

Vegetation changes in floodplain meads in relation to changing management and weather patterns over 34 years

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Abstract

Traditionally managed floodplain hay meadows are among the most biodiverse but threatened habitats in Europe, and especially in Britain. The adjoining floodplain hay meadows, Pixey, Yarnton West and part of Oxey mead, an 87 hectare site northwest of Oxford, are some of the most diverse hay meadows of all and one of the largest such sites in Britain. This study follows a study of the floral composition from 1988 to 2022. Since 1988 traditional management has been largely abandoned and the extent of flooding appeared to have changed.

The vegetation was studied using permanent quadrats in 1988, 2017 and 2022. Frequency data for each species were recorded in 1988 and 2017, percent cover data in 2022. Overall species richness in vascular plants except grasses, including many of the most characteristic species of meads, declined considerably between 1988 and 2017 but recovered slightly between 2017 and 2022. Short-lived plants, especially annuals, declined particularly but several long-lived perennials also declined. Those species most tolerant of wet parts declined less than others, and a few species increased slightly. The grasses were not recorded in 1988 but *Arrhenatherum elatius*, *Holcus lanatus* and *Festuca rubra* increased between 2017 and 2022.

There are two main reasons for these changes: 1. an exceptional July flood in 2007. Summer floods are rare but have happened occasionally with the meadow recovering over several years under the traditional cutting and grazing regime. 2. Since the 1980s hay has not been cut until a dry spell after 12 July and sometimes not at all, with the aim of protecting the biodiversity, instead of the traditional time of late June. The aftermath grazing has been erratic and sometimes absent. These changes have led to the decline in many meadow plant species and an increase in coarse grasses. Reverting to the traditional regime should reverse the decline in plant diversity. Variation between years is likely anyway in response to weather conditions and flooding.

Keywords: hay meadows; plant diversity; flooding; cutting/grazing regime; declines; long-term study

Introduction

Meadows that are cut for hay in midsummer and usually then grazed have been vital for a balanced farming system throughout Europe for millennia. Since about 1945 with intensifying agriculture they have largely lost their original function of producing high quality hay and there has been little financial incentive to continue the traditional regime. The result has been a huge decline in these meadows across Europe. The destruction of hay meadows in Britain has been particularly severe with a much-quoted figure of 97% decline since 1945 that is probably an under-estimate. This has been the subject of considerable concern as they are among the most biodiverse habitats in Europe in plant and invertebrate species and full of colour and life, especially in May and June, and of considerable cultural significance throughout. The meadows in the lowlands have disappeared mainly through ploughing and re-seeding or application of artificial fertilisers, often for silage, or for housing developments. This decline has been addressed in many meetings including at least one at the European parliament (European Parliament, 2012) but with little effect. Some of the richest of British hay meadows are those on floodplains, known as meads in the Oxford region, and now one of the most endangered habitats in Britain. Those on the floodplains of the Thames north-west of Oxford, the adjoining meads of Pixey, Yarnton West and a part of Oxey mead run to around 87 hectares in total and have remained as unimproved traditional hay meadows retaining much of their flora and fauna and have SSSI status (Natural England, 1986). Less than 1500 ha of similar meads remain in the country as a whole, most as small sites less than 10 ha (Jefferson & Pinches, 2011; Rothero, Lake & Gowing, 2016). These Oxford meads, then, are among the most extensive and diverse in the country. In an era of rapidly changing management practice, they can be seen as monitors for hay meadows generally. They were designated Special Areas of Conservation (SACs) in 2005 (English Nature, 2005).

The earliest clear record of hay being cut on these meads is from 1142 (Jefferson & Pinches, 2011) but environmental evidence suggests that there were hay meadows here in Roman times (Robinson, 2011). These may have become disused until late Saxon times, perhaps the ninth century AD but possibly earlier (McDonald, 2011, Robinson, 2011). Since the 13th century, thirteen cherry balls, each with a name of one local property owner, were drawn randomly to allocate strips, known as lots, to villagers. The last time these were used was in 1978, after which the hay was sold as a single lot (Baggs *et al.*, 1990).

Traditional management of hay meadows

The sooner the cut comes once the plants are grown and flowering towards the end of June the better the quality of the hay as more nutrients are retained in the above-ground parts of the plants. The hay crop was used to feed domestic animals over the winter months and was needed in quantity. Hay meadows were left to grow in the spring to be cut for hay in early-mid summer. In the 20th century it was recommended that the hay be cut in the first dry spell after St. John the Baptist's day, 24 June (McDonald 2011), perhaps the traditional day, although Baggs *et al.* (1990) stated that Pixey and Yarnton were cut on 'successive Mondays' after St. Peter and Paul's day, 29 June, mainly owing to a shortage of people available to cut it. Bowskill *et al.* (2023) have shown that the best dates for cutting will be the traditional date or even earlier in recent times owing to an earlier growing season

since about 1990. They recommend cutting 20-30 June to reduce nutrients on the meads and, as a result, maintain or increase plant diversity. After the hay cut, grass and associated plants were raked into lines and then tossed each day for a few days to dry it out effectively before stacking into a haystack or a barn. There will have been some variation in the date the meads were cut as it was partially dependent on the weather. After this there could be a second hay cut in some years if growth conditions allowed. The meads were 'thrown open to livestock' after the cut, or after the second cut if appropriate. In 1817 it was deemed appropriate to allow livestock in on St. Bartholomew's day, 24 August (Baggs *et al.*, 1990), though previously it would have varied. Grazing animals, usually cattle for the first flush in August but sheep and sometimes horses later, would be put out onto the cut meadow to graze on the aftermath each year. Traditionally they could stay until March (Baker, 1937), but would be removed when the meadow flooded. The extent of flooding varies from year to year with the weather. The Oxford meads in recent years have usually started flooding in the early winter. Flooding deposits nutrients from further upstream replenishing some of the meads' fertility.

