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Published version:

DOI:10.1071/WF07114

Davide Ascoli, Rachele Beghin, Riccardo Ceccato, Alessandra Gorlier, Giampiero Lombardi, Michele Lonati, Raffaella Marzano, Giovanni Bovio, Andrea Cavallero (2009). Developing an Adaptive Management approach to prescribed burning: a long-term heathland conservation experiment in north-west Italy. International Journal of Wildland Fire, Volume 18, Pages 727–735, September 2009, http://dx.doi.org/10.1071/WF07114

Developing an Adaptive Management approach to prescribed burning: a long-term heathland conservation experiment in north-west Italy

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Abstract

Calluna vulgaris-dominated heathlands are globally important habitats and extremely scarce outside of north-west Europe. Rotational fire, grazing and cutting by local farmers were dominant features of past heathland management throughout Europe but have been abandoned, altering the historical fire regime and habitat structure. We briefly review research on *Calluna* heathland conservation management and provide the background and methodology for a long-term research project that will be used to define prescribed fire regimes in combination with grazing and cutting, for management of *Calluna* heathlands in north-west Italy. We outline the ecological and research issues that drive the fire experiment, making explicit the experimental design and the hypotheses that will be tested. We demonstrate how Adaptive Management can be used to inform decisions about the nature of fire prescriptions where little formal knowledge exists. Experimental plots ranging from 600 to 2500 m^2 are treated according to one of eight alternative treatments (various combinations of fire, grazing and cutting), each replicated four times. To date, all treatments have been applied for 4 years, from 2005 to 2008, and a continuation is planned. Detailed measurement of fire characteristics is made to help interpret ecological responses at a microplot scale. The results of the experiment will be fed back into the experimental design and used to inform heathland management practice in north-west Italy.

Additional keywords: *Calluna vulgaris*, cultural landscape, fire behavior, fire effects, Vauda experiment.

Introduction

Calluna vulgaris Hull. (*Calluna*)-dominated heathland is one of the dominant cultural landscapes (as in Farina 2000) of the Atlantic regions of north-west and Central Europe (Gimingham 1972; Thompson *et al.* 1995; Webb 1998). Heathlands developed roughly 4000 years ago as a result of forest clearance and they have been maintained by anthropogenic disturbance regimes, primarily a combination of burning, grazing and cutting (Gimingham 1972; Webb 1998; Goldammer *et al.* 2007). Outside their main distribution area, *Calluna* heathlands occur in isolated areas of eastern and southern Europe and throughout their range are of considerable nature-conservation, landscape, aesthetic and cultural value (Gimingham 1960; Hobbs and Gimingham 1987; Thompson *et al.* 1995).

Heathlands are currently under threat from a range of impacts and reductions in their overall distribution have led them to be classified as greatly endangered (Habitats Directive 92/43/EEC) (Rose *et al.* 2000). The abandonment of traditional management practices has led to conversion to woodland (Thompson *et al.* 1995; Webb 1998); increased atmospheric nitrogen and sulfur deposition causes early replacement of *Calluna* by grasses such as *Molinia* spp. (Heil and Diemont 1983; Marrs *et al.* 2004; Terry *et al.* 2004; Brys *et al.* 2005; Britton and Fisher 2007) and inappropriate fire and grazing management can lead to *Calluna* being out-competed by *Pteridium* (Watt 1955; Snow and Marrs 1997). Climate change in the coming decades also poses a significant threat to the integrity of heathland areas and will impact on accidental fire regimes (Goldammer *et al.* 2007).

Calluna heathland conservation management is thus a critical issue and has been intensively studied (Hobbs and Gimingham 1987). A range of different management regimes, including prescribed burning (FAO 2006), grazing at different stocking rates, and mechanical cutting have been proposed for maintaining heathland habitats throughout Europe (Whittaker and Gimingham 1962; Hobbs and Gimingham 1984; Hester *et al.* 1991; Sedláková and Chytrý 1999; Pakeman *et al.* 2003; Niemeyer *et al.* 2005; Vandvik *et al.* 2005; Britton and Fisher 2007; Goldammer *et al.* 2007).

