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Nine years of change in the flora of Ellerburn Bank, a limestone grassland in the North York Moors

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Introduction

Limestone grassland is one of the most biodiverse habitats on Earth at a small scale (Wilson *et al*., 2012). Floristic richness within Europe can reach 80 species per m^2 (Butaye *et al.*, 2005) and many plants are found in no other habitat. Limestone grassland also supports important invertebrate communities as well as specialist birds (UK Steering Group, 1998). However, it is also one of Europe's most threatened habitats (WallisDeVries *et al.*, 2002). In 1998 there was a maximum of 41,000 hectares of lowland calcareous grassland remaining in the UK (UK Steering Group, *loc. cit.*). Loss of habitat continues from forestry, conversion of pastureland to crops and land abandonment (WallisDeVries *et al., loc. cit.*), leading to reductions in the area and increases in the isolation of habitat patches (Fisher & Stöcklin, 1997). Quality reductions come from the abandonment of traditional agricultural practices leading to land-use intensification such as increased fertilization, herbicides, reseeding and frequent or early mowing (WallisDeVries *et al.*, *loc. cit.*). They may also result from overgrazing, undergrazing leading to the encroachment of scrub, Bracken *Pteridium aquilinum* and coarse grasses (Bobbink & Willems, 1987), and atmospheric nitrogen deposition leading to loss of richness (van den Berg *et al.,* 2011). The latter threats mean that their quality may decline even if sites are enclosed in protected areas, due to pervasive forces beyond the control of reserve managers (van den Berg *et al., loc. cit.*) or as a consequence of suboptimal management. Indeed, JNCC declared that only 29% of Sites of Special Scientific Interest (SSSI) and 27% of Special Areas of Conservation (SAC) on lowland calcareous grassland in the UK were in favourable condition in 2006, below the average for habitats in general (Williams, 2006). Optimal management is difficult to achieve because the effects of different practices can vary depending on local conditions (Klimek *et al.*, 2007) and the taxonomic group under consideration (WallisDeVries *et al., loc. cit.*).

Ellerburn Bank is a 2.91ha grassland site sloping south-east on oolitic limestone on the southern edge of the North York Moors near Pickering (SE853849: VC62). Despite its modest size, it is one of the most extensive areas of unimproved limestone grassland remaining in the North York Moors (Sykes, 1993). It was notified as a SSSI in 1983 and has been managed as a nature reserve by the Yorkshire Wildlife Trust (YWT) since 1966, having been informally managed for nature conservation perhaps for the previous decade (Yorkshire Wildlife Trust, 2012). The flora and fauna of the site is exceptional for the region, with over 150 species of plant recorded (Sykes, *loc. cit.*) including large displays of Cowslip *Primula veris* in spring, orchids in early summer (Plate 1, centre pages) and Felwort *Gentianella amarella* in late summer (Leadley & Richards, 2012). Flowering plants of regional note include Dropwort *Filipendula vulgaris*, Woolly Thistle *Cirsium eriophorum,* Saw-wort *Serratula tinctoria*, Fly Orchid *Ophrys insectifera* and Greater Butterfly Orchid *Platanthera chlorantha*. The site is noted for its extensive Lepidoptera fauna (Frost, 2005), including butterflies of regional note such as Dark Green Fritillary *Argynnis aglaja* and Dingy Skipper *Erynnis tages*, and the site also supports a population of Glow-worm *Lampyris noctiluca*. Management of the reserve currently consists of low-intensity winter grazing by Hebridean sheep (Leadley & Richards, *loc. cit.*) and rotational scrub clearance (often burnt on site). The site is listed as in 100% favourable condition by Natural England (2014) and light winter grazing is its official management advice (English Nature, 2004). The upper, north-western margin borders an agricultural field and consists of a Bronze Age earthwork (a double ditch and bank) partially covered with Hawthorn *Crataegus monogyna* and Blackthorn *Prunus spinosa* scrub, whilst the lower, south-eastern side bordered by forestry, consists of a patchwork of taller grass and Gorse *Ulex europaeus* scrub (Fig. 1, Plate 1c, centre pages).

From 1999 to 2011, with the exception of 2001 due to the Foot-and-Mouth disease epidemic, the bank and surrounding areas of Dalby Forest were visited in the first week of July as part of the second year Ecology Field Course run by the Department of Biology at the University of York. In the early years of this field course it was noticed that one of the taller grasses, False Brome *Brachypodium sylvaticum*, common around the scrubby fringes of the reserve, also occupied large visible patches across the central and south-eastern parts of the pasture where colonization of young woody scrub plants was noticeable (see Plates I(b), I(c) and I(d), centre pages). It was decided to attempt to monitor the spread of False Brome and woody scrub as well as their potential effects on the other flora from year to year. 24 permanent $1m^2$ quadrats (Fig 1) were sited throughout an area where small woody scrub plants and False Brome were noticeable in 2003, from which time they were systematically surveyed for flowering plants. The quadrats were re-surveyed in five of the nine years subsequent to that (2004, 2005, 2008, 2009, 2011). Changes to the structure of the degree programme at York in 2012 necessitated running the field course earlier in the year, in May and then June. Although the quadrats were surveyed in 2012 and 2013, the different survey dates make the data less comparable with those from previous years because of the different apparency of above-ground parts of the plants used for identification. It therefore seems timely to summarize here some of the findings from the initial years of survey work.

During or just prior to the years of study reported here, the following management on the reserve was carried out (Yorkshire Wildlife Trust, *loc. cit.*): in February 1999, a strip of Gorse adjacent to the south-eastern boundary of the reserve, extending south-west from quadrats 5 and 6 (Fig. 1), was removed by British Trust for Conservation Volunteers. In November 1999, an area of Gorse on the south-eastern boundary of the Reserve, close to quadrats 18 and 22, was probably removed by contractors. Other small areas of scrub on the earthwork and Gorse further south from the study quadrats were removed in 1999. In October 2001, because of absence of grazing due to the Foot-and-Mouth epidemic, a strip of long grass along the north-eastern and south-eastern boundaries of the reserve was mown. This may have encroached over quadrats 5, 9, 10, 13, 18 and 22. In 2003 an area of Hawthorn saplings immediately to the north of quadrats 15, 20, 23, and 24 was removed by strimming. In January 2007 a small area of scrub on the earthwork was cleared by a National Park volunteer group. In October 2007 YWT staff cut and treated an area of Gorse to the north-east of the study quadrat area but also in the vicinity of quadrats 17, 18, 21-24. In January/February 2008 the Hobs volunteer group also cut and burnt an extensive area of scrub along the earthwork and Gorse close to quadrats 5, 6, 9 and 10. Bracken was cleared along the north-eastern reserve boundary in 1998 and 2008.