This management continued for centuries. Although the hay can still be useful as winter feed for some animals, and can sometimes fetch a good price, the sites can currently be cut and grazed in the traditional way only with government subsidies.

Management since the 1980s

The Environmentally Sensitive Area scheme, introduced in 1987, and its successor, the Countryside Stewardship scheme supported by Natural England, recommended delaying the cut for hay meadows until after 12 July. This would allow for many plants to set seeds and any breeding bird species, most importantly the curlew, to have fledged their young. It should also provide a stronger surface for the heavy machinery that is now used to cut the hay that could otherwise lead to severe soil compaction. As Gowing *et al.* (undated) have stressed, a late cutting such as this will mean that fewer nutrients are removed with the hay cut to the detriment of plant diversity, especially if July is wet and it is delayed further. Cutting should be done during a dry spell and, if there are no vulnerable birds on the site, they recommend the traditional time of mid-late June if dry.

Management on the Oxford Meadows

The result of these changes and recommendations is that cutting has been done somewhat erratically in many of the remaining hay meadows including these Oxford meads. Aftermath grazing has also been erratic, usually by sheep but with no grazing at all in some years. Table 1 shows the dates of cutting and aftermath grazing from 1989 to 2023 in those years for which we have records.

Other considerations

The groundwater levels in the meads are shallow, <1 m deep in winter and usually partially over the surface for some of the winter, <2 m in summer even in the driest summers (Gardner, 1991, Macdonald *et al.*, 2007). The meads appear to be nearly flat but there are small differences in topography and some apparent channels that give rise to differences in soil water levels and length of waterlogging (Gardner, 1991) in addition to the water table being highest next to the River Thames.

**Table 1. Dates of hay cut and stock introduced (where data available).
From Gardner (1991), Hedley-Lawrence (pers. comm.), personal
observation**

Year	Date of hay cut	Date stock introduced
1989	10 July	10 Oct: sheep
1990	10 July	28 Aug: sheep
2007	No cut with July flood	No aftermath grazing
2008	Pixey cut by 21 July	
2011		sheep
2012	Autumn, hay was cut but stacked in high and broad 'towers' and not removed due to flooding.	No aftermath grazing
2013	Yarnton West start 7 July	Sheep on Pixey Aug-Sept, off by 13 October
2014	Pixey 15 July	
2015	Yarnton West 17 July	Sheep on Pixey by 31 July; off by 20 August
2016	Yarnton West 15 July	Sheep on Pixey by 22 October
2017	Pixey 25 August	Sheep
2019	16 July	Through autumn
2020	16 July	Through autumn
2021	16 July	Yarnton aftermath grazed by cattle until mid October. Pixey had no aftermath grazing due to the poor fencing along the A34.
2022	22 July	Yarnton aftermath grazed by cattle. Pixey not grazed, as 2021.
2023	Main part of Pixey early September; small section at south end earlier.	Yarnton aftermath grazed by cattle. Pixey not grazed.

There have been numerous attempts over the centuries to control the flow of the Thames. This came to a crescendo in the 17th century when there was a concerted effort of dredging and adding locks to allow barges to reach up the Thames as far as Lechlade for the burgeoning wool trade (Baker, 1937). Further restrictions on water flow were introduced in the late 18th and early 19th centuries, raising the water levels by these meads (McDonald, 2009). Currently in this area the King's Lock on the Thames between Yarnton West and Pixey meads and Godstow Lock below Pixey can regulate water levels, usually keeping them high. The likelihood is that winter flooding increased in frequency and length after 1800 and records from Thames water indicate a number of high floods on the meads in the early 20th century (McDonald, 2009). Further barriers, or bunds, have been created between the meads and the river in the 20th century following dredging to relieve river traffic problems and these may have limited the flooding in places, though they may hold the water on the meadows once it has reached them. Gowing *et al.* (2002) have emphasised the importance of the water table level as a major influence on the

plant community in floodplains as they can change towards swampy grasslands if it is persistently high. Gerard *et al.* (2008), in their experimental meadows in Belgium, recorded different nutrient levels depending on the length of flooding with lower nitrogen but higher phosphorus levels in frequently flooded sites.

The flora

The flora of these Oxfordshire floodplain meads corresponds mainly to the community labelled by the National Vegetation Classification as MG4 *Alopecurus pratensis-Sanguisorba officinalis* grassland (Rodwell *et al.*, 1992), a grassland specifically found on unimproved traditional hay meadows on floodplains. Small parts of the meads may be closer to related grasslands and a more focussed community was designated MG15 *Alopecurus pratensis-Poa trivialis-Cardamine pratensis* grassland by Prosser *et al.* (2023). Conservation of MG4 grassland relies on the water regime with sufficient aeration during the growing season; cutting for hay in mid-summer; aftermath grazing, and nutrient levels that are not too high as this would allow tall grasses to dominate (Wheeler *et al.*, 2004). Prosser *et al.* (2023) divided MG4 into four subtypes mainly dependent on the extent and duration of flooding. Much of the meads in this study corresponded, at least initially, to the most species-rich of these subtypes, MG4a, the *Dactylis glomerata* subtype.

