

Contents lists available at [ScienceDirect](http://ScienceDirect.com)

Global Ecology and Conservation

journal homepage: www.elsevier.com/locate/gecco

Original research article

Fate of semi-natural grassland in England between 1960 and 2013: A test of national conservation policy



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ARTICLE INFO

Article history:

Received 22 September 2015

Received in revised form 7 October 2015

Accepted 7 October 2015

Keywords:

Grassland

Semi-natural

GIS

SSSI

Improved grassland

Agriculture

ABSTRACT

It is well documented that significant losses in semi-natural grassland occurred across Europe during the second half of the twentieth century. However, comparatively few studies have investigated and quantified the fate of large numbers of individual grassland areas. This is important for understanding the causes of decline, and consequently establishing new policies to conserve and restore lost habitats. This study addresses this problem; GIS was used to compare historic survey data collected between 1960 and 1981 with two contemporary spatial datasets of habitats in England. The datasets included the Priority Habitats Inventory 2013 and the Land Cover Map 2007 and this was undertaken for different types of semi-natural grassland across England. Considerable decreases occurred across the different grassland types, with a loss of 47% of studied semi-natural grasslands sites in England over 32–53 years. Of this, the majority of grassland was lost to conversion to agriculturally-improved grassland or arable cultivation, 45% and 43% respectively. Changes to woodland and urban areas were also evident, but on a much smaller scale. Sites receiving statutory protection as a Site of Special Scientific Interest were found to have retained more grassland (91%), compared with non-protected sites (27%), thus highlighting the effectiveness of this aspect of current conservation policy in England, and the need for this to continue in the future.

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1. Introduction

Semi-natural unimproved grasslands are sites of considerable conservation importance, both in the UK and Europe. Such sites support a high richness and diversity of species including butterflies (Van Swaay, 2002), invertebrates and birds (Barnett et al., 2004; Vickery et al., 1999), some of which are rare or threatened (Webb et al., 2010). Unimproved grasslands also deliver ecosystem services such as carbon sequestration (Hopkins and Holz, 2006), cultural services (Green, 1990) and contribute to livestock production (Bullock, 2011). Grasslands in the UK are considered early-successional habitats that would rapidly turn into scrub and woodland without human-mediate grazing and cutting management. They are therefore referred to as semi-natural habitat (Duffey, 1974; Poschod and WallisDeVries, 2002). Unimproved grasslands are those created from low-intensity, traditional land management, that have not been subject to agricultural improvement through the use of artificial fertilisers and/or re-sowing (Bullock, 2011).

The extent of species-rich, semi-natural, unimproved grassland across Europe declined considerably during the second half of the twentieth century (Critchley et al., 2004), contributing to a major decline across the twentieth century as a whole. In England and Wales, an estimated 97% of unimproved grassland was lost between 1932 and 1984 (Fuller, 1987).

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The decline has been largely attributed to the intensification of agriculture and abandonment of remaining semi-natural grassland areas, which occurred during and after the Second World War (Fuller, 1987; Bourn and Thomas, 2002; Poschlod and WallisDeVries, 2002). Agricultural improvement has led to the establishment of highly impoverished plant communities typically dominated by a limited range of competitive species, such as perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*) (Stace, 2010), whilst the use of fertilisers and herbicide treatments have helped maintain these highly-productive, species-poor swards (Fuller, 1987). Wet grasslands were also targeted for crop production, particularly during the 1980's where drainage technology advanced further (Green, 1990). Areas which were abandoned reverted to scrub and woodland through natural succession (Poschlod and WallisDeVries, 2002). These were typically inaccessible, or small and isolated fragments of grassland, within otherwise arable landscapes resulting in logistical difficulties of maintaining appropriate grazing management on these sites.

It has been a major challenge to examine in detail the processes driving declines in cover of semi-natural grasslands in England (Blackstock et al., 1999). The loss of semi-natural grasslands is widely recognised—one of the first large reviews was conducted by Fuller (1987), using various agricultural and land-use survey data. Fuller (1987) revealed that only 0.6 M ha of semi-natural and rough grasslands remained in lowland England and Wales, accounting for only 11% of the total grassland area. Since this period, there have been few studies investigating the changing quantities of unimproved grassland in England (King, 2002). One such study examined the extent and condition of around 500 semi-natural grassland sites which were not designated as SSSI, in England between 1980 and 2003 (Hewins et al., 2005). They concluded that 24% of the sites surveyed had a similar botanical composition to improved or neglected (inadequately managed) grassland, suggesting further losses of semi-natural grassland between these periods. However, few studies have examined the fate of individual areas of semi-natural grassland (Burnside et al., 2003). One such study quantifying the fate of unimproved grassland was undertaken for the South Downs, Sussex. Using aerial photography and GIS, Burnside et al. (2003) concluded that the area of unimproved grassland had decreased from 4729 ha in 1971 to 1976 ha in 1991 (−58%). Losses were predominantly attributed to the conversion of grasslands to arable land, although increases in urban areas and plantations were also reported. Similarly, in Hooftman and Bullock (2012) compared land-use maps from the 1930s with the UK Land Cover Map of 2000 and revealed that 97% of semi-natural managed grasslands had been converted to intensive agriculture, becoming improved grassland or arable.

