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Effectiveness of *Calluna*-heathland restoration methods after invasive plant control

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ABSTRACT

Restoring natural communities after invasive plant control is one of the fundamental challenges of ecological restoration. Despite advances in invasive control methods, restoration failures caused by a lack of native community re-establishment are common. This is especially frequent in the upland heathlands of Great Britain invaded by *Pteridium aquilinum*. As a consequence, active revegetation methods are needed to increase the performance of native plant species. Here, we assessed the effectiveness of *Calluna*-heathland vegetation restoration treatments on the developing plant community composition in combination with a set of recommended *Pteridium*-control methods applied at the local scale. Four stand-alone replicated experiments were set up in two regions of Great Britain. The experiments had a similar randomized block split- or split–split-plot design with six *Pteridium*-control treatments applied randomly to the main-plots (10 m × 40 m); and *Calluna*-heathland vegetation site-specific restoration treatments applied to sub- and sub-sub-plots. The restoration treatments included stock-poof fencing, fertilizing, harrowing, seeding and prescribed litter-burning. The results showed that the effectiveness of site-specific *Calluna*-heathland restoration methods applied in conjunction with *Pteridium*-control methods was very low. Only sheep grazing and prescribed *Pteridium*-litter burning favoured the restoration of *Calluna*-heathland community composition. In contrast, fencing, fertilizing and harrowing were ineffective. Surprisingly, *Calluna* seeding only showed short-term positive effects when applied with asulam spray treatments. Considering the costs and benefits of the restoration measures studied as part of this integrated *Pteridium*-control/heathland restoration programme, the most successful methods were sheep grazing and prescribed *Pteridium*-litter burning; both are traditional methods of heathland management. It seems that effective restoration actions should initiate gradual change that aims to create a continuous transition to a more desirable conservation value state.

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1. Introduction

Restoring natural communities after invasive plant control is one of the fundamental challenges of ecological restoration and conservation biology (Hulme, 2006). Despite advances in invasive control methods, restoration failures caused by a lack of native community re-establishment are common (Kettenring and Adams, 2011). Among the general causes of the failure to achieve a community dominated by native species includes the recurrence of the original invader or the colonization of new invaders (Firn et al., 2010) and limitations in the propagule supply of the native species (Prach and Hobbs, 2008). As a consequence, active revegetation methods are needed to increase the performance of the native plant species and favour the development of an appropriate native plant community that can then serve as natural barriers to reinvasion (Kettenring and Adams, 2011). Within this general context, it is crucial to base native species restoration after invasive plant control on a sound understanding of restoration practice and species re-establishment techniques. Therefore, knowledge of native community response and the effectiveness of active native revegetation methods are essential to guide future invasive plant control methods.

Pteridium aquilinum is a serious invasive weed of upland and marginal land in many parts of the world (Marrs and Watt, 2006), including Great Britain, where it often occurs in dense stands and considerably reduces the conservation value of upland heaths and acid-grasslands (Pakeman and Marrs, 1992). The current agricultural/conservation policies in the UK are to reduce *P. aquilinum* infestation, and restore either *Calluna*-heathland or acid-grassland.

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However, *P. aquilinum* is difficult to control because it has a high productivity producing a dense frond cover and deep litter, which combine to reduce understory vegetation (Marrs et al., 2000), and an extensive underground rhizome system with large carbohydrate reserves (Le Duc et al., 2003). Even though control measures reduce its dominance or abundance they do not necessarily result in native species recovery. It is, therefore, important to implement effective vegetation restoration methods to enhance the recovery of communities composed of native species.

The upland heathlands of Great Britain are semi-natural landscapes with high conservation value (Pakeman and Marrs, 1992). They are dominated by slow-growing dwarf shrubs, such as *Calluna vulgaris*, *Vaccinium myrtillus* and *Vaccinium vitis-idaea*, and have associated diverse invertebrate fauna and bird assemblages (Thompson et al., 1995). Therefore, there is a great policy interest in conserving these heathland ecosystems (EC Habitat Directive 92/43/EEC) and to restore degraded heaths where possible (Thompson et al., 1995). Various restoration techniques such as grazing, fertilizing, harrowing, seeding and prescribed litter-burning have been suggested for use in restoring heathland after *Pteridium*-control, however, the effectiveness of these heathland restoration techniques after invasive species control needs to be assessed urgently to inform management decisions. Management decisions can then be based on both scientific knowledge as well as economic considerations (Kettenring and Adams, 2011).