McDonald & Hawker (1989) recorded the flora of the meads in 1988 to provide a baseline for monitoring any future changes, alongside hydrological monitoring. This was mainly in relation to the proposed gravel extraction by Hanson Associates due to start in 1989 at the nearby Worton Rectory Farm. Gravel extraction ceased in 2008 and the area was landscaped and parts re-planted by 2012 (Hanson, 2013).

By 2017 the flora in the meads appeared to have changed since McDonald and Hawker's 1988 survey with some of the most colourful and prominent species, such as *Leucanthemum vulgare*, *Primula veris*, *Centaurea nigra* and others appearing to have declined.

The SSSI and SAC designations require the maintenance of the floristic diversity for which these meads were notified. Any gradual change can only be detected by long term study. The aim of this study was to record the flora in 2017 and 2022 following the 1988 survey to monitor changes in species composition, richness and diversity 34 years apart.

Methods

The positions of McDonald and Hawker's survey of 1988 were recorded precisely, and the two further surveys, in 2017 and in 2022, used the same exact sites to make the results as comparable as possible.

McDonald and Hawker (1988) recorded sixteen 10x10 m 'stands'. These were sited across the meads to cover all the differences in the flora and included positions close to the gravel extraction so most likely to be affected by it, and those unlikely to be affected, seen as control sites. They recorded the insect-pollinated flowering plants but did not record the grasses owing to limited time and resources at the time of the survey.

Ten 1 m² quadrats were recorded within each stand, two in each corner and two in the centre. Frequency data for all plants except grasses were recorded by dividing each quadrat into 25 equal sub-units and recording the number of sub-units in which each species occurred.

The subsequent recording in 2017 replicated this method on each stand and included the grasses as well. In 2022 % cover of each species, including grasses, was recorded in the same quadrats.

For the results presented here all the stands have been combined. There was little change in the water levels that had been an initial stimulus for McDonald & Hawker's (1988) study and, with a few exceptions noted below, most species showed similar trends in all stands. Grasses are treated separately from the main comparisons as there are no results from 1988.

Results

Number of species of vascular plants present (excluding grasses)

Species evenness and total number of species recorded in each stand were smaller in both 2017 and 2022 compared with 1988 (Table 2, Fig. 1). The overall species richness was smallest in 2017 and, though there was a little increase between 2017 and 2022, both results are much less than in 1988. There is a smaller number of species in the 50% and 75% quartiles of abundance across all the stands (see also Table 3). This means that the distribution is less even, with just a few abundant species. The cumulative species curves (Fig. 1) show that the decline is evenly spread across the sites with all the curves showing a similar shape.

Table 2. Rank frequency of species in 1988, 2017 and 2022

Year	50% quartile (no. species)	75% quartile (no. species)	Total no. species
1988	8	15	68
2017	5	11	47
2022	3	6	55

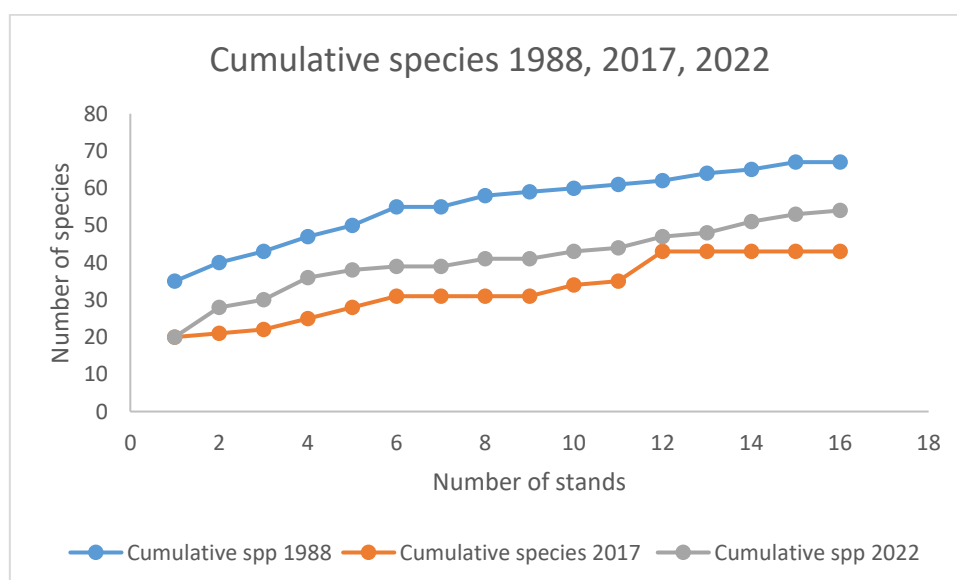


Figure 1. Cumulative number of vascular plant species excluding grasses recorded over the sixteen 10x10 m stands

