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Upper Teesdale: changes in upland hay meadow vegetation over the past twenty to thirty years - results presented from botanical surveys

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Upland hay meadows are one of the rarest grassland types in the UK. Upper Teesdale holds some of the best examples of MG3b *Anthoxanthum odoratum - Geranium sylvaticum* upland hay meadow habitat and has been well studied over the years. The resulting botanical data has never been gathered into one place.

The use of inorganic fertiliser on grasslands increased greatly during the 20th century and is now widespread. Where permitted it is applied on meadows and grasslands in Upper Teesdale, sometimes alongside farmyard manure (FYM), and there is a perception amongst some landowners that higher levels of nutrients are required to maintain botanical quality under the cold and wet climate of the area.

This project was designed to collate the existing botanical data for upland hay meadows in Upper Teesdale and relate this to management information, especially inorganic fertiliser use. The findings will be used to advise on the future management of hay meadows and SSSIs. They will also be taken into consideration in the future development of agri-environment schemes.

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Further information
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2. Abstract

Upland hay meadows are one of the rarest grassland types in the UK. Upper Teesdale holds some of the best examples of MG3b *Anthoxanthum odoratum - Geranium sylvaticum* upland hay meadow habitat and has been well studied over the years. The resulting botanical data has never been gathered into one place. The use of inorganic fertiliser on grasslands increased greatly during the 20th century and is now widespread. Where permitted it is applied on meadows and grasslands in Upper Teesdale, sometimes alongside farmyard manure (FYM), and there is a perception amongst some landowners that higher levels of nutrients are required to maintain botanical quality under the cold and wet climate of the area. This project was designed to collate the existing botanical data for upland hay meadows in Upper Teesdale and relate this to management information, especially inorganic fertiliser use. The results presented here show that overall Upper Teesdale upland hay meadows have declined in botanical quality over the past twenty to thirty years. Agri-environment schemes have not maintained the botanical quality of Upper Teesdale upland hay meadows, although the best meadows are found in SSSIs that have been in management agreements. The findings of this study suggest that the declines in botanical quality may be associated with increases in soil fertility, as indicated by significant increases in Ellenberg fertility indices (N) and SS-Nutrient scores between the baseline and recent surveys for the majority of meadows. As a consequence we recommend that a precautionary approach should be applied to nutrient additions, either in the form of FYM or inorganic fertiliser in order to maintain and enhance botanical quality. The priority for conservation management action should be the SSSI meadows that have been in management agreements and these meadows should receive very low nutrient inputs - no inorganic fertilisers and very low applications of FYM. The effectiveness of changes in nutrient management should be assessed by careful monitoring.

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- The upland hay meadows of Upper Teesdale are the most species-rich in the country. The best examples of MG3b *Briza media* sub-community habitat are found here. This area is of high conservation importance and as such has been designated as a Site of Special Scientific Interest (SSSI), Special Area Of Conservation (SAC) and Special Protection Area (SPA).

- Studies have shown that traditional farm management is important in maintaining the botanical quality of upland hay meadows. Agri-environment schemes aim to encourage farmers to adhere to traditional management practices: hay making is preferred; later cutting dates are implemented; farmyard manure (FYM) applications of up to 12t/ ha^{-1} /yr are allowed; inorganic fertiliser use is restricted; stocking densities are controlled and shutting-up dates (the date at which livestock are removed from the meadows to allow the hay crop to grow) are brought forward.

- The use of inorganic fertiliser increased greatly during the 20th century and its use has resulted in reduced species richness and diversity in all semi-natural grasslands where this has been measured.

- It has been suggested that the high elevation (above 300m), high rainfall and cold temperatures found in Upper Teesdale require the management of upland hay meadows to be different to that elsewhere in the North Pennines and other parts of the UK. There is an assertion that higher levels of nutrients, in the form of inorganic fertiliser, need to be added to these meadows in order to maintain and sustain botanical diversity and yields and to prevent the spread of rushes.

- This project was designed to gather together all available botanical data for upland hay meadows in Upper Teesdale and relate this to management information. The aim of the project was to capture, store, manipulate, analyse and manage data relating to upland hay meadows in Upper Teesdale and present this in a geographic information system (GIS). The data was analysed in order to answer these questions:
  1) Have Upper Teesdale upland hay meadows declined in botanical quality over time?
  2) Have agri-environment schemes maintained the botanical quality of Upper Teesdale upland hay meadows?
  3) Is there any evidence to suggest that inorganic fertiliser use is an acceptable management option for Upper Teesdale upland hay meadows in order to maintain and sustain botanical quality?

- After collating botanical survey data from meadows in Upper Teesdale, repeat surveys of the same meadow were identified and examined to see whether any meaningful comparisons could be made. Ninety-eight pairs of meadows were identified with a comparable baseline survey and latest survey.

- A set of derived variables was calculated from the botanical data: number of grasses, number of wildflowers, number of species, Shannon diversity index (H'), positive indicator species score (P+), negative indicator species score (N-), total meadow score (TM); Ellenberg fertility index (N); SS-Nutrient score; Ellenberg moisture index (F); SS-Moisture score; Ellenberg pH index (R) and fit to the National Vegetation Classification (NVC).

- A selection of common key indicator species was chosen from the botanical data to investigate in closer detail.

- Management data was collated for meadows in Upper Teesdale. Information was gathered on type and length of management agreements, SSSI designations and number of years of inorganic fertiliser applications. Documented information on cutting times, length of spring grazing, rates of FYM and inorganic fertiliser applications was limited. Therefore the analysis was restricted to investigating differences in management agreements and number of years of inorganic fertiliser applications.

- Soil data was collated from 43 meadows in Upper Teesdale, the earliest dating from 2002.

- For data analysis, Upper Teesdale meadows were grouped in various ways as follows:

    a. The Upper Teesdale meadows were grouped into two, depending on differences in their management agreements:
        1) Meadows were either SSSI that had been in targeted SSSI Management Agreements (MA) or in Wildlife Enhancement Schemes (WES) that stipulated only FYM applications of up to 12t/ ha^{-1} /yr and no inorganic fertiliser additions (51 meadows)
        2) Meadows were SSSI and managed as ESA Tier 1, or non SSSI meadows and managed as ESA Tier 1. Meadows managed as ESA Tier 1 can have applications of inorganic fertilisers (47 meadows)

    b. The Upper Teesdale meadows were grouped into two, depending on differences in historic inorganic fertiliser inputs:
        1) Either meadows only received FYM applications before the baseline survey period (27 meadows) or;
        2) Meadows received FYM applications *and* inorganic fertiliser inputs before the baseline survey period (71 meadows).

    c. The Upper Teesdale meadows were grouped into five different categories depending on how many years inorganic fertilisers had been applied:
        1) 1st category: only FYM and never received inorganic fertiliser inputs (15 meadows)
        2) 2nd category: FYM and 3 – 6 years inorganic fertiliser inputs (13 meadows)
        3) 3rd category: FYM and 7 – 10 years inorganic fertiliser inputs (16 meadows)
        4) 4th category: FYM and 11 - 19 years inorganic fertiliser inputs (16 meadows)
        5) 5th category: FYM and 20+ years inorganic fertiliser inputs (38 meadows)

- The differences in derived variables, differences in key indicator species, differences between groups and changes between the baseline and latest surveys were analysed using analysis of variance (ANOVA GLM), paired sample t-tests, redundancy analysis (RDA) and regression.

- *Upper Teesdale upland hay meadows have significantly declined in botanical quality.* Botanical quality (referring to the positive indicator species score and total meadow score) has significantly declined by 40%. Botanical quality has declined in 64% of upland hay meadows over the last 20 to 30 years, whilst 15% have stayed the same and the remaining 21% have increased in botanical quality. In the majority of meadows, number of species, Shannon diversity index (H'), positive indicator species score (P+) and total meadow score (TM) have significantly declined.

- The frequency of species indicative of MG3 and MG8 (*Cynosurus cristatus - Caltha palustris* wet upland hay meadow) has significantly declined: Lady's-mantle, bugle, quaking grass, common knapweed, pignut, meadowsweet, wood crane's-bill, rough hawkbit, devil's-bit scabious, great burnet and globeflower, whilst other mesotrophic grassland species have increased: Yorkshire fog, perennial rye-grass, creeping buttercup, eyebright, hay rattle and lesser trefoil.

- Soft rush has been found to have slightly increased in frequency across Upper Teesdale meadows, whilst sharp-flowered rush appears to favour the wetter meadows that have had less nutrient inputs in both the baseline and the latest surveys. Sharp-flowered rush has not significantly increased.

- Upper Teesdale upland hay meadows are generally increasing in Ellenberg fertility index and SS-Nutrient score. Previous studies have shown that factors such as intensive spring grazing can increase Ellenberg indices in addition to increases in nutrients.

- There has been no significant increase in Ellenberg moisture index, SS-Moisture scores or Ellenberg pH index across all Upper Teesdale upland hay meadows. Although, some meadows appear to be getting wetter, an equal number have become drier. Meadows in the 2nd fertiliser use category seem to be wetter, with lower fertility and higher moisture scores with greater frequency of some wet loving species such as sharp-flowered rush.

- *Agri-environment schemes have not maintained the botanical quality of Upper Teesdale upland hay meadows.* SSSI meadows that have been in a MA or WES have greater botanical quality than meadows which have been managed as ESA Tier 1, although the targeted management has not prevented SSSI meadows from declining. Number of grasses, number of species, Shannon diversity index, positive indicator species score and total meadow score significantly declined in both SSSI meadows that have been in a MA or WES and meadows managed as ESA Tier 1.

- SSSI meadows that were managed in a MA or WES are now the remaining remnants of good MG3/MG8 upland hay meadows, where species such as bugle, Lady's-mantle, quaking grass, marsh marigold, common knapweed, wood crane's-bill, rough hawkbit, ragged robin, great burnet, devil's-bit scabious and globeflower are found.

- Many of the MG3/MG8 indicator species are found in extremely low frequencies in meadows managed as ESA Tier 1. Number of grasses, and species such as creeping buttercup and Yorkshire fog are found in greater frequencies in meadows managed as ESA Tier 1 in comparison to SSSI meadows that have been in a MA or WES. These species are indicative of higher nutrient levels.

- Upper Teesdale SSSI meadows that have been in a MA or WES have lower fertility scores and higher moisture scores than meadows which have been managed as ESA Tier 1.

- Upper Teesdale upland hay meadows that have only received FYM applications in the past have greater botanical quality than meadows that have received historic inorganic fertiliser additions.

- There is a positive association between the length of time that inorganic fertilisers have been added to meadows and declining botanical quality. Lady's-mantle is now restricted to meadows that have only received FYM applications and species such as bugle, quaking grass, common knapweed, rough hawkbit, great burnet, devil's-bit scabious and globeflower show a preference for meadows that have received inorganic fertiliser additions for less than ten years. Perennial rye-grass, creeping buttercup and Yorkshire fog have increased in Upper Teesdale meadows that have received long-term inorganic fertiliser inputs.

- *This report has not found any evidence to suggest that inorganic fertiliser use is an acceptable management option for Upper Teesdale upland hay meadows in order to maintain and sustain botanical quality.* There is a positive association between the length of time that inorganic fertilisers have been added to meadows and increasing fertility scores. There is also a positive correlation with soil phosphorous levels and the Ellenberg fertility index.

- Redundancy analysis shows declining botanical quality over time was associated with increasing fertility scores, higher phosphate levels and long-term inorganic fertiliser use. Species such as orchids, sedges and rare wildflowers are now found infrequently in the latest surveys.

- Nutrient levels could be increasing in meadows since inorganic fertiliser use has become commonplace in agriculture. The use of inorganic fertiliser has been shown by many studies to reduce botanical quality in lowland and upland grasslands. FYM has a high nutrient content, especially phosphorous, and is added to most of the meadows. FYM and inorganic fertilisers are broadly equivalent; both add nutrients and levels should be controlled to prevent nutrient enrichment. SSSI meadows that have been in a MA or WES have received little in the way of inorganic fertilisers, if these meadows have increased in fertility it may be due to the high phosphorous content of FYM. Studies have shown that atmospheric nitrogen deposition is increasing globally. Such studies have shown a correlation between nitrogen deposition and the botanical quality of grassland suggesting that inorganic fertiliser use could be reduced as nitrogen deposition is increasing.

- There are many other factors that could have contributed to the observed decline in botanical quality. Studies have shown agricultural practices may act in combination and as a consequence it is difficult to implicate any one individual management practice with declines. Intensive spring grazing for long periods of time can reduce species richness and diversity; a shift from hay making to silage production can quickly reduce wildflowers and increase the number of grasses; earlier cutting times can reduce the abundance of later flowering plants, sowing grass seeds changes the botanical composition. In combination with increases in nutrients, these practices can rapidly reduce botanical quality. However, the relative contribution of these interacting factors could not be explored in this study due to a lack of comprehensive documented information.