From 1998 to 2004 a creep grazing regime was used, which saw 21 sheep being grazed progressively on three enclosed paddocks on the centre of the pasture, from south-west to north-east, the last of which covered the area of the study quadrats, for around 18 days on each during the winter period. An extra paddock was grazed in 1999 extending grazing north-east. In 2003 grazing pressure was increased from 21 sheep to 40 sheep which grazed the four successive pastures, still in a creep grazing routine. From 2005-2010 a continuous winter grazing regime was used. Approximately 30 Hebridean sheep were located on the site between October and March. Overall then, annual grazing was the main management activity immediately affecting the quadrated area, though some scrub removal took place immediately adjacent to the quadrated area, and over the north-eastern part of it in October 2007.

In this article we first summarize the community of flowering plants found in the permanent quadrats. We then test four hypotheses of vegetation change related to the efficacy of management of calcareous grassland sites which motivated the work: that False Brome is increasing in frequency in the sampled area; that woody scrub plants are increasing in frequency in the sampled area; that richness and alpha diversity are decreasing over time; and that the Ellenberg indicator nitrogen scores (Hill *et al.*, 1999) are increasing over time.

Methods

Twenty-four permanent 1m^2 quadrats were sited across an area of the central and south-eastern parts of the pasture measuring 120m x 40m using a stratified random design (Fig 1, Appendix 1). The total area was divided into twelve 20m x 20m units and two 1m^2 quadrats were randomly sited in each. The corners of each 1m^2 quadrat were marked by six inch steel nails hammered into the ground. In subsequent years the quadrats were relocated by metal detector, aided in later years by the use of a hand-held GPS receiver.

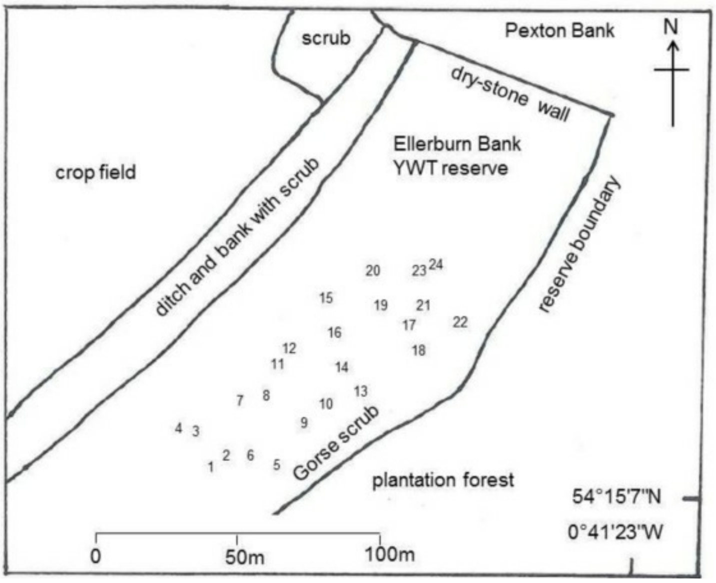

Figure 1: Map of the northern part of Ellerburn Bank showing the location of the survey quadrats and local surroundings.

Plants were recorded using a semi-quantitative method. A gridded quadrat consisting of 25 divisions of 20cm x 20cm was placed over each 1m^2 location. Presence/absence of each plant species was recorded in each of these sub-units of the quadrat and the number of these subunits totalled to give an occupancy score between 0 and 25, representing how widely that plant occurred in each quadrat. This method allowed year-to-year consistency and is relatively rapid, given that surveying had to be completed in 2-3 days each year and by different students in each year. Leaf shape was generally sufficient to allow accurate identification for the herbs but presence of a grass was only recorded if a flowering stem was present, allowing accurate identification. The exceptions were Cock's-foot *Dactylis glomerata,* whose fleshy leaves are distinctive, and False Brome, whose wide tough and yellow leaves are also distinctive. One grass, Creeping Bent *Agrostis stolonifera*, was also initially identified by leaf alone but subsequent observations cast doubt on the efficacy of this identification and only flowering stems were used in subsequent years. However, because of this inconsistency, this plant is eliminated from the analyses below requiring occupancy estimates. Mosses were not recorded.

Two teams of two students conducted the surveying each year. This arrangement facilitated speedy recording and allowed students to consult each other in case of doubt. Each team was armed with a flower guide (Fitter *et al.*, 1996) and a grass guide (Fitter *et al.*, 1984), along with the species list from previous years' surveying. In addition, each team received close tuition on plant identification during their first quadrats from the first author, who revisited them at approximately hourly intervals during surveying to handle identification queries. All students had previously participated in a class quadrating practical on the bank as part of the field course, giving them some experience with plant identification. Despite this effort to minimize identification errors, some students found it difficult to distinguish some plants by leaf shape, particularly Common Knapweed *Centaurea nigra* and Field Scabious *Knautia arvensis*, which can have quite similar leaves to the inexperienced eye. Year-to-year fluctuation in occupancy may, therefore, to some extent reflect year-to-year variability in identification error. However, consistent temporal trends are still likely to represent real changes in the plant community.

The community composition of all plants within quadrats was explored graphically using Non-metric Multidimensional Scaling (NMDS), implemented using the metaMDS function in the vegan package in R (R Core Team, 2014). NMDS is an ordination analysis in which differences in community composition are summarized in a small number of dimensions (normally two) for ease of visualization. Species and quadrats close together in a plot of the NMDS axes show closer associations in occupancy across quadrats. Occupancy data were $\log_{10}(x+1)$ transformed prior to analysis.