In an attempt to reduce further losses of semi-natural grasslands, a number of policies and initiatives have been introduced in England. The basic unit of statutory protection in England is the Sites of Special Scientific Interest (SSSI), which are areas of land selected for 'special interest by reason of any of its flora, fauna, or geological or physiographical features' (JNCC, 2015a). The first SSSI were established in the 1950s under the National Parks and Access to the Countryside Act 1949, which were later re-notified under the Wildlife and Countryside Act 1981 (DEFRA, 2009). The number of sites notified since this period can be seen in Fig. 1. The Countryside and Rights of Way Act 2000 strengthened the 1981 Act by providing enhanced protection for SSSI in England and Wales, through refusal of consent for damaging activities, increased power to act on third party damage and penalties for deliberate damage (DEFRA, 2009). Most SSSI are privately owned and form parts of working farms, estates and forests, although there are some sites which are managed by public bodies or non-government organisations (JNCC, 2015b). At each site, a land management advisor will provide the owner with guidance on management practices including grazing management and scrub control, where to find sources of funding and their legislative responsibilities (Natural England, 2012). Statutory protection through SSSI has also been implemented in Scotland and Wales; however these are notified by Scottish Natural Heritage and Natural Resources Wales, respectively. Similar conservation schemes exist in other countries, including the Natura 2000 network of nature protection areas across Europe, which comprises of Special Areas of Conservation (SAC) and Special Protection Areas (SPAs), designated under the Habitats Directive and the 1979 Birds Directive, respectively (European Commission, 2015). Like SSSI, these sites are likely to be privately owned and have their own management plan, although this part is still in the early stages (European Commission, 2015).

Over 68% of remaining semi-natural grasslands in England were designated as SSSI by 2008 (Natural England, 2008), however, of these only 43% were described as being in a favourable condition, whilst 40% were recovering (Natural England, 2008). Grasslands must qualify under specific habitat criteria to be notified as a SSSI, which includes meeting high botanical standards and size guidelines (JNCC, 2015a). There is evidence that species-rich grassland outside this statutory protection are more vulnerable to degradation and loss, hence the need to understand the threats to these grasslands (Hewins et al., 2005). In addition to this statutory protection, agri-environment schemes provide funding to farmers, in return for managing their land in a way that will benefit biodiversity or the environment (Kleijn and Sutherland, 2003) including the conservation, restoration or re-creation of semi natural grasslands.

It is important to identify changes in land cover, as this can provide us with a greater understanding of the causes of declines and consequently where future management and restoration should be targeted. Investigating these changes in designated and non-designated sites will reveal the effectiveness of the current protection in England, which can also be applied to Scotland and Wales, and may highlight grassland areas that would benefit from this type of statutory protection.

In this paper we quantify changes in semi-natural grassland across England between 1960 and 2013, by comparing historic grassland survey data with the Priority Habitats Inventory (Natural England, 2013) and the Land Cover Map 2007 (Morton et al., 2011) using Geographical Information Systems (GIS). We also investigate whether a grassland site receiving statutory protection as a Site of Special Scientific Interest, was more likely to have retained its original habitat during this period. The aims of this study are to assess (i) the extent of decline in semi-natural grasslands over the latter half of the

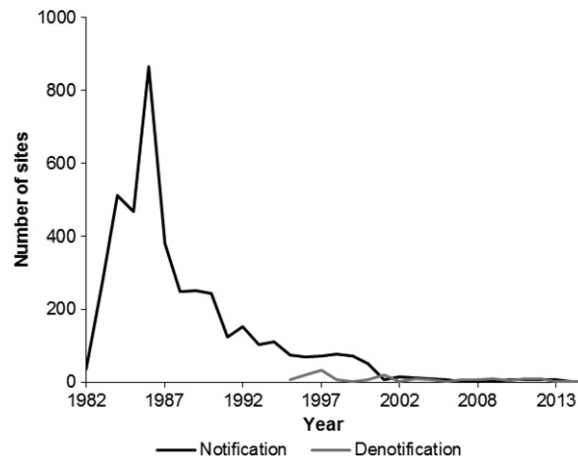


Fig. 1. The number of sites which were notified and de-notified in England between 1982 and 2015.

20th, and early 21st, century, (ii) the fate of lost grasslands, and (iii) whether national conservation policy has succeeded in protecting biodiverse grassland sites.