- Major declines in botanical quality have been identified. This report highlights issues concerning the use of inorganic fertilisers for long periods of time and has shown major declines in botanical quality. Clearly, changes in farm management have taken place that are now affecting one of the last remaining strongholds of upland hay meadows in the UK.

4. Introduction

The conservation of species-rich semi-natural grasslands in the UK has become an increasing priority in recent years owing to huge declines in the extent of these habitats (Blackstock *et al.* 1999; Jefferson, 2005). Many lowland grasslands have been replaced by arable fields; whilst agricultural intensification to increase yield and productivity in grasslands has reduced plant species diversity (Fuller 1987; Blackstock *et al.* 1999; Hodgson *et al.* 2005; Jefferson 2005). Modern agriculture involves more efficient machinery, a switch from hay to silage production, re-seeding with productive grasses, addition of inorganic fertilisers, changes in spring and autumn grazing and earlier cutting dates. In combination, these factors can lead to substantial changes in the species composition of grasslands over time (Smith and Jones 1991; Smith and Rushton 1994; Kirkham and Tallowin 1995; Smith *et al.* 1996b; 2000; 2008; Kirkham *et al.* 2007; Critchley *et al.* 2007).

Upland hay meadows corresponding to the National Vegetation Classification community *Anthoxanthum odoratum – Geranium sylvaticum* (MG3) (Rodwell, 1992) are one of the rarest grassland types in the UK. They are characterised by high plant species diversity, most notably the sub-community MG3b *Briza media* with an average of 35 species per $2m^2$ (Rodwell, 1992). Due to their rich biodiversity and the presence of scarce plants they are recognised as a 'priority habitat' in England (ie they are listed as a habitat of principal importance under section 41 of the Natural Environment and Rural Communities Act 2006) and as an Annex 1 habitat under the EC Habitats Directive 6520 (Northern Hay Meadows - British types with *Geranium sylvaticum*).

Several scarce wild flower species are found in this grassland type that are not found in other grasslands in the UK, notably Lady's-mantles (*Alchemilla vulgaris* agg.), globeflower (*Trollius europaeus*) and melancholy thistle (*Cirsium heterophylum*). Estimates of the remaining extent of the community range from 750 - 1,100 ha (Blackstock *et al.,* 1999; Jackson and McLeod, 2000). These are likely to be over-estimates. The core resource is now confined to the upland valleys of County Durham, Northumberland, Cumbria, North Yorkshire and Lancashire (Jefferson, 2005; Pacha and Petit, 2008). Of this, the upper valleys of the North Pennines are a major stronghold.

A number of studies have demonstrated the importance of traditional farm management in maintaining the plant species diversity of upland hay meadows (Smith and Jones 1991; Smith and Rushton 1994; Smith *et al.*, 1996b; Pacha and Petit, 2008; Kirkham *et al*. 2007; Critchley *et al.* 2007). Traditional farm management includes additions of low inputs of nutrients in the form of farmyard manure (FYM), no inorganic fertilisers, a variable hay-cut date extending from July to September, autumn grazing with cattle and spring grazing with sheep (Smith *et al.*, 1996b; Jefferson, 2005). In 1987, the Pennine Dales Environmentally Sensitive Area (ESA) was established. The ESA scheme was superseded by the Higher Level Stewardship (HLS) Scheme in 2005. Both ESA and HLS were introduced to encourage farmers to maintain, enhance and restore beneficial agricultural practices, thus safeguarding areas of particularly high landscape, wildlife or historic value. Since the late 1980s, farmers in the North Pennines have been invited to enter agri-environment schemes with defined management prescriptions on a voluntary basis. The scheme prescriptions for upland hay meadows aim to maintain the floristic diversity of meadows or enhance those that had previously declined through agricultural intensification or lack of management (Smith 1988; Critchley *et al.*, 2003). Payments are made to participating farmers for adopting prescribed beneficial farming practices. Despite the existence of these schemes, the plant species diversity of upland hay meadows in the Pennine Dales continued to decline into the 21st century (Critchley *et al.* 2007)

The use of inorganic fertiliser increased greatly during the 20th century and its use has resulted in reduced species richness and diversity in all semi-natural grasslands where it has been measured (i.e. Thurston 1969; Mountford *et al.* 1993; Marrs 1993; Janssens *et al.* 1998; Jones and Hayes 1999; Smith *et al.* 1996 a, b; 2000; 2008; Stevens *et al.* 2004; White *et al.* 2004). An increase in soil fertility favours competitive, fast-growing species which dominate the sward and inhibit establishment of less competitive species (Wells *et al.* 1989; Grime 2001; Smith *et al.* 1996 a, b; 2000; 2008; White *et al.* 2004).

A field-trial, running from 1990 – 2004, at Colt Park, Ingleborough National Nature Reserve, concerned a semi-improved *Lolium perenne* – *Cynosurus cristatus* (MG6) upland hay meadow habitat at an altitude of 300m. During this experiment, different combinations of traditional management practices were trialled, along with more modern methods. The use of inorganic fertiliser was found to reduce plant species diversity: a decrease in wildflowers was accompanied by an increase in competitive grasses. The 'no fertiliser' input regime resulted in the greatest number of wildflowers; however, when fertiliser input was stopped, plant species diversity did not increase straightaway (Smith *et al.* 1996b, Smith *et al.* 2008). Persistent residual soil fertility is an issue, particularly in the case of phosphorus, and this is likely to enable competitive grasses to continue to dominate (Janssens *et al* 1998; Hejeman *et al.* 2007; Smith *et al.* 2008). A further four year field-trial took place at Gillet farm in Upper Teesdale (1989 – 1993), also at 300m altitude. This concerned a species rich *Anthoxanthum odoratum* – *Geranium sylvaticum* (MG3b) upland hay meadow habitat and a number of combinations of management practices were investigated. The use of inorganic fertiliser was found to reduce plant species diversity and increase the cover of the grasses perennial rye-grass (*Lolium perenne*) and Yorkshire fog (*Holcus lanatus*) (Smith *et al.* 1996a).

In 1963, a large site within the North Pennines was declared a Site of Special Scientific Interest (SSSI): Upper Teesdale SSSI. At this time, SSSI status did not offer any protection to habitats. With the adoption of the Wildlife and Countryside Act (1981), SSSIs were afforded statutory protection. Land owners with SSSIs were required to notify the Nature Conservancy Council before any work could be carried out that may damage the habitats. In the 1980s, Upper Teesdale was extensively surveyed, and re-notification of the SSSI in 1990 led to an enlargement of the total area of the designated site. The Upper Teesdale SSSI now covers 14,365 ha and comprises an extensive upland area, containing a number of nationally rare habitat types (Hedley 2003). However, changes over the last 40 years as a result of more modern farming practices, including the application of inorganic fertilisers, have resulted in 'fewer herb-rich meadows of the old sort' and indications that 'Globeflower is much rarer than in former times' (Bradshaw 1965; 2003; Hedley 2003).

The upland hay meadows in Upper Teesdale are the most species-rich in the country (Bradshaw 1965; 2003; Bellamy 1965; Hedley 2003). The best examples of MG3b habitat are found here. This area is therefore of high conservation importance. These habitats depend on beneficial farm management, but for farming to continue, it must be economically viable. Although field experiments at Colt Park and Gillet farm were conducted in upland hay meadows above 300m and Gillet farm is in Upper Teesdale (Smith *et al.* 1996a, Smith *et al.* 1996b), there is a view that not enough is known about the upland hay meadows in Upper Teesdale. It has been suggested by several farmers that the high elevation, high rainfall and cold temperatures found in the dale make the required management of upland hay meadows different to that elsewhere in the North Pennines and other parts of the UK. It has also been suggested that the results from long-term grassland experiments undertaken in recent decades do not apply to the Upper Teesdale situation. It has been asserted that higher levels of nutrients, in the form of inorganic fertiliser, need to be added to these meadows in order to maintain and sustain diversity and yields and to prevent the spread of rushes.

Objectives

In discussion with Upper Teesdale farmers, Natural England identified the need for an exercise to collate and analyse botanical survey data and hay meadow management information. This exercise would enable the overall status of upland hay meadows in Upper Teesdale to be assessed and would provide area-specific information to guide decision-making on the future management of upland hay meadows.

The aim was to create an electronic spreadsheet/database from data gathered from botanical surveys and farm management information of Upper Teesdale upland hay meadows. This spreadsheet would be used to create an accompanying Geographical Information System (GIS) and analysed in order to answer the following questions:

1) Have Upper Teesdale upland hay meadows declined in botanical quality over time?

2) Have agri-environment schemes maintained the botanical quality of Upper Teesdale upland hay meadows?

3) Is there any evidence to suggest that inorganic fertiliser use is an acceptable management option for Upper Teesdale upland hay meadows in order to maintain and sustain botanical quality?

5. Methodology

5.1 Site description

Upper Teesdale stretches from the source of the Tees near Cross Fell, along the valley to Middleton-in-Teesdale (Bradshaw 1965; 2003). This is a large dale, encompassing a multitude of habitats, from upland hay meadows to woodlands and peatlands. This project was designed to look at upland hay meadows found at the highest altitudes, where information had not been previously collated. In order to collate the most comprehensive dataset possible during a two month period, the upland hay meadows in 'upper' Upper Teesdale were chosen – those found above 300m (1000ft). For the purposes of this report, 'Upper Teesdale' refers to the area up-stream of High Force waterfall, through Langdon Beck and into Harwood-in-Teesdale, where the highest altitude meadows are found (Figure 1 and Figure 2).

5.2 Botanical data collation

Upper Teesdale is renowned for its diverse upland hay meadows and has been well studied over the last sixty years. Many people have taken an interest in the botany, history and management of the upland hay meadows; however, this information has never been collated. The aim of the first part of the project was to gather together all the botanical surveys that have been undertaken in Upper Teesdale. It took two months to collate the surveys and they are listed here:

1. Dr Margaret Bradshaw surveyed 14 quadrats (0.5m x 0.5m) in meadows in Teesdale and Weardale in the 1950s and published a paper presenting the results in 1962. The quadrats measured percentage cover (%) (Bradshaw 1962).

2. Wells (undated) undertook a number of miscellaneous grassland surveys in the 1960s, 1970s and 1980s, some of which were in Upper Teesdale. These were mainly species lists, with some frequency measures (Wells undated).

3. Sandra Lye, 1977, completed her master's thesis on upland hay meadows; this included a survey of 130 meadows in Upper Teesdale. These surveys included a full species list but no frequency data (Lye 1977).

4. Hopkins and Blakemore, 1982, undertook over 100 surveys in Teesdale; these comprised quick indicator species lists with frequency indicated (DAFOR - Dominant, Abundant, Frequent, Occasional, and Rare). These were not used in this study as the species lists were too short (Hopkins and Blakemore 1982).

5. Jones (1984) completed a PhD thesis on Upper Teesdale upland hay meadows and undertook many detailed 1m x 1m quadrats across a few upland hay meadows, measuring percentage cover (%) (Jones 1984).

6. Dr M. V. Prosser and a few other surveyors undertook 100 upland hay meadow surveys in 1984 and interviewed Upper Teesdale farmers. Prosser wrote comprehensive habitat descriptions of each meadow, including information on general FYM applications and inorganic fertiliser inputs. Each survey had a comprehensive species list with an assessment of plant frequency using DAFOR (Prosser *et al.* 1988a).

7. In 1988, Prosser *et al.* went back and surveyed around 30 of these meadows in more detail, including the use of 1m x 1m quadrats, measuring percentage cover (%) (Prosser *et al.* 1988b).

8. In 1988, 26 meadows from farms that were entering the ESA scheme (Environmentally Sensitive Area) were surveyed. On each meadow, 5 fixed quadrats were placed and the plant species and frequencies were recorded on a 5 point scale (5 = dominant, 4 = abundant, 3 = frequent, 2 = occasional and 1 = rare). The same quadrats were monitored over a number of years, up until 2002. The data was retrieved from AEMA (Agri-Environment Monitoring Archive) at Natural England.

9. SSSI meadows began to be surveyed from about 1999/2000 up until present. Each survey consists of a description of the condition of the meadow, with a list of the key indicator species and a frequency score (usually 5 = dominant, 4 = abundant, 3 = frequent, 2 = occasional and 1 = rare). There are 60 SSSI Meadows in Upper Teesdale. The paper survey forms were archived in the 'yellow monitoring files' now held off-site by TNT, these have now been scanned and are available electronically. Further electronic copies are stored on the 'S' drive at Natural England and electronic information is kept in the database 'ENSIS'.

10. The North Pennines AONB Partnership began surveying meadows in Upper Teesdale in 2006 and continues to do so. Ninety-seven meadows have been surveyed in Upper Teesdale through the AONB Partnership's Hay Time project. These surveys take 45 minutes to complete and consist of a full species list with frequency scores (5 = dominant, 4 = abundant, 3 = frequent, 2 = occasional and 1 = rare) and percentage cover estimates (%) (Figure 1).