To identify if woody scrub plants and False Brome were associated with particular plant communities, the herb and grass occupancies within quadrats were subjected to Detrended Correspondence Analysis (DCA), another ordination analysis, using the decorana function in the vegan package in R. The analysed data omitted False Brome and woody scrub plants and were $\log_{10}(x+1)$ transformed prior to analysis, with rare species downweighted. The extracted axis scores for each quadrat were correlated against the mean occupancy of Hawthorn and False Brome within quadrats, as a statistical test of association between those species and the community of other plants.

Temporal changes in the occupancy of False Brome, of woody scrub plants, richness and alpha diversity and of the occupancy-weighted Ellenberg indicator nitrogen scores (Hill *et al.*, *loc. cit.*) were analysed by linear mixed effect models with repeated measures, with quadrat coded as a fixed factor repeat-measured across year, and with year as a covariate. Analysis was conducted in SPSS v.21. Alpha diversity was scored using Simpson's index on the occupancy data, which is recommended for small sample sizes (Magurran, 2004), using the inverse index $1/D$, where larger values indicate a more even community, in which species have more similar occupancies to each other; Ellenberg nitrogen scores for flora scale from 1 (extremely infertile) to 9 (extremely fertile) (Hill *et al. loc. cit.*).

Results

<u>The plant community</u>

A total of 62 species (Appendix 2) was recorded over the six survey years, comprising 42 forbs (of which 6 were legumes), 12 grasses, 1 sedge and 7 woody scrub plants. A rank occupancy chart (omitting Creeping Bent) (Fig 2) shows that the most common twelve plants account for

79% of the average occupancy and that other plants have very low occupancy. These twelve were, in decreasing rank occupancy order, Common Bird's-foot-trefoil *Lotus corniculatus*, Glaucous Sedge *Carex flacca*, Salad Burnet *Sanguisorba minor*, Field Scabious, Rough Hawkbit *Leontodon hispidus*, Quaking Grass *Briza media*, Cock's-foot, Common Knapweed, Upright Brome *Bromopsis erecta*, Lady's Bedstraw *Galium verum*, Red Clover *Trifolium pratense*, False Brome, Fairy flax *Linum catharticum*, Ribwort Plantain *Plantago lanceolata* and Yellow Oat-grass *Trisetum flavescens*. Several of these are central to the entomological interest of the site, with Common Bird's-foot-trefoil and Red Clover supporting Common Blue Butterfly *Polyommatus icarus*, Six-spotted Burnet *Zygaena filipendulae,* Narrow-bordered Five-spotted Burnet *Z. lonicerae*, Burnet Companion *Euclidia glyphica* and Dingy Skipper. Cock's-foot and False Brome are favoured foodplants of many grass-feeding butterflies, including Small Skipper *Thymelicus sylvestris*. Other recorded plants included Hairy Violet *Viola hirta*, which supports Dark Green Fritillary, and Common Rock-rose *Helianthemum nummularium,* which supports Brown Argus *Aricia agestis*, whilst in the recent past Cowslip has held populations of Duke of Burgundy *Hamearis lucina* and Milkwort *Polygala vulgaris* supported Small Purple-barred *Phytometra viridaria* (Sutton & Beaumont, 1989). The woody scrub plants were, in order of decreasing rank occupancy: Hawthorn, Dog Rose *Rosa canina*, Gorse, brambles *Rubus fruticosus* agg, Pedunculate Oak *Quercus robur*, Blackthorn and Scots Pine *Pinus sylvestris*. Other plants of note for their vivid floral displays include Common Spotted Orchid *Dactylorrhiza fuchsii* (see Plate I (a), centre pages) and Felwort; and the regionally scarce Dropwort, Fly Orchid (see front cover) and Woolly Thistle.

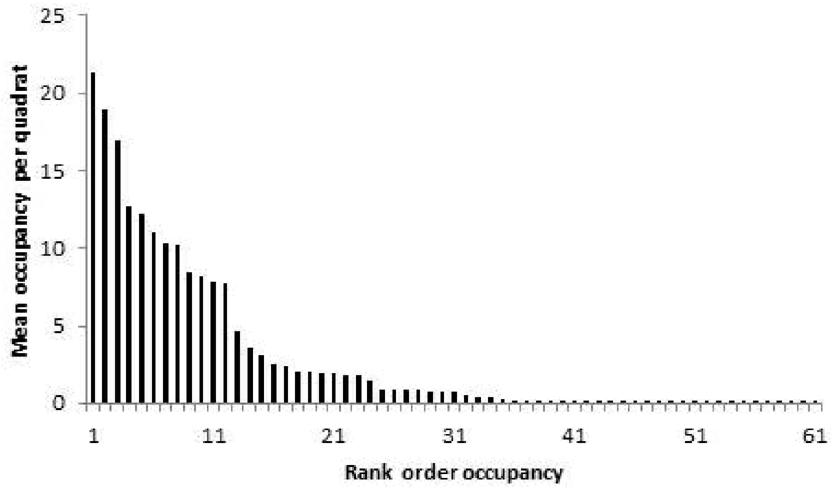

Figure 2: Rank occupancy plot of the plant species recorded. Precise occupancy values, with standard errors, are given in Appendix 2.

An ordination of quadrats using NMDS shows close associations between the twelve most ubiquitous plants, as expected (Fig 3b): those with low scores on the first axis (Fig 3a) include Sweet Vernal Grass *Anthoxanthum odoratum* (code F), Yorkshire Fog *Holcus lanatus* (code b), Gorse (code Gg) and Wild Strawberry *Fragaria vesca* (code W), along with three occasionals: Chickweed *Stellaria media* (code z), Woolly Thistle (code O) and Bearded Couch Grass *Elymus caninus* (code S), whilst on the opposite end of the first axis lie Rockrose (code Z), Meadow

Buttercup *Rananculus acris* (code u) and Blackthorn (code s), which tended not to be associated with the former group. On the second axis, the lowest scores come from the same three occasionals plus Hogweed *Heracleum sphondilium* (code a) and Dog Rose (code v). At the opposite end of this axis are Sweet Vernal Grass (code F), Bramble (code w), and Sweet Violet *Viola odorata* (Jj). The scrub plants (e.g. Pedunculate Oak, code t), with the exception of Hawthorn (code P), tend to occur on the fringes of the core set. False Brome (code H) has a slightly negative score on both axes and is most closely associated with Hogweed (code a), eyebrights *Euphrasia officinalis* s.l. (code T) and Meadow Vetchling *Lathyrus pratensis* (code e) within the core community. Plants not associated with False Brome include Wild Thyme *Thymus polytrichus*, Harebell *Campanula rotundifolia*, Common Rock-rose and Felwort. Common Spotted Orchid (code R) is associated with Goatsbeard *Tragopogon pratensis* (code Cc), Upright Brome *Bromopsis erecta* (code J), and Quaking grass (code l).

