Research article

Has golf-course management had an effect on the plant species composition and character of a calcareous grassland?

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Lowland calcareous grassland in the UK is a priority habitat designated under the UK Biodiversity Action Plan. Calcareous grasslands used to be common in north-western Europe and were utilized for grazing livestock such as sheep and cows. Many calcareous grasslands in England have been either agriculturally ‘improved’ through the addition of fertilizer and herbicides to increase productivity or have been ploughed up to make way for arable production, which has led to a dramatic decrease in the area of calcareous grassland.

Minchinhampton Common is an area of lowland calcareous grassland located within the English county of Gloucestershire. In 1889, a golf course was laid out on the common for the use and enjoyment of local people.

The first objective of this project was to investigate whether the presence of the golf course on Minchinhampton Common and associated golf-course management activities have had an effect on the composition and character of the calcareous grassland. The second objective was to investigate whether abandoned golf-course features on Minchinhampton Common, such as old fairways and old greens can recover to resemble undisturbed calcareous grassland.

Significant differences were found between the undisturbed calcareous grassland and the fairways, greens and pathways in terms of vegetation height, plant species composition, botanical diversity and soil characteristics. This demonstrates that the presence of the golf course and the management carried out to maintain it has had an effect on the composition and character of the calcareous grassland.

Significant differences were found when the fairways and greens were compared with the abandoned old fairways and old greens. This shows that after 15 years of abandonment the old fairways and old greens are no longer similar to the fairways and greens, but they are still different from the undisturbed calcareous grassland. It is hypothesized that to aid recovery, the abandoned features should be cut annually and the clippings removed. This will decrease the nutrient status of the soil and reduce the competitiveness of grasses, thus providing greater opportunities for the establishment of forb species typical of nutrient poor calcareous grasslands in north-western Europe.

Key words: calcareous, grassland, management, mowing, fertilisation, restoration, golf.

Introduction

Calcareous grasslands are distributed over soils developed on a solid alkaline geology or superficial cover, which is typically composed of a calcium carbonate geochemistry including rocks such as limestone and chalk.¹ Lowland calcareous grasslands are famous for their composition of grasses, forbs and mosses and can have a species richness of over 50 species per metre square.²

The plant communities associated with calcareous grasslands in north-western Europe are usually semi-natural and originated as a result of anthropogenic forest clearance in pre-historic times.³ Once the pre-historic forests had been cleared, plant species from open habitats formed species-rich grasslands, which were especially evident on calcareous slopes and plateaus.³

Calcareous grasslands were traditionally used in agriculture as grazing land, typically for sheep and cows.⁴ ⁵ Management is crucial for the survival of calcareous grasslands to prevent succession to woodland, thus holding calcareous grasslands in a state of plagio-climax.

Due to changes in agricultural production since World War II, many calcareous grasslands have been artificially
fertilized and treated with herbicides to increase productivity to the detriment of plant species diversity. Calcareous grasslands have also been converted to arable production by ploughing or have been abandoned.

Lowland calcareous grasslands are a United Kingdom Biodiversity Action Plan (UKBAP) priority habitat. It is difficult to estimate the area of land that was once covered by lowland calcareous grassland in the past due to the lack of detailed maps. However, it is estimated that there is only 33 000–41 000 ha of lowland calcareous grassland left in the UK. The remaining areas of lowland calcareous grassland are of special importance and need to be conserved for the benefit of future generations.

There are few sports that have such an intimate relationship with the countryside as golf. There are in excess of 25 000 golf courses in the world and 10% of these are located in the UK. The area required for a single golf course is estimated to be between 50 and 60 ha on average, meaning that golf courses potentially account for 0.6% of the total land area of Britain.

To provide swards that are suitable for the playing of golf it is necessary to cut and fertilize the turf. Activities such as regular mowing and fertilization hereafter referred to as ‘golf course management’, aim to produce dense swards of grasses with minimal numbers of other plant species, thus producing grass surfaces that will provide a smooth and true roll of a golf ball. Work by Adams and Gibbs has shown that the addition of fertilizer and high light intensities (caused by frequent mowing to a low height) improves the ability of grasses to produce tillers which increases the density of grass plants in the sward, and effectively reduces the potential chance of other plant species occurring.