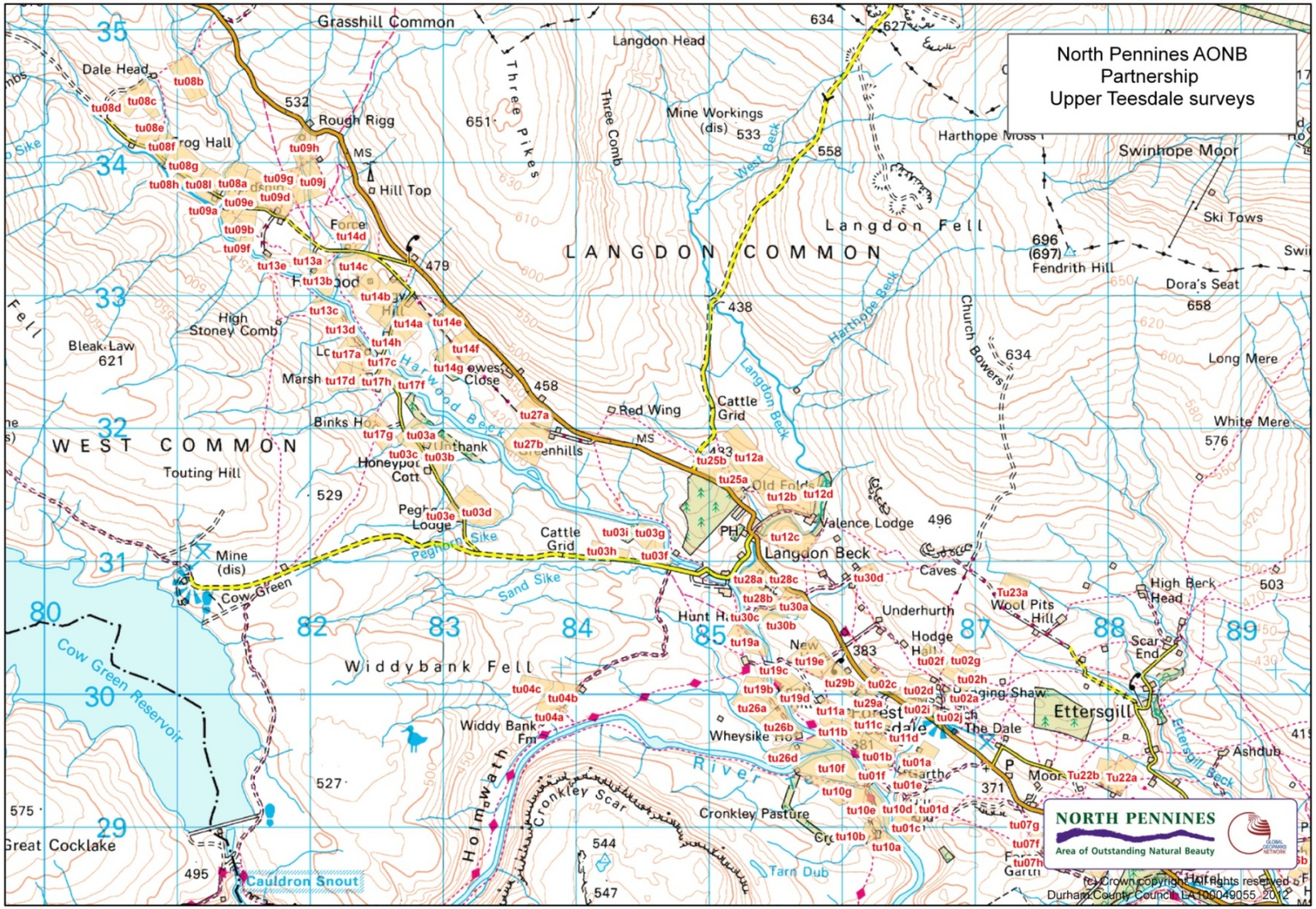

Figure 1. GIS map layer showing the surveys undertaken by the North Pennines AONB Partnership in Upper Teesdale; individual survey plots are indicated by the red label codes (tu…).

5.3 Matching up botanical surveys: Matched pairs

Once the surveys had been collated, a spreadsheet was created recording the details of each farm, meadow and corresponding survey. The spreadsheet was interrogated in order to identify meadows that had repeat surveys over time. Each repeat survey was checked against earlier surveys to see if any meaningful comparisons could be made – could the first survey (‘*the baseline survey*’) be compared to one of the later surveys? For example, of the 100 surveys undertaken by Prosser *et al.* (1988a) - ‘*the baseline survey*’ - a number of the same meadows had also been surveyed by the North Pennines AONB Partnership - ‘*the latest survey*’. Once the surveys had been matched into pairs of baseline and latest surveys, they were input to an Excel spreadsheet. Plant species information was corrected for nomenclature following Stace (2010). It took one month to match the pairs and input the data.

Ninety-eight pairs of meadows were identified with a comparable baseline and latest survey. Each meadow pair was carefully inspected, and the two sets of botanical data evaluated to determine whether direct comparison was possible, or if the data required further manipulation or transformation to enable valid comparison. For example, the Prosser surveys and the North Pennines AONB Partnership surveys paired up well as both surveys were comprehensive species lists with frequency recorded in a five-point scale (where 1 = rare, 2 = occasional, 3 = frequent, 4 = abundant, 5 = dominant). Thirty-eight pairs of meadows compared well with similar survey methodology.

The ESA monitoring data was compared, giving a further 26 matched pairs of data. The quadrat data for the baseline surveys (1988) and the quadrat data for the latest surveys (2002) were averaged to give one species list per meadow and an averaged 5 point scale of frequency (where 1 = rare, 2 = occasional, 3 = frequent, 4 = abundant, 5 = dominant) was derived. The additional 34 matched pairs had to be reduced or transformed in some way. A number of SSSI surveys were used as the latest survey; however these surveys only included the key indicator species. When a baseline survey was compared to a SSSI survey, the baseline survey was reduced to the key indicator species (Appendix Table B). When Lye’s surveys were used as a baseline, the latest survey had to be transformed to presence/absence data – this was only done in eight cases.

Once the data had been appropriately manipulated to enable comparison, each matched meadow pair consisted of a baseline survey with a species list and each species with a measure of frequency, and a latest survey with a species list and each species with a measure of frequency. 90 matched meadow pairs had frequency measured in a five point scale (1 = rare, 2 = occasional, 3 = frequent, 4 = abundant, 5 = dominant) and eight matched meadow pairs had only presence and absence data. This data formed the ‘Upper Teesdale botanical survey data spreadsheet’.

The earliest baseline survey was one of Margaret Bradshaw’s quadrats from 1962, followed by a couple of Wells (undated), a few of Lye’s (1977) but the majority were Prosser’s surveys from 1984 – 1988, plus the ESA baselines of 1988. The latest SSSIs surveys dated from 1999 – 2011; the latest ESA monitoring was from 2002 and North Pennines AONB Partnership surveys were between 2006 – 2011. The majority of surveys had approximately 20-25 years between them, with some having more (up to 49 years) and the ESA surveys having 14 years between them. There were various reasons why surveys could not be paired or matched with any other surveys: some baseline surveys were comprehensive multiple quadrats on one meadow which would need a repeat survey following the same methodology (i.e. Jones’ quadrats (1984)); some meadows were now pastures or did not have a repeat survey; some baseline surveys were too limited to compare to a comprehensive later survey; many meadows had a later survey but did not have a baseline survey.

5.4 Collating management data

The latest GIS map of Upper Teesdale, showing where the SSSI meadows are located, was checked and SSSI status was then typed into the spreadsheet with the corresponding meadow (Figure 2). These SSSI meadows fall within the large Upper Teesdale SSSI boundary, but have been specifically designated for their hay meadow interest features (i.e. areas of MG3 or MG8 are found within them). Eighteen of the 22 farms (holdings) in the spreadsheet have SSSI meadows. All holdings with SSSI status have information kept in paper format in the 'red ownership files'; these have been scanned and are available electronically. These files date from the early 1980s and contain information on the SSSI meadows that were invited to be in targeted SSSI Management Agreements (MA) and later Wildlife Enhancement Schemes (WES). MA and WES stipulate that FYM applications are allowed (at 12t/ ha^{-1}/ year); inorganic fertiliser inputs are strictly prohibited. Not all SSSI meadows went into MA or WES during the 1980s but by the end of the 1990s most SSSI meadows were managed through a MA or WES.

MA and WES specify that remaining ESA Tier 1 meadows on the holding, or remaining SSSI meadows not covered by MA or WES, may have limited inorganic fertiliser additions: 'Applications should not exceed current levels and in any case should not be higher than 25 kg nitrogen, 12.5 kg phosphate and 12.5 kg potash per hectare per year (1 cwt per acre 20:10:10) and 12.5 tonnes per hectare (5 tons per acre) FYM on meadows' (DEFRA, 2002).

The 'red ownership files' contain correspondence between farmers and English Nature (or predecessor) advisors. The majority of letters in the 1980s and into the 1990s concern the use of inorganic fertilisers. These letters provide evidence that inorganic fertiliser use was prevalent even in the early 1980s and that farmers wanted to apply inorganic fertilisers to SSSI upland hay meadows. Before MA or WES came into place, there were no restrictions on the management of SSSI meadows. The management information from the 'red ownership files' was used to work out which meadows had received inorganic fertilisers, when applications had started and for how many years the meadows received applications. This information was typed into the spreadsheet.

Eighteen holdings went into ESA in 1987 or 1988. Information for each of the holdings is archived in files available electronically via Natural England. These files were consulted to check for management information and to record which meadows were managed as ESA Tier 1. This information is also stored on Natural England's electronic database, AESIS, which holds archived information from ESA holdings. ESA Tier 2 meadow option (stipulating no inorganic fertiliser use) did not start until 1992, and as most of the SSSI meadows were in WES by then, there were few ESA Tier 2 meadows. When MA and WES expired, SSSI meadows were moved into ESA Tier 2, or moved straight into Higher Level Stewardship (HLS). All relevant information was input into the spreadsheet.

Higher Level Stewardship (HLS) began in 2005, but the majority of Upper Teesdale holdings were moved from ESA into HLS between 2010 and 2012. The start dates for HLS agreements were checked on 'Genesis', an online database held at Natural England, which stores the information for Environmental Stewardship schemes. The majority of meadows in Upper Teesdale are now managed under HLS as HK7 (restoration of species-rich, semi-natural grassland) with a few classed as HK6 (maintenance of species-rich, semi-natural grassland). Approximately 49 meadows which were managed as ESA Tier 1, where inorganic fertiliser could be applied, are now being managed under HK7, which stipulates no inorganic fertiliser inputs. All relevant information was input into the spreadsheet.

For every matched pair of botanical data, it was possible to work out when inorganic fertiliser applications began and for how many years the meadows continued to receive applications. Attempts were made to gather information from the management files on timing of grazing, stocking levels, liming and yield to enable this information to be included in the analysis, however such information was only recorded sporadically. There was no information on exact rates of inorganic fertiliser applications or on frequency and rates of FYM applications. For this reason, it had to be assumed that the farmers were adding FYM at 12t/ $ha^{-1/}$ year. Potentially this data could be gathered directly from the farmers but it would only be useful if a large set of information could be collated. Due to the lack of other management data, the analysis was restricted to looking at differences between SSSI meadows and ESA Tier 1 meadows and the number of years each meadow had received inorganic fertiliser applications.

5.5 Collating soils data

There were no records of soils data before 2002. Recent soils data was collated from AESIS, AEMA, Genesis and the North Pennines AONB Partnership. Altogether there were 43 meadows with soils data but this only related to the latest surveys.

5.6 Geographical Information System (GIS)

The completed spreadsheet with the 98 matched pairs of data was input into GIS by Susannah Haley at Natural England. The GIS file and accompanying maps are available from Natural England.