A plot of the first two DCA axes (scrub plants and False Brome not included) (Figure 4) shows similar sets of species associations. The mean occupancy of False Brome within a quadrat was significantly positively correlated with the DCA1 score for that quadrat (r_s = 0.44, n = 24, P = 0.03) but not any of the other DCA axis scores. The mean occupancy of Hawthorn within a quadrat was significantly positively correlated with the DCA2 score for that quadrat (r_s = 0.47, n = 24, P = 0.02) but not with any of the other DCA axis scores.

Figure 3. Non-metric Multidimensional Scaling (NMDS) plots of the plant communities sampled.

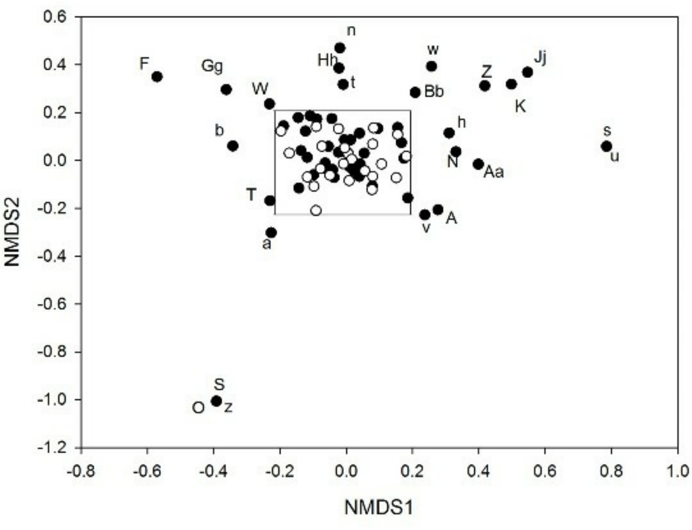

Figure 3a. Species (letter codes identified in Appendix 2) are filled circles and quadrats are open circles. The central box is the area plotted below.

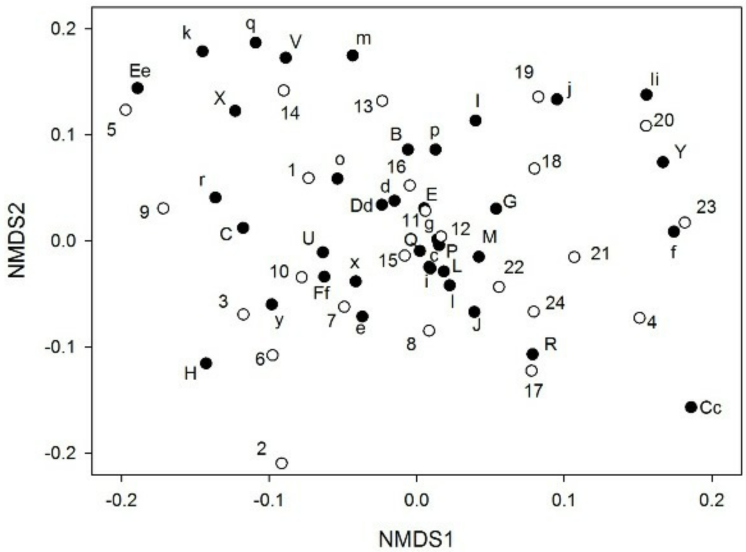

Figure 3b. The centre of the plot denoted by the box in Fig. 3a at a finer axis scale, with quadrats also identified by number used in Fig.1 and Appendix 1, and species identified by letter codes in Appendix 2.

Figure 4: Detrended Correspondence Analysis plot of the plant communities sampled, showing axes 1 and 2.

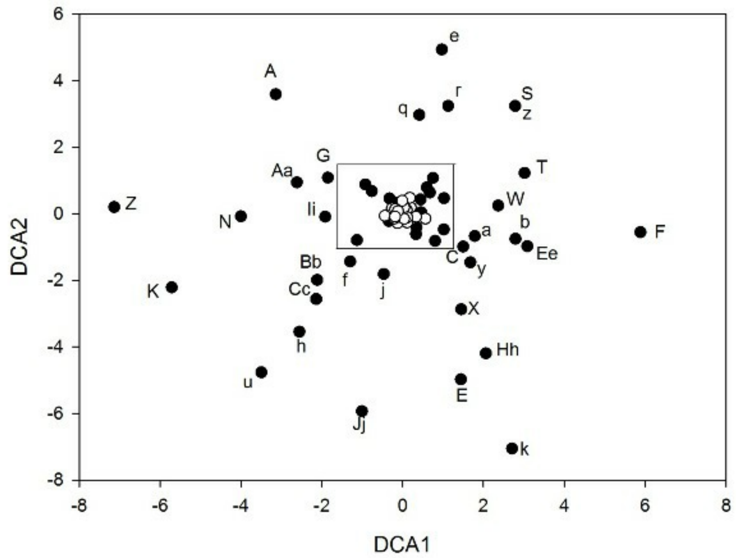

Figure 4a. Species letter codes identified in Appendix 2 are filled circles and quadrats are open circles. The central box is the area plotted below.