The majority of research concerning *Calluna* heathland management has been completed in its main oceanic distribution area, and in the United Kingdom in particular, where *Calluna* moorlands represent a significant financial and cultural resource through their use for grouse shooting (Hobbs and Gimingham 1987). Comparatively little work has taken place in southern Europe (Valbuena *et al.* 2000; Calvo *et al.* 2002; Bartolomé *et al.* 2005) and even less in Italy, where information about heathland sensitivity to land-uses and climate changes is very scarce. Heathlands in this area are subject to a very different environment, occurring in a continental rather than oceanic climate and on mineral rather than peat soils, and further studies are needed of regionally critically threatened habitats.

In Italy, *Calluna* heathlands are mainly located on the north-west side of the Po River Plain (Mugion 1996) bordering the foot of the Alps (Fig. 1). They are relic ecosystems that developed, similar to elsewhere, on nutrient-poor, acid soils as a result of forest clearance, and were maintained by anthropogenic disturbance in the form of pastoral burning, grazing and harvesting *Calluna* and *Molinia* for forage (Sartori *et al.* 1988; Mugion and Martinetto 1995). In the post-WWI period, heathlands covered extensive areas (Pavari 1927), but today they are limited to isolated patches. Remnant heathlands have a high nature-conservation value as they represent an important shelter for several plant and animal species. Moreover, they are a unique cultural landscape and a tourist attraction of the region.

Fig. 1. *Calluna* heathland landscape in north-west Italy.

The majority of remaining heathlands have been designated as ‘Managed Nature Reserves’ in order to safeguard them from degradation. Paradoxically, this protection is often applied in a passive way, through a removal of any management or disturbance, rather than via the adoption of suitable management plans. A recent study of landscape dynamics in NW Italian nature reserves (Garbarino *et al.* 2006) demonstrated that the lack of management has caused the loss of ~50% of the heathland habitat over the last 50 years.

At the Managed Nature Reserve (MNR) of Vauda, in the Piemonte Region of north-west Italy, a long-term fire experiment has been established to determine the effects of various prescribed fire regimes on heathland dynamics. The study has been developed as part of a multidisciplinary management experiment that aims to provide users of the MNR with a suitable management plan for conservation of the *Calluna* heathlands through the wise use of prescribed burning, grazing and cutting.