2. Methods

2.1. Survey data

Between 1960 and 1981, the vegetation composition of around 2000 grassland sites across 37 counties in England were surveyed using a standardised method (Ratcliffe, 1977). Some of the data collected were used in the Nature Conservation Review (NCR) (Ratcliffe, 1977), which aimed to identify the most important places for nature conservation in Great Britain. The data period was restricted to 1981, as this coincided with the introduction of the Wildlife and Countryside Act 1981, which took forward the idea of SSSI and created over 4000 more (Fig. 1) (DEFRA, 2009). Most of the sites in the survey were not designated as receiving statutory protection, however there were some sites that were National Nature Reserves (NNRs) and Sites of Special Scientific Interest (SSSI) at the time of the survey. At each site, the cover of vascular plant species was recorded from between two and six randomly positioned square quadrats. The majority of the quadrats were 1 m × 1 m, however there were a small number of sites where 2 m × 2 m quadrats were used. The location of each quadrat was recorded by a six figure British National Grid reference giving an estimated spatial accuracy of ±100 m.

The grassland at each site was assigned to one of the published British National Vegetation Classification (NVC) communities described by Rodwell (1992) using the computer programme Tablefit (Hill, 1996). Sites were assigned to the NVC community with the highest goodness-of-fit. Based upon species composition and constancy, Tablefit calculates percentage fit between the observed species composition and that specified for each NVC subcommunity in turn (Bastow Wilson et al., 2000). Once each site had been assigned to a NVC community, sites were further classified into one of four grassland types; calcareous grassland, lowland heath and dry acid grassland, mesotrophic grassland and wet grassland, categories used by Blackstock et al. (1999). Sites were allocated to a grassland type, using descriptions of different NVC communities and grasslands types (Natural England, 1999) which can be seen in Table 1. Six sites did not fall conclusively into one of the four grassland categories and were removed from further study. These grassland types are closely analogous to those forming separate categories in the land cover classes in LCM2007 (Morton et al., 2011) and the priority habitats in the inventory (Table 1), which is important for the following analyses. Both datasets (LCM2007 and the Priority Habitats' Inventory) can determine the location and extent of semi-natural grassland in England. The Priority Habitats' Inventory is better at identifying small areas of semi-natural habitat which are often undetected in the LCM2007, which has a minimum mappable unit of 0.5 ha and is poor at detecting linear features (e.g. strips of remnant semi-natural grassland on steep slopes). Therefore the priority habitats inventory was used in the first instance to locate semi-natural grassland, followed by the LCM2007 which is useful for classifying the land cover of the remaining areas.

2.1.1. GIS analysis

The location of each quadrat surveyed was imported into ESRI ArcGIS v10. A 100 m buffer was generated around each individual quadrat which matched the spatial accuracy (±100 m) of the quadrat location, to represent a grassland site and hence forth, the quadrat point with the 100 m buffer will be referred to as a site. Since only the quadrat location was recorded and not the size and extent of the grassland areas which were surveyed in the 1960s, the quadrats are assumed to have been located towards the middle of the grassland, as a representative sample of the grassland site. To validate this assumption and justify the use of a 100 m buffer, an independent dataset of vegetation surveys conducted across the South

Table 1

The four categories of grassland, with the corresponding Biodiversity Action Plan (BAP) name, National Vegetation Classification community, Priority habitat and Land cover type.

Grassland type	Biodiversity Action Plan (BAP) name	NVC communities	Priority habitat	Land cover type
Calcareous grassland	Lowland calcareous grassland	CG1-9	Lowland calcareous grassland, Upland calcareous grassland	Calcareous grassland
Lowland heath and dry acid grassland	Lowland dry acid grassland	U1-4	Lowland dry acid grassland, Lowland heathland, Lowland meadows	Acid grassland, Dwarf shrub heath
	Lowland heath	H1-H8		
Mesotrophic grassland	Lowland meadows	MG4, MG5	Coastal and Floodplain grazing marsh, Lowland calcareous grassland, Lowland dry acid grassland, Lowland heathland, Lowland meadows, Upland heathland	Neutral grassland
	Semi-improved grassland (nb not a UKBAP type)	MG1, MG6, MG9, MG10		
Wet grassland	Upland hay meadows	MG3		
	Purple moor-grass and rush pastures	M22-M26	Coastal and Floodplain grazing marsh, Lowland fens, Lowland meadows, Purple moor grass and Rush pastures	Bog, Fen marsh and swamp, Neutral grassland

West of England in the 1970s as described in Wells (1975) was used. The dataset had various vegetation types recorded on an Ordnance Survey Map, thus allowing areas of semi-natural grassland to be manually geo-referenced in ArcGIS. Over 40 separate grassland areas were geo-referenced, which encompassed 163 of the sites in this study. Using this geo-referenced layer of grassland and the layer of sites, a tabulate intersection was performed, which allowed the area of geo-referenced grassland inside each site to be identified. The percentage of geo-referenced grassland in each site was calculated and an average of 74.5% (± 1.95 SE) was found, suggesting that at least three-quarters of the 100 m area around the quadrat point was grassland at the time of the original survey.