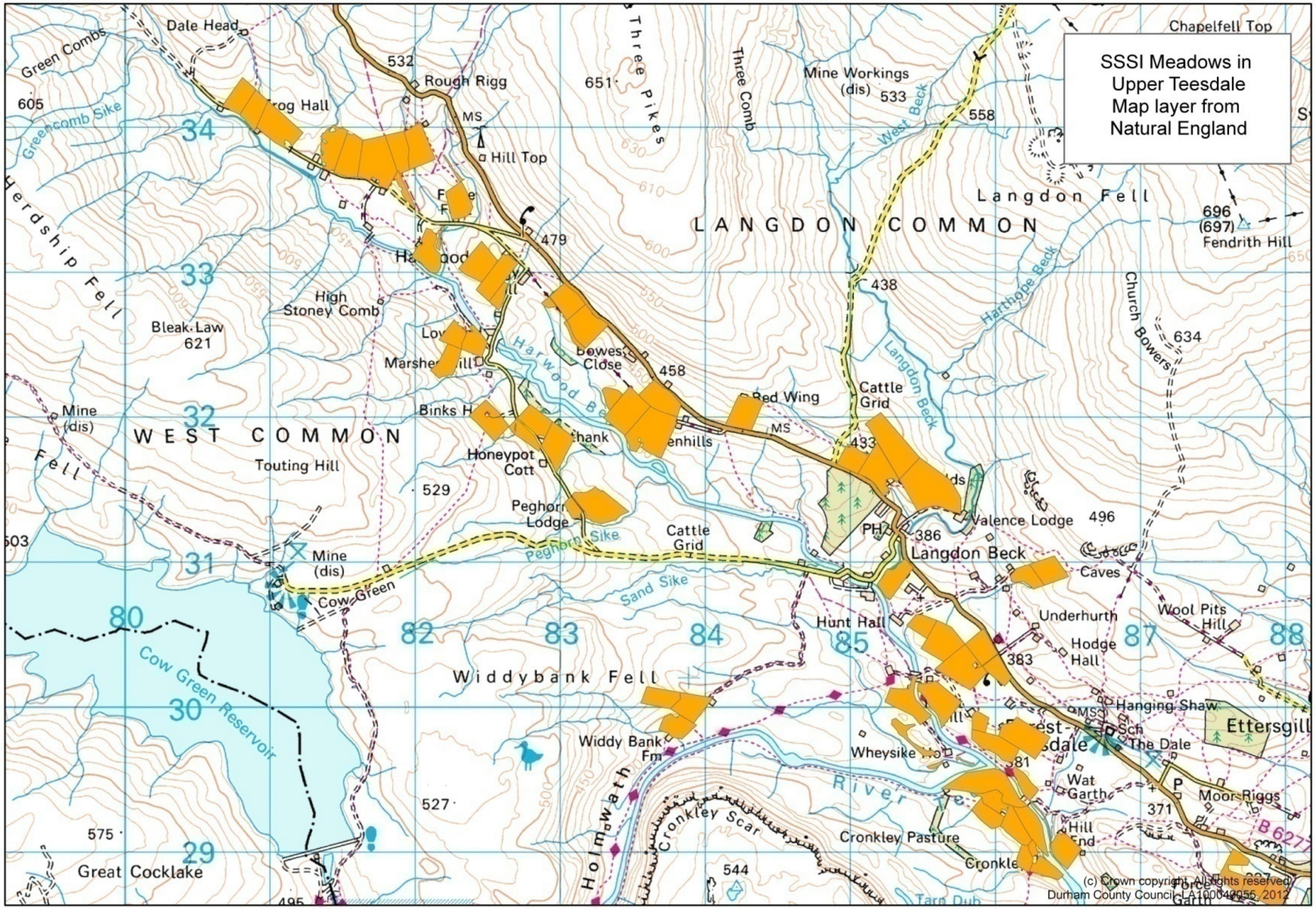

Figure 2. GIS map layer from Natural England showing the SSSI meadows in Upper Teesdale.

5.7 Calculating derived variables for each matched meadow pair

Derived variables are used by ecologists and statisticians to help to explain or categorise botanical compositional data for further data analysis. In the section below, the way each derived variable was calculated from the botanical data in the spreadsheet is explained.

a) Numbers of species and Shannon diversity index

For each baseline and latest survey of the matched meadow pairs, the number of species was counted and totalled from the botanical species list ('number of species' (or species richness)). For example, one baseline survey had 35 species, whereas the paired latest survey had 25 species, so the species richness declined by 10 in that particular meadow. In addition to species richness, the number of grasses and rushes ('number of grasses') and the number of wildflowers and sedges ('number of wildflowers') were counted up and totalled for each baseline and latest survey of the matched meadow pair. The Shannon diversity index (H') was calculated (from the species lists and botanical frequency data) for each baseline and latest survey of the matched meadow pairs. The calculation for this is in Appendix 2. Shannon Diversity Index was used as a measure for assessing good botanical composition; the more species there are, with a range of frequencies, the better the diversity index. Species richness, number of grasses, number of wildflowers and H' values were input into rows of data in the spreadsheet corresponding to the baseline or latest survey they related to.

b) Meadow scores

For each baseline and latest survey of the matched meadow pairs, the botanical data was used to calculate positive indicator species score (P+), negative indicator species score (N-) and total meadow score (TM). Four hundred grassland plant species have been assigned a score ranging from -2 through to +4 (O'Reilly/North Pennines AONB Partnership (2006). For example, creeping buttercup (*Ranunculus repens)* scores -2 and wood crane's-bill (*Geranium sylvaticum*) scores +3 (see Appendix Table A for a list of key indicator species with their corresponding scores). The plants typical of upland hay meadows have a higher positive score, plants that are found in all grasslands receive zero (neutral species) and plant species that are competitive or 'weedy' receive negative scores. The score was multiplied by the frequency for each species and totalled for the positive indicators and the negative indicators. Adding both the score for the positive indicator species and the negative indicator species gives the total meadow score (O'Reilly/North Pennines AONB Partnership 2006). The P+, N- and TM values were input into rows of data in the spreadsheet corresponding to the baseline or latest survey they related to.

c) SS-Suited Species

The SS-Nutrient and SS-Moisture score was calculated for each baseline and latest survey of the matched meadow pairs. This is a score devised by ADAS (Agriculture Department Advisory Service) (ADAS 2006) in order to work out how nutrient-rich or moisture-rich a habitat is. Using the species list for each survey, scores for the individual species were added up and averaged. Each species is given a 1, 0, or -1 category: 1 = suited to high nutrient availability or high moisture; 0 = suited to moderate nutrient availability or moderate moisture; -1 = suited to low nutrient availability or low moisture. The SS-Nutrient and SS-Moisture values were input into rows of data in the spreadsheet corresponding to the baseline or latest survey they related to.

d) Ellenberg Indices

Each plant species has been given a value along a scale for: fertility (Ellenberg fertility index (N): 1 = infertile to 9 = high fertility); moisture (Ellenberg moisture index (M): 1 = very dry to 12 = submerged plants); and pH (Ellenberg pH index (R): 1 = very acidic to 9 = calcareous) (Hill *et al.* 2000). The Ellenberg indicator index for fertility, moisture and pH was calculated for each baseline and latest survey of the matched meadow pairs as follows: the frequency of each species was converted to % cover and scaled to total 100%. The Ellenberg indicator index for each species was multiplied by the percentage cover for that species and divided by 100. These values were summed to get the Ellenberg indicator value. The Ellenberg N, F, and R values were input into rows of data in the spreadsheet corresponding to the baseline or latest survey it was related to (see Appendix Table A for Ellenberg values of key indicator species).

e) National Vegetation Classification (NVC)

All semi-natural British plant communities have been classified into common species assemblages (NVC classifications) based on field surveys throughout Britain, begun in 1975 (Rodwell 1992). In order to classify communities into NVC using the computer program TABLEFIT (Hill,1996) a good species list with plant frequencies or cover/abundance values are required. The options for frequency are Braun-blanquet (a five point scale of frequency) and DOMIN (a ten point scale). Braun-blanquet was used as this is very similar to the five point scale of frequency used. The Upper Teesdale botanical survey data spreadsheet was converted into a format read by TABLEFIT by using CanoImp, a program within Canoco (Leps and Smilauer 2003) and fed into CORNTABL and DATAENTER. TABLEFIT is a program that can classify sites to the NVC using ‘goodness of fit’. The TABLEFIT output gives 5 recommendations to the NVC, in order of goodness of fit: 0 - 49 % = very poor; 50 – 59 % = poor; 60 – 69 % = fair; 70 – 79 % = good; 80 – 100 % = very good. The goodness of fit to the MG8 and MG3b classification was input into the spreadsheet for each meadow.

5.8 Key indicator species

A selection of plant species were chosen from the Upper Teesdale spreadsheet to examine in greater detail. These species were found in frequencies high enough to allow for further analysis. Appendix Table A lists these species with their corresponding meadow scores and Ellenberg values.

a) Key negative indicator species

Seven key negative indicator species were chosen: soft brome (*Bromus hordaceus),* Yorkshire fog (note; this does have a score of zero but was grouped with the negative indicator species in this case), sharp-flowered rush *(Juncus acutiflorus),* soft rush *(Juncus effusus),* perennial rye-grass, creeping buttercup and white clover (*Trifolium repens)*. Soft brome is an annual grass that can spread across meadows and cause a reduction in yields because it has a long, tough stalk and little leaf; Yorkshire fog is commonly found in meadows; it has been suggested that sharp-flowered rush, soft rush and creeping buttercup are increasing in upland hay meadows; perennial rye-grass and white clover are common in improved grasslands.

b) **Key positive indicator species with a score of +1 or +2**

Eleven key positive indicator species with a score of +1 or +2 were chosen: sweet vernal grass (*Anthoxanthum odoratum),* marsh marigold *(Caltha palustris),* pignut *(Conopodium majus),* crested dog's-tail *(Cynosurus cristatus),* eyebright *(Euphrasia arctica),* meadowsweet *(Filipendula ulmaria),* self-heal *(Prunella vulgaris),* meadow buttercup *(Ranunculus acris),* hay rattle *(Rhinanthus minor),* lesser trefoil *(Trifolium dubium)* and red clover (*Trifolium pratense)*. These plant species are common across upland hay meadows in Upper Teesdale.

c) **Key positive indicator species with a score of +3**

Ten key positive indicator species with a score of +3 were chosen: Lady's-mantle (*Alchemilla vulgaris* agg.) were often grouped in the surveys, or at low frequencies, so the species were grouped into the genus), bugle (*Ajuga reptans),* quaking grass *(Briza media),* common knapweed *(Centaurea nigra),* wood crane's-bill, rough hawkbit *(Leontodon hispidus),* ragged robin *(Lychnis flos-cuculi),* great burnet *(Sanguisorba officinalis),* devil's-bit scabious and globeflower. These species are found in the best examples of upland hay meadows in Upper Teesdale and are indicators of MG3b/MG8 habitat.

5.9 Management Groups

Once the spreadsheet was complete and contained all the botanical and management data available for 98 matched pairs of data, the meadows could be grouped into appropriate categories to compare in statistical analysis.

a) **SSSI in targeted management agreements (MA or WES) or meadows managed as ESA Tier 1**

The Upper Teesdale meadows were grouped into two, depending on differences in their management agreements (referred to as '*management groups'*). Meadows were either SSSI that had been in a MA or WES that stipulated only FYM applications of 12t/ ha^{-1} /yr; or meadows were SSSI (managed as ESA Tier 1) or non SSSI meadows (managed as ESA Tier 1) and have been allowed to apply inorganic fertilisers. 51 SSSI meadows had been in a MA or WES and 47 meadows were managed as ESA Tier 1. Changes between the baseline and latest surveys were investigated and the differences between the two management groups were compared.

b) **Historic inorganic fertiliser inputs before the baseline survey period**

Using documented evidence from past surveys and information stored in the 'red ownership files' it was possible to work out whether inorganic fertiliser had been applied to meadows before the baseline survey period. Either meadows only received FYM applications before the baseline survey period (27 meadows), or meadows received FYM applications and inorganic fertiliser inputs before the baseline survey period (71 meadows) (referred to as '*historic fertiliser groups*') (NOTE: This equates to comparing 1st and 2nd category with 3rd, 4th and 5th categories explained in the following section). Changes between the baseline and latest surveys were investigated and the differences between the two historic fertiliser groups were compared.

c) Length of time (number of years) meadows have received inorganic fertilisers (fertiliser categories)

Due to lack of comprehensive management information, the only factor that could be looked at in greater detail was the length of time (in number of years) that meadows had received inorganic fertiliser. It was possible to give a value (in years) for each meadow and this allowed the meadows to be grouped. This is a crude measure as it is unknown what rates of FYM or inorganic fertiliser have been added, but under the circumstances this is the only way of grouping the data further as no quantitative information has been documented.

The meadows were grouped into 5 different categories (‘*fertiliser category’)*, depending on how many years inorganic fertilisers had been added. ‘1st and 2nd categories’ have only been allowed to add FYM *before* the baseline surveys, and ‘3rd, 4th and 5th categories’ have been allowed to add FYM *and* inorganic fertiliser inputs *before* the baseline survey period. Over time, ‘1st category’ continued having no inorganic fertiliser inputs; ‘2nd category’ had inorganic fertiliser inputs between 3 – 6 years before the use was stopped; ‘3rd category’ had 7 – 10 years inorganic fertiliser use; ‘4th category’ had 11 – 19 years inorganic fertiliser use and ‘5th category’ had over 20 years inorganic fertiliser use (i.e. records show that these meadows have had inorganic fertiliser inputs before the baseline survey period and during the entire interval until the latest surveys). Changes between baseline and latest surveys were investigated and differences between fertiliser categories were compared. Further details on these categories are given below:

1st Category: Never received inorganic fertiliser inputs. This category only includes SSSI meadows as all ESA Tier 1 meadows have received inorganic fertiliser for over seven years. All 15 Upper Teesdale meadows in this category are SSSI meadows that went into MA or WES early in the 1980s and have been allowed to add FYM applications.