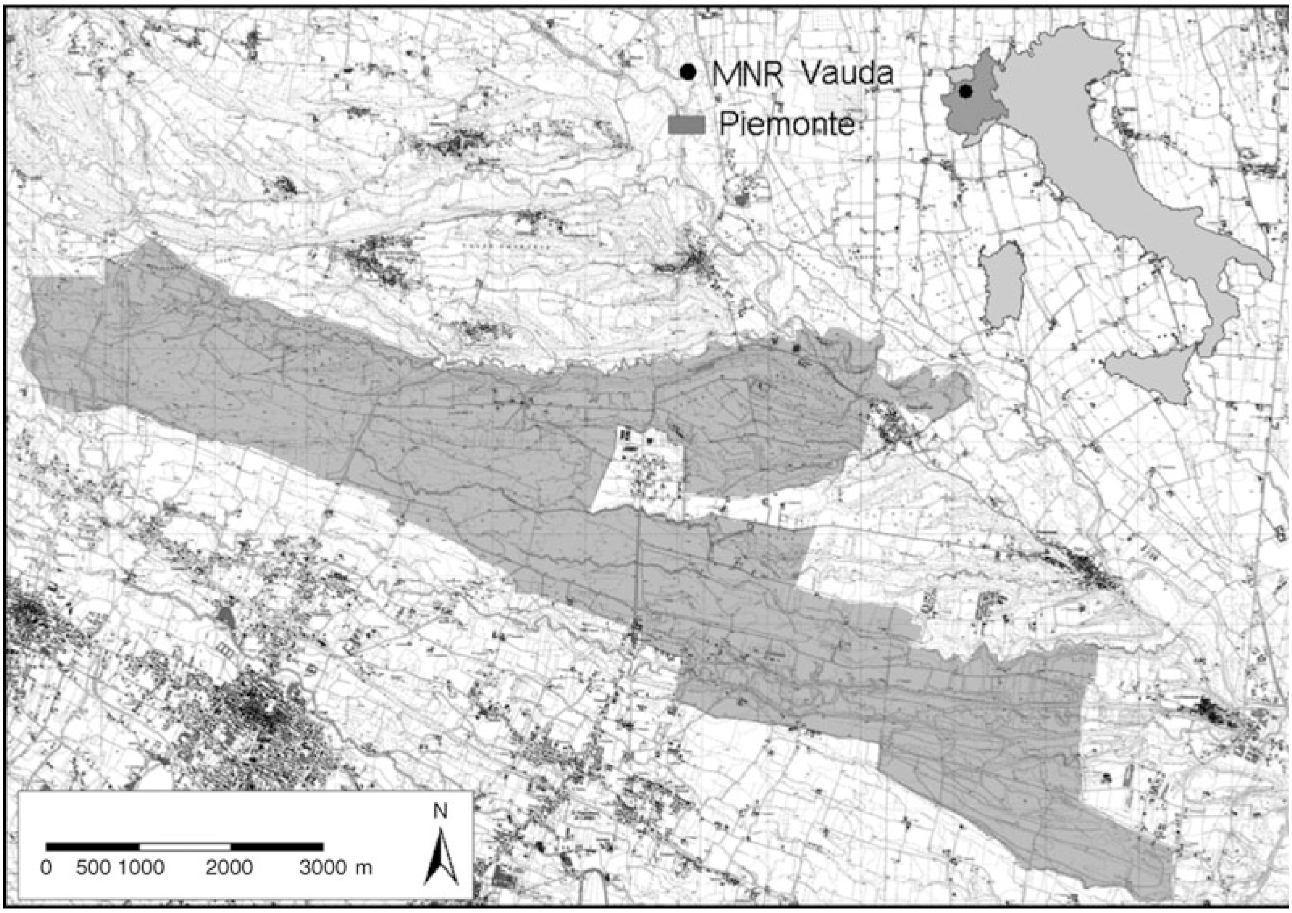
The present paper discusses the fire research issues at Vauda and describes the rationale for the use of Adaptive Management (as in Holling 1978) to design the fire experiment. It provides an important example of how ‘adaptive learning experiments’ can be used to develop sustainable, evidenced-based, best-practice approaches for prescribed burning where little formal knowledge exists. Long-term fire experiments are a rare but important feature of fire ecology research and our work has significance for those considering developing similar programs.

Calluna heathlands at the MNR of Vauda

Site location and climate

The MNR of Vauda covers an area of 2635 ha and is located ~20 km N-NE of Torino (7°41′17″E, 45°13′13″N), at an altitude ranging from 240 to 480 m (Fig. 2). The climate is continental, with roughly 81% of the mean annual rainfall (1000–1100 mm) falling between April and November. The driest month is March with, on average, 35 mm of rain and 0.3 days of snow. The mean annual temperature is 11.8°C, with monthly means ranging from 1.6°C in January to 21.9°C in August (Nimbus 1993–2004; http://www.nimbus.it, accessed 29 May 2009).

Fig. 2. The Managed Nature Reserve (MNR) of Vauda boundaries and the surrounding urban development.



Vegetation and soils

The Reserve is located on a stream terrace plateau, formed in the Late Pleistocene by the Stura di Lanzo River, and is dissected by several creeks (Mugion and Martinetto 1995). Most of the land is level or very gently sloping (<2% slope). The soils are acidic, rich in silt and clay and classified as Typic Fragiudalf (USDA–NRCS 1999). The major vegetation associations on the plateau are characterized by different stages of succession towards the alliance of *Quercion robori-petraeae*, and to a lesser extent to the *Carpinion* forests (Oberdorfer 1957), ranging from open heathland, belonging to the *Calluno–Ulicetea* phytosociological class (Sindaco *et al.* 2003), to *Populus tremula* L. (European aspen) and *Betula pendula* Roth (silver birch) thicket stands, and *Molinia arundinacea* Schrank (tall moor grass) grasslands. Forests dominate the creek slopes.