The effect of golf-course management activities on the plant species composition of calcareous grassland has not previously been investigated in detail. This research project was designed to investigate if the management of a golf course on an area of calcareous grassland has had an effect on the calcareous grassland character and plant species composition. Previous studies have not been carried out to investigate whether calcareous grasslands can recover after the cessation of golf-course management activities. Therefore, this project aimed to investigate if calcareous grassland can recover after cessation of golf-course management activities.

**Study site and methods**

**Site attributes**

The study was carried out on Minchinhampton Common Site of Special Scientific Interest (SSSI) in Gloucestershire, England (National Grid Reference SO 855 010). Minchinhampton Common is a 182.7 ha area of lowland calcareous grassland and was designated as an SSSI in 1972. Minchinhampton Common also lies within the Cotswolds Area of Outstanding Natural Beauty (AONB) and some areas of Minchinhampton Common are designated as Scheduled Ancient Monuments (SAMs). Minchinhampton Common lies on Jurassic limestone with the majority of the site located on a hilltop plateau which is between 200 and 209 m above sea level. As a result of the underlying limestone geology, the soils of the Commons are of an alkaline nature (pH > 7.0). The grassland is classed as CG3 Bromus erectus grassland and is indeed dominated by B. erectus, along with grasses such as Brachypodium pinnatum and various other fescue species.

**Site history and land use**

Minchinhampton Common is owned and managed by the National Trust. Minchinhampton Common is a public common and is utilized by the public for many recreational activities and the grazing of livestock. In 1889, a golf course was laid out on Minchinhampton Common (Fig. 1) and was managed by Minchinhampton Golf Club Limited. Due to the period in history when the golf course was constructed minimal earth moving was carried out due to a lack of mechanical earth moving equipment. Instead, the existing features present on Minchinhampton Common were used to form the golf course. Areas were levelled to provide tees and the greens and the fairways were simply mown out of the calcareous grassland.

The layout of the golf course has seen many changes since 1889. The most drastic changes came in the early 1990s, when it was decided that the golf course could no longer safely cross the several, now busy B class roads which traverse Minchinhampton Common. The decision was taken...
to relocate several greens to more suitable locations and the alignment of many other holes was adjusted to improve safety. These changes caused many old golf-course features such as greens and fairways to be abandoned.

Resulting from past and present golf-course management activities, six different types of grassland can be identified on Minchinhampton Common, these being fairways, greens, old fairways, old greens, rough calcareous grassland and pathways.

**Sampling design**

The experiment was conducted using a block design where eight blocks were mapped on a plan of Minchinhampton Golf Course. Each block contained areas of each of the six different grassland types. The location of the blocks was constrained by the locations of the old golf-course features, but the blocks did provide a good representation of the whole site. Care was taken to ensure that sampling sites within the blocks were close together to reduce possible error, but the exact locations of the sampling sites were chosen at random.

**Sampling methods**

The in-situ sampling was conducted during July 2006. Within each 1 m² quadrat, the plant species present were identified, recorded and a percentage cover value for each species estimated. A vegetation cover chart was used to standardize estimation of percentage cover for each species to reduce error and variation within the data set.

Vegetation height was measured using the drop disk method. The vegetation height was measured at each corner of the quadrat and in the centre of the quadrat. This allows a mean vegetation height to be calculated.

Soil compaction was measured using a shear vane penetrometer which records the pressure required to break the soil structure. The soil compaction was measured at each corner of the quadrat and in the centre of the quadrat. This allows a mean soil compaction value to be calculated.

Due to the SSSI and SAM designations, digging on the site to collect soil samples is not permitted, therefore a small steel soil sampler was used. A sample of soil was taken from each of the 25 sub-sections of the quadrat that was representative of the whole quadrat area. The soil samples were placed in cold storage to await later analysis. Soil collected from the experimental site was analysed for total nitrogen, available phosphorus, percentage organic matter and soil pH by a professional laboratory.

**Statistical analysis**

To test for significant differences between grassland types, analysis of variance (ANOVA) was employed using the statistical software package SPSS 14.0. Where the assumptions of ANOVA were not met, various transformations of the data were applied. If the assumptions of ANOVA were not met using transformed data, a Friedman test was carried out again using SPSS 14.0.

Where the data did conform to the principles of ANOVA, post-hoc tests were carried out using SPSS 14.0. Tukey tests were employed to look for differences between grassland types.