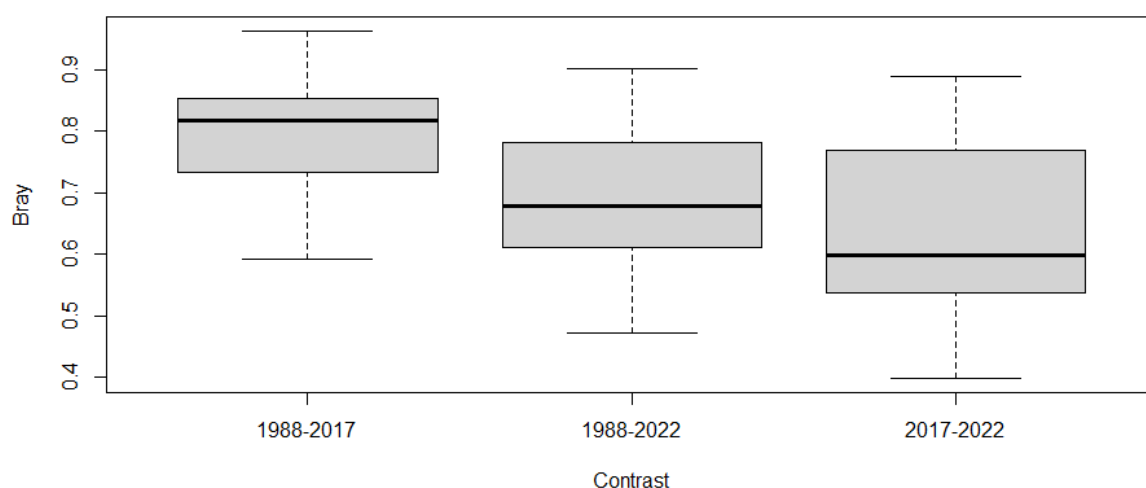


Figure 2. Bray-Curtis box plots for the three two-way comparisons between years

Using species presence/absence in each stand, plant community ecological dissimilarity was compared between years by generating Bray-Curtis dissimilarity boxplots. The Bray-Curtis dissimilarity is a number between 0 and 1. If 0, the two sites share all the same species; if 1, they do not share any species.

The greatest contrast in species composition is between 1988 and 2017 and the least between 2017 and 2022. The intermediate contrast between 1988 and 2022 shows that some species had recovered to a limited extent between 2017 and 2022.

Species abundance

The results shown above are based solely on species presence, but the quantity of each species within a stand differs between surveys. Table 3 shows results for each of the 33 species/taxa that were recorded in at least eight of the 16 stands in any one year. It shows the number of stands in which each occurred in each of the three years studied, and the mean frequency for each species out of 25 in 1988 and 2017, % cover in 2022.

For the great majority there was a decline in numbers and cover and, for many, this decline is considerable though some have increased a little and recolonised or regrew above-ground parts between 2017 and 2022.

We found a significant difference in prevalence of plant species across the sixteen stands by year (ANOVA, $F(1) = 34.3$, $P < 0.001$). Prevalence was significantly greater in 1988 than in 2017 or 2022. There was no significant difference in prevalence between 2017 and 2022 (Fig. 3).

Table 3. Sixteen 10x10 m stands were recorded. The number of these in which each species occurred in each year is given. For 1988 and 2017, mean frequency occurrence in 25 20x20 cm squares in each of ten 1 m² quadrats in each 10x10 m stand, so a mean of 160 values out of 25 is given; for 2022 mean % cover in each 1 m² quadrat

Species	No. stands present/16			Frequency/25		% cover
	1988	2017	2022	1988	2017	2022
<i>Sanguisorba officinalis</i>	16	16	16	18.2	6.9	17.0
<i>Filipendula ulmaria</i>	16	14	13	4.4	2.9	5.2
<i>Rumex acetosa</i>	16	10	8	2.3	0.5	0.11
<i>Lotus corniculatus</i>	16	13	16	5.8	1.4	1.01
<i>Vicia cracca</i>	16	10	9	2.6	1.2	0.27
<i>Lathyrus pratensis</i>	16	13	15	2.8	1.1	0.78
<i>Ranunculus acris</i>	16	14	15	14.0	5.8	1.9
<i>Plantago lanceolata</i>	16	9	12	6.6	1.3	0.46
<i>Trifolium pratense</i>	16	8	12	9.5	0.24	2.2
<i>Prunella vulgaris</i>	16	6	10	6.2	1.3	0.46
<i>Centaurea nigra</i>	15	7	14	4.3	0.7	4.2
<i>Cerastium fontanum</i>	15	2	0	1.6	0.02	0
<i>Ranunculus bulbosus</i>	15	0	0	12.1	0	0
<i>Leucanthemum vulgare</i>	14	7	7	6.1	0.7	0.14
<i>Silaum silaus</i>	14	7	14	2.9	0.8	0.97
<i>Leontodon hispidus/saxatilis</i>	14	3	3	2.7	0.08	0.36
<i>Taraxacum</i> agg.	14	2	10	9.1	0.08	0.21
<i>Carex flacca</i>	14	10	12	3.8	0.27	4.6
<i>Trifolium repens</i>	13	1	3	5.5	0.01	0.07
<i>Carex panicea</i>	12	3	4	3.0	0.1	0.1
<i>Rhinanthus minor</i>	12	4	1	9.6	0.38	0.04
<i>Succisa pratensis</i>	11	7	10	5.5	1.5	4.6
<i>Scorzonoides autumnalis</i>	11	0	1	3.4	0	0.006
<i>Ophioglossum vulgatum</i>	11	0	3	1.5	0	0.06
<i>Trifolium dubium</i>	10	0	0	2.5	0	0
<i>Ranunculus repens</i>	10	3	2	4.2	0.07	0.03
<i>Primula veris</i>	9	5	8	2.1	0.06	0.28
<i>Lysimachia nummularia</i>	9	0	4	0.94	0	0.05
<i>Tragopogon pratensis</i>	9	2	5	0.19	0.03	0.08
<i>Ajuga reptans</i>	9	0	3	0.84	0	0.04
<i>Equisetum palustre</i>	9	1	8	0.36	0.01	0.58
<i>Linum catharticum</i>	8	1	4	1.91	0.006	0.04
<i>Galium verum</i>	2	9	7	0.07	2.1	2.1