To indicate the coverage of semi-natural grassland in 2013, the Priority Habitats' Inventory, obtained from Natural England was used (Natural England, 2013). The Priority Habitats' Inventory provides the geographic extent and location of 27 Natural Environment and Rural Communities Act (2006) Section 41 habitats of principal importance across England (Natural England, 2013). The layer is based upon Ordnance Survey MasterMap, individual habitat inventories, ENSIS (Natural England's SSSI database), aerial photography and other data sources (Natural England, 2013). The area and type of priority habitat contained within each site was calculated in ArcGIS, using the tabulate intersection function in the spatial analyst toolbox. Sites were considered to have retained their original habitat if at least 75% of the buffer contained the priority habitat category equivalent to the original grassland type of each site, as designated from NVC (see Table 1). Using the 75% threshold a total of 848 sites were examined, including 384 in calcareous, 20 in lowland heath and dry acid grassland, 371 in mesotrophic and 73 in wet grassland. The Digital Elevation Model (DEM) was also used to identify if there were any differences in lowland and upland grassland sites.

2.2. Land cover change

To determine the fate of sites where grassland had been lost, we used the LCM2007. The LCM2007 is available as a vectorised GIS layer and maps 23 land cover classes which are based on the UK's terrestrial Broad Habitats (Jackson, 2000), derived from analysis of satellite data. Areas of lost grassland were defined as sites which contained $\geq 75\%$ of no-priority habitat, as revealed from the previous analysis. These sites were intersected with the LCM2007, in order to determine what land cover had replaced the grassland.

2.3. Grasslands in protected areas

Protected areas across England were identified using the digital boundary data for SsSSI, obtained from Natural England (Natural England, 2014a). The dataset contains the location of SsSSI between 2014 and 1981 (including sites which were formed before this period and then re-notified under the Wildlife and Countryside Act 1981). The area in which a SSSI intersected with a site was calculated. Where a SSSI covered 75% or more of a site, the site was classified as being protected, whereas those with less than 75% were categorised as non-protected. Again the value of 75% was used to determine whether the site has retained its original grassland habitat or whether there had been a change, in both 'protected' and 'non-protected' sites.

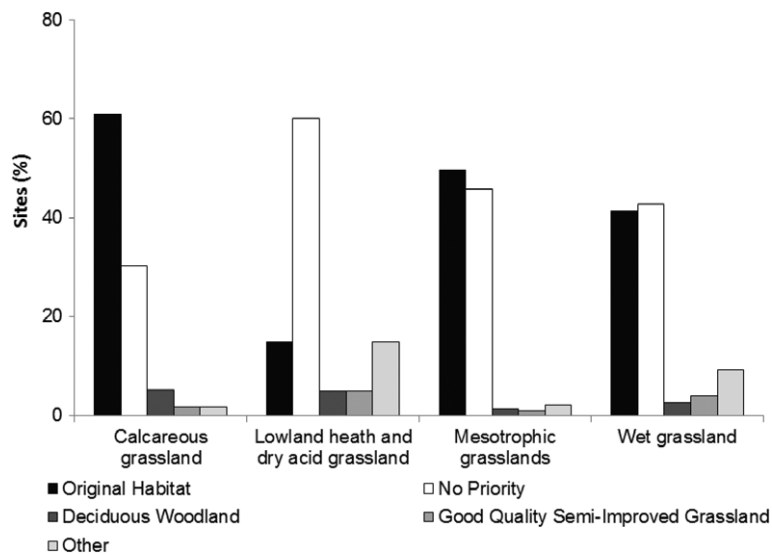


Fig. 2. The percentage of sites which have remained as grassland (original habitat), changed priority habitat (deciduous woodland, good quality semi-improved grassland and other) or are no longer designated as a priority habitat, in each of the four grassland types across England between 1960 and 2013.

2.4. Statistical analysis

To investigate the proportion of sites converted to different land covers, Chi-squared tests were used to examine whether current land cover across lost grassland sites fitted a null hypothesis of a random distribution of different types. Similarly, a Chi-squared test was also used to determine if the number of sites which retained their grassland fitted a null hypothesis of equal distribution between protected and unprotected sites. For both analyses, separate Chi-squared tests were performed for each of the four grassland types.