A recent study promoted by MNR land-managers in the course of the European action Interreg IIIA (Regione Piemonte 2004) examined species richness by habitat type and recorded 58 habitats according to Corine Biotopes and more than 600 plant species; the study demonstrated the importance of the Reserve and revealed that it held several regional rare and endangered species in wetland sites located in the heathland matrix, such as *Carex hartmanii* Cajander and *Eleocharis carniolica* Koch (Pignatti *et al.* 2001; Borghesio 2004; Regione Piemonte 2004). Moreover, the Reserve represents one of the few strips of land for nesting birds in the local area (123 bird species were registered by Cattaneo (1990)).

Site history

The MNR of Vauda was established in 1993 to preserve the characteristic heathland of the area. Its boundaries coincide with a pre-existing military firing range, which has helped to preserve the heathlands from urban expansion and agricultural development for at least two centuries. In addition to military access, shepherds were allowed to harvest forage and use the area for cattle grazing. Similarly to heathland management in north-west Europe (Gimingham 1972; Webb 1998; Goldammer *et al.* 2007), fire was applied by graziers to reduce the tree cover and to maintain pastures for livestock. Periodical burning in winter and subsequent grazing and cutting have strongly influenced and subsequently maintained the vegetation structure and composition of the heathlands.

Over the last 40 years, changes in land use and management have altered the traditional fire regime, while grazing and cutting practices have either been of comparatively low intensity or entirely absent (Borghesio 2004). The present fire regime is characterized by uncontrolled winter fires (February–March), with some sites burnt accidentally every year under extreme fire weather conditions. Shortened fire return-intervals have caused the transformation of heathlands into grasslands dominated by *Molinia* spp. (Mugion 1996). In some areas, particularly those near the urban interface, fire has been completely excluded. Here, less frequent disturbance due to fire suppression and extensive grazing and cutting has enabled species like *Populus tremula* and *Betula pendula* to form large, dense stands of juvenile trees that, in the absence of disturbances, later develop into woodlands with the establishment of *Quercus robur* L. (Pedunculate oak) and other species of the *Quercion robori-petraeae* and *Carpinion* alliances (Mugion 1996). These changes affect the characteristic biodiversity of the heathland ecosystem (Mugion and Martinetto 1995; Borghesio 2004; Regione Piemonte 2004) and suitable management actions are required to protect these habitats.

The Adaptive Management process at Vauda

Adaptive Management (AM) is an iterative process of decision-making for natural resource management that is used to minimize the risks associated with a disturbance or change of management regime where significant uncertainty exists over habitat response (Holling 1978). Given the lack of knowledge about *Calluna* fire ecology in continental regions and the absence of long-term experimental studies of prescribed burning in Italy (Leone *et al.* 1999; Ascoli 2008), we have adopted some of the principles of AM to design a 'management experiment' (Walters and Holling 1990). AM requires:

1. Establishment of clear objectives (Holling 1978).

2. Identification of alternative management actions (hypotheses) that integrate existing interdisciplinary experience and scientific information (Walters 1997).
3. Formulation of performance indicators to monitor and assess management effectiveness (Andersen *et al.* 1998).
4. Iterative feedback to management policies and practices by learning from the experimental management outcomes (Taylor *et al.* 1997).

Management objectives at Vauda

The management objectives at the MNR are to:

- Regenerate the *Calluna* heathland, creating a mosaic of even-aged stands of different stages that corresponds to a reference heathland structure and species composition as defined by the Interreg III Project (Regione Piemonte 2004).
- Limit tree encroachment and competition with characteristic heathland species, and reduce the land area undergoing secondary succession by minimizing tree-stump resprouting capability or inducing stump mortality.
- Enhance species and structural diversity, creating a mosaic of heathlands, grasslands and woodlands.

