year, with maxima in May and October and minima in January and July. Average yearly temperature is 12°C, with minimum (1.3°C) in January, and maximum (22°C) in July (Biancotti & Bovo, 1998).

The Vauda is a fragment of a much larger heathland that existed until the beginning of the 20th century. Since then, most of the heathland has been converted to agriculture and settlements. The Nature Reserve was spared because it has been used as military training area since the early 19th century. Military activities continue to this day.

Plant communities include not only typical *C. vulgaris*-dominated formations, but also wide expanses of grasslands, where *C. vulgaris* is subordinate to Poaceae such as *Molinia arundinacea* Schrank, *Crysopogon gryllus* L. (Trin.), *Agrostis canina* L., *Festuca tenuifolia* Sibth. (Guglielmetto-Mugion, 1996). There is also a widespread presence of pioneer woods, dominated by *P. tremula* and *B. pendula.* The Vauda has been used for centuries as a pasture for cattle and sheep, and grazing is still practised. Herds of cattle (totalling c. 100 animals) graze from late May to early July. One herd of c. 300 sheep also uses the area in May-June. Numbers of grazing animals have been constantly decreasing in recent years. Mechanical mowing is

practised on about 5% of the area by local farmers once per year (usually mid-September). Fires usually occur in Winter or early Spring (December to April), and are probably started by the shepherds who graze their animals in the Vauda, however, since burning natural vegetation is illegal, those who start the fires do so anonymously (Ascoli & Bovio, 2013).

Field methods and analyses

From 1999 to 2013, a network of 61, 50m-radius sample plots was surveyed at yearly intervals. The network covers a total area of 49.9 ha (4.7% of the area of the heathland in the Reserve) and is evenly spread over the entire area of the Vauda heathland (fig. 1). Plots were located at randomly-chosen nodes of a 250m-sized grid created in MapInfo GIS 4.0, but the low accuracy (±80m) of GPS receivers in 1999 caused slight shifts from the locations selected by the GIS software. In any case, as the positioning error was random, the relative proportions of vegetation types represented in the

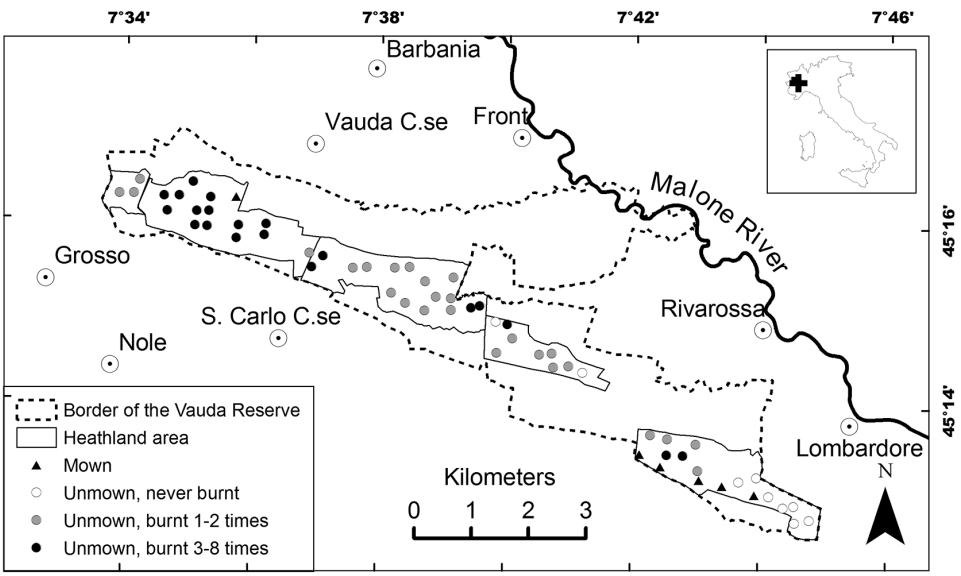

Fig. 1 - Map of the Vauda Nature Reserve and the main towns in its vicinity. The broken line marks the reserve border, while the thin continuous line shows the extent of heathland in the area. The rest of the Reserve is mainly covered by *Quercus-Carpinus* woods. The 61 sample plots are also shown, with different symbols representing mown/unmown and different frequencies of burning observed between 1999 and 2013.

plots can be considered an unbiased sample of the vegetation composition of the Vauda heathland during the 15-year period. Most of the plots were visited once per year in late Spring (between 17 May and 17 June), thus providing 15 visits in 52 plots. The remaining nine plots were visited 6 (four plots), 8 (four plots) and 13 (one plot) times.