3. Results

3.1. The proportion of semi-natural grassland

There have been considerable decreases in semi-natural grassland sites between the 1960s and 2013 (Fig. 2). Of the 848 semi-natural grassland sites studied in England, 47% were no longer their original semi-natural grassland type by 2013 (Fig. 3). The greatest percentage loss occurred in lowland heath and dry acid grassland (85%). Similar percentage decreases were revealed for mesotrophic and wet grasslands, where 50% and 59% of sites respectively, were lost over the period studied. More calcareous grassland sites have remained compared with other grassland types, with the number of sites decreasing from 384 in 1960 to 234 in 2013 (39%). The majority of sites where grassland had been lost were designated as no-priority habitat, including 30% in calcareous, 60% in lowland heath and dry acid, 46% in mesotrophic and 41% in wet grassland. However, there were also a small proportion of sites which had changed to a different habitat in the priority habitats inventory—mostly deciduous woodland or good-quality semi-improved grassland. In total, 3% of sites were classified as deciduous woodland, 2% were categorised as good quality semi-improved grassland and 3% had apparently changed to other habitats in the priority habitats inventory. The ‘Other’ habitat category includes coastal sand dunes, maritime cliff and slope, mudflats, reedbeds and other grasslands.

3.2. The fate of lost grassland

The majority of grassland sites were lost to the improved grassland land cover class (45%) or to arable and horticulture (43%). Similar patterns in arable and improved grassland conversions were seen across all grassland types (Fig. 4), although the proportion of improved grassland was greater in mesotrophic and wet grassland. Conversions to woodland, built up areas and rough low-productivity grassland were evident, but to a much lesser extent (2%, 1% and 2% respectively). Calcareous and mesotrophic grasslands both had significant proportions lost to the ‘other’ category, 12% and 5% respectively, which mostly contained other grasslands but also freshwater and inland rock. The number of semi-natural grassland sites converted to different land cover types between the 1960s and 2013 varied significantly across England, in calcareous ($X^2 = 86.33$, $df = 5$, $p < 0.001$, $N = 67$), mesotrophic ($X^2 = 132.87$, $df = 5$, $p < 0.001$, $N = 96$) and wet grassland ($X^2 = 39.90$, $df = 5$, $p < 0.001$, $N = 15$). Sample sizes were too small to test in lowland heath and dry acid grassland.

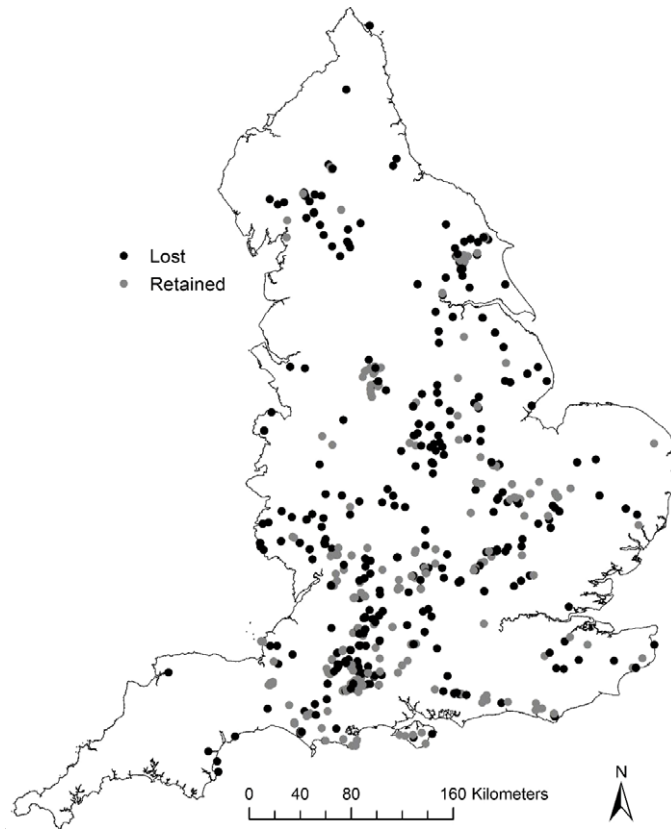


Fig. 3. The location of sites where the original grassland type has been retained (grey dots, $n = 449$) and sites where grassland has been lost (black dots, $n = 397$) over the 32–53 year period across England.

