Can species-poor grassland be diversified? A case study of lowland hay meadow restoration at Llanerchaeron, Ceredigion, Wales

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SUMMARY

As part of the 'Save Our Magnificent Meadows' project, a two hectare field was converted to hay meadow on the National Trust's Llanerchaeron Estate in west Wales. The field had previously been heavily grazed by sheep. Green hay was collected from an established meadow and spread by hand onto the receptor site in 2014, in order to increase the number of plant propagules present. The field was then managed as a hay meadow, with aftermath grazing. There was a significant increase in both positive indicator species and forb cover over the five year period from 2013-2017. In 2013, there was less than one positive indicator species/quadrat compared to 4.6 positive indicator species/quadrat in 2017. The results are discussed in relation to the change in management from intensive sheep grazing to hay making with aftermath grazing, and the spreading of green hay to increase the number of plant propagules present.

BACKGROUND

A review of twenty-eight studies from across Europe found that restoring species-rich grassland can result in higher wildlife diversity, such as plant diversity, pollinating insect diversity and abundance of farmland birds (Dicks *et al.* 2013). Six studies found positive effects of restoration within five years, 11 studies within 5-10 years and two studies did not show any positive change until after 11 years. However, seven studies found no positive changes in the taxa that were measured. There is further evidence that restoration of species-rich grassland from agriculturally improved grassland may not be as effective or as swift as arable reversion, particularly on clay soils where fertilizer has been applied (Peel 2017a, Peel 2017b, Walker *et al.* 2004).

Extensification of the management of agriculturally improved swards, such as changing from silage making to hay making and aftermath grazing following the cessation of fertilizer inputs has been found to reduce competitive species, such as perennial rye-grass *Lolium perenne* (Walker *et al*. 2004). Other factors limiting restoration of species-rich grassland include low species pools resident in the soil seed bank, high soil nutrients from fertilizer applications, and restrictions to follow-up management, such as aftermath grazing which may create germination gaps for forbs and finer graminoids (Walker *et al.* 2004, Shellswell 2016, Shellswell *et al.* 2016). Thus, increasing the diversity of grassland is not always guaranteed and can take considerable time. As part of the national Save Our Magnificent Meadows project, a UK-wide partnership between 11 non-governmental organizations aimed at conserving and restoring species-rich grassland, a grassland undergoing restoration was monitored to improve understanding of the processes and timescales involved.

The Llanerchaeron Estate is located in the Aeron valley, near Aberaeron, West Wales (SN479601). It was bequeathed to the National Trust in 1989. In 1992, 8.5 ha of grassland, which was part of a parkland area, was converted to traditional hay management, with the aim of increasing the botanical diversity in the grassland. Management comprised annual hay making between July and August, with sheep and cattle aftermath grazing. No additional seed was brought onto the meadows. Since the change in management, an anecdotal increase in plant diversity has been reported. The meadow is now fully established and has around 50 species of grasses and herbs, suggesting significant potential to increase local plant diversity.

In 2013, the National Trust decided to expand this management. A species-poor field called 'River Meadow', less than 1 km away from the donor site 'Parkland', was identified as the recipient site. Prior to 2013, River Meadow had been intensively grazed by sheep all year, creating a very short uniform sward. This management appeared to restrict the diversity of broadleaved flowering plants, which did not have an opportunity to flower and set seed. The Trust proposed changing the management of River Meadow from intensive sheep grazing to hay making with aftermath cattle grazing, coupled with spreading brush-harvested seed from the donor site.

Rapid assessment, a sampling method monitoring positive indicator species, was employed as a simple survey approach to assessing the change in plant frequency and richness over time (Magnificent Meadows 2016). The purpose of the monitoring at Llanerchaeron was to quantify whether the plant diversity and frequency increased at the receptor site River Meadow, how fast this occurred, and whether the diversity of indicator species was becoming more similar to the donor site, Parkland.

ACTION

Management of the donor site: The donor grassland, Parkland, has been managed as a hay meadow with aftermath cattle grazing since 1992. This involved shutting the field for the hay crop by excluding grazers in the spring, usually in March. Hay was cut in July or August depending on the weather, followed by aftermath grazing in the autumn. In 2014, this management regime was altered for a single year to enable

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seed to be gathered. In July 2014, seed was collected using a small brush seed harvester pulled behind a quad bike and spread by hand on the receptor site within an hour of collection at the donor site.