Detrended correspondence analysis (DCA) was carried out using the CANOCO 4.5 software package. Vegetation data relating to the different grassland types were input in to CANOCO 4.5. The output resulted in coordinates to plot the position of each quadrat on a graph, to show patterns in vegetation and grassland type.

Information about the ecological conditions of a site can be gained from the flora present. Professor H. Ellenberg defined a series of plant tolerance scales to the factors of nitrogen, reaction (pH), moisture and light for use with vascular plants of central Europe. These have been adapted and recalculated for the use with British flora under Module 6 of the Ecological Factors controlling biodiversity in the British Countryside programme (ECOFACT).

Weighted Ellenberg values for each parameter were calculated by multiplying the percentage cover of each species present in a quadrat by the Ellenberg indicator value assigned to that species for a single parameter. These values are then summed to give a score for each quadrat. The quadrats are then grouped into grassland types, allowing an average score for each grassland type to be calculated.

Plant species present on the study site were classified as being a good, intermediate or bad indicator of calcareous grassland characteristics. For this classification, research was carried out using Ellenberg Indicator Values for the parameters of nitrogen and pH. The National Vegetation Classification (NVZ) was also used to investigate species abundance and frequency in CG3 B. erectus grassland (Table 1). It was found that the groupings assigned for tolerance to nitrogen was similar to the groupings used in a study by Bakker.

**Results**

**Vegetation height**

There was a significant difference (Friedman test, $\chi^2 = 34.143$, df = 5, $P < 0.001$) in vegetation heights between grassland types (Fig. 2). The old fairways, old greens and the pathways had a lower mean vegetation height than the surrounding rough calcareous grassland. The old fairways and old greens also have a greater mean vegetation height than the currently managed fairways and greens.

**Plant species richness**

Plant species richness was significantly different (ANOVA, $F_5, 35 = 34.901, P < 0.001$) between grassland types
The old fairways and old greens were significantly more species rich than the currently managed fairways and greens respectively. In addition, the previously managed old fairways had a significantly greater species richness than the surrounding rough calcareous grassland.

Percentage ground cover results

Calcareous grasslands comprise many different layers of vegetation and therefore the total percentage ground cover can often exceed 100% (Fig. 4).\(^\text{15}\)

Figure 3. Differences in plant species richness between the different grassland types. (Significant differences were tested using Tukey tests, grassland types sharing the same letter were not significantly different \((P < 0.05)\).)

Figure 4. Mean percentage ground cover of each grassland type in terms of percentage grass cover, percentage forb cover and percentage bare ground.

When compared with the currently managed fairways and greens. However the rough calcareous grassland surrounding the golf course had a high percentage cover of grasses.

Percentage forb cover

The percentage forb cover was significantly different (Friedman test, \(\chi^2 = 28.154, \text{df} = 5, P < 0.001\)) between grassland types (Fig. 4). The results show that the old fairways and old greens had a higher mean percentage of forb cover when compared with the surrounding rough calcareous grassland. The old fairways and old greens had a greater mean percentage of forb cover than the currently managed fairways and greens.
Percentage bare ground

The difference in percentage of bare ground was significantly different (Friedman test, $\chi^2 = 15.958$, df = 5, $P = 0.007$) between grassland types (Fig. 4). The grassland types which had the lowest mean bare ground values were the fairways, greens and also the previously managed fairways. The old greens had a greater amount of bare ground than the currently managed greens, which were covered by a dense sward of grass species with very few gaps. This observation relates to the low mean percentage cover of forb species and the high average percentage grass cover (Fig. 4). Very little difference in percentage bare ground was found; however, the pathways showed the greatest percentage of bare ground, which was visually evident on site.

Total soil nitrogen

The results show that there was a significant difference (Friedman test, $\chi^2 = 29.857$, df = 5, $P < 0.001$) between grassland types (Fig. 5). The amount of total nitrogen present in the currently managed fairways was greater than the previously managed old fairways, showing a fall in the total nitrogen level of the soil under the old fairways. The old greens show a higher level of total nitrogen than the current greens which was the opposite of the expected result.

Weighted Ellenberg indicator: nitrogen

The results show that there was a significant difference (Friedman test, $\chi^2 = 27.0$, df = 5, $P < 0.001$) between grassland type in terms of weighted Ellenberg nitrogen indicator value (Fig. 6). These results suggest that golf-course management could have had an effect on the species composition of the areas managed as golf-course features.