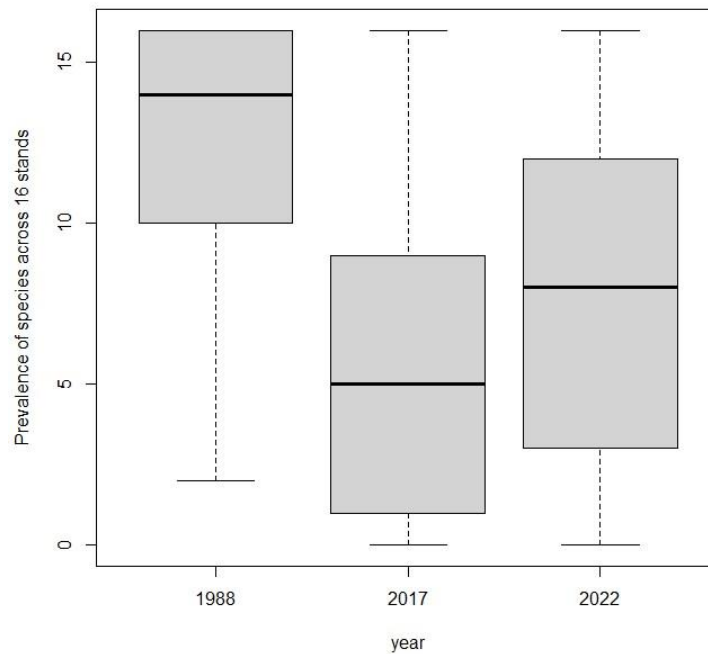


Figure 3. Prevalence of all species except grasses across sixteen stands in the years of study

There was a significantly greater frequency of plant species across the sixteen stands in 1988 than in 2017 (t-test, $t = 4.9612$, $P < 0.001$) (Fig. 4).

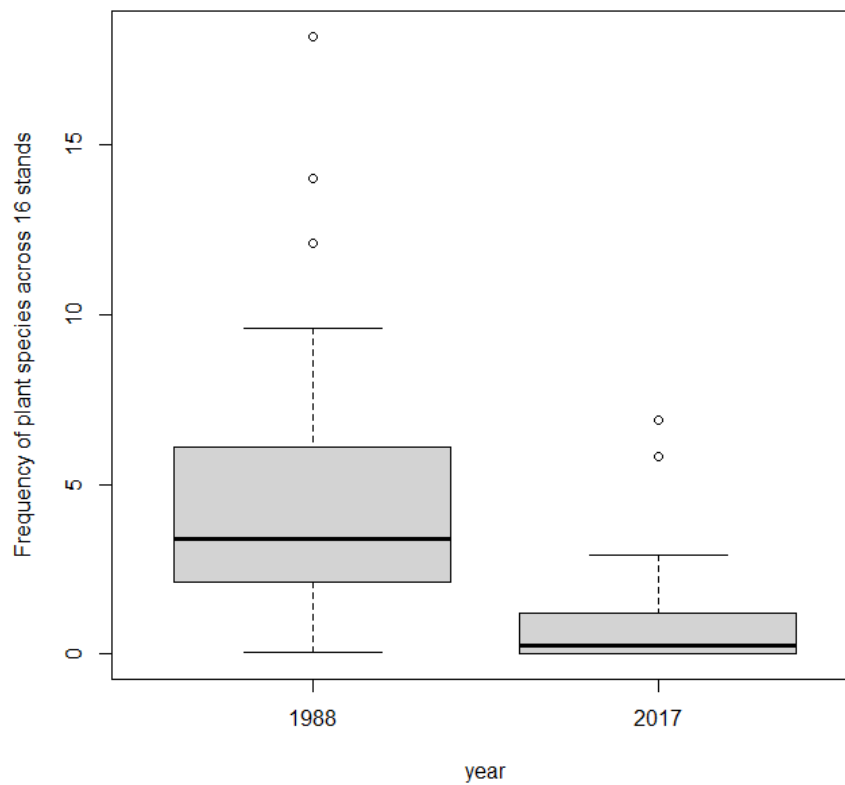


Figure 4. Frequency of all species except grasses across sixteen stands in 1988 and 2017

Several species are of particular interest:

Sanguisorba officinalis

This is perhaps the defining, and most characteristic, plant of ancient hay meadows, especially those on floodplains. It was the most abundant species present in all three years of study but declined by more than 60% overall between 1988 and 2017. The % cover estimate in 2022 suggests that it was still at a much lower abundance than in 1988 although in two of the 16 stands, both at the southern end of Pixey Mead, it had increased since 1988, bucking the trend in all other stands. There remain no plants where the hay 'towers' had been in place in 2012-13 (see Table 1).

Filipendula ulmaria

This species, characteristic of the wetter parts of the meads, shows a small decline since 1988 but the decline is much less than many species. In four of the 16 stands it had increased, these being among the wetter stands.

Leucanthemum vulgare

Another characteristic, common and flamboyant plant of mainly the drier parts of these hay meadows, the decline of this species has been particularly obvious visually, the sheets of large ox-eye daisies seen in 1988 having, in effect, disappeared.

Silaum silaus

This is another particularly characteristic plant of ancient hay meadows. Although it declined considerably between 1988 and 2017 it appears to have made something of a comeback since then.

Succisa pratensis

There is a most unusual population of this plant on these meads that flowers in early June, long before other populations in Oxfordshire that start flowering in late July or August. There has been a considerable decline since 1988 but it remains present in most of the stands in which it occurred.