Existing scientific knowledge

In order to define an appropriate prescribed fire regime to meet our management objectives, it is first essential to determine the independent and interacting effects of fire season, frequency, intensity and severity on plant responses (Bond and van Wilgen 1996). Extensive literature concerning *Calluna* heathland management by prescribed burning exists from the oceanic strongholds of their distribution (e.g. Whittaker and Gimingham 1962; Gimingham 1972; Hobbs and Gimingham 1987; Niemeyer *et al.* 2005; Goldammer *et al.* 2007). Though we have little specific knowledge from our region, we can draw on research completed elsewhere and identify several issues:

Fire season

The season when vegetation is burnt has pronounced effects on plant resilience to fire (Bond and van Wilgen 1996) while fire intensity interacts with season, increasing in dry, hot and windy periods (Andersen *et. al.* 1998). We will apply fire treatments in winter for three key reasons:

1. Fire has the greatest impact on plants during periods of active growth because carbohydrate and nutrient reserves have been depleted (Bond and van Wilgen 1996) and consequently prescribed fires during the dormant season in winter are likely to be less severe.
2. The Fire Management Plan of the Piemonte Region (Regione Piemonte 2007) authorizes prescribed fire only in the dormant season (Ascoli 2008).
3. We wish to mimic historic fire regimes and evidence shows that shepherds used fire in winter to eliminate dry biomass and stimulate plant production in the following growing season (Mugion and Martinetto 1995; Borghesio 2004).

Fire frequency

How often fires occur determines the state of the population when it is burnt and therefore its post-fire response (Bond and van Wilgen 1996). Fire return interval also interacts with intensity through its effect on fuel load (Andersen *et al.* 1998). We still do not know how many years are needed for a *Calluna* stand to reach a structure and composition that satisfy the management objectives and that are resilient to a new fire treatment. We will therefore study fire frequency under the 'adaptive' approach and thus have not fixed the return interval of fire.

In the UK, current advice for heathland (moorland) management is that *Calluna* stands should be burnt roughly on a 15–20 year rotation (Scotland's Moorland Forum 2003) or when ~20 cm tall (Natural England 2007), though recent studies question the wisdom of such blanket prescriptions and suggest that greater variation in fire regimes will benefit both land-management and nature conservation objectives (Davies *et al.* 2008). Existing advice from the UK suggests that it takes from 8 to 25 years for heathlands to reach the recommended minimum height for burning, depending on the amount of browsing and local soil and climatic conditions (SEERAD 2001*a*, 2001*b*). No references are however available to compare the growth rates of *Calluna* in north-west Italy and the UK.

Fire behavior

In heathlands, fires characterized by low fireline intensity (Byram 1959), ranging from 50 to 500 kW m^{-1}, can be achieved in burns that spread against the wind (backfire); whereas wind-driven fires (headfire) display higher fireline intensities of up to 4000 kW m^{-1} (Kayll 1966; Hobbs and Gimingham 1984; Davies *et al.* 2006). Peak temperatures in headfires have been observed to range from 220 to 940°C in the canopy and from 140° to 840°C at the ground surface (Whittaker 1961; Kenworthy 1963; Hobbs and Gimingham 1984; Davies 2005). This range of behaviors is influenced by weather variables (wind speed and direction are particularly important), micro-relief, fuel distribution and moisture (Kayll 1966; Hobbs and Gimingham 1984; Davies *et al.* 2006). Such factors may vary between burns but also within a burn; consequently, over the course of a fire treatment, they may affect the spatial pattern of fire behavior within the burned area (plot). The fire behavior heterogeneity can strongly influence the survival and post-fire recruitment of plants (Bond and van Wilgen 1996), thus producing variation in fire severity at broad and fine scales (Atkins and Hobbs 1995).

In order to assess prescribed fire effects and cope with their heterogeneity within a burn, we will link fire behavior characteristics to effects using a 'microplot-scale analysis' (Smith *et al.* 1993; Fernandes *et al.* 2000). This will consist in correlating at a subplot scale vegetation responses (e.g. tree stem mortality) to fire behavior descriptors such as: rate of spread and Byram's (1959) fireline intensity, flame temperatures and their duration at different heights measured using an infrared camera, and flame peak temperatures at ground level and a depth of 1 cm below-ground using heat-sensitive pellets (Omega undated). We stress the importance of using the microplot quantification of fire characteristics *v.* a macroplot approach for three key reasons:

1. It is able to describe the whole burn and its variability (Fernandes *et al.* 2000).
2. It provides a consistent number of repetitions and a wider range of observations to establish reliable models in regression analyses with a relatively low number of burns (Smith *et al.* 1993); consequently, considering the fact that in Italy, conducting experimental burns is particularly difficult (Mazzoleni and Esposito 1993; Ascoli 2008), the microplot approach is preferable.
3. The understanding of fire behavior effects on *Populus* survival and *Calluna* regeneration success is critical and requires a detailed analysis.