2nd Category: 3 – 6 years inorganic fertiliser inputs. This category only includes SSSI meadows as all ESA Tier 1 meadows have received inorganic fertiliser for over seven years. These Upper Teesdale SSSI meadows have been allowed to receive FYM applications, plus have had 3 – 6 years inorganic fertiliser inputs *after* the baseline surveys were undertaken. All 13 meadows in this category are SSSI meadows that came into MA or WES in the late 1980s or early 1990s.

3rd Category: 7 – 10 years inorganic fertiliser inputs. These meadows are mainly SSSI meadows (bar one). These Upper Teesdale SSSI meadows have been allowed to receive FYM applications, plus have had 7 – 10 years inorganic fertiliser inputs, *before and after* the baseline survey. The 15 SSSI meadows in this category eventually went into MA or WES in the late 1980s early 1990s (plus one meadow was ESA Tier 1).

4th Category: 11 - 19 years inorganic fertiliser inputs. These Upper Teesdale meadows have been allowed to receive FYM applications, plus have had 11 - 19 years inorganic fertiliser inputs. The 16 meadows in this category have had inorganic fertiliser inputs *before and after* the baseline surveys were undertaken. Half of the meadows were SSSI meadows which finally went into MA or WES in the late 1990s and half were ESA Tier 1 meadows.

5th Category: 20+ years inorganic fertiliser inputs. These Upper Teesdale meadows have been allowed to receive FYM applications, plus have had 20+ years’ inorganic fertiliser inputs. The 38 meadows in this category have had inorganic fertiliser inputs *before and after* the baseline survey and have continued to do so until the latest survey. All meadows are ESA Tier 1, and six are SSSI but managed as ESA Tier 1. Recently, many farms in Upper Teesdale have moved from the ESA scheme into HLS. Most of the ESA Tier 1 meadows in this category are now classed as HK7 (which only permits FYM applications and no addition of inorganic fertiliser). However, the latest surveys were undertaken before this move into HLS.

5.10 Data Analysis

a) ANOVA General Linear Model (GLM)

An analysis of variance, general linear model (ANOVA GLM) was carried out in MINITAB (Dythan 2007). An analysis of variance looks at the differences between groups (i.e. management group; historic fertiliser group and fertiliser categories). For each group, the means (average values) of the derived variables explained in section 5.7 and key indicator species explained in section 5.8 were compared. In turn, each group was input into the 'model' box and each derived variable was input into the 'responses' box. The baseline and latest survey data was analysed separately. Unfortunately it was not possible to look at any interactions between more than one group since the groups had an unequal number of meadows in each. An Anderson-Darling normality test was carried out on the residuals of each test and the p-values were accepted if the data followed a reasonably straight line. A post-hoc Tukeys test was carried out on the fertiliser categories in order to separate out which categories were significantly different to the others.

Statistically significant differences were graded from * = ≤ 0.05 (slightly significant), ** = ≤ 0.01 (significant), *** = ≤ 0.001 (highly significant).

NOTE Please refer to tables in the Results section and the Appendix for p-values as there were too many to present in the text. If a difference has been noted in the text, it will have a significant corresponding p-value in the table.

b) Paired sample t-tests

Paired sample t-tests were carried out in MINITAB. For each group: management group; historic fertiliser group and fertiliser categories, the differences between means of derived variables and key indicator species were compared between baseline and latest survey. Paired sample t-tests not only compare means between baseline and latest surveys, but also compare any change between individual matched pairs. The baseline survey data is input into the 'first sample' box and the latest survey data is input into the 'second sample' box.

Statistically significant differences were graded from * = ≤ 0.05 (slightly significant), ** = ≤ 0.01 (significant), *** = ≤ 0.001 (highly significant).

NOTE Please refer to tables in the Results section and the Appendix for p-values as there were too many to present in the text. If a difference has been noted in the text, it will have a significant corresponding p-value in the table.

c) Redundancy Analysis in CANOCO

The Upper Teesdale botanical survey data spreadsheet was converted using CanoImp and analysed using the community ecology package CANOCO (Leps and Smilauer 2003). The botanical survey data with the species list and plant species frequency was used as the 'species' data file. The groups: management group; historic fertiliser group and fertiliser categories, plus baseline and latest surveys were used as the 'environment' file. The derived variables were used as 'supplementary' data. To begin with, a Detrended Correspondence Analysis (DCA) was carried out on the plant species data to check the lengths of gradient. Detrending by segments was highlighted, using inter-species correlations and log transformed.

The lengths of gradients were under 4 so a linear model was needed and a Redundancy Analysis (RDA) was performed.

The ‘species’ data, ‘environment’ data and ‘supplementary’ data were input into CANOCO, highlighting ‘inter-species correlations’, ‘log-transformed’, ‘do not use forward selection’ and the Monte Carlo Permutation test box was ticked. To test for the significant effects of the groups (management group; historic fertiliser group; fertiliser categories; baseline and latest surveys groups), the ‘environment’ data file was input as the ‘environment’ file and the ‘covariable’ file. One by one, each group was used as a ‘covariable’ and deleted from ‘environmental’ so that the individual effects of each group could be partitioned out (partitioning of the variance). A Monte Carlo permutation test was performed on each test and the Trace, F-value and P-value recorded. Those treatments with $p \leq 0.05$ were classed as significantly effecting the species composition.

d) Analysis of soils data

Forty three Upper Teesdale upland hay meadows with recorded soils data were separated out from the spreadsheet and analysed independently, using the same derived variables and groups as explained in the above sections. However, as this was a reduced dataset, the five fertiliser categories were too small to make a useful comparison. The five categories were reduced to three categories of inorganic fertiliser use: 1st: FYM applications, and 0-6 years inorganic fertiliser inputs; 2nd: FYM applications, and 7 – 10 years inorganic fertiliser inputs; 3rd: FYM applications, and 10+ years inorganic fertiliser inputs.

A second RDA was conducted using CANOCO with the 43 meadows that had soils data, following the same approach as detailed above.

e) Regression

Relationships between total meadow score and Ellenberg fertility index across 98 meadows were correlated and the relationship between phosphorous levels (ppm) and Ellenberg fertility index of 43 meadows were correlated using regression in MINITAB.

6. Results

6.1 Botanical quality in Upper Teesdale upland hay meadows

Upper Teesdale upland hay meadows are generally declining in botanical quality

There were a number of trends which were apparent when the 98 pairs of meadows were compared over time from the baseline survey to the latest survey. The number of species declined from a mean of 37 species in the baseline surveys to a mean of 31 species in the latest surveys (T=4.97, p<0.001) and Shannon diversity index declined from a mean of 3.37 H’ in the baseline surveys, to a mean of 3.20 H’ in the latest surveys (T=5.28, p<0.001) (Appendix Table C).

Positive indicator species score declined from a mean of 107 in the baseline surveys to a mean of 69 in the latest surveys (T=5.87, p<0.001), a 36 % reduction in meadow quality. Sixty-one meadows (62%) had a decline in positive indicator species score and of these, 46 meadows (47%) had a decline in positive indicator species score of over 100. Thirteen meadows remained the same (13.5%) and 23 meadows increased (23.5%) in positive indicator species score (Figure 3 and Appendix Table C).

Total meadow score declined from a mean of 90 in the baseline surveys, to a mean of 54 in the latest surveys (T=5.87, p<0.001), a 40% reduction in meadow quality. Sixty-three meadows (64%) had a decline in total meadow score and of these, 48 meadows (49%) had a decline in the total meadow score of over 90. Fourteen meadows remained the same (15%) and 20 meadows increased (21%) in total meadow score (Appendix Table C).

Altogether 13 key indicator species declined significantly across Upper Teesdale upland hay meadows between the baseline and the latest surveys: bugle, Lady’s-mantle, quaking grass, soft brome, common knapweed, pignut, meadowsweet, wood crane’s-bill, rough hawksbit, meadow buttercup, great burnet, devil’s-bit scabious and globeflower. Twelve of these species are positive indicators and only one, soft brome, is a negative indicator. Four positive indicator species with a score of +3: Lady’s-mantle, quaking grass, wood crane’s-bill and great burnet declined significantly by over half of the frequency found in the baseline surveys (Figure 4). Five species increased significantly: Yorkshire fog, soft rush and creeping buttercup are negative indicators; and hay rattle and lesser trefoil are annual plants that are positive indicators (Table 1).

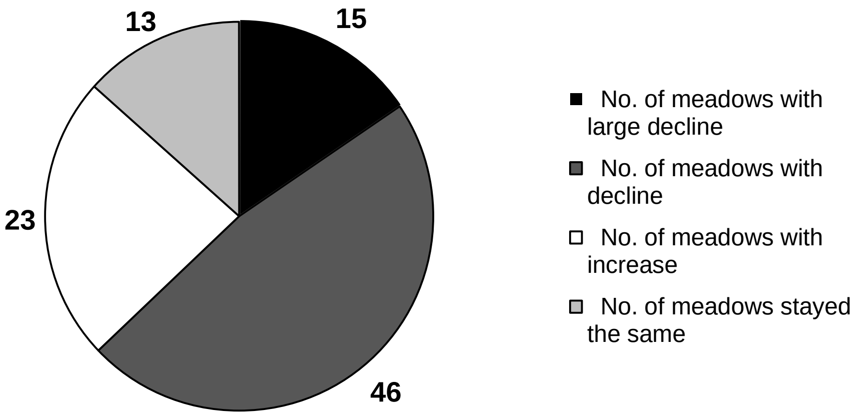

Figure 3. Positive indicator species scores in Upper Teesdale meadows. Fifteen meadows had a 'large decline' (a decline of over 100), 46 meadows had a decline (a decline of over five), whilst 13 meadows remained the same and 23 meadows increased (a score of over five).

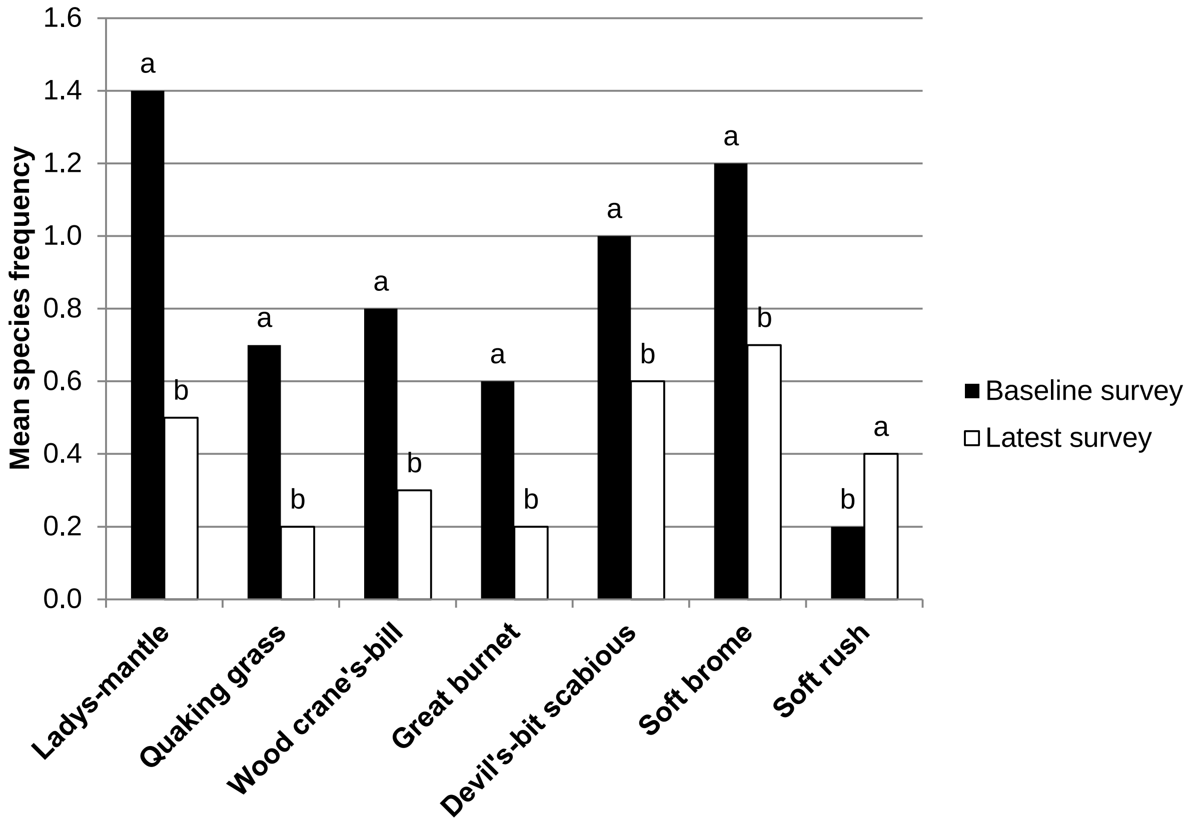

Figure 4. Mean species frequency in Upper Teesdale meadows. Changes in frequency of five key positive indicator species (typical MG3b upland hay meadow species) with a score of +3 and two negative indicator species between baseline and latest surveys in Upper Teesdale meadows. Statistically significant differences are shown between the baseline and latest surveys: a = the highest value, b = the lowest value.