Primula veris

Cowslips only occur in the driest parts of the meads but again there has been a considerable decline in what was an abundant species in the dry parts. It had made a slight recovery by 2022 but cover was still much lower than in 1988.

Centaurea nigra

Though widespread in many habitats it is a prominent colourful feature of these meads and here flowers a little earlier than other populations. Again we see a marked decline to 2017 followed by something of a recovery by 2022.

Ophioglossum vulgatum

A local plant mainly of unimproved grasslands in Oxfordshire, there appears, again, to be a large decline with none recorded in 2017 but a slight recovery in 2022. It could have remained under ground in 2017, or possible that it was overlooked if particularly small.

Lysimachia nummularia

Another low-growing species widespread in 1988 that was not recorded in 2017, though small quantity was seen again in 2022. *Prunella vulgaris* and *Ajuga reptans* show a similar pattern.

Perennial legumes

Lotus corniculatus, *Vicia cracca*, *Lathyrus pratensis*, *Trifolium pratense* and *Trifolium repens* have all declined with the largest declines shown by the low growing clovers and to a lesser extent *Lotus corniculatus*. The scrambling *Vicia cracca* and *Lathyrus pratensis* have fared a little better.

Taraxacum species

Another considerable decline is noted for dandelions although the microspecies were not distinguished in these surveys. These meads are particularly significant for dandelion microspecies and the following mead specialists have been recorded: *T. akteum*, *T. anglicum* (some large patches in wet areas) *T. fulgidum*, *T. haematicum*, *T. subundulatum* (the commonest species over much of the meads), *T. tamesense* and *T. valens*. Others recorded are the non-specialist but local *T. amplum*, *T. bracteatum*, *T. multicolorans* and *T. nitidum* and the more widespread *Taraxacum aequilobum*, *T. ancistrolobum*, *T. coartatum*, *T. ekmanii*, *T. pseudohamatum*, *T. sinuatum* and *T. stenoglossum* (A.J. Richards, pers. comm.; J. Holt, pers. comm.).

Rhinanthus minor

This species has declined almost to disappearance between 1988 and 2022. It is an annual, hemi-parasitic on the roots of various species, especially grasses, and characteristic and often abundant in hay meadows.

Some other plants

The annual plants *Trifolium dubium* and *Linum catharticum* and the often short-lived perennials *Ranunculus bulbosus*, *Cerastium fontanum*, *Leontodon* and *Scorzoneroideis* spp., have shown particularly large declines. *Cerastium fontanum*, *Ranunculus bulbosus* and *Trifolium dubium* were not recorded at all in 2022 despite occurring in ten or more stands in 1988.

Galium verum

This is the only species of those that were recorded in at least half of the stands that has increased, and it has increased considerably, since 1988.

Other species

31 further non-woody species, excluding grasses, were recorded in six or fewer stands and all were sparse within these stands:

Allium vineale, *Anacamptis morio*, *Caltha palustris*, *Cardamine pratensis*, *Carex acutiformis*, *Carex hirta*, *Carex nigra*, *Carex riparia*, *Cirsium arvense*, *Crepis biennis*, *Crepis capillaris*, *Galium album*, *Galium aparine*, *Geranium dissectum*, *Geranium molle*, *Heracleum sphondylium*, *Jacobaea aquatica*, *Juncus articulatus*, *Juncus conglomeratus*, *Juncus inflexus*, *Silene flos-cuculi*, *Medicago lupulina*, *Myosotis scorpioides*, *Persicaria maculosa*, *Polygala vulgaris*, *Potentilla reptans*, *Potentilla*

erecta, *Rumex crispus/obtusifolius*, *Serratula tinctoria*, *Stellaria graminea*, *Thalictrum flavum*.

With such small quantities any trends may well have arisen by natural variation, although 22 species were recorded in fewer stands in 2017 and/or 2022 than in 1988 and only two species clearly in more in 2022 than 1988, *Thalictrum flavum* (1988: 1, 2022: 3) and *Allium vineale* (1988: 1, 2022: 4), the others showing no or negligible change. *Allium vineale* has become much more prominent at the north end of Pixey, reflected by the increase in some stands. From anecdotal observations, *Anacamptis morio*, once numerous on Yarnton West mead, has declined considerably and is confined now to the driest parts. Seedlings of *Crataegus monogyna* (nine stands) and *Quercus robur* (three stands) were recorded in 1988 but none in 2017; *Crataegus* in two stands in 2022.

There are further species on the meads, especially in the small wetter areas that did not occur in any of the stands. These include *Dactylorhiza incarnata*, *Eleocharis uniglumis*, *Fritillaria meleagris*, *Galium palustre*, *G. uliginosum*, *Lysimachia vulgaris*, *Oenanthe fistulosa*, *O. silaifolia*, *Pedicularis palustris*, *Scrophularia auriculata*, *Triglochin palustre*, *Valeriana dioica* and *V. officinalis*.

Grasses

In 2017 and 2022 at least seventeen species of grass were recorded in more than one stand (Table 4). Three further species, *Helictochloa pratensis*, *Phleum pratense* and *Trisetum flavescens* were recorded in a single stand each in 2022. Seven species increased their range between 2017 and 2022, most clearly *Festuca rubra*, *Holcus lanatus* and *Arrhenatherum elatius*. *Festuca rubra* in particular in 2022 had a mean cover of 24% across all sixteen stands, three stands with >40% cover, and four with <5% cover. *Arrhenatherum elatius* dominates sections of the meads along the banks and bunds near the river where there were none of our stands, and is evidently spreading. The three grass species recorded in 2022 but not in 2017 were all present in small quantity, although *Agrostis stolonifera* was widespread. Six species have similar distributions in the two years and five species have declined including one of the defining species for MG4 grassland, *Alopecurus pratensis/geniculatus*. It is possible that some grasses were overlooked if not in flower, although this is unlikely to have affected the main trends.