The presence of signs of mechanical cutting of the vegetation (mowing, coded as yes or no) and of recent fires that burnt >30% of the plot was recorded on each visit. Moreover, within the 50m-radius, estimates were recorded of the area covered by four types of vegetation, namely: "Grass", with a diverse assemblage of herbaceous species (*M. arundinacea*, *C. gryllus*, *F. tenuifolia*, *Danthonia decumbens* (L.) DC and *Carex* spp being the most frequent species); "Heather", where the most abundant plant in terms of cover was *C. vulgaris*; "Shrubs", which included saplings of Birch *B. pendula*, Aspen *P. tremula*, Alder buckthorn *Frangula alnus* Mill., Bramble *Rubus* spp and Bracken fern *Pteridium aquilinum* (L.) Kuhn.; "Trees", that is woody plants >1.5m high (groves of Birch and Aspen, which, as they age, are colonized by other woody species such as Oaks *Quercus* spp, Chestnut *Corylus avellana* L. and Black locust *Robinia pseudacacia* L.).

At the analysis stage, the 61 plots were subdivided in four groups (fig. 1), namely: Plots mown at yearly intervals (n =6), Plots that were never mown and never burned during the 14-year period (n = 9), Plots that were not mown but burned 1-2 times between 1999 and 2013 (n = 26), Plots that were never mown but burned 3-8 times between 1999 and 2013 (n = 20).

RESULTS

At the scale of the 61 sample plots, over the 15-years period, massive changes occurred in the vegetation. Two patterns are evident: the strong decrement of grass (from 52% to 30%), which corresponds to an expansion of trees (from 11% to 35%). In contrast, the area occupied by heather and shrubs did not change much (fig. 2).

In plots that did not burn, there was a strong decrement of grass, which almost halved, from 69% to 37%. Yearly loss of grassland was therefore -2.1% of the total area (7.1 ha) of the nine plots that never burned. In contrast, Heather, Shrubs and Trees increased by more moderate amounts (respectively, 0.7%, 0.6% and 0.8% yearly increments, figs. 3 and 4).

In plots that burned one or two times, there was a general stability of Heather (from 14 to 12%), but large increases of Trees (from 12% to 48%

of the sampled area, or +2.4% per year) and corresponding decrements of Grass (from 47% to 24%, that is -1.5% per year) and Shrubs (from 24 to 15%, that is -0.6% per year, figs. 3 and 4).

In plots that burned three or more times, Heather was very sparse (about 4-7%). Shrub cover fluctuated around much higher levels (range between 44% and 36%). However, there was a marked expansion of trees (from 16% to 38% or +1.5% per year) and a corresponding contraction of grass (from 38% to 20% or -1.2% per year).

All four vegetation types were stable during the 15 years in mown plots (fig. 3).

DISCUSSION

Massive habitat change occurred in the Vauda in only 15 years. Most of the herbaceous habitats, which are the richest plant communities in the Vauda, will soon be completely encroached by *B. pendula* and *P. tremula*. Pioneer woods are species-poor, and they are composed by broad-ranging plants of low conservation value (Borghesio, 2009). Plant species diversity