Fire severity

The ecology of *Populus tremula* is very similar to that of *Populus tremuloides* Michx. (quaking aspen) (De Chantal *et al.* 2005; Latva-Karjanmaa *et al.* 2006), which has been widely studied in North

America. Brown and DeByle (1987, 1989) studied prescribed fire effects on *P. tremuloides* and observed that high fireline intensity kills the epigeous part of individuals of larger diameter than low-intensity fires, suggesting we should aim for high-intensity burns to maximize stem mortality. However, at Vauda, the *P. tremula* population is characterized mainly by young thicket stands with diameter at breast height (DBH) of <10 cm. Brown and DeByle's (1987) results show that the probability of stem mortality for a DBH of 10 cm is up to 90% both for low and moderate fire severities, as defined by the authors using char height. Moreover, *P. tremuloides* shows a high resilience to fire by suckering from the roots. When apical dominance is reduced by post-fire stem mortality, sucker-stimulating cytokinins increase in the roots, where buds are protected from heat by the soil stratum, resulting in high sprout capability (Brown and DeByle 1989). Brown and DeByle (1987, 1989) concluded that 'a strong relationship between suckering and fire severity was not demonstrated'. This suggests that at Vauda high (headfire) and low (backfire) fireline intensities probably have the same management implications for tree survival: dramatic resprouting is unavoidable. There is evidence, however, that grazing and cutting after fire will be effective in limiting the density of *Populus* suckers (Bartos and Mueggler 1981; Wright and Bailey 1982; Bailey *et al.* 1990; Dockrill *et al.* 2004).

Unlike for *Populus tremula*, there is abundant scientific literature about the effects of burning on *Calluna* (Hobbs and Gimingham 1987). Several studies have recognized the importance of temperature residence time as a key factor in understanding post-fire *Calluna* sexual and vegetative regeneration (Kenworthy 1963; Kayll 1966; Hobbs and Gimingham 1984; Davies 2005). *Calluna* seed germination is increased at exposure to 120°C for 30 s, 60 s at the same temperature slightly depresses it, whereas 60 s at 160°C is, by contrast, lethal (Whittaker and Gimingham 1962). Thus, although fire may kill seeds at the soil surface, the germination of those that are partially protected may be stimulated (Gimingham 1960).

The residence time of high temperatures may also affect belowground buds and resprouting from dormant adventitious buds (Mohamed and Gimingham 1970). In dry conditions, management and wild-fires, characterized by temperatures lasting long enough to ignite the surface organic horizon, have a deleterious effect on *Calluna* resprouting potential, seed survival and seedling establishment (Kayll and Gimingham 1965; Mallik and Gimingham 1985; Legg *et al.* 1992).

Field and laboratory fire experiments in a variety of vegetation types have shown how the residence time of temperatures at the ground surface depends on fuel characteristics and fire rate of spread (these two factors being interlinked themselves). The duration of raised temperatures increases with greater fuel loads and lower fuel moisture content (Kenworthy 1963; Wright and Bailey 1982; Neary *et al.* 1999; Molina and Llinares 2001; Davies 2005), and is longer in backfires compared with headfires (Mendes-Lopes *et al.* 2003; Davies 2005). In the UK, 'muirburn' practice is mainly characterized by headfires burnt as 25- to 30-m wide strips (Hobbs and Gimingham 1987; SEERAD 2001*b*). Backfires may be used in *Calluna* stands older than 20–25 years old (Kayll 1966; Hobbs and Gimingham 1987), though their use is now discouraged by some agencies (Natural England 2007) over concern about damage to peat, litter layers and mosses. Several field, wind-driven fire experiments within the range of management fire prescriptions have been conducted and none measured residence times of temperatures at ground level over 400°C greater than 60 s (Kenworthy 1963; Kayll 1966; Hobbs and Gimingham 1984; Davies 2005). Similar results have been observed in grass headfires (Wright and Bailey 1982; Bóo *et al.* 1996), which are fast-moving fires with a low amount of heat release to the soil (Neary *et al.* 1999). Consequently, in terms of impact on *Calluna* regeneration potential at Vauda in stands roughly 15 years old, headfires are likely to be preferable to backfires for achieving management objectives.