Available soil phosphorus

There was a significant difference (ANOVA, $F_5, 35 = 29.590$, $P < 0.001$) between the different grassland types in terms of available phosphorus in the soil (Fig. 7). The currently managed greens had a high level of available phosphorus in the soil. The lower amount of phosphorus in the previously managed old greens shows that after abandonment the amount of available phosphorus in the soil begins to fall. This relationship was true of the current fairways and old fairways, although the magnitude of the decrease was smaller than that of the greens.

Percentage soil organic matter

There was a significant difference (ANOVA, $F_5, 35 = 18.308$, $P < 0.001$) between all the grassland types in terms of percentage soil organic matter (Fig. 8). The currently managed fairways had a greater percentage of soil organic matter when compared with the old fairways. The opposite relationship was true of the greens, indicating that after abandonment the amount of soil organic matter increases. The soil under the rough calcareous grassland...
showed the greatest percentage of soil organic matter of all the six types of grasslands.

**Soil pH**

Soil pH was tested, but no significant differences were found between the different grassland types \((P > 0.05)\).

**Weighted Ellenberg indicator value: reaction (pH)**

The results show that there was a significant difference (Friedman test, \(\chi^2 = 27.429, \text{ df } = 5, P < 0.001\)) between grassland types in terms of weighted Ellenberg reaction indicator value (Fig. 9). This suggests that golf-course management could have had an effect in altering the pH of the soil. However, the soil analysis results (see section on Soil pH) prove that there is no significant difference in soil pH between the grassland types.

**Soil compaction**

There was a significant difference (ANOVA, \(F_{5,35} = 3.004, P = 0.023\)) between the grassland types in terms of soil compaction (Fig. 10). The currently managed greens had the greatest soil compaction and interestingly the soil compaction of the old greens had reduced since abandonment. The relationship is opposite of that of the fairways. The currently managed fairways had a lower soil compaction than the previously managed old fairways.

**Detrended correspondence analysis**

The results of the DCA on grassland types show that there were differences between the grassland types (Fig. 11). The greens are extremely different from the other types of grassland and this is reflected by the distance the greens have been plotted away from the other grassland types. The green points (circle 1) and the old green points (circle 2) have been ringed (Fig. 11). The arrow shows the direction of change caused by golf-course management and abandonment. The rough points have been ringed (circle 3) (Fig. 11) to show that after 15 years of abandonment the old greens are still different from the surrounding rough calcareous grassland, which is reflected by the old greens (circle 2) being plotted above the rough calcareous grassland (circle 3) (Fig. 11).

**Calcareous grassland indicator species**

The results (Fig. 12) show that with the intervention of golf-course management, the grassland loses plant species indicative
Discussion

Condition of current golf-course features

In this study, areas subject to golf-course management activity (fairways, greens and pathways) differed in vegetation height, species richness and soil characteristics from the rough calcareous grassland on Minchinhampton Common. The rough calcareous grassland is treated as a control in the analysis, representing conditions in the absence of golf-course management.

There was a significant difference in vegetation heights between the currently managed fairways, greens and pathways when compared with the rough calcareous grassland. This can be explained by the golf-course management mowing regime that maintains the vegetation height of the fairways, greens and pathways swards at constant heights throughout the year. With increased cutting frequency, tillering is promoted, which increases the density of grasses in the sward. This improves the quality of the turf for the playing of golf but reduces the nature conservation value of calcareous grassland as plant species diversity is decreased. The plant species diversity of the fairways and greens was indeed found to be lower than that of the rough calcareous grassland. In addition, the amount of good calcareous grassland indicator species present on the fairways and greens was lower than that of the rough calcareous grassland.

Golf-course management, involving fertilization of the fairways and greens, also causes a decrease in plant species diversity. Fertilization increases the productivity of grasses, causing an increased competition for light, which leads to a decline in species diversity. The addition of nitrogen has been found to lead to increased production of tillers by grasses such as *Lolium perenne*, which increases the ability of grasses to compete for light. Shoot competition for light and root competition for soil resources have been linked to explain plant species diversity loss after fertilization. Competition caused by fertilization is also dependent on a relationship between the nutrients nitrogen and phosphorus, as both can be limiting for plant growth. The addition of a phosphorus-based fertilizer without nitrogen causes an increase in above-ground biomass which has a negative effect on plant species diversity. It was found by Willems *et al.* that when a nitrogen-based fertilizer without phosphorus was used, the above-ground biomass growth was only slight when compared with a control plot, but plant species diversity was also reduced. Nitrogen encourages the growth of plants, which in turn increases the rate of phosphorus uptake by plants from the soil.