Table 1. Changes in frequency of key indicator species between baseline and latest surveys in Upper Teesdale meadows. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant).

	Plant species	Baseline surveys (mean frequency)	Latest surveys (mean frequency)	Significant difference
Key Negative Indicator Species	Soft Brome	1.2 a	0.7 b	T=2.72,p=0.008***
	Yorkshire fog	1.7 b	2.2 a	T=-2.57,p=0.012**
	Soft rush	0.2 b	0.4 a	T=-2.07,p=0.041*
	Creeping buttercup	2 b	2.2 a	T=-1.72,p=0.009***
Key positive indicator species with a score of +1 or +2	Pignut	1.3 a	1 b	T=2.13,p=0.036**
	Meadowsweet	1.4 a	0.9 b	T=3.13,p=0.002***
	Meadow buttercup	2.3 a	2 b	T=1.86,p=0.066*
	Hay rattle	2.2 b	2.6 a	T=-2.16,p=0.033**
	Lesser trefoil	0.04 b	0.3 a	T=-3.09,p=0.003***
Key positive indicator species with a score of +3	Lady's-mantle	1.4 a	0.5 b	T=7.49,p<0.001***
	Bugle	0.8 a	0.5 b	T=3.29,p=0.001**
	Quaking grass	0.7 a	0.2 b	T=5.26,p<0.001***
	Common knapweed	1. a	0.7 b	T=2.25,p=0.027**
	Wood crane's-bill	0.8 a	0.3 b	T=4.06,p<0.001***
	Rough hawkbit	1.4 a	1.1 b	T=2.17,p=0.032**
	Great burnet	0.6 a	0.2 b	T=3.50,p<0.001***
	Devil's-bit scabious	1. a	0.6 b	T=3.30,p<0.001***
	Globeflower	1. a	0.6 b	T=3.58,p=0.001***

6.2 Fertility, moisture and pH in Upper Teesdale upland hay meadows

Upper Teesdale upland hay meadows are generally increasing in Ellenberg fertility index and SS-Nutrient score whilst botanical quality is declining

SS-Nutrient score increased from a mean of -0.52 in the baseline surveys to a mean of -0.38 in the latest surveys (T=-4.39, p<0.001) and Ellenberg fertility index increased from a mean of 4.28 to a mean of 4.44 (T=-5.38, p<0.001) (Appendix Table C). Sixty-six meadows (67%) had an increase in Ellenberg fertility index of which 12 meadows (12.5%) had a large increase of over 0.50. Nine meadows (9.5%) remained the same and 22 meadows (23%) decreased in Ellenberg fertility index (Figure 5).

The botanical quality of upland hay meadows in Upper Teesdale has declined over the time period studied, as defined by either declines in positive indicator species score or total meadow score (section 6.1). At the same time, there has been an increase in Ellenberg fertility index. Overall, 50 meadows (51%) had a decline in botanical quality (in terms of either positive indicator species score or total meadow score) and an increase in Ellenberg fertility index between the baseline and latest surveys; 11 meadows (12%) increased in botanical quality whilst decreasing in Ellenberg fertility index; and 11 meadows (12%) remained the same for both. Conversely, eight meadows (9%) declined in botanical quality and declined in Ellenberg fertility index over time, and 12 meadows (13%) increased in botanical quality and increased in Ellenberg fertility index (Figure 6).

There were no statistically significant associations for Ellenberg pH index, SS-moisture score or Ellenberg moisture index since some Upper Teesdale meadows have become much wetter or more acidic and an almost equal number of meadows have become much drier and less acidic: ie six meadows have become much wetter (an Ellenberg moisture index of over 0.50), 43 meadows have become wetter (an increase in Ellenberg moisture index of over 0.04), whilst ten meadows have remained the same. Conversely, 38 meadows have become drier (an Ellenberg moisture index of over 0.04) and 1 meadow has become much drier (an Ellenberg moisture index of over 0.50). This pattern is similar for pH (Figure 7).

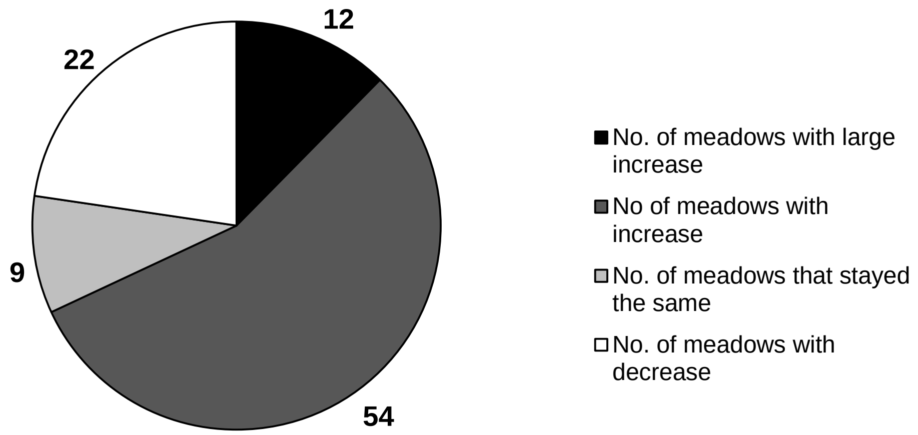

Figure 5. Ellenberg fertility index in Upper Teesdale meadows. A pie-chart showing the number of meadows in Upper Teesdale that have had an increase or a decrease in Ellenberg fertility index. Twelve meadows had a large increase (an index of over 0.50), 54 meadows had an increase (an increase of over 0.04), whilst nine meadows remained the same and 22 meadows decreased (an index of over 0.04).

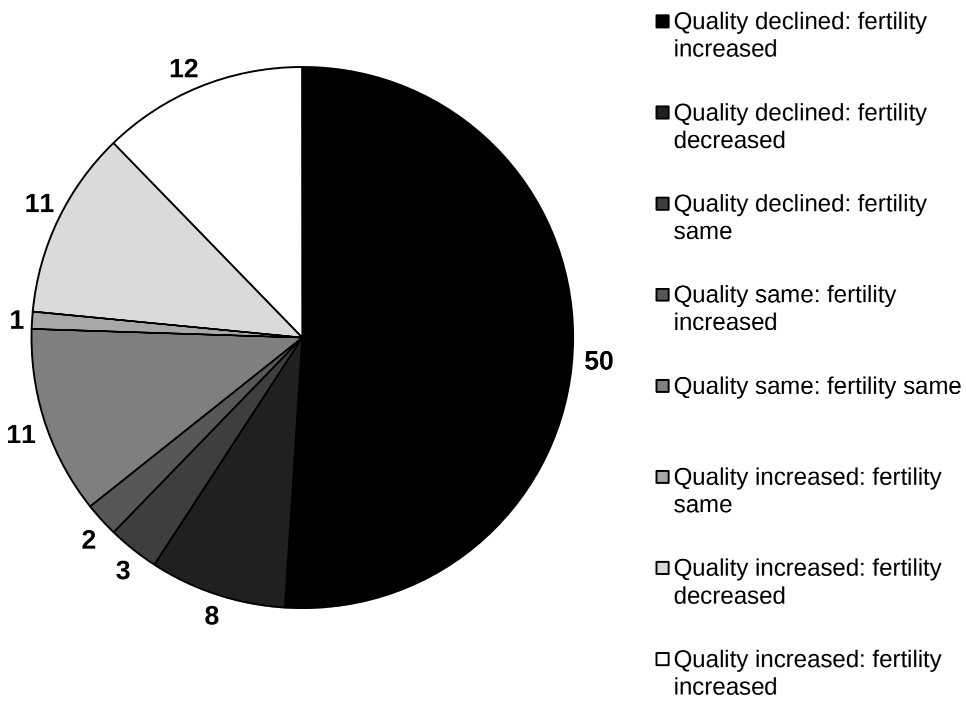

Figure 6. Botanical quality (referring to positive indicator species score or total meadow score) and fertility scores. A pie-chart showing a correlation between botanical quality and fertility scores: fifty meadows (51%) declined in botanical quality and increased in Ellenberg fertility index; 11 meadows (12%) increased in botanical quality and decreased in Ellenberg fertility index; 11 meadows (12%) remained the same for both; conversely, eight meadows (9%) declined in botanical quality and declined in Ellenberg fertility index, and 12 meadows (13%) increased in botanical quality and increased in Ellenberg fertility index.

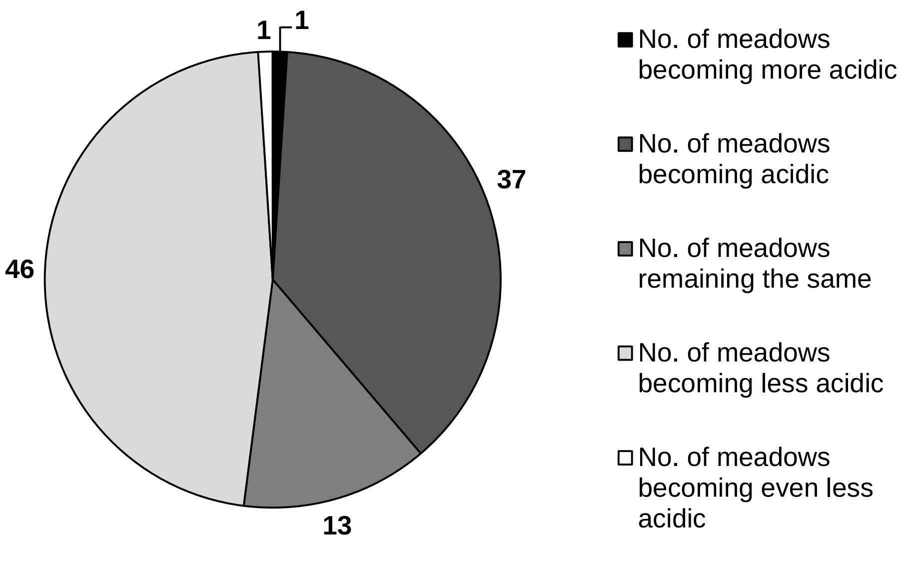

Figure 7. Ellenberg pH index in Upper Teesdale meadows. A pie-chart showing the number of meadows in Upper Teesdale that have had an increase or decrease in Ellenberg pH index. One meadow has become more acidic (an index of over 0.50), 37 meadows have become acidic (an increase of over 0.04), whilst 13 meadows have remained the same. Conversely, 46 meadows have become less acidic (an index of over 0.04) and 1 meadow has become much less acidic (an index of over 0.50).

6.3 Botanical quality in Upper Teesdale SSSI meadows and ESA Tier 1

Upper Teesdale SSSI meadows that have been in a MA or WES have greater botanical quality than meadows which have been managed as ESA Tier 1, although the targeted management has not prevented the SSSI meadows from declining

Number of wildflowers, species number, positive indicator species score and total meadow score were all significantly higher in the baseline surveys in Upper Teesdale SSSI meadows that have been in a MA or WES, compared to those meadows which have been managed as ESA Tier 1 (Table 2). Over time, number of grasses, species number, Shannon diversity index, positive indicator species score and total meadow score significantly declined in both SSSI meadows that have been in a MA or WES and meadows managed as ESA Tier 1, with number of wildflowers also declining in SSSI meadows that have been in a MA or WES (Table 3). This change over time has led to the number of grasses recorded in the latest surveys being higher in meadows managed as ESA Tier 1, in comparison to SSSI meadows that have been in a MA or WES. In the baseline surveys, species number was higher in SSSI meadows that have been in a MA or WES, compared to those managed as ESA Tier 1. However, as species number has declined by an average of 8 species (an average of 20% decline) within SSSI meadows that have been in a MA or WES compared to an average of 2 species (an average of 6% decline) in meadows managed as ESA Tier 1, there is no longer a difference in species number between the two groups in the latest surveys. Despite a decline in botanical quality over time, number of wildflowers, total meadow score and positive indicator species score (Figure 8) are still much higher in Upper Teesdale SSSI meadows that have been in a MA or WES compared to those managed as ESA Tier 1.

The fit to MG3b classification was better in SSSI meadows that have been in a MA or WES in comparison to meadows that have been managed as ESA Tier 1 in both the baseline and the latest surveys, although over time, the fit to MG3b has reduced in the SSSI meadows that have been in a MA or WES (Table 4; Table 5). In general, the best fit to either classification has ranged from 29 – 50 which is classed as ‘very poor’ fit.