Management of the receptor site: The receptor site, River Meadow, was intensively sheep grazed until early 2014. A survey of River Meadow in 2013 identified very low numbers of positive indicator species, including common knapweed, common cat's-ear, meadow buttercup and self-heal. These were found in areas that were less accessible to sheep, indicating that it was possible that some wild flower species were present throughout the entire field.

In February 2014, the sheep were withdrawn from the field and it was 'shut-up' to enable a hay crop to be grown and taken. The grass was harvested in mid-July 2014, cutting the sward as short as possible, scalping the soil surface and exposing small areas of bare ground. There were very few docks *Rumex* spp. and common ragwort *Senecio jacobaea* plants present prior to the works, and an increase in these species was considered to be a potential negative impact of the management. Harrowing to expose bare ground was thus not undertaken, to reduce the risk of an increase in these plants. At the end of July 2014, shortly after hay harvest, the brush-harvested seed was spread across the meadow to increase the number of propagules. Cattle were introduced to River Meadow immediately after the seed had been spread to trample it into the soil. Livestock were considered to be more effective than rolling the field, as it was possible that the short sward could prevent seed contact with the soil.

Light grazing was continued throughout the rest of the summer, autumn and overwinter, and was withdrawn in April 2015. The presence of livestock had two purposes: i) to tread seeds into the soil, making contact between the seed and substrate to increase germination, and ii) maintain a short sward to aid the germination and growth of the hemi-parasite yellow rattle *Rhinanthus minor*, which is shade intolerant. From 2015-17, an annual hay-making cycle was undertaken, with hay cutting during July-August followed by aftermath grazing by sheep and cattle.

Survey method: To quantify changes in species diversity, a positive indicator species survey was set up using the "rapid assessment method" (Magnificent Meadows 2016). This involved sampling random 1 x 1 m quadrats, and identifying the presence of indicator species and estimating the percentage cover of forbs in each quadrat. All surveys were undertaken prior to hay cutting between mid-June and mid-July at the peak of flowering for the majority of indicator species.

Positive indicator species were identified at the donor site in 2013 and surveyed using the rapid assessment method in 2015 and 2017 (Table 1). Seventeen quadrats were undertaken in 2015 and 20 quadrats in 2017. The average number of positive indicator species/quadrat and forb cover/quadrat in the donor site was used as the target to compare the restoration of the recipient site.

In River Meadow, 50 quadrats were surveyed in 2013, 83 in 2014, 20 in 2015 and 2016, and 21 in 2017. The number of quadrats was reduced to around 20 evenly spaced samples on a grid to reduce the time to complete the survey as the intensive sampling undertaken in 2013 and 2014 was unsustainable. Percentage cover of forbs was not recorded in 2014.

Data analysis: All analyses were undertaken in the programme R 3.1.1 (R Development Core Team 2014) using the package MASS (Venables & Ripley 2002). Generalized linear models were used to analyse the following three response variables: (1) 'Positive indicator species' for the donor site Parkland was assessed for normality and, following confirmation, analysed using a normal distribution. (2) 'Positive indicator species' for the receptor site River Meadow was not normally distributed and was over-dispersed, and hence was analysed using a negative binomial distribution with a log-link. (3) The 'percentage cover of forbs' response variable was arcsine transformed and analysed using a normal distribution.

The single explanatory variable used was year, and the mean positive indicator species for River Meadow and percentage forb cover for River Meadow and Parkland and their standard errors were calculated by back-transforming the test estimates. Post-hoc tests to assess for significance between means were undertaken using the package phia (Rosario-Martinez 2015) with the link=TRUE for negative binomial distributed data.

Table 1. List of positive indicator species used to assess meadow restoration, identified from surveys of the donor site.

Species	
Black/common knapweed	*Centaurea nigra*
Common bird's-foot trefoil	*Lotus corniculatus*
Common cats-ear	*Hypochaeris radicata*
Crested dog's-tail	*Cynosurus cristatus*
Lesser stitchwort	*Stellaria graminea*
Lesser trefoil	*Trifolium dubium*
Meadow buttercup	*Ranunculus acris*
Meadow vetchling	*Lathyrus pratensis*
Red clover	*Trifolium pratense*
Self-heal	*Prunella vulgaris*
Smooth hawk's-beard	*Crepis capillaris*
Sweet vernal-grass	*Anthoxanthum odoratum*
Yellow rattle	*Rhinanthus minor*

CONSEQUENCES

Donor site: The average number of positive indicator species/quadrat present in the donor site, Parkland, was not significantly different between 2015 and 2017 (2015 = 7.11, 2017 = 7.2; $F_{1,35} = 0.062$, $p = 0.80$) and the average was 7.16. The mean percentage cover of forbs did differ between 2015 and 2017 (2015 = 50.2, 2017 = 72.5; $F_{1,35} = 12.9$, $p = 0.001$); the average cover was 62.5%.