Forb species were present on the currently managed fairways as the cover and density of grasses in the sward is not uniform. Gaps are created by deaths of plants, machinery scars, damage caused by the striking of golf balls and
activities of animals, most notably cattle hoof marks and casting earthworms.\textsuperscript{24}

The soil nitrogen levels of the fairways and greens were lower than that of the surrounding calcareous grassland, which contradicts the predictions made by the weighted Ellenberg nitrogen results. This is because the fairways and greens are more productive than the surrounding calcareous grassland and therefore have an elevated use of nutrients. Applications of fertilizer are required to maintain nutrient levels and grass productiveness. The phosphorus levels of the greens and old greens are higher than the other grassland types, suggesting that the greens have, throughout their history, had phosphorus applied in fertilizer or organic form.

The soil organic matter percentage of the greens is lower than that of the surrounding calcareous grassland. This can be explained by the regular removal of organic matter by scarifying, which is part of the golf-course management regime. Soil pH was found to vary slightly between grassland types, which is not what was predicted by the weighted Ellenberg reaction indicator values. This is because golf-course management has had the effect of changing the plant species present on the areas used as golf-course features, but has not drastically changed the pH of the soil.

The soil compaction of the greens is high due to regular mowing and rolling which is required to maintain the sward to a high standard. These practices involve the use of machinery which compacts the soil. Trampling of the greens by golfers and cattle will also contribute to soil compaction. The above is also true of the fairways which have a higher soil compaction value than the surrounding rough grassland. It is hypothesized that the fairways have a lower soil compaction value than the greens due to less intense golf-course management activity and a reduced effect caused by trampling.

**Condition of old golf-course features**

In this section, the old greens and old fairways are compared with the current fairways and current greens, which are treated as controls in the analysis to assess the extent of change caused as a result of cessation of golf-course management activities. The old fairways and old greens are also compared with the rough calcareous grassland to assess whether the abandoned features are becoming more similar in their characteristics to those of undisturbed calcareous grassland.

The previously managed old fairways and old greens after 15 years of abandonment had a lower average vegetation height when compared with the surrounding rough calcareous grassland, but a greater vegetation height than the currently managed fairways and greens. The only management these areas have received since abandonment is defoliation by grazing cattle. There is no evidence, from observations and from discussions with the golf-course manager, to suggest that the old golf-course features provide preferential grazing for the cattle thus causing the vegetation height to be low when compared with the surrounding rough calcareous grassland.

Vegetation height is strongly affected by species richness and the species composition of the sward. Species richness of the previously managed old fairways and old greens increased after abandonment, and the number of good calcareous grassland indicator species present on the old fairways and old greens was greater than that of the fairways and greens. The old fairways and old greens had significant coverings of *Plantago lanceolata*, *Ranunculus repens* and *Leontodon autumnalis*. These findings are in agreement with a study by Olff and Bakker.\textsuperscript{25} An increase in low growing rosette plant species such as *P. lanceolata* and *L. autumnalis* and a decrease in tall growing plant species such as *B. erectus* have the effect of decreasing the overall vegetation height of the previously managed old fairways and old greens. The increase in species diversity is triggered by the reduction of nutrient availability as a result of the cessation of fertilizer application.\textsuperscript{26}

The short vegetation height of the old fairways and old greens at abandonment as a result of golf-course management may have had the effect of aiding the establishment of rosette plant species, thus increasing species richness. A study by Bakker\textsuperscript{18} suggests that short turf produced as a result of heavy grazing will provide more sites suitable for the establishment of rosette plant species such as *L. autumnalis*. The competition for light is an important factor to consider when looking at species richness. The quantity of light and also the quality of light at soil level is positively correlated to the emergence and survival of seedlings.\textsuperscript{26} The amount of surface vegetation affects the quantity of light reaching the soil surface, therefore the less surface vegetation, the more the light can reach the soil surface. The amount of surface vegetation also changes the quality of light reaching the soil surface,\textsuperscript{18} which can reduce emergence and affect seedling establishment.\textsuperscript{27} The effect of trampling and grazing by cattle\textsuperscript{28} opens gaps in the sward which provide opportunities for regeneration\textsuperscript{29} thus increasing species diversity. The higher the light availability, the better the chance is that seedlings will germinate and survive.\textsuperscript{28}