There were few differences in the key negative indicator species between SSSI meadows that have been in a MA or WES in comparison to meadows that have been managed as Tier 1, although sharp-flowered rush frequency was significantly greater in SSSI meadows that have been in a MA or WES compared to those meadows managed as ESA Tier 1 (Appendix Figure A). In both baseline and latest surveys, seventeen positive indicator species had greater frequency in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1: Lady’s-mantle, bugle, quaking grass, marsh marigold, common knapweed, crested dog’s-tail, eyebright, meadowsweet, wood crane’s-bill, rough hawkbit, ragged robin, self-heal, hay rattle, red clover, great burnet, devil’s-bit scabious and globeflower. Six positive indicator species declined in both groups between the baseline and latest survey; Lady’s-mantle, bugle, quaking grass, meadowsweet, wood crane’s-bill and great burnet (Figure 9). In summary, SSSI meadows that have been in a MA or WES have more positive indicator species than meadows managed as ESA Tier 1, however, both groups of meadows have experienced a decline in botanical quality (see Appendix 4 for comprehensive descriptions of all species declines and differences between groups: Appendix Table D, E, F, G, H and I; Figure A and B).

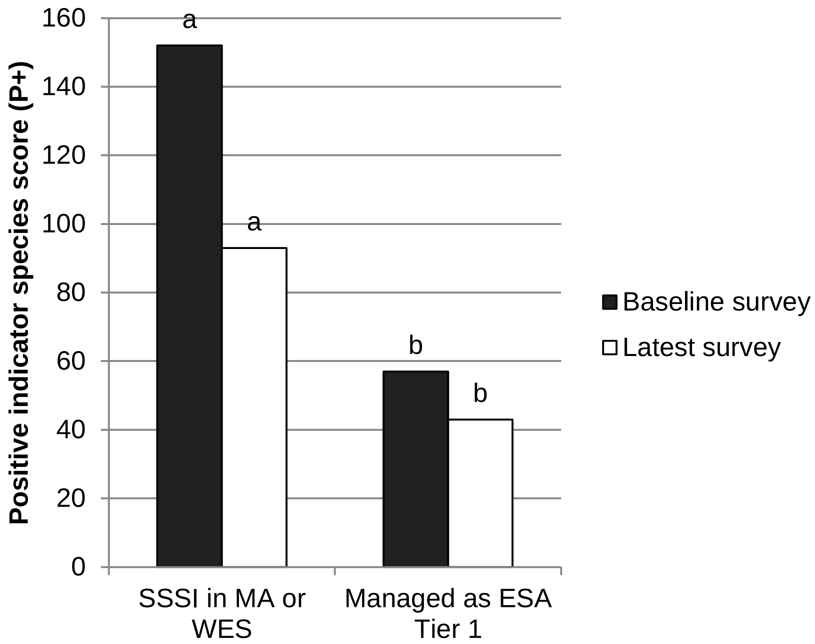

Figure 8. Positive indicator species score (P+) in different management agreements. The differences between management groups and changes over time in positive indicator species score (P+) between SSSI meadows that have been in a MA or WES and meadows managed as ESA Tier 1. Both differences between management groups and changes over time are significantly different; statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Table 2. Number of species, diversity and meadow scores in different management agreements. The differences in number of species, diversity and meadow scores between SSSI meadows that have been in a MA or WES and meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Management group		
Number of species, diversity and meadow scores	**Survey type**	**SSSI in MA or WES**	**Managed as ESA Tier 1**	**Significant difference**
Number of Grass Species	**Baseline**	**10**	**12**	N.S
	Latest	**8 b**	**11. a**	**$F_{1,97}$=8.36,p=0.005*** **
Number of Wildflowers	**Baseline**	**30 a**	**21 b**	**$F_{1,97}$=15.01,p<0.001*** **
	Latest	**24 a**	**19 b**	**$F_{1,97}$=6.60,p=0.012** **
Number of Species	**Baseline**	**40 a**	**32 b**	**$F_{1,97}$=4.92,p=0.029** **
	Latest	**32**	**30**	N.S
Shannon Diversity Index (H')	**Baseline**	**3.45**	**3.29**	N.S
	Latest	**3.22**	**3.19**	N.S
Positive Indicator Species (P+) Score	**Baseline**	**152 a**	**57 b**	**$F_{1,97}$=41.62,p<0.001*** **
	Latest	**93 a**	**43 b**	**$F_{1,97}$=65.25,p<0.001*** **
Negative Indicator Species (N-) Score	**Baseline**	**-18**	**-16**	N.S
	Latest	**-16**	**-15**	N.S
Total Meadow Score (TM)	**Baseline**	**134 a**	**41 b**	**$F_{1,97}$=49.49,p<0.001*** **
	Latest	**77 a**	**28 b**	**$F_{1,97}$=73.67,p<0.001*** **

Table 3. Number of species, diversity and meadows scores in baseline and latest surveys. The changes in number of species, diversity and meadow scores between baseline and latest surveys in Upper Teesdale meadows; grouped by SSSI meadows that have been in a MA or WES or meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Management group					
	SSSI in MA or WES			Managed as ESA Tier 1		
Number of species, diversity and meadow scores	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
Number of Grass Species	**10. a**	**8 b**	**T=4.79,p<0.001*** **	**12. a**	**11 b**	**T=3.13,p=0.003*** **
Number of Wildflowers	**30 a**	**24 b**	**T=4.07,p<0.001*** **	**21**	**19**	N.S
Number of Species	**40 a**	**32 b**	**T=4.71,p<0.001*** **	**32 a**	**30 b**	**T=2.11,p=0.041***
Shannon Diversity Index (H')	**3.45 a**	**3.22 b**	**T=4.70,p<0.001*** **	**3.29 a**	**3.19 b**	**T=2.63,p=0.012** **
Positive Indicator Species (P+) Score	**152 a**	**93 b**	**T=5.71,p<0.001*** **	**57 a**	**43 b**	**T=2.56,p=0.014** **
Negative Indicator Species (N-) Score	**-18**	**-16**	N.S	**-16**	**-15**	N.S
Total Meadow Score (TM)	**134 a**	**77 b**	**T=5.92,p<0.001*** **	**41 a**	**28 b**	**T=2.64,p=0.011** **

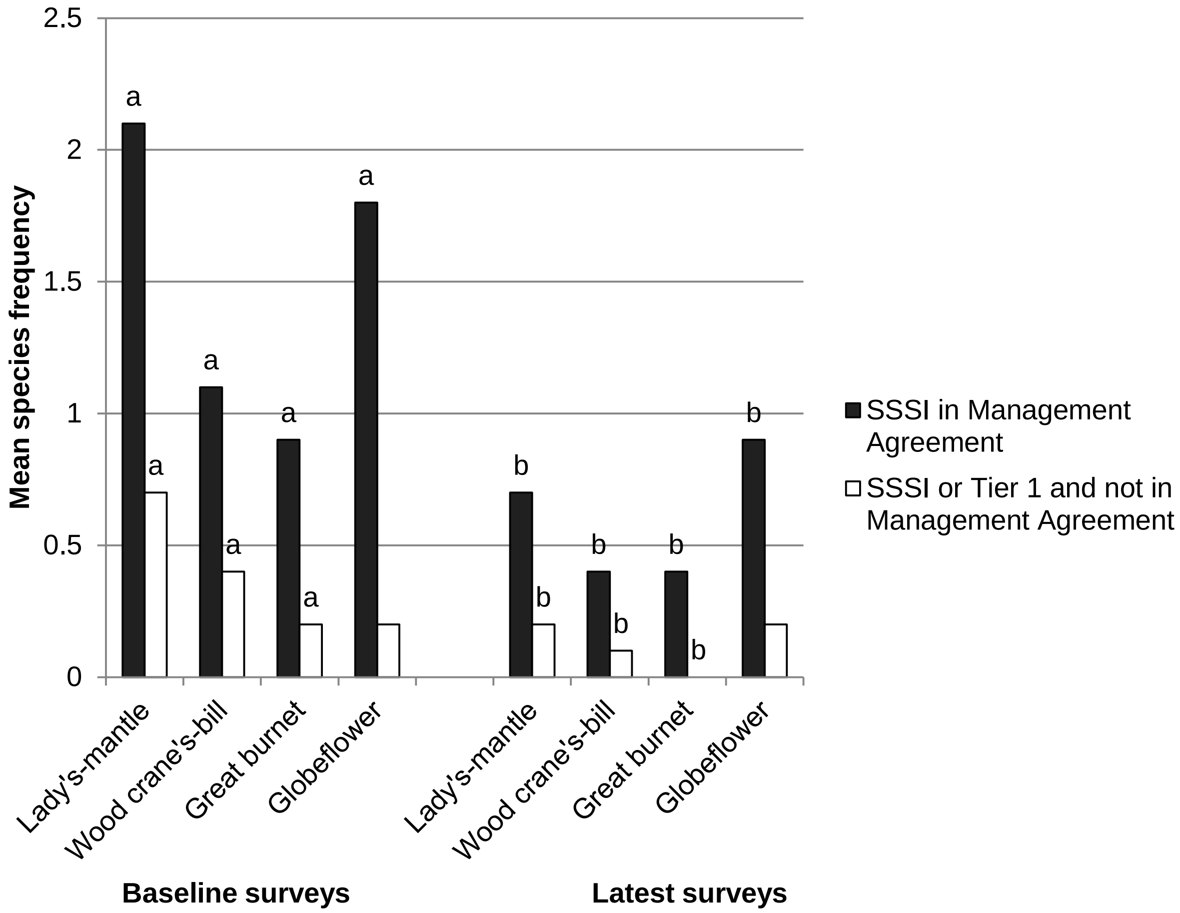

Figure 9. Mean species frequency in different management agreements. The differences between management groups and changes over time in the frequency of Lady's-mantle, wood crane's-bill, great burnet and globeflower between Upper Teesdale SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Both differences between management groups and changes over time are significantly different, apart from globeflower which has no differences in the management groups in the latest surveys. In this Figure, statistically significant differences are shown between the baseline and latest surveys: a = the highest value, b = the lowest value.

6.4 Fertility in Upper Teesdale SSSI meadows and ESA Tier 1

Upper Teesdale SSSI meadows that have been in a MA or WES have lower fertility scores and higher moisture scores than meadows which have been managed as ESA Tier 1.

The findings suggest that in the baseline survey period Upper Teesdale SSSI meadows that have been in a MA or WES were less fertile than those managed as ESA Tier 1; Ellenberg fertility index and SS-Nutrient score were all significantly lower (Table 4). Over time, Ellenberg fertility index and SS-Nutrient score increased in both management groups (Table 5, Figure 10). Although the scores have increased over time, in the latest surveys, Ellenberg fertility index and SS-Nutrient score remain significantly lower, in Upper Teesdale SSSI meadows that have been in a MA or WES compared to those managed as ESA Tier 1.

Figure 11 shows phosphorous levels (ppm) for the 43 Upper Teesdale meadows that have had soil samples taken recently (over the last 10 years). Phosphorous levels (ppm) were significantly higher in meadows managed as ESA Tier 1 compared to SSSI meadows that have been in a MA or WES ($F_{1,42} = 5.16$, $p=0.028$). Potassium (K), magnesium (M) and nitrogen (N) were not significantly different (K: 128; 122, M: 168; 218, N: 0.78; 0.80, SSSI in MA or WES; meadows managed as ESA Tier 1 respectively).

The findings suggest that in the baseline survey period Upper Teesdale SSSI meadows that have been in a MA or WES were wetter than those managed as ESA Tier 1; SS-Moisture score was higher, although there were no significant differences in Ellenberg moisture index or Ellenberg pH index. Over time there have been no significant changes in SS-Moisture score, Ellenberg moisture index or Ellenberg pH index so that in the latest surveys SSSI meadows that have been in a MA or WES continue to have higher moisture scores than meadows managed as ESA Tier 1 (Table 4 and 5).

The results from the 43 meadows that have had soil samples taken recently show that pH measurements were significantly less acid (5.8) in Upper Teesdale SSSI meadows that have been in a MA or WES and more acid (5.6) in those meadows that have been managed as ESA Tier 1 ($F_{1,42} = 4.83$, $p=0.034$).