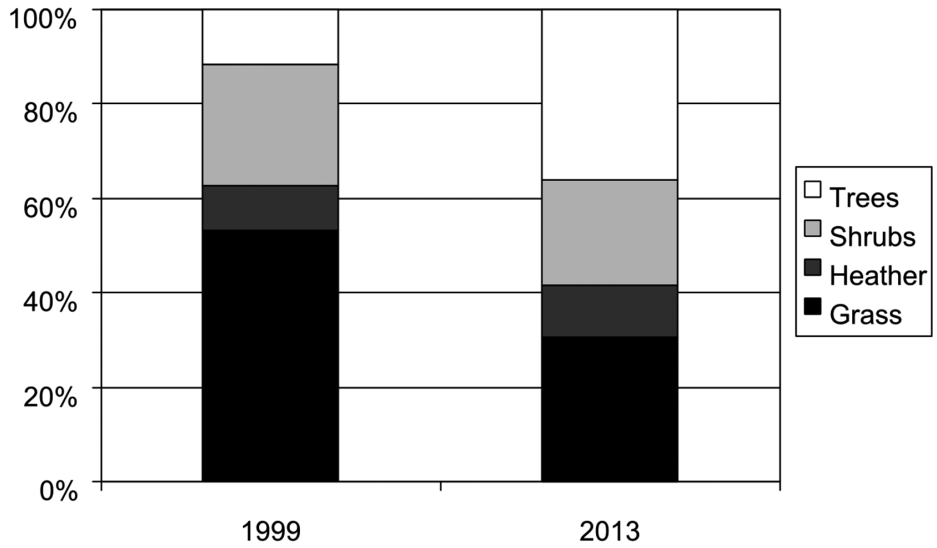

Fig. 2 - General patterns of habitat change in the Vauda, in 61 sample plots monitored from 1999 to 2013.