Discussion

Our initial observation of declines in many of the characteristic species is confirmed strongly by the results of these surveys and may be characteristic of the changes in other hay meadows on floodplains. As these Oxford meads are among the most diverse floodplain meadows in the country this is a cause for considerable concern. It could be the result of several factors:

1. The gravel extraction adjacent to the meads affecting the water table or causing pollution in the meads.
2. Agricultural run-off from nearby fields and/or the continued presence of major roads, the A40 and A34, running alongside parts of the site. These could have affected nutrient levels or pollution mainly around the edges or near the roads.
3. The unexpected freak flooding of the site in July 2007, Oxford's 'worst floods in living memory' (Hughes, 2017).
4. Changes in cutting/grazing regime.

Table 4. Number of stands/16 in 2017 and 2022 in which each grass species that was recorded in more than one stand occurred

Species	2017	2022
<i>Anthoxanthum odoratum</i>	15	14
<i>Cynosurus cristatus</i>	13	13
<i>Lolium perenne</i>	13	5
<i>Arrhenatherum elatius</i>	12	15
<i>Dactylis glomerata</i>	12	11
<i>Festuca rubra</i>	11	16
<i>Holcus lanatus</i>	11	15
<i>Hordeum secalinum</i>	11	11
<i>Deschampsia cespitosa</i>	11	7
<i>Bromus racemosus/commutatus</i>	10	10
<i>Briza media</i>	8	9
<i>Alopecurus pratensis/geniculatus</i>	6	2
<i>Poa pratensis/trivialis</i>	6	1
<i>Schedonorus pratensis</i>	2	2
<i>Agrostis stolonifera</i>	0	9
<i>Agrostis capillaris</i>	0	4
<i>Bromopsis erecta</i>	0	3

5. A reflection of natural fluctuations in the proportions of these plants in response to variation between years in weather conditions and flooding. We do not know directly how much the flora on our sites varied between 1988 and 2017 but Wallace & Gowing (2011) studied the flora of parts of these meads between 2006 and 2010. They recorded changes over those five years.

From what we have recorded there is no evidence for the gravel extraction having any major long-term effect. The water table appears to be largely unaffected. The sixteen sites recorded by McDonald & Hawker (1988) were chosen to cover stands both close to and stands far from the gravel extraction, but they have mainly changed in concert, with any differences more likely to be the result of other factors. There also appears to be little direct evidence of pollution, although nutrient enrichment may have had some effect on the growth of grasses at the expense of some of the other plants.

The extent of flooding differs markedly between years with the weather and there have been changes in river management over the centuries. Before 1900 it is likely that floods were more extensive as locks were then almost entirely used to stop river flow further down (Floods in Oxford, Undated). Floods happen almost entirely in the winter months. Since 1988 there have been particularly extensive floods in at least seven winters including, most recently, 2012-13, 2019-20 and 2020-21 (Weather at Oxford: Reports, D. Gowing pers. comm.). There was a March flood in 1947 (Floods in Oxford, undated). From the end of March and through the growing season flooding has been occasional only. The flood in July 2007 was the only major summer flood on these meads since a June flood in 1903 (Floods in Oxford, undated). It came on 24 July following an exceptionally wet May and June

as well as July and the flood lasted for more than a week, with drainage from the meads impeded by the bunds along the river.

Prosser *et al.* (2023) noted that the four sub-communities of MG4 grassland that they recognised form an 'interchangeable gradient' along small differences in extent and timing of flooding. A single site may have all four together. Transition from the *Dactylis glomerata* sub-community, MG4a, characteristic of the least flooded MG4 grassland, to the *Holcus lanatus* sub-community, MG4c, or *Agrostis stolonifera* sub-community, MG4d, both occurring where there is more flooding, can be rapid, with up to a 60% change in a single year. The 2019-20 and 2020-21 winter floods could explain the increase of *Holcus lanatus* and *Agrostis stolonifera* between 2017 and 2022. It seems that we have witnessed something of the transition from MG4a to the considerably less species-rich MG4c/d. Prosser *et al.* (2023) emphasised that transition back to the more species-rich MG4a is likely to take much longer, perhaps twenty years.

Many characteristic meadow plants are sensitive to flooding in the growing season (Gowing *et al.*, 2002) so the 2007 summer flood could be particularly significant. Two of the most obvious and characteristic species present on these meads, *Leucanthemum vulgare* and *Primula veris*, are long-lived perennial plants that grow mainly in the drier parts. They, along with some other perennials, are likely to have suffered their severe declines at least partly because of this July flood. *Sanguisorba officinalis* is more tolerant of flooding than many meadow plants (Gattringer *et al.*, 2017) but still declined in numbers and cover though not as markedly. Recovery of some of these is likely to be slow. Ten and fifteen years after the flood, in 2017 and 2022, it could be a major reason why they are nowhere close to their abundance in 1988. It is noteworthy that *Filipendula ulmaria*, a species characteristic of the wetter parts of the meads and of the sub-community most associated with the wetter parts, MG4d, suffered much less decline than many other species though it is still in lower abundance than in 1988.

Dry springs and/or summers, such as the summer droughts of 2018 and 2019 may lead to different problems, especially for the short-lived plants that have declined markedly since 1988.