Receptor site: The number of positive indicator species per quadrat at the receptor site, River Meadow, increased significantly between 2013 and 2017 ($\chi^2 = 95.3$, d.f. = 5, 198,

Table 2. Results of comparison of mean number of positive indicator species and percentage forb cover per quadrat between years at River Meadow.

Years compared	**Positive indicator species**		**Percentage forb cover**	
	χ^2	**p**	**F**	**p**
2013 - 2014	38.55	<0.001		
2014 - 2015	18.41	<0.001		
2013 - 2015			45.91	<0.001
2015 - 2016	4.15	0.083	3.85	0.051
2016 - 2017	0.11	0.737	17.37	<0.001

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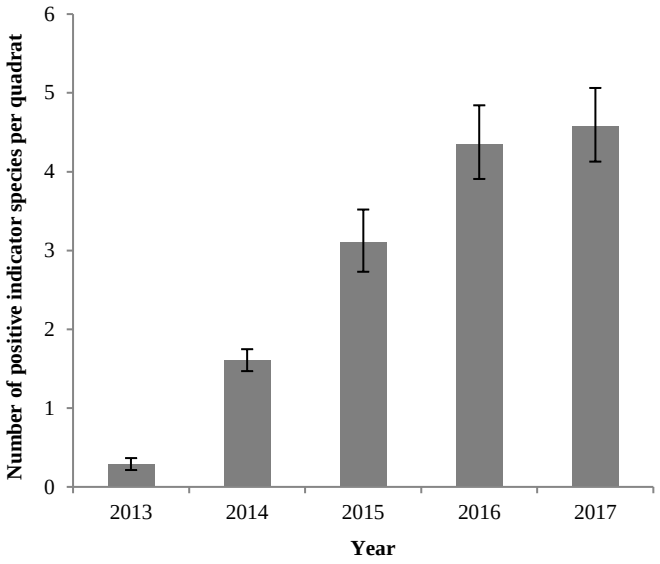

Figure 1. Number of positive indicator species present per quadrat in each year at River Meadow before (2013) and after (2015-2017) the transfer of green hay and the change to meadow management in 2014. For comparison, the average number of species present in the donor site in 2015 and 2017 was 7.16.

$p < 0.0001$; Figure 1). Positive indicator species increased significantly between 2013 and 2014, and 2014 and 2015. There was a non-significant increase between 2015-2016 and 2016-2017 (Table 2).

The percentage cover of forbs at the receptor site increased significantly between 2013 and 2017 ($F = 141$, d.f. = 4,189, $p < 0.0001$; Figure 2). There was a significant increase in forb cover between 2013-2015, and 2016-2017, but not between 2015 and 2016 (Table 2).

The frequency at the receptor site of common knapweed, common cat's-ear, meadow buttercup and self-heal, all of which were found at low levels before the hay transfer during 2014, increased with the change in management and spreading of seed. In particular, yellow rattle (Figure 3) appeared at the same time the brush-harvested seed was added. It was found in half of the quadrats by 2016 and in all quadrats in 2017. Some

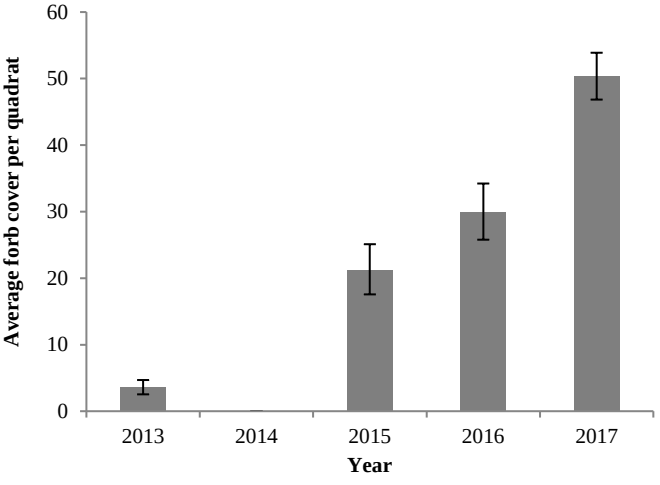

Figure 2. Average forb cover per quadrat for each year (excluding 2014) at River Meadow before (2013) and after (2015-2017) the transfer of green hay and the change to meadow management in 2014. For comparison, the average forb cover in the donor site in 2015 and 2017 was 62.5%.