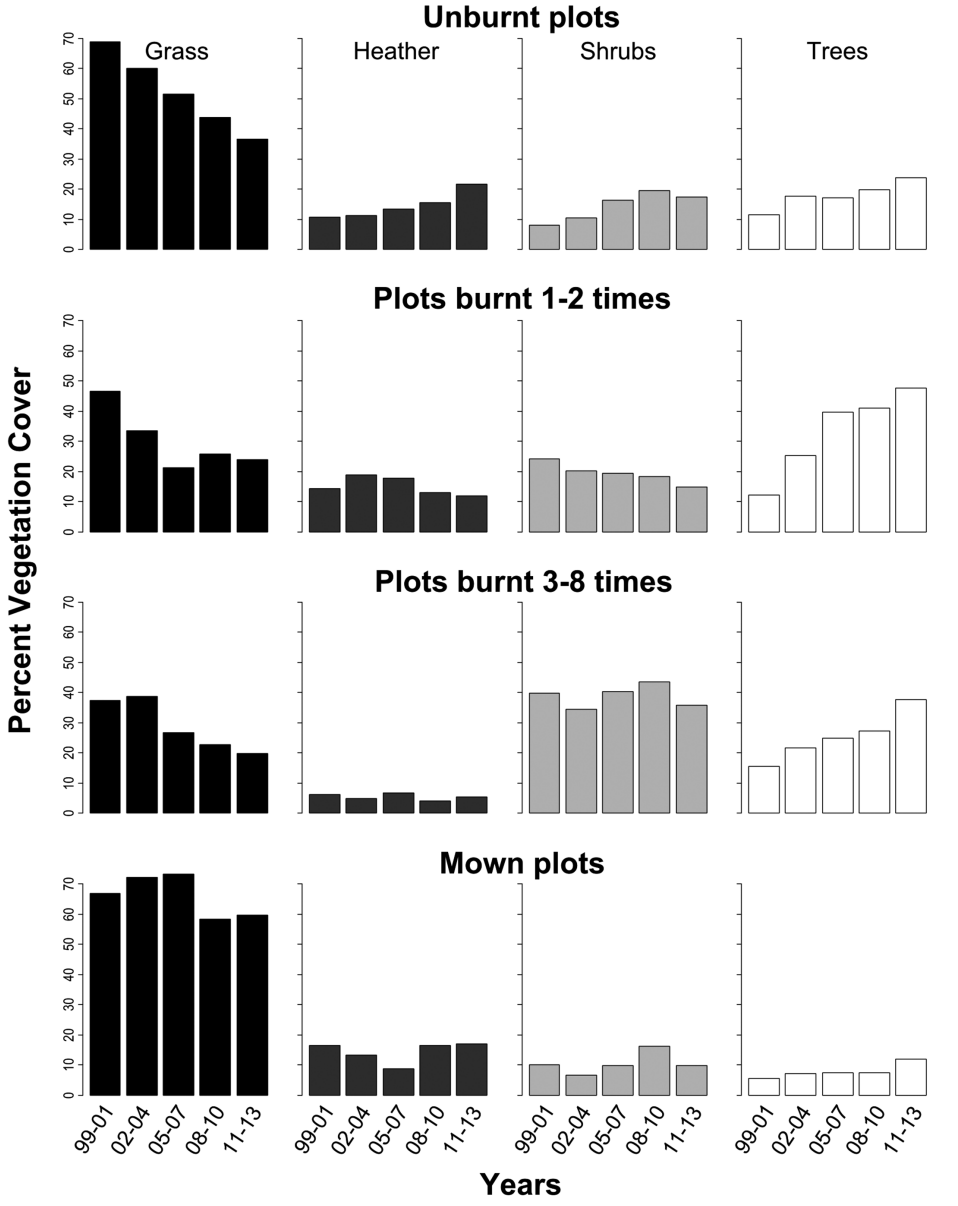

Fig. 3 - Changes in vegetation structure between 1999 and 2013 in sample points that were mown or burned at different time intervals.

in the Vauda was more than 750 species at the beginning of 20th century (Ferrari, 1913) while current richness is about 3-500 species (L. Borghesio, unpublished). Much of this loss might be due to the replacement of grasslands by low-diversity woody plant communities. At the same time, vegetation trends will cause concurrent changes in the fauna. Indeed, research on birds, butterflies and dung beetles in the Vauda already showed loss of open habitat species (Cattaneo & Biddau, 2000; Borghesio, 2004). A major biodiversity crisis is already occurring and will escalate in the near future.

Rapid deterioration of habitat quality implies that management actions are urgently needed to avoid major and irreversible biodiversity loss. However, contrasting with the guidelines commonly adopted in other European countries, in Italy the use of fire alone will not be sufficient to control pioneer trees. Tree cover increased in all plots under fire frequencies ranging from zero to more than one every other year. Indeed, the fastest rates of tree expansion were observed at intermediate burning rates (1-2 fires in 15 years), suggesting that, counterintuitively, fires can stimulate rather than contrast tree encroachment. Figure 4 shows how fast tree encroachment can be in plots that were burned at intermediate frequencies. In contrast, tree expansion was slower in plots that did not burn at all.

In plots that never burned, grassland decreased massively, suggesting that it will disappear in as little as 15 years from now. The decrement of grass in these plots was due to the expansion of all three types of woody vegetation, trees, shrubs and heather. Trees will eventually take over and expand over the entire area, encroaching into heather stands, but in the absence of fires, at the current rate of 0.8% per year, trees will take more than 50 years to expand over the entire area, especially in patches occupied by dense *C. vulgaris*, which has strong allelopathic properties (Ballester *et al.*, 1982) and can suppress other plants for long times. Thus, in unburnt areas, change is initially fast, but after the rapid disappearance of grassland a more (sub) stable situation might develop, in which trees will slowly shade out and grow into residual heather patches. However, this is no excuse for not taking action, as tree groves, once established, are extremely difficult and costly to restore to heathland (e.g. Gimingham, 1992).

At burning frequencies of 1-2 times in 15 years, grass strongly decreased. The apparent stability of Shrub vegetation through time should be interpreted as a dynamic equilibrium, in which young shrubs expand into grassy patches, while older ones grow into the Tree vegetation type (Ascoli & Bovio, 2010). Intermediate burning frequencies had the strongest positive effect on tree cover, that expanded at a rate of 2.4% per year. This might be the due to two factors. First, heather is sensitive to fire, especially