The cutting and grazing regimes are likely to have affected many of these species. Since traditional cutting ceased in 1978, cutting for hay has been erratic and the shift to 12 July as the earliest potential cutting date in the late 1980s may allow the plants to set seed but is around three weeks after it could traditionally have been cut. There is currently more flexibility but in many recent years the meads have been cut well after 12 July, as cutting has always been dependent on a dry spell to allow the hay to dry before baling. In some wet years the meads have not been cut at all. Left to a later date fewer nutrients will be removed with the cut. In recent years the aftermath has mainly been grazed only by sheep rather than the historically more significant cattle, often for a brief period and sometimes not grazed at all. Low intensity or no grazing leads to a build-up of a 'thatch' of dead grass on the surface and the plants that will be favoured will mainly be the dominant grasses (Gerard *et al.*, 2008). This has clearly happened to some extent on these meads. Gerard *et al.* (2008) emphasised the marked effect of mowing in their experimental grassland restoration scheme in Belgium, with dominant grasses much less abundant in their mowed sites. Bowskill *et al.* (2023), recommending an earlier cut, and a second cut if possible as a result of earlier plant growth in recent years, emphasised

the importance of reducing nutrients in floodplain hay meadows to retain biodiversity.

The decline of the annual *Rhinanthus minor* is particularly significant here as it is hemi-parasitic on some of the vigorous grasses that are threatening to oust many other species (Bullock and Pywell, 2005). Its disappearance from almost all its sites on these meads by 2022 is likely to be the result of some combination of these factors or even possibly from increased nitrogen deposition. It is typical of the drier parts of hay meadows (Prosser *et al.*, 2023) but will need the opportunity to germinate and may be most able to penetrate the roots of weakened grasses. It is likely that seeds remain.

The large number of dandelion microspecies recorded on these meads by Richards and Holt (pers. comm.), including seven found almost exclusively on such hay meadows underlines their importance generally. There has been a marked decline of dandelions on our study sites and it is possible that some microspecies have gone altogether. It would be most desirable to have further comprehensive surveys of the dandelions.

Alongside the decline of nearly all the other characteristic meadow plants, the increase of *Galium verum* since 1988 is a delightful gain, though a surprising one since in the survey by Prosser *et al.* (2023) it was characteristic of the driest MG4 grasslands. The local increase of *Allium vineale*, characteristic of dry grassland but not normally in hay meadows, is similarly unexpected. The increase of *Thalictrum flavum* in some parts, usually a riverside plant, was probably as a result of wetter conditions. Recovery from a summer flood will have happened before and, with sensitive management, these meads can recover again.

Since the hay is now usually cut by heavy machinery, compaction of the soil is a potential problem that will affect the flora, one of the reasons for the recommended July date. It remains to be seen whether this is affecting the flora.

It is clear that the flora of these meads has changed considerably since 1988. A question remains as to how much it changed between 1988 and 2017 and how quickly it can regain its species richness. Wallace and Gowing (2011), in their 2006-2010 study, found a significant reduction in species richness on these meads between 2007 and 2008 after the July 2007 flood followed by a partial recovery in 2009-10 where the hay had been cut and removed in 2008 but significantly poorer recovery in those parts that were not cut in 2008. A considerable thatch developed where there was no hay cut. They showed that, as we recorded, the low-growing plants were the most vulnerable and least able to recover. They recorded increases in grasses that can tolerate waterlogging such as *Deschampsia cespitosa*, *Alopecurus pratensis*, *Schedonorus pratensis* and *Poa trivialis*.

It is clear that the relative abundances of these mead species has varied between years as well as over decades and centuries. There will be increases and decreases of particular species every year with differing weather patterns, and different river management. We should not expect the flora to remain the same, but the marked declines of so many of the characteristic mead species between 1988 and recent years is concerning. Fortunately, all are still present even if in much smaller quantities. With suitable management they could increase and, though some may increase quickly, for many this increase is likely to be slow.

Another summer flood is, naturally, a possibility but these are very rare. The winter flooding regime is likely to remain under similar control to what it has been in

recent years. The apparent trend for more frequent extensive winter flooding may well continue and, if so, it may lead to a continuing change from species-rich MG4a to the poorer MG4c or MG4d (Prosser *et al.*, 2023).

Leaving the hay until mid-July at the earliest seems to be having a negative effect, allowing some coarse grass species to increase at the expense of many of the broad-leaved plants. This is likely to be exacerbated if the cut is delayed further by wet weather or neglect. Aftermath grazing is important too and lack of aftermath grazing will have further allowed the large grasses to gain in strength. To return to a regime that is similar to the one that created these meads in the first place, involving cutting from late June onwards, with as light machinery as is possible, sometimes a second cut and grazing the aftermath until it ceases to be possible in the winter must surely be the way to restore the flora of these meads to some variant of the colourful diverse vegetation that was present in 1988.

In conclusion, the summer flood in 2007 and the changes in cutting and grazing regime appear to have been the main causes of the observed changes. These changes since 1988 have nearly all been negative. Reestablishing the traditional cutting and grazing regime seems the clearest way to maintain the meads for the future.

The designations of these Oxford meads as SSSI and SAC require them to be maintained for their species richness. With meads of such importance nationally, sensitive conservation must surely be a priority.

Other species-rich meadows have shown a loss of diversity in the flora (Bowskill *et al.*, 2023, Gowing *et al.*, undated). The changes in cutting and grazing regime following from the loss of traditional management will have affected all such meadows. Long-term studies such as this one give us a chance to examine both the extent and the possible reasons for these changes and how best to conserve them. The results presented here have implications for the management of floodplain meadows across Europe.

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