The nutrient content of soils has a direct impact on the species richness of calcareous grassland.\textsuperscript{30} The nutrient status in terms of nitrogen and phosphorus in the soil declined after the abandonment of the old fairways. This has occurred as a result of the cessation of fertilizer application and declining soil organic matter content. The available phosphorus content of the old greens fell when compared with the greens, for the same reasons. However the total nitrogen value of the old greens was higher than that of the greens. This could be due to the fact that some of the old greens were managed for a longer period of time than the greens that are currently used and therefore there are differences between the two types. It is important to
remember that it is not total nitrogen which is important but nitrogen mineralization. The weighted Ellenberg nitrogen indicator value results suggested that the greens would have a higher total nitrogen value than the old greens, which is not true. This is because golf-course management has had the effect of encouraging the development of plant species that require high nitrogen quantities to be present on the greens. Fertilization is required as the greens are very productive and nutrients are lost due to golf-course management activities.

The percentage soil organic matter increases in the soil under the old greens as organic matter is no longer removed through scarification. The percentage soil organic matter of the old fairways decreases, which is due to the regular mowing of the currently managed fairways which returns large amounts of organic matter back in to the soil.

The soil compaction of the old greens falls after abandonment towards the value of the surrounding rough calcareous grassland as a result of no longer being mown, rolled or trampled by golfers.

Pathway grassland type
It was found that the pathways were different to the rough calcareous grassland in terms of vegetation height and species richness, which has been caused by the intense trampling by golfers. Trampling is known to decrease the species richness of calcareous grasslands. Trampling has also been shown to have a negative effect on plant productivity resulting in less growth and reduced need to cut the pathways. The soil compaction of the pathways was greater than that of the currently managed fairways and surrounding rough calcareous grassland. Soil compaction increases bulk density and causes a smaller amount of pore space to be available in the soil. The soil compaction of the pathways is higher than the currently managed fairways and the rough calcareous grassland and is therefore a contributing factor that can be used to explain the decrease in species richness and reduced vegetation height.

Conclusion
This study has shown that golf-course management does have an effect on the species composition and character of calcareous grassland. However it has also shown that on cessation of golf-course management activities, the nature conservation value of areas of calcareous grassland used as golf-course features begins to increase. Surprisingly the old fairways and old greens were more species rich than the surrounding rough calcareous grassland. This could be due to the fact that some areas of the calcareous grassland at Minchinhampton Common are not in good condition, as identified in the Minchinhampton Common SSSI citation. It would therefore be useful to examine other calcareous grassland sites in Gloucestershire to establish the relative condition of Minchinhampton Common. Any other calcareous grasslands examined could also be compared with the old fairways and old greens to provide a greater understanding of their condition as calcareous grassland.

The nature of this study did not allow for the following of the same quadrats through time. Therefore this study only provides a snap shot of the condition of the six grassland types at the same point in time. To improve and consolidate the findings of this study, it would be necessary to set fixed quadrats and record changes annually before and since the abandonment of the old greens and old fairways. This would show conditions before abandonment which could be compared with the changes in conditions after abandonment. Similarly it would be necessary to set fixed quadrats and record changes annually before the change of use from calcareous grassland to golf course. This would then show the conditions before golf-course management began allowing the changes in species composition and soil characteristics to be compared and attribute golf-course management as the definitive cause of any changes found.

It should be possible to maintain a good quality golf course on Minchinhampton Common whilst improving the nature conservation value of both the grassland occupied by the golf course and the surrounding calcareous grassland. Work should be carried out to reduce nutrient levels in the soil by cutting and collecting the grass in autumn after the seeds have been shed. The resulting thinner, more species-rich sward will be a significant benefit for the nature conservation value of the calcareous grassland and also improve the quality of the golf course. Similar cutting and collecting should be carried out on the old fairways and old greens to reduce soil nutrient levels and encourage the establishment of more plants typical of lowland calcareous grassland in north-western Europe.

Future study should be aimed at monitoring changes in the condition of fixed quadrats on Minchinhampton Common following management activities briefly described earlier. The work should ensure that management is tailored to the needs of the site to improve the nature conservation value of Minchinhampton Common for future generations.

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