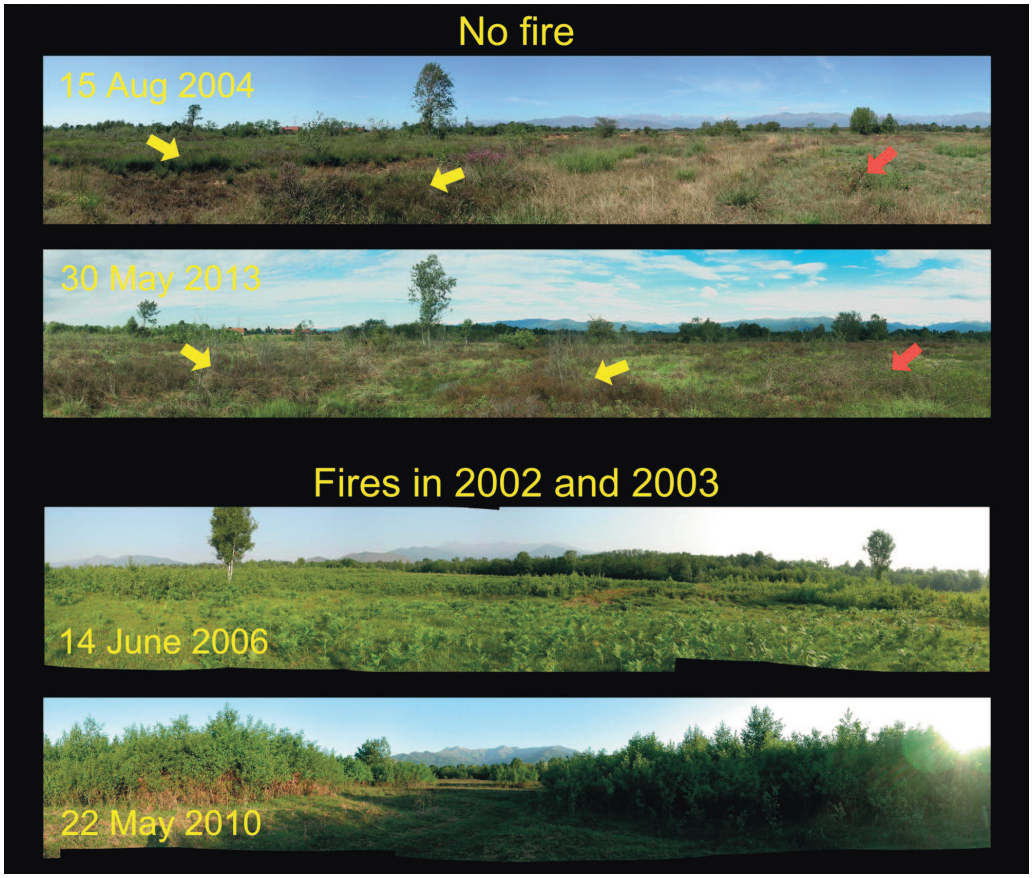

Fig. 4 - Comparison of landscape photographs taken at two sample plots at different time intervals. Above, Plot 351, in the western part of the Vauda, near Lombardore. This plot did not burn between 1999 and 2013. In nine years (2004-2013), the grassland (red arrows) disappeared due to encroachment of low shrubs (mostly Bramble *Rubus* sp. and Alder buckthorn *Frangula alnus*), but patches dominated by Heather *Calluna vulgaris* (yellow arrows) persisted with little change, suggesting that dense heather stands are resistant to encroachment by other woody plants. In the lower part of the figure, Plot 44, near Grosso, in the eastern part of the Reserve. This plot burned in 2002 and 2003. Three years after the fire, in 2006, part of the grassland had been encroached by Bracken fern *Pteridium aquilinum* and short saplings of Aspen *Populus tremula*. Just four years later, in 2010, Aspen completely invaded the plot and was 2-3 m tall, destroying heathland vegetation in the plot.

in its mature phase (Gimingham, 1960). Thus, when burned at intervals of 5-7 years, heather is unable to expand into grasslands, in contrast to what is observed in unburned sites. In turn, the inability of allelopathic heather to expand into grassland facilitates the expansion of pioneer trees through root suckering (see after). Second, in Italian heathlands, woody plants grow fast (Borghesio, 2009), and *B. pendula* and *P. tremula* can become >2m high in as little as four years, as figure 4 shows. This means that, at low burning frequencies, pioneer trees rapidly form shady stands where little grassy undergrowth develops, and soil humidity is higher than in open habitats: these groves are unlikely to burn. Indeed, most fires in the Vauda stop within few meters of the groves' edges, and rarely kill trees taller than 5 m (L. Borghesio, unpublished). In summary, at fire frequencies of one in 5-7 years, grassland is rapidly lost, and might disappear in as little as 10-15 from now.