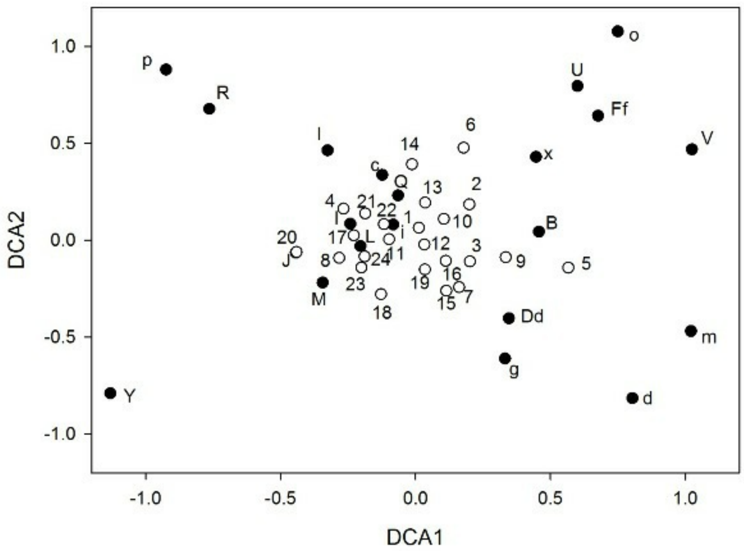

Figure 4b. The centre of the plot denoted by the box in Fig. 4a at a finer axis scale, with quadrats also identified by number used in Fig. 1 and Appendix 1, and species identified by letter codes in Appendix 2.

<u>Changes through time</u>

The 1m^2 quadrats varied in mean plant species richness from 16 to 23, with the lowest value in any year being 14 and highest 28, a two-fold difference (Appendix 3). A linear mixed effects model showed that richness per quadrat significantly increased slightly over time at a rate of about 0.2 species per year (F = 10.2, df = 1,36, P = 0.003) and differed amongst quadrats (F = 5.21, df = 23, 36, P < 0.001). Richness was not correlated with the occupancy of False Brome (r_s = -0.202, n = 24, P = 0.345) nor with the commonest scrub plant: Hawthorn (r_s = 0.387, n = 24, P = 0.062).

Simpson's diversity (1/D), calculated on occupancy within 1m^2 quadrats, varied from an average of 9.9 to 15.0 with the highest value in any year being 18.1 and lowest value 6.5 (Appendix 3), a nearly three-fold difference. A linear mixed effects model showed that diversity per quadrat increased slightly but significantly over time at a rate of about 0.2 units per year (F =22.68, df = 1,33, P < 0.001) and differed amongst quadrats (F = 6.31, df = 23, 11, P = 0.002). Simpson's index was not significantly correlated with either False Brome occupancy (r_s = -0.053, n = 24, P = 0.806) or the occupancy of the commonest scrub species (Hawthorn) (r_s = 0.173, n = 24, P = 0.418).

Weighted average Ellenberg nitrogen scores per quadrat varied from 3.1 to 3.6 across quadrats, with the highest annual figure being 3.9 and lowest 2.9 (Appendix 3). A linear mixed effects model showed a small but significant decline (0.01 units per year) in average nitrogen scores over time (F = 4.22, df = 1, 54, P = 0.045) and a significant difference between quadrats (F = 9.27, df = 23, 85, p < 0.001).

Quadrats varied considerably in their occupancy by False Brome, from zero in all years in one quadrat to a mean of over 21 in another, with 25 reached in at least one year by four quadrats (Appendix 3). A linear mixed effects model shows no significant effect of year on False Brome occupancy ($F = 0.341$, df = 1, 68, $P = 0.561$), though occupancy differed between quadrats ($F = 27.5$, df = 23, 92, $P < 0.001$). This suggests that the quantity of False Brome shows no overall trend from year to year, though it differs from place to place.

Quadrats varied in their woody scrub species occupancy from zero in all years in two quadrats to a highest average of 11.5, with the highest value reached in a single year being 20 (Appendix 3). Occupancies were square root transformed prior to analysis to normalize the variance. There was no significant effect of year on scrub species occupancy ($F = 2.803$, df = 1, 64, $P = 0.099$) but occupancy differed between quadrats ($F = 12.1$, df = 23, 110, $P < 0.001$). This suggests that the quantity of scrub shows no overall trend from year to year, though it differs from place to place.

Discussion

The data presented here do not suggest that False Brome or woody scrub plants have noticeably increased across the sampled area of Ellerburn Bank over the period investigated, but both groups of plants are well represented in the quadrats. The spread of woody scrub through succession to a woodland climax (Tansley, 1922) is a well-known reason for the loss, and reduction in quality, of calcareous grassland in Europe and requires careful management (Butuye *et al.*, *loc. cit.*). At Ellerburn Bank, two interventions are taken to reduce scrub invasion: winter grazing by sheep (Leadley & Richards, *loc. cit.;* YWT*, loc. cit.*) and less frequent cutting by hand. In addition, grazing by wild vertebrates such as deer and Rabbits *Oryctolagus cuniculus* occurs. The optimal level of scrub removal is hard to gauge. At Ellerburn Bank, the central area of pasture, including the area covered by the quadrats, is intended to be maintained as calcareous grassland, leaving scrub to the fringes of the reserve. Hence, it would probably be preferred if there were no scrub at all over the quadrated area. The fact that scrub maintains a noticeable and constant presence indicates that the current level of grazing should not be lowered in future, otherwise one could expect scrub to encroach more rapidly over the pasture, necessitating further targeted cutting activity in order to maintain the quantity of grassland. Higher levels of grazing may help reduce the problem of scrub encroachment from the fringes, but may harm flora less tolerant of grazing or trampling. The scrub around the fringes is tolerated as it provides wind shelter and a mosaic of taller vegetation, adding structural and biological diversity to the site that is necessary for many of the grassland invertebrates. Although the management plan (YWT*, loc. cit.*) calls for annual removal of parcels of scrub from the earthwork and south-eastern boundary, in practice such interventions have been less frequent, perhaps meaning that sources of scrub seeds that can encroach over the meadow are more numerous than would be ideal, and that the shorter-growth regenerating areas are actually encroaching onto the pasture rather than remaining around the fringes of the reserve.