In this paper we assessed the effectiveness of *Calluna*-heathland vegetation restoration treatments on the developing plant community composition in combination with a set of recommended *Pteridium*-control methods applied at the local scale. We performed four experiments focusing on restoring *Calluna*-heathland vegetation and measuring its impact over a 10 years period. Previous analyses of data from these experiments have assessed the effectiveness of the control treatments on *P. aquilinum* performance (Cox et al., 2007; Stewart et al., 2008) and on the developing understorey flora at the individual species level (Cox et al., 2008). Here, we focus on the effects of site-specific *Calluna*-heathland restoration methods on the response of both *C. vulgaris* and the plant community composition. We hoped to answer the following questions: (1) How does the plant species composition response change following vegetation restoration treatments applied at individual sites? (2) When combined with *Pteridium*-control methods do these vegetation restoration methods enhance *Calluna* restoration? (3) Are different seeding methods increasing *C. vulgaris* cover? (4) What are the most effective vegetation restoration methods for each site?

It was expected that this approach would lead to improve the practicality and effectiveness of vegetation restoration treatments for restoring and managing plant species composition, and inform the development of future agri-environment policies which focus on the enhancement of *Calluna*-dominated heathlands suffering from invasion by *P. aquilinum*.

2. Methods

2.1. Site location and description

Four stand-alone, replicated experiments designed to control *P. aquilinum* and restore *Calluna* heathland (H12; Rodwell, 1991) were set up in two regions of Great Britain (Table 1); Cannock in the English midlands and Hordron Edge in the Peak District. Exact methodological details are available in Le Duc et al. (2003), only a brief summary and scheme are given here (Table 1 and Supplementary data).

2.2. Experimental design

In each experiment, before treatment application, two (Cannock 1, 2 and 3) and three (Hordron Edge) replicate blocks were randomly located in areas of dense bracken depending on the available area (Table 1). In three experiments (Cannock 1, 2 and Hordron Edge), a randomized block (block = replicates) split-plot or split–split-plot experimental design was used with the same six *Pteridium*-control treatments applied randomly to the main-plots (10 m × 40 m). The six *Pteridium*-control treatments were: (1) untreated (experimental-control); (2) cut once/year in June (Cut1pa); (3) cut twice/year in both June and August (Cut2pa); (4) a single June cut in year one followed by asulam spraying in year two (CutSpray); (5) asulam in year one only (Spray); (6) asulam in year one followed by a single June cut in year two (SprayCut). Generally, single cuts took place in June, second cuts and asulam application in August. Herbicide application was by knapsack sprayer (as Asulox, Bayer CropScience PLC; 4.4 kg active ingredient ha^{-1}; 11 L Asulox in 400 L water ha^{-1}). The fourth experiment (Cannock 3) also had a randomized block experimental design (blocks = replicates) but had only two main-plot treatments; control and cut twice/year (Cut2pa).

Unlike the *Pteridium*-control main-plot treatments, the sub- and sub-sub-plot treatments were site-specific and were designed to enhance heathland (especially *Calluna*) species regeneration. All treatments were applied in complete factorial combinations within nested designs (split- or split–split-plot; Table 1), and were designed to match individual site characteristics. In the Hordron Edge experiment the effect of sheep grazing *versus* no sheep grazing was tested at the sub-treatment level (fenced = Fen *vs*. grazing = NoS), and three *C. vulgaris* seeding methods were tested at the sub-sub-treatment level, these were: (a) no *C. vulgaris* addition – natural regeneration; (b) *C. vulgaris* seed addition as brash, 13 t ha^{-1} of *C. vulgaris* stems cut at 20 cm added with 12 kg ha^{-1} of *Agrostis castellana* as a nurse crop (CvBr), and (c) *C. vulgaris* seed added as 1.2 t ha^{-1} of heathland litter, sucked from under mature *C. vulgaris* together with the same nurse crop (CvLt). At Cannock 1 and 2 the fertilizer addition ENMAG (Zeneca, London, UK) was applied at 150 kg ha^{-1} (Fer) to enhance *Calluna* introduction and establishment, and harrowing using a chain harrow (Frt) were tested at the sub-treatment level. At Cannock 3 prescribed *Pteridium*-litter burning (Bur) was tested at the sub-treatment level and *Calluna* seeding with brash and nurse crop of *A. castellana* (CvBr) at sub-sub-treatment level. At all experimental levels there were no-treatment comparisons.

2.3. Monitoring

In 1993 species composition was measured in selected random sub-plots in each experiment to ensure that the vegetation and bracken variables were similar; these data were not used here. The vegetation composition was monitored in all experiments in June from 1994 to 2003, i.e. before the application of the cutting treatments. Quadrats (1 m × 1 m) were placed at two or three pre-selected random co-ordinates on 1 m grids within each sub-(sub-) plot (Table 1), and the cover of all vascular plant, bryophytes and lichen species recorded visually. Species nomenclature follows Stace (2010) for vascular plants, Atherton et al. (2010) for bryophytes and Dobson (2011) for lichens.

2.4. Data analysis

Statistical analyses were performed in the R software environment (v.2.12.2; R Development Core Team, 2011), using the *nlme*

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