In areas that burned three or more times heather was as very low levels. Shrubs tended to cover a larger proportion of frequently burned plots (around 40% versus 10-20% of the area in plots with lower fire frequencies), suggesting that fires maintain woody vegetation into a younger, shorter development stage. However, even in frequently burned plots, the most noticeable trend was a reduction of grass and a parallel increase of trees, even though rates of change in this case were lower than those recorded in plots with lower fire frequencies. Extrapolation in time suggests that, even frequently burned plots, will be completely encroached by trees in about 40 years. The expansion of trees in frequently burned plots might in part be due to low rates of fuel buildup (i.e., the accumulation of highly flammable dry grass residues on the ground), which lowers fire temperatures and the damage that fire causes to woody plants. Moreover, the characteristics of the species involved also make them resistant or resilient to fire. *P. tremula* forms extensive underground root systems (Bärring, 1988), and reproduces mostly by suckering, which is stimulated by fire (Gom & Rood, 2000). Massive root suckering by Aspen in response to burning is the main cause of the abundance of shrubby vegetation in frequently burned plots. These results confirm the hypotheses of Ascoli and Bovio (2010), who also observed the rapid expansion of root suckering plants in response to experimental fires in the Vauda. On the other hand, *B. pendula* responds to fire by developing a thick basal cork layer, which defends it from low-temperature fires (Atkinson, 1992). Thus, both species possess adaptations to fire resistance and will spread in areas affected by low-intensity fires.

Plots where mechanical vegetation cutting was done showed little tem-

poral change. While mowing is an effective means to contrast tree expansion, it has negative effects on heathland flora and fauna. In particular, late seasonal species, such as the rare *Gentiana pneumonanthe* L., as well as the threatened butterfly *Maculinea alcon* (Denis & Schiff.) that feeds on it in its larval stages (Nowicki *et al.*, 2005) will be negatively affected by mowing. That said, mechanical cutting might represent a cost-effective method to control the expansion of woody plants, and should be adopted more widely, within the framework of a clearly defined management plan.

The management implications of this study are applicable to all Northern Italian heathlands. Woody encroachment occurs rapidly and threatens both habitat and species diversity in the Vauda. With no action, many species of heathland plant and animals will soon disappear (Borghesio, 2004). Most likely, the same will also occur in all the other patches of protected lowland heathland remaining in Italy. Prescribed fire seems to have rather limited potential to control tree encroachment in Italian heathlands. However, fire is an important tool to avoid the accumulation of highly flammable fuel (dry vegetation), and it is necessary for the maintenance of plant species richness, in particular of low, bulbous species (e.g. Orchidaceae, Amaryllidaceae, Iridaceae) that are competitively inferior to heather and tall grasses. Heather stands should be burned when they reach a height of 25cm, because at this stage species richness begins to decrease in heather stands (Harris *et al.*, 2011). In Northern Italy, heather reaches this size in five to seven years after a fire, but this study shows that fire frequency of one in seven years exerts a strong stimulating effect on the expansion of pioneer trees. Thus, fire is needed to preserve the heathland, but at the same time, appropriate heather burning rates will cause massive encroachment by pioneer trees. The only way out of this conundrum seems to be to use fire together with other management techniques. Mechanical cutting might be useful, especially in hotspots of tree encroachment. Localized use of non-toxic herbicides, such as Glyphosate, might also be experimented, as it has been done in northern Europe (Price, 2002; Klimkowska *et al.*, 2010). Finally, restoring appropriate grazing intensities by herbivore mammals will also be crucially important. The Vauda has been maintained for centuries by combination of fires, grass and tree cutting, and grazing of cows, sheep and goats. It is likely that the concurrent use of all of these actions will be necessary to preserve it in the future. While both fire and herbivory cause the removal of plant material, they should be considered complementary, and not alternative management tools, as their effects are multiplicative rather than additive (Hean & Ward, 2012). Indeed, research in the Vauda has shown that combinations of prescribed burning and verte-

brate herbivory have the highest potential for controlling woody plants (Ascoli *et al.*, 2013). Research is needed to ascertain appropriate loads of grazing/browsing and the most effective herbivore species mix (e.g. sheep, cows, donkeys and goats (Critchley *et al.*, 2013)). Experience has already been matured in central Europe on the use of domestic and wild herbivores for controlling woody plants (Tschöpe *et al.*, 2011) and it should be developed also in Southern Europe.

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