Management options and hypotheses

Our brief review of existing relevant research allows us to form the following alternative management options for *Calluna* heathland conservation:

1. Winter headfires or winter backfires.
2. Winter fires or grazing or cutting.
3. Use of winter fires, grazing, cutting alone or, winter fires combined with grazing or mowing.

We can also form the following hypotheses:

i. Headfires with a fireline intensity ranging from 500 to 3000 kW m^{-1} and a return interval of 15–20 years are suitable to regenerate *Calluna* stands and kill the epigeous part of trees.
ii. Fire behavior does not have significant effects on the *Populus tremula* resprouting potential.
iii. Grazing and cutting after fire will control the dramatic *Populus* resprouting.

Experimental design

To test our hypotheses, we will utilize a randomized block design. We chose four experimental areas (blocks) characterized by homogenous *Calluna* stands in the building phase (as in Watt 1955) with an early stage of *Molinia* and juvenile tree encroachment. Each block is composed of eight experimental units (plots) ranging from 600 to 2500 m^2, each subject to one of eight treatments (Table 1):

Table 1. Synthetic description of treatments
For grazing, stocking rate ≈ 20 grazing days per livestock unit per hectare

Treatment	Description	Size (m^2)	Season	Frequency (year)
F	Fire ignited upwind along a 25-m line	1250	Winter	Undetermined
G	Grazing	2500	Spring	1
C	Cutting with phytomass removal	600	Spring	Undetermined
FG	Fire (F) followed by Grazing (G)	2500	Winter–Spring	Undetermined – 1
FC	Fire (F) followed by Cutting (C)	600	Winter–Spring	Undetermined – 2
FF	Fire ignited upwind along a 25-m line	1250	Winter	1
CC	Cutting with phytomass removal	600	Spring	2
U	Unmanaged control	600	–	–

- **F**: Winter prescribed fire every *n* years is designed to assess fire behavior effects (head- *v.* backfire) at a microplot scale; the fire return interval will be determined by feeding back results of long-term vegetation monitoring.
- **G**: Grazing each year in springtime is designed to test the hypothesis that grazing and browsing animals may control (or at least stop) *Populus tremula* and *Betula pendula* encroachment, even at a light stocking-rate, as already shown by several authors in other environments (Bailey *et al.* 1990; Garmo *et al.* 1993; Lombardi and Cavallero 2000). It involves local graziers in the area; stocking rates (average stocking rate ≈ 20 grazing days per livestock unit per hectare, corresponding on average to 20% of carrying capacity) and animal

species will be considered each year according to the interactive monitoring of vegetation responses.

- **C**: Cutting every *n* years with phytomass removal assesses cutting effects and, similarly to F, does not fix a return interval.
- **FG**: Winter prescribed fire every *n* years with subsequent grazing each year in springtime. This approximates the traditional fire and grazing practices of the area.
- **FC**: Winter prescribed fire every *n* years with subsequent cutting every 2 years in springtime. This approximates the traditional fire and cutting practices of the area.
- **FF**: Winter fire every year simulates a high-frequency wildfire regime.
- **CC**: Cutting every 2 years in springtime with phytomass removal simulates an intensive harvesting regime for forage.
- **U**: A control plot (untreated) assesses the absence of management.

The last three treatments approximate current dynamics at Vauda. All treatments have been applied since winter 2005.

Precautionary measures against wildfire include a 3-m firebreak around the perimeter of each plot area and containment of the fires during burning by spraying water along the plot perimeters; the prescribed fires are performed with the support of the State Forestry Corps and Volunteer Firefighter Teams of the Piemonte Region.