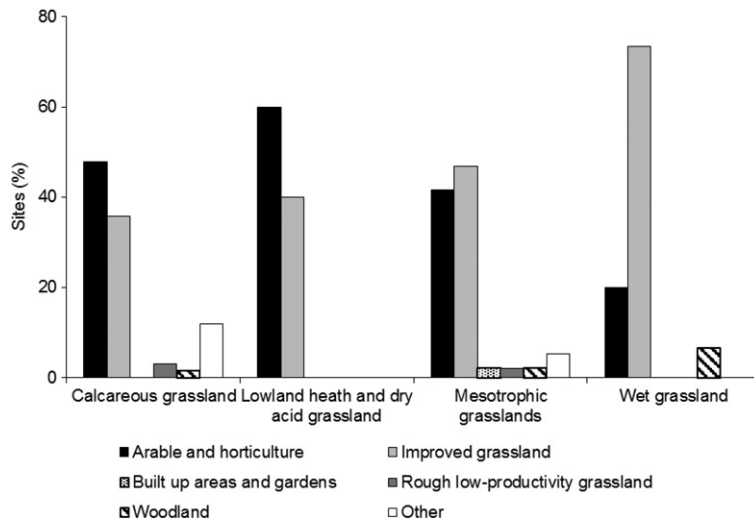


Fig. 4. The percentage of semi-natural grassland sites which have been converted to a different land cover (arable and horticulture, built up areas and gardens, improved grassland, rough low-productivity grassland, woodland and other), across the four grassland types in England between 1960 and 2013.

3.3. Retention of grasslands in protected sites

Protected sites retained considerably more semi-natural grassland than non-protected sites (Fig. 5). Of the 355 protected sites, 322 (91%) retained their original habitat, whereas only 148 of the 546 non-protected sites (27%) remained as species-rich grassland. These differences were significant in calcareous ($X^2 = 106.88$, $df = 1$, $p < 0.001$, $N = 168$), mesotrophic ($X^2 = 118.13$, $df = 1$, $p < 0.001$, $N = 152$) and wet grassland ($X^2 = 14.23$, $df = 1$, $p < 0.001$, $N = 31$). Sample

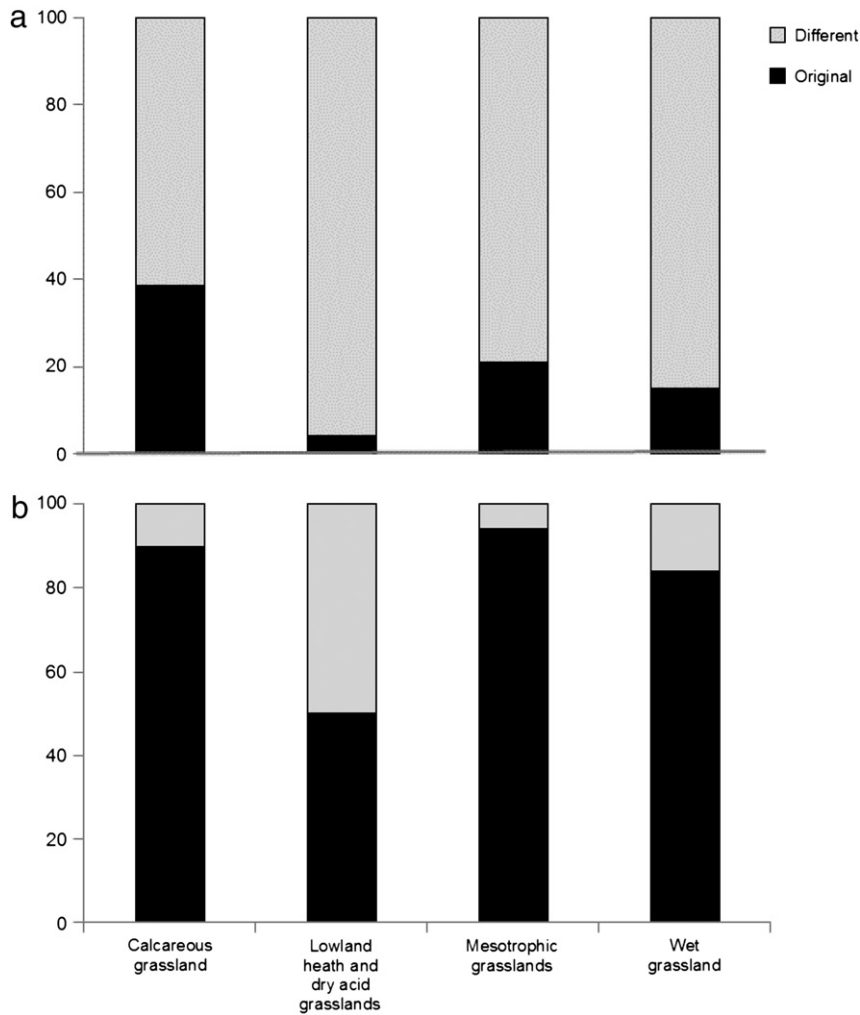


Fig. 5. The percentage of sites which have remained as grassland (original) habitat in (a) non-protected and (b) protected sites, across each of the four grasslands types in England between 1960 and 2013.

sizes were too small to test in lowland heath and dry acid grassland. In both protected and non-protected sites, a greater percentage of lowland heath and dry acid grassland sites were lost, compared with the other three grassland types, 50% and 96% respectively (Fig. 5).