One of the possible negative consequences of limited scrub invasion is that it facilitates the spread of coarse grasses, such as False Brome. This was one of the plants found to have significantly increased in calcareous grasslands in Dorset in recent decades (Newton *et al.*, 2011). Despite being abundant in our quadrats, this study provides no evidence for a recent increase on Ellerburn Bank. Nine years is a relatively short timescale compared to the timescale of decades on which Newton's study was based, and yet the data solidly reject any rapid increase but suggest that once established, False Brome does not inevitably continue to spread.

False Brome occupancy was significantly correlated with the first DCA axis (Fig. 4) whilst Hawthorn was significantly correlated with the second. This suggests that both are non-randomly distributed in relation to the other plants in the community. Non-random associations in space could be caused by a number of different factors, including proximity to a seed or vegetative growth source, establishment success and competitive exclusion of other plants. Since these studies were observational rather than experimental, it is difficult to distinguish these different possibilities, although competitive exclusion of stress-tolerating plants by competitors would be expected (Newton *et al.*, *loc. cit.*). NMDS (Fig. 3) suggests that False Brome tends not to be associated with several low-growing stress-tolerators such as Wild Thyme, Harebell, Common Rock-rose, Felwort and Rough Hawkbit but that it is more associated with Hogweed, Meadow Vetchling, Eyebright and Yellow Oat-grass. Whatever the causes of these associations, these data do suggest that potential winners and losers were the frequency of False Brome to either increase or decrease further, and they also suggest what is added and lost through allowing a certain quantity of False Brome to establish on site. Given that False Brome persists anyway around the scrubby fringes of the reserve, there is an argument for increasing the intensity of grazing and scrub removal to avoid further establishment of False Brome across the grassland at the expense of the shorter stress-tolerators.

Apart from scrub invasion, one further reason to expect increases in False Brome frequency is the deposition of atmospheric nitrogen leading to eutrophication (Newton *et al.*, *loc. cit.*, van den Berg *et al*., *loc. cit.*). Sampling from across the UK has shown that nitrogen deposition significantly predicts reductions in floral diversity and evenness and the absence of rare plants. Being on the North York Moors, Ellerburn Bank is expected to receive a high nitrogen deposition load, estimated at 20.4 $kgha^{-1}yr^{-1}$ in 2008 (data from the Centre for Ecology and Hydrology in van den Berg *et al*., *loc. cit.*). This is within the range of critical loads for adverse effects on calcareous grassland based on field experiments (Bobbink *et al.*, 2010). Comparisons of two long term quadrats on the bank between 1990 and 2008 showed a slight increase in Shannon diversity, a slight decrease in evenness and a slight reduction in richness (data from van den Berg *et al*., *loc. cit.,* courtesy of Leon van den Berg). The majority of managed sites in the UK with a similar nitrogen load actually increased in richness and evenness over the same time period, whilst several decreased (van den Berg *et al.*, *loc. cit.*, their Fig. 3), and those that increased tended to have a higher soil pH. In addition, those that experienced an increase in grazing pressure tended to experience reductions in their average Ellenberg nitrogen index. Ellerburn Bank is sited on shallow, free-draining alkaline soil and experienced an estimated increase in grazing pressure between 1990 and 2008 of approximately four times (data from van den Berg *et al*., *loc. cit.*). Grazing is likely to be the chief intervention responsible for the (slight) downward trajectory of the Ellenberg nitrogen scores shown in the present study, and this adds to the above arguments for at least maintaining the current level of grazing pressure. If, as expected, nitrogen deposition remains a problem in the future, grazing should probably be increased to compensate.

Part of the interest in maintaining the flora of the reserve is the conservation of the invertebrate community that depends on it. The butterflies have received most attention in this regard; a monitoring transect begun in 2010 (YWT*, loc. cit.*) showed that the most abundant species were Small White *Pieris rapae,* Green-veined White *Pieris napi* (ubiquitous species not relying on the calcareous grassland but visiting flowers such as Knapweeds and Scabious), Meadow Brown *Maniola jurtina* and Small Heath *Coenonympha pamphilus* (both grass feeders). Small Skipper is another common grass-feeder. Dingy Skipper and Common Blue are other abundant butterflies, and both rely on the Common Bird's-foot-Trefoil which our quadrats show to be one of the most abundant plants in the calcareous grassland. Common Rock-rose (supporting Brown Argus), Milkwort (supporting Small Purple-barred moth), and violets (supporting Dark Green Fritillary) are frequent but less dominant components of the community; both Common Rock-rose and violets are more common on the earthwork than in the area of our quadrats but management needs to take account of them given that these butterflies are less common on site and regionally. Should the Duke of Burgundy ever return to the vicinity, it will still find abundant Cowslips.

Taken together, our results suggest that current management of the calcareous grassland at Ellerburn Bank is currently sufficient to offset the deleterious effects of atmospheric nitrogen deposition, but a significant presence of woody scrub and False Brome persists, which is probably undesirable away from the reserve fringes. There is a case for more frequent scrub removal at the reserve fringes and increased grazing pressure on the grassland to prevent further encroachment of scrub and the effects of atmospheric nitrogen deposition. Intermittent monitoring will be necessary in future to gauge whether the current situation continues. To facilitate this, we have provided details of the permanent quadrat locations in Appendix 1, a summary of the species' occupancies from our survey in Appendix 2, and the average properties of the quadrats in Appendix 3. Future monitoring work could also specifically target the plant species of regional note (such as Fly Orchid and Woolly Thistle) which were not best surveyed using the present methods, but which should feature highly in management priorities.

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Appendix 1. Locations of permanent quadrats on Ellerburn Bank. Quadrat number refers to identities on the map in Fig. 1 and in Fig. 3b.