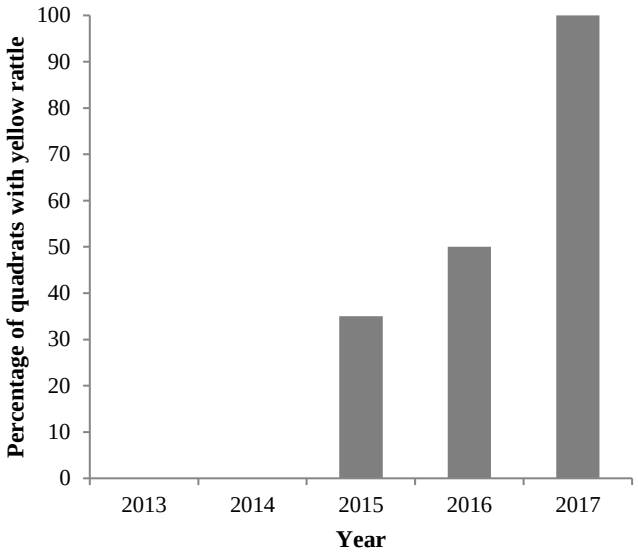

Figure 3. Percentage of quadrats with yellow rattle present at River Meadow before (2013) and after (2015-2017) the transfer of green hay from a donor site and the change to meadow management in 2014.

species decreased in frequency, notably common bird's-foot-trefoil, lesser stitchwort and red clover. Self-heal initially increased in frequency between 2013 and 2016, to 20% of quadrats, but then fell back to less than 5% of quadrats in 2017.

DISCUSSION

The change in management regime from intensive sheep grazing to hay making resulted in a significant increase in the number of indicator species between 2013 and 2014 (Figure 4). However, this was limited to a few species, including common bird's-foot trefoil, lesser stitchwort and red clover, which were already known to be present within the field. The addition of brush-harvested seed in the summer of 2014 (after the rapid assessment survey) increased the number of positive indicator species from 2015 onwards, particularly yellow rattle which was not present prior to 2015. The application of seed alongside the change in management means that the increase in positive indicator species cannot be attributed solely to one single action, and it is not possible to assess whether a change in management alone would have resulted in an increase in species richness without the addition of propagules.

Although there was an overall increase in positive indicator species and forb cover, this increase was not seen between all years. It appears that there was a sharp rise in species in the first year following the change in management (2014) and the second year with the addition of seed (2015). The average number of indicator species per quadrat continued to increase in 2016 and 2017 but at a much lower rate. Future monitoring may show whether this wass the beginning of a plateau, with slower recruitment of positive indicator species into the sward, or was a temporary slowdown of species recruitment due to extraneous factors, such as weather, or biological factors, including delayed seed germination and establishment of some species. Weather conditions were extremely dry during the spring and summer of 2017 causing desiccation of young plants, and this could have accounted for a lack of new species recruitment in this year. It is also striking that several species present at low frequency throughout the sward in 2016 (common bird's-foot trefoil and lesser stitchwort) were absent

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Figure 4. River Meadow a) in 2013, before restoration began, and b) in 2016, two years after seed was spread and management changed. Photographs: Corrinne Benbow and Victoria Squire.

from the sample in 2017, while other species (common knapweed, crested dog's-tail and self-heal) decreased. Although forb cover increased between 2016 and 2017, this was due to an increase in cover of the positive indicator species already present in 2016 rather than the recruitment of new species to the sward at River Meadow. The changes in cover of forbs observed at the donor site may also be due to a number of factors, such as changes in weather between years. Other factors, such as slight variations in management, may also have affected forb cover. The average cover/quadrat of the two years (2015 and 2017), 62.5%, has been used as the target by which to judge whether the restoration of River Meadow is progressing in the desired direction.

The National Trust's vision for this field is to see it continue to improve over the years through continued hay meadow management, no fertilizer or farm yard manure application, and mixed cattle and sheep grazing over the winter. The rapid assessment survey at River Meadow has shown that a change in management plus reintroduction of propagules can result in a quick increase in the number of positive indicator species. The number of positive indicator species and forb cover are still lower in River Meadow than at the donor site Parkland. However, the restoration is still at an early stage, and it was not expected that diversity and cover would become comparable to the donor site within the first five years. Surveillance will be continued to monitor whether species diversity and forb cover continue to increase, and eventually reach levels comparable to that of the donor site.

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