4. Discussion

This study has used a novel approach to quantify the losses of semi-natural grassland in England between 1960 and 2013. Over the 53-year period we calculated that 47% of semi-natural grassland sites have been lost. This study has, for the first time, quantified the fate of these grasslands, where 88% of lost sites were found to have been converted to either arable land or improved grassland. There is strong evidence to show that more semi-natural grasslands were lost from sites which were not protected as SSSI.

4.1. The extent of decline in semi-natural grasslands over the latter half of the 20th, and early 21st, century

Losses of semi-natural grassland were found across each of the four grassland types; calcareous (39% loss), lowland heath and dry acid (85%), mesotrophic (50%) and wet (59%). These values are similar to those reported in other studies in the UK (Blackstock et al., 1999; Fuller, 1987; King, 2002). More calcareous grassland remained compared with the other three grassland types and this may be explained by the greater number of upland sites found within this category, since upland sites are likely to be too steep and unsuitable for arable farming, and are thus more protected from significant agricultural intensification (Northern Ireland Environmental Agency, 2005; Van Swaay et al., 2013).

However the proportions of lost sites were very similar in lowland (39%) and upland (37%) calcareous grassland. The greatest losses in grassland sites occurred in the lowland heath and dry acid category. Lowland heaths are known to have undergone severe declines in England, where only one sixth of the heathland present in the 1800s remains (JNCC, 2014). These losses were mainly attributed to agriculture and urban developments (JNCC, 2014). However, this may be exaggerated by the small sample size for this grassland category compared with calcareous and mesotrophic grasslands, where more quadrats were surveyed in the historic dataset. This pattern was also observed in Blackstock et al. (1999).

4.2. The fate of lost grasslands

The greatest losses across all grassland types were to improved grassland and arable (45% and 43% respectively). This suggests agricultural intensification continued to be a major cause of grassland decreases, even decades after the major changes associated with the Second World War, and the initial increase in grassland improvement brought about by new chemical fertilisers and pesticides in the 1960s and 1970s. Similar findings of losses through intensification in later decades were reported in the UK between 1990 and 2000 (Howard et al., 2003) and in the South Downs between 1971 and 1991 (Burnside et al., 2003). Fuller (1987) reported increases of improved grassland between 0.6 M ha and 1.2 M ha in 1932 to 4.2 M ha in 1984, but with even larger proportions of semi-natural grassland being lost to arable cultivation. This study suggests that in the years following Fuller's review, proportional losses to arable farming may have declined, since the percentage of sites changing to arable and improved grassland between 1960 and 2013 were roughly equal. The reduction in the amount of land converted to arable may be explained by the greater yields and production rates that were achieved in arable farming post-1980s, meaning that less fields were required for conversion. Greater yields and production during this period could be due to several factors including larger and more powerful tractors able to cultivate more challenging soils, improved crop nutrition and improved under drainage (Droy, 2010). There were larger proportions of wet grassland lost to improved grassland than to arable cultivation compared with other grassland types. This is most likely due to less fertile or otherwise constrained soils for arable agriculture.

Although it is not possible to determine which exact processes were responsible at each site, agricultural intensification involves a number of activities that are detrimental to semi-natural grasslands, including ploughing, fertiliser addition, drainage, re-seeding, and replacement of hay-cutting by silage (Fuller, 1987; Poschlod and WallisDeVries, 2002). Vickery et al. (2001) report a two- to threefold increase in inputs on grasslands in Britain since 1940s, peaking in 1980s. The detrimental effects of fertiliser addition have been well established through a number of experimental studies, including the classic Park Grass Experiment (Silvertown et al., 2006). Mountford et al. (1993) found that the annual application of as little as 25 kg ha⁻¹ of fertiliser increased the coverage of agriculturally productive grasses within two years, whereas 50 kg ha⁻¹ caused a significant decline in species richness within three years.

The increase in agricultural intensification during the second half of the 20th century was required to keep pace with human food demands, both in England and across the world (Firbank et al., 2013). With targets of doubling global food production by 2050 (Tomlinson, 2013) increased food production needs to be achieved without increasing the area of land for agriculture, which could lead to further losses of biodiversity (Garnett et al., 2013; Tilman et al., 2011). The concept of "sustainable intensification" has been introduced as a potential solution for this problem (Firbank et al., 2013). This is the idea that food production can be increased through higher yields without an increase in environmental harm, but preferably with environmental benefits (Firbank et al., 2013). Firbank et al. (2013) reported that some farms in Britain have managed to practice sustainable intensification by increasing food production, whilst reducing pollution and enhancing biodiversity. The idea of increasing food production without increasing the area of agricultural land, suggests that although semi-natural grasslands may still be lost in the future in England, this is likely to be at a much lower and slower rate than in the last few decades. Similar predictions were put forward in Bullock (2011).