Quadrat Number	Latitude	Longitude
1	54°15'8.30"N	0°41'34.25"W
2	54°15'8.53"N	0°41'33.76"W
3	54°15'8.70"N	0°41'34.50"W
4	54°15'8.78"N	0°41'34.81"W
5	54°15'8.50"N	0°41'33.05"W
6	54°15'8.68"N	0°41'33.44"W
7	54°15'9.28"N	0°41'33.69"W
8	54°15'9.35"N	0°41'33.17"W
9	54°15'9.04"N	0°41'32.39"W
10	54°15'9.23"N	0°41'32.07"W
11	54°15'9.71"N	0°41'33.27"W
12	54°15'9.97"N	0°41'33.11"W
13	54°15'9.75"N	0°41'31.72"W
14	54°15'9.46"N	0°41'31.37"W
15	54°15'10.66"N	0°41'32.14"W
16	54°15'10.05"N	0°41'32.01"W
17	54°15'10.52"N	0°41'30.57"W
18	54°15'10.24"N	0°41'30.44"W
19	54°15'10.50"N	0°41'31.39"W
20	54°15'10.97"N	0°41'31.55"W
21	54°15'10.75"N	0°41'30.34"W
22	54°15'10.65"N	0°41'29.59"W
23	54°15'10.93"N	0°41'30.82"W
24	54°15'10.97"N	0°41'30.53"W

Appendix 2. Complete plant list and mean (SE) occupancy (out of 25) per quadrat. Species are assigned a letter code identifying them in the ordination plots (Figures 3 & 4).

Species (code)	**Mean Occupancy** (SE)	**Species (code)**	**Mean occupancy** (SE)	**Species (code)**	**Mean occupancy** (SE)
Achillea millefolium (A)	0.06(0.06)	*Filipendula vulgaris* (V)	0.77(0.34)	*Primula veris* (q)	1.95(0.65)
Agrimonia eupatoria (B)	2.56(0.45)	*Fragaria vesca* (W)	0.70(0.25)	*Prunella vulgaris* (r)	0.88(0.23)
Agrostis capillarum (C)	0.06(0.03)	*Galium verum* (X)	8.17(1.78)	*Prunus spinosa* (s)	0.01(0.01)
Agrostis stolonifera (D)	N/A	*Gentianella amarella* (Y)	0.87(0.20)	*Quercus robur* (t)	0.03(0.02)
Anacamptis pyramidalis (E)	0.02(0.01)	*Helianthemum nummularium* (Z)	0.08(0.06)	*Ranunculus acris* (u)	0.01(0.01)
Anthoxanthum odoratum (F)	0.03(0.03)	*Heracleum sphondylium* (a)	0.56(0.24)	*Rosa canina* (v)	0.20(0.13)

Anthyllis vulneraria (G)	1.76(0.52)	*Holcus lanatus* (b)	0.74(0.25)	*Rubus fruticosus* agg. (w)	0.06(0.04)
Brachypodium sylvaticum (H)	7.76(1.45)	*Knautia arvensis* (c)	12.72(0.56)	*Sanguisorba minor* (x)	16.96(1.44)
Briza media (I)	11.08(0.52)	*Koeleria macrantha* (d)	0.38(0.08)	*Scabiosa columbaria* (y)	0.19(0.07)
Bromopsis erecta (J)	8.44(0.99)	*Lathyrus pratensis* (e)	0.14(0.78)	*Stellaria media* (z)	0.01(0.01)
Campanula rotundifolia (K)	0.08(0.05)	*Leontodon hispidus* (f)	12.17(2.01)	*Taraxacum officinale agg.* (Aa)	0.13(0.05)
Carex flacca (L)	18.99(0.58)	*Linum catharticum* (g)	4.68(0.55)	*Thymus polytrichus* (Bb)	0.31(0.15)
Centaurea nigra (M)	10.23(0.90)	*Listera ovata* (h)	0.02(0.02)	*Tragopogon pratensis* (Cc)	0.05(0.02)
Centaurea scabiosa (N)	0.45(0.16)	*Lotus corniculatus* (i)	21.33(0.38)	*Trifolium pratense* (Dd)	7.86(0.84)
Cirsium eriophorum (O)	0.05(0.05)	*Medicago lupulina* (j)	0.15(0.04)	*Trifolium repens* (Ee)	0.85(0.54)
Crataegus monogyna (P)	1.93(0.43)	*Ophrys insectifera* (k)	0.03(0.02)	*Trisetum flavescens* (Ff)	3.10(0.39)
Dactylis glomerata (Q)	10.38(0.55)	*Pilosella officinarum* (l)	2.10(0.30)	*Ulex europaeus* (Gg)	0.10(0.06)
Dactylorrhiza fuschii (R)	2.46(0.44)	*Pimpinella saxifraga* (m)	0.92(0.24)	*Veronica chamaedrys* (Hh)	0.03(0.02)
Elymus caninus (S)	0.01(0.01)	*Pinus sylvestris* (n)	0.01(0.01)	*Viola hirta* (Ii)	1.99(0.52)
Euphrasia officinalis agg. (T)	0.13(0.77)	*Plantago lanceolata* (o)	3.63(0.65)	*Viola odorata* (Jj)	0.05(0.03)
Festuca rubra (U)	1.82(0.24)	*Polygala vulgaris* (p)	1.50(0.34)		

Appendix 3. Changes in the 1m^2 quadrats across years. Quadrats are identified by their number in Appendix 1. Numbers in each cell denote species richness, Simpson's diversity (1/D), occupancy weighted Ellenberg nitrogen score, False Brome occupancy, and woody scrub species occupancy.

Quadrat	2003	2004	2005	2008	2009	2011
1	21, 11.24, 3.85, 7, 4	23, 15.22, 3.43, 11, 7	21, 12.77, 3.59, 7, 5	24, 14.65, 3.48, 4, 6	24, 12.72, 3.40, 5, 7	22, 15.25, 3.41, 11, 7
2	17, 6.47, 3.50, 24, 4	17, 9.56, 3.66, 25, 4	21, 11.72, 3.63, 24, 3	21, 11.43, 3.35, 21, 8	17, 12.62, 3.69, 19, 7	19, 11.32, 3.67, 14, 9
3	19, 11.22, 3.67, 20, 0	17, 10.63, 3.41, 21, 0	21, 14.80, 3.57, 16, 0	21, 13.93, 3.48, 15, 0	22, 14.06, 3.54, 20, 0	20, 13.60, 3.43, 16, 0