All plots are fenced for rational grazing and wildlife exclusion.

Ecological responses survey and performance indicators

Pretreatment site characterization and the monitoring of post-treatment vegetation response are essential to assess the effectiveness of management (Andersen et. al. 1998). Pre- and post-treatment sward spatial structure and species frequency are measured using the vertical point quadrat method (Wilson 1963) along fixed-line transects (10 m long; two to four per experimental plot) to quantify the species contribution and cover (CS). The CS will be periodically monitored in each plot and compared with the control as defined by the Interreg IIIA project (Regione Piemonte 2004). Pre- and post-treatment tree stand structure and composition are assessed on fixed belt transects (2 × 10 m; two to four per experimental plot). During the seasons following treatments, canopy cover, stem mortality, sprouting capability (number and size of sprouts) and complete plant death (i.e. top-kill and failures to resprout) are monitored to assess treatment effect and stand development with regards to desired structure.

At a landscape scale, pre- and post-management land-use maps, rendered in a geographical information system (GIS) environment from aerial digital photos (Johnson 1990; Garbarino *et al.* 2006), will allow us to compute landscape metrics and compare landscape structure changes with management policies.

Conclusion

The research project at Vauda developed from dialogue between scientists and land managers; only with a continuing interaction between them will it be possible to cope with uncertainties and define suitable management actions. At present, we must be careful to not jump to far-reaching conclusions as the treatments have only been applied since winter 2005; nevertheless the short-term results will feed back in a second step of the project in which the changeover to a 'landscape management experiment' is desirable (Walters and Holling 1990; Andersen *et al.* 1998). We are aware of the difficulties in translating research results into prescriptions that are applicable by land managers at a landscape level. Recommendations for landscape-scale management will be based on continual review of the results of the formal experiment.

Like all fire experiments, ours is affected by logistic and resource constraints. In Italy, prescribed burning is complicated by the lack of scientific knowledge (Calabri 1988; Leone *et al.* 1999; Xanthopoulos *et al.* 2006; Ascoli 2008), and this breeds mistrust in public administration and is reflected in gaps in the rules, legal constraints and the lack of qualified personnel. Organizing fire experiments in Italy is therefore even more complex than usual and often lacks the flexibility that is required to take advantage of suitable conditions quickly (Buresti and Sulli 1983; Mazzoleni and Esposito 1993; Massaiu 1999; Ascoli 2008). Despite these constraints, our experiment will stimulate further discussion and will contribute to the development of a prescribed burning expertise in Italy as it is happening throughout Europe, where the 'wise use of fire' has been and still is one of the key objective of Europe-wide research projects such as Fire Torch (Rigolot and Gaulier 2000; Botelho *et al.* 2002; www.crc.ensmp.fr/europe/firetorch/index.html, accessed 29 May 2009) and Fire Paradox (Rego *et al.* 2007; www.fireparadox.org/, accessed 29 May 2009).

The AM process presented here is highly formalized and designed to produce scientific understanding of ecological processes as well as suitable management regimes. The approach has lessons for fire managers globally, including those managing heathlands in other regions. It is indeed ironic that while in Italy or Germany (Goldammer *et al.* 2007) scientists and managers are striving to implement novel fire management, in some of the strongholds of knowledge of fire impacts on *Calluna*-dominated vegetation, there is still simplistic discussion about banning burning in some moorland habitats (Davies *et al.* 2008). In the face of climatic, environmental and social change, fire management must strive to be evidence-based and the principles of AM, carefully observing the impacts of alternative management interventions and learning from one's successes and failures, should be common to all fire management plans.

Acknowledgements

G. Bovio and A. Cavallero were research supervisors for the project. We thank the Ente di Gestione dei Parchi e delle Riserve Naturali del Canavese, Regione Piemonte (Land Administrators of the MNR of Vauda) for providing financial, logistical and technical support to the present study. Special thanks to Matt Davies, The University of Edinburgh, for fruitful discussions, paper editing and for challenging us to develop the Adaptive Management angle.

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