A small proportion of semi-natural grassland was also converted to woodland. Analysis using the Priority Habitats Inventory revealed that 3% of sites had changed to deciduous woodland. In addition, analysis of the no-priority habitat sites using the LCM2007, revealed further conversions to broadleaved woodland, as seen in Hooftman and Bullock (2012). Given that conversions into coniferous woodland were not found, and that woodland planting in the latter twentieth century was in the vast majority coniferous (Mason, 2007), woodland sites are likely to have developed through natural succession due to inadequate management and abandonment (Green, 1990; Lindborg et al., 2008), rather than the planting of woodlands. Inadequate management is a serious threat facing the existence and biodiversity of semi-natural grasslands and currently 6.57% of SSSI unit areas are not meeting the Public Service Agreement (PSA) target due to inappropriate scrub control (Natural England, 2015). The inadequate management is largely attributed to under-grazing, particularly on calcareous grasslands (Bullock, 2011), which is reflected here.

Urbanisation was responsible for the loss of only 1% of grassland sites across England. Urbanisation has been responsible for the loss of important habitats, such as heathlands (Hooftman and Bullock, 2012), and neutral grasslands (Haines-Young et al., 2000). The latter is reflected in the findings of this study, where mesotrophic grasslands were the only sites lost to urbanisation. The methods used in this study may underestimate the impact of this particular land use because smaller buildings potentially remain undetected by the LCM2007. Moreover, since the value of 75% was used to determine the main habitat, it is possible that smaller portions of the site may have still been urbanised. This problem may exist with other land cover changes, suggesting that changes are likely to be an underestimate, and thus conversions to improved grassland or arable land may be even more dramatic. Furthermore, in this study a site representing an area of semi-natural grassland has

been categorised in 1960 and 2013 using the 75% threshold within a 100 m buffer, but it is possible that a greater percentage of grassland could have been lost from outside the buffer area. Similarly the quality or condition of the grassland retained is unknown, except that the criteria for inclusion in the priority habitats inventory was met.

4.3. Has national conservation policy succeeded in protecting biodiverse grassland sites?

In England 74 894 ha of semi-natural grassland lies within SSSI, which represents 68% of the total remaining resource (Natural England, 2008). This study has demonstrated the importance of statutory protection of sites of nature conservation values. Protected sites retained 91% of their original grassland habitat, compared with only 27% in non-protected sites. These results demonstrate the effectiveness of SSSI in preventing habitat destruction, through providing greater power to Natural England to refuse harmful activities and giving increased responsibility to farmers and land-owners by inducing a punishable offence for neglect (DEFRA, 2009). Only 9% of protected sites lost their original grassland habitat and the majority of these losses were to improved grassland. Around 5016 ha of SSSI units are described as being in adverse condition due to fertiliser use, overgrazing or other agricultural activities (Natural England, 2015). This may explain how a few sites in this study were eventually lost to improved grassland. It is important to note that for this analysis de-notified SSSI were not included. De-notifications are rare events, which occur where the special interest has been lost and when there is no potential for this to be restored (Natural England, 2014b). Only 4% of sites from the SSSI database were de-notified and many of these would not have intersected with the studied grasslands, thus the estimate for the number of sites that were effectively protected is unlikely to be an overestimate.

In addition to the maintenance and conservation of existing semi-natural grassland sites, the restoration and re-creation of grassland on agricultural land in the UK is becoming more widespread. A review of restoration techniques, found that extensive management can be used to restore or recreate species-rich grasslands on previously agricultural soils, although the process may be very slow (Walker et al., 2004). This study has quantified and identified the location and fate of lost semi-natural grasslands in England, which is an important step towards planning for large-scale restoration. Some indication that this is already taking place on a scale detectable beyond single sites may be found in the small number of sites which were classified 'good-quality semi improved grassland' in the priority habitats inventory. These likely represent sites which were originally lost to improvement, but have subsequently been partially restored in recent years, mostly under agri-environment schemes. The numerous sites identified in this study which have been converted to improved grassland or arable land, thus have the potential to be restored back to semi-natural grassland, or at least see an increase in species richness.

5. Conclusions

This study has shown that semi-natural grassland sites categorised into four grassland types declined considerably in England between 1960 and 2013, with a total loss of 47%. The majority of sites have been lost to either grassland improvement or arable cultivation, with much smaller changes to woodland and urbanisation also evident. Statutory designation of sites of high wildlife value clearly has a strong beneficial effect of protecting sites from destruction. This suggests the need for continued protection through well-managed SSSI, but also identifies the locations and potential for restoration and re-establishment of grasslands in sites lost to arable land or improved grassland.

Acknowledgements

This research was funded by National Capability funding from the Natural Environmental Research Council (Project no. NEC05593). We thank all the surveyors involved with the collection of the historic survey data. Thanks to Sam Amy for her assistance with Tablefit. We appreciate the reviewers for valuable comments that improved the manuscript.

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