4	22, 10.66, 3.44, 0, 11	20, 9.39, 3.15, 0, 10	18, 10.75, 3.41, 0, 10	19, 12.24, 3.19, 1, 11	24, 15.62, 3.43, 4, 20	23, 13.68, 3.35, 3, 7
5	23, 14.95, 3.61, 0, 7	23, 14.44, 3.49, 2, 3	20, 12.48, 3.55, 4, 3	26, 14.71, 3.31, 4, 2	19, 14.18, 3.62, 4, 4	23, 14.23, 3.41, 1, 3
6	22, 10.41, 3.60, 5, 3	23, 11.84, 3.38, 8, 2	22, 12.56, 3.65, 3, 2	20, 11.04, 3.65, 7, 2	24, 14.05, 3.39, 9, 2	25, 14.73, 3.64, 13, 2
7	21, 11.00, 3.49, 10, 0	17, 11.66, 3.11, 15, 0	21, 12.88, 3.47, 11, 0	20, 13.24, 3.24, 15, 0	13, 11.19, 3.36, 18, 0	18, 12.28, 3.29, 17, 0
8	17, 8.48, 3.44, 22, 0	17, 9.65, 3.15, 25, 0	19, 12.57, 3.42, 17, 0	21, 12.78, 3.42, 19, 0	18, 11.18, 3.23, 20, 1	23, 12.66, 3.31, 23, 1
9	19, 11.37, 3.29, 22, 1	15, 9.29, 3.36, 25, 3	21, 12.76, 3.50, 23, 4	22, 13.56, 3.32, 15, 4	21, 12.51, 3.29, 18, 2	15, 11.52, 3.42, 21, 3
10	26, 15.54, 3.40, 24, 1	17, 10.34, 3.40, 25, 0	22, 13.78, 3.31, 6, 1	18, 12.36, 3.11, 8, 0	16, 10.82, 3.33, 10, 1	20, 12.56, 3.44, 10, 1
11	26, 16.19, 3.47, 10, 1	19, 10.69, 3.14, 8, 0	18, 11.81, 3.64, 8, 0	19, 13.39, 3.55, 17, 1	25, 17.65, 3.33, 10, 2	23, 13.84, 3.44, 12, 1
12	21, 10.86, 3.27, 1, 2	20, 10.87, 3.21, 2, 2	24, 15.60, 3.40, 4, 0	25, 15.15, 3.37, 9, 4	17, 11.57, 3.68, 1, 0	20, 11.78, 3.42, 2, 1
13	21, 13.65, 3.24, 1, 0	24, 17.07, 3.01, 3, 0	22, 13.76, 3.10, 0, 0	22, 13.85, 2.94, 4, 1	16, 10.82, 3.33, 10, 1	22, 14.73, 2.97, 0, 2
14	24, 15.09, 3.34, 2, 2	21, 12.70, 3.35, 0, 2	25, 12.61, 3.58, 0, 0	28, 16.90, 3.74, 19, 5	16, 9.93, 3.43, 1, 0	20, 14.08, 3.71, 4, 2
15	18, 11.61, 3.17, 0, 0	18, 12.54, 3.23, 0, 2	19, 11.51, 3.41, 0, 0	21, 13.05, 3.28, 7, 0	19, 11.10, 3.15, 1, 0	20, 11.88, 3.17, 4, 3
16	20, 11.79, 3.31, 8, 0	24, 15.48, 3.31, 14, 2	28, 16.54, 3.31, 7, 4	26, 18.09, 3.35, 10, 2	19, 13.49, 3.35, 18, 3	25, 14.73, 3.23, 15, 1
17	16, 9.48, 2.97, 7, 2	16, 9.63, 3.23, 7, 1	15, 9.10, 3.36, 3, 0	16, 10.89, 3.31, 0, 3	14, 10.12, 2.95, 5, 0	19, 9.96, 2.91, 2, 1
18	20, 11.42, 3.26, 14, 1	22, 12.62, 3.09, 1, 0	26, 15.87, 3.45, 9, 1	21, 12.64, 3.23, 8, 1	20, 11.88, 3.14, 7, 1	23, 15.44, 3.20, 10, 2
19	20, 10.82, 3.16, 0, 3	20, 11.57, 3.08, 0, 7	28, 17.39, 3.38, 0, 3	21, 10.98, 2.98, 1, 1	20, 13.22, 3.14, 0, 5	27, 12.08, 3.04, 0, 4
20	24, 11.78, 3.21, 0, 4	21, 12.78, 3.42, 0, 4	16, 11.02, 3.47, 0, 3	25, 15.56, 3.35, 0, 5	20, 12.73, 3.15, 0, 4	24, 14.63, 3.10, 0, 6
21	14, 8.85, 3.42, 2, 1	20, 12.25, 3.36, 3, 5	25, 12.79, 3.01, 6, 1	21, 13.91, 3.46, 0, 6	21, 12.16, 3.33, 1, 5	19, 12.30, 3.17, 1, 0
22	22, 12.47, 3.55, 7, 2	19, 10.53, 3.54, 5, 2	20, 12.07, 3.66, 6, 3	20, 11.39, 3.17, 7, 0	21, 13.24, 3.47, 9, 0	24, 14.38, 3.47, 10, 0
23	19, 10.04, 3.30, 0, 0	17, 10.13, 3.20, 0, 3	23, 12.10, 3.46, 2, 0	24, 12.97, 3.38, 0, 0	18, 10.00, 3.24, 1, 0	19, 12.35, 3.16, 0, 1
24	21, 10.45, 3.03, 0, 0	16, 9.59, 2.87, 0, 0	20, 12.02, 3.21, 0, 0	17, 12.42, 3.12, 5, 0	15, 10.04, 3.10, 0, 2	19, 11.27, 3.03, 0, 1

Plate I. Ellerburn Bank. See pp 96-111.

Above left (a): View of the sward looking south. Visible are Common Spotted Orchids, Common Bird's-foot-trefoil, Salad Burnet, Upright Brome, Quaking Grass and Cock's-foot.

Above right (b): Looking east along the reserve, a patch of invading scrub, mainly Hawthorn, surrounded by the wide yellow leaves of False Brome.

Below left (c): Gorse invading the south-eastern part.

Below right (d): View of the sampled area at Ellerburn Bank, looking north-east. Small Hawthorn and Gorse bushes are visible in the grass, with yellow patches of False Brome.

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