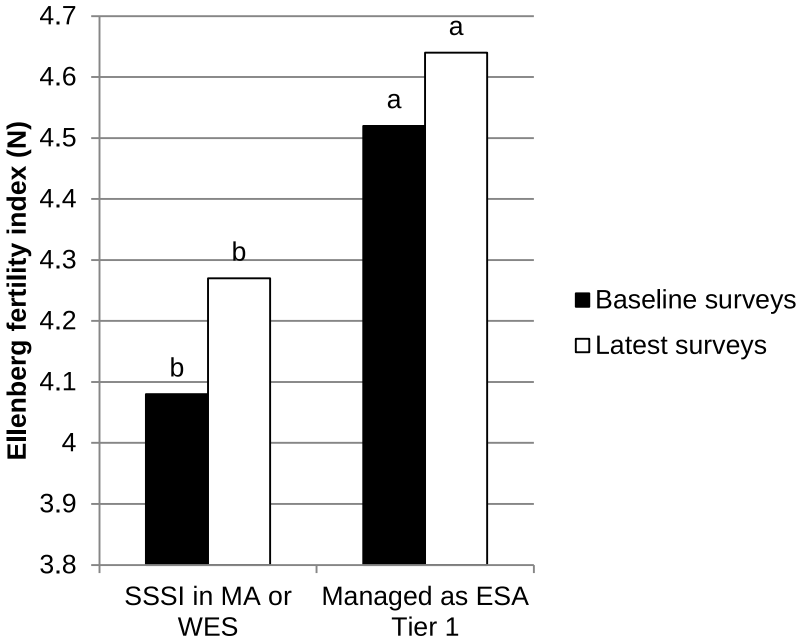

Figure 10. Ellenberg fertility index (N) in different management agreements. The differences between management groups and changes over time in the Ellenberg fertility index (N) between Upper Teesdale SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Both differences between groups and changes over time are significantly different. In this figure, statistically significant differences are only shown between the different groups, not between the baseline and latest survey: a = the highest value, b = the lowest value.

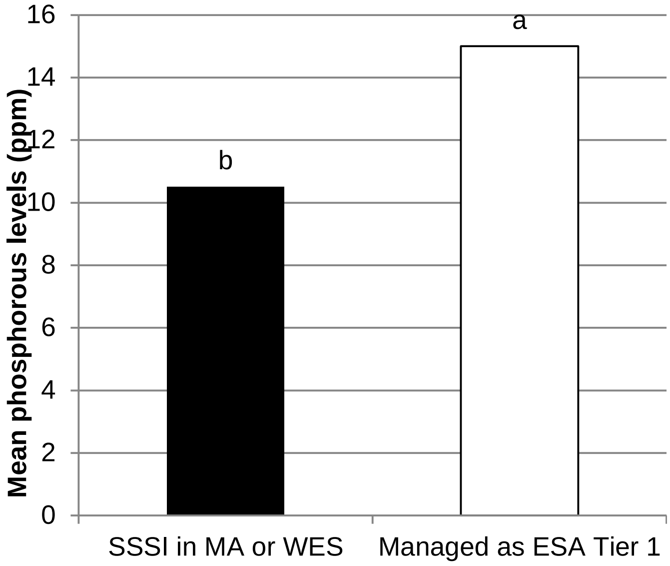

Figure 11. Phosphorous levels (ppm) in different management agreements. The differences in the mean phosphorous levels (ppm) between Upper Teesdale SSSI meadows that have been in a MA or WES those meadows managed as ESA Tier 1 (a total of 43 meadows, soil samples taken from 2002 - present). 11 ppm = Index 1.4; 15 ppm = Index 1.9. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value: $F_{1,42} = 5.16$, p=0.028.

Table 4. SS species scores, Ellenberg indices and best fit to NVC in different management agreements. The differences in SS species scores, Ellenberg indices and best fit to NVC between Upper Teesdale SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Management group		
SS Species score, Ellenberg indices and NVC	**Survey type**	**SSSI in MA or WES**	**Managed as ESA Tier 1**	**Significant difference**
SS-Nutrient Score	**Baseline**	**-0.69 a**	**-0.33 b**	**$F_{1,97}$=17.97,p<0.001*** **
	Latest	**-0.52 a**	**-0.23 b**	**$F_{1,97}$=14.03,p<0.001*** **
SS-Moisture Score	**Baseline**	**0.49 a**	**0.28 b**	**$F_{1,97}$=5.54,p=0.021** **
	Latest	**0.50 a**	**0.30 b**	**$F_{1,97}$=6.78,p=0.011** **
Ellenberg Fertility Index (N)	**Baseline**	**4.08 a**	**4.52 b**	**$F_{1,97}$=28.65,p<0.001*** **
	Latest	**4.27 a**	**4.64 b**	**$F_{1,97}$=21.11,p<0.001*** **
Ellenberg Moisture Index (M)	**Baseline**	**5.93**	**5.8**	N.S
	Latest	**5.99 a**	**5.82 b**	**$F_{1,97}$=4.55,p=0.035** **
Ellenberg pH Index (R)	**Baseline**	**5.71**	**5.7**	N.S
	Latest	**5.71**	**5.7**	N.S
MG8 Best Fit	**Baseline**	**29 b**	**36 a**	**$F_{1,97}$=6.93,p=0.01** **
	Latest	**39**	**41**	N.S
MG3b Best Fit	**Baseline**	**50 a**	**38 b**	**$F_{1,97}$=15.59,p<0.001*** **
	Latest	**45 a**	**38 b**	**$F_{1,97}$=4.37,p=0.039** **

Table 5. SS species scores, Ellenberg indices and best fit to NVC in baseline and latest surveys. The changes in SS species scores, Ellenberg indices and best fit to NVC between baseline and latest surveys; grouped by SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Management group					
	SSSI in MA or WES			Managed as ESA Tier 1		
SS Species score, Ellenberg indices and NVC	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
SS-Nutrient Scores	**-0.69 a**	**-0.52 b**	**T=-3.89,p<0.001*** **	**-0.33 a**	**-0.23 b**	**T=-2.23,p=0.031** **
SS-Moisture Scores	**0.49**	**0.5**	N.S	**0.28**	**0.3**	N.S
Ellenberg Fertility Index (N)	**4.08 b**	**4.27 a**	**T=-4.74,p<0.001*** **	**4.52 b**	**4.64 a**	**T=-2.84,p=0.007*** **
Ellenberg Moisture Index (M)	**5.93**	**5.99**	N.S	**5.8**	**5.82**	N.S
Ellenberg pH Index (R)	**5.71**	**5.71**	N.S	**5.7**	**5.7**	N.S
MG8 Best Fit	**29 b**	**39 a**	**T=-3.46,p=0.001*** **	**36 b**	**41 a**	**T=-2.58,p=0.013** **
MG3b Best Fit	**50 a**	**45 b**	**T=2.80,p=0.007*** **	**38**	**38**	N.S

6.5 Botanical quality and historic fertiliser inputs

There is an association between historic inorganic fertiliser inputs and declining botanical quality.

In the baseline survey period, number of wildflowers (Figure 12), positive indicator species score and total meadow score were all significantly higher in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM *and* inorganic fertiliser additions before the baseline survey period (Table 6). Over time, number of grasses, number of wildflowers, number of species, Shannon diversity index, positive indicator species score and total meadow score have all significantly declined in both of the groups (Table 7). In the latest surveys, number of wildflowers, positive indicator species score and total meadow score remain significantly higher in the meadows that only received FYM additions before the baseline survey period compared to those meadows that have had historic inorganic fertiliser applications (Table 6).

The only negative indicator species found in greater frequencies in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period was sharp-flowered rush (Appendix Table J). Soft rush increased in meadows that only had FYM additions before the baseline survey period, whereas creeping buttercup and perennial rye-grass increased in meadows that had FYM and inorganic fertiliser additions before this period. (Appendix Table J and K).

In both baseline and latest surveys, thirteen positive indicator species had significantly higher frequency in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period: Lady's-mantle, bugle, quaking grass, marsh marigold, common knapweed, eyebright, meadowsweet, rough hawkbit, ragged robin, hay rattle, red clover, devil's-bit scabious and globeflower. Wood crane's-bill, meadowsweet (Appendix Figure D), Lady's-mantle, quaking grass and globeflower declined in both groups between the baseline and latest surveys (Figure 13). Self-heal, bugle and devil's-bit scabious declined in meadows that only had FYM additions before the baseline surveys, whereas common knapweed, rough hawkbit and great burnet declined in meadows that that had FYM and inorganic fertiliser additions before this period. Lesser trefoil increased in meadows that FYM additions before the baseline survey period, in contrast, hay rattle increased in meadows that had inorganic fertiliser additions before this period.

In summary, there are more key positive indicator species in the meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period, and there has been a decline in the majority of these species across the two groups (see Appendix 5 for comprehensive descriptions of all species declines and differences between groups: Appendix Table L, M, N, O).

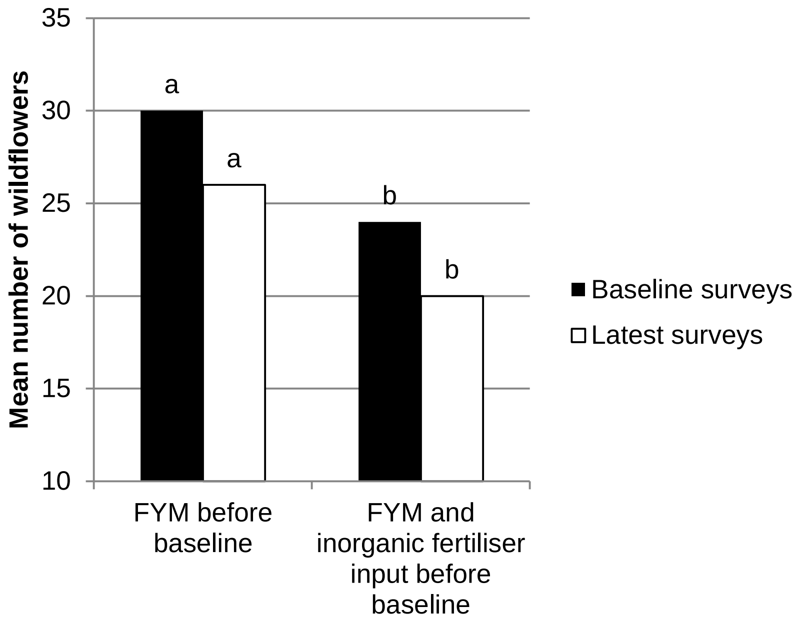

Figure 12. Number of wildflowers and historic fertiliser groups. The differences between historic fertiliser groups and changes over time in mean numbers of wildflowers between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before this period. Both differences between management groups and changes over time are significantly different. Statistically significant differences are shown between the baseline and latest surveys: a = the highest value, b = the lowest value.

Table 6. Number of species, diversity and meadow scores in different historic fertiliser groups. The differences in number of species, diversity and meadow scores between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b= the lowest value.

		Historical fertiliser inputs before baseline survey period		
Number of species, diversity and meadow scores	**Survey type**	**FYM before baseline period**	**FYM and inorganic fertiliser input before baseline period**	**Significant difference**
Number of Grass Species	**Baseline**	**9**	**11**	N.S
	Latest	**7**	**9**	N.S
Number of Wildflowers	**Baseline**	**30 a**	**24 b**	**$F_{1,97}$=4.32,p=0.04***
	Latest	**26 a**	**20 b**	**$F_{1,97}$=7.39,p=0.008*** **
Number of Species	**Baseline**	**40**	**35**	N.S
	Latest	**33**	**30**	N.S
Shannon Diversity Index (H')	**Baseline**	**3.48**	**3.33**	N.S
	Latest	**3.26**	**3.19**	N.S
Positive Indicator Species (P+) Score	**Baseline**	**165 a**	**85 b**	**$F_{1,97}$=19.932,p<0.001*** **
	Latest	**102 a**	**57 b**	**$F_{1,97}$=34.70,p<0.001*** **
Negative Indicator Species (N-) Score	**Baseline**	**-18**	**-17**	N.S
	Latest	**-15**	**-15**	N.S
Total Meadow Score (TM)	**Baseline**	**147 a**	**68 b**	**$F_{1,97}$=23.11,p<0.001*** **
	Latest	**87 a**	**42 b**	**$F_{1,97}$=40.98,p<0.001*** **

Table 7. Number of species, diversity and meadow scores in baseline and latest surveys. The changes in number of species, diversity and meadow scores between the baseline and latest surveys; grouped by meadows that only had FYM additions before the baseline survey period compared to meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Historical fertiliser inputs before the baseline survey period					
	FYM before baseline period			**FYM and inorganic fertiliser input before baseline period**		
Number of species, diversity and meadow scores	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
Number of Grass Species	**9 a**	**7 b**	**T=3.94,p=0.001*** **	**11a**	**9 b**	**T=4.21,p<0.001*** **
Number of Wildflowers	**30 a**	**26 b**	**T=2.84,p=0.009*** **	**24 a**	**20 b**	**T=2.93,p=0.005*** **
Number of Species	**40 a**	**33 b**	**T=3.54,p=0.002*** **	**35 a**	**30 b**	**T=3.65,p<0.001*** **
Shannon Diversity Index (H')	**3.48 a**	**3.26 b**	**T=3.77,p=0.001*** **	**3.33 a**	**3.19 b**	**T=3.89,p<0.001*** **
Positive Indicator Species (P+) Score	**165 a**	**102 b**	**T=4.51,p<0.001*** **	**85 a**	**57 b**	**T=2.56,p=0.014** **
Negative Indicator Species (N-) Score	**-18**	**-15**	N.S	**-17**	**-15**	N.S
Total Meadow Score (TM)	**147 a**	**87 b**	**T=4.64,p<0.001*** **	**68 a**	**42 b**	**T=4.25,p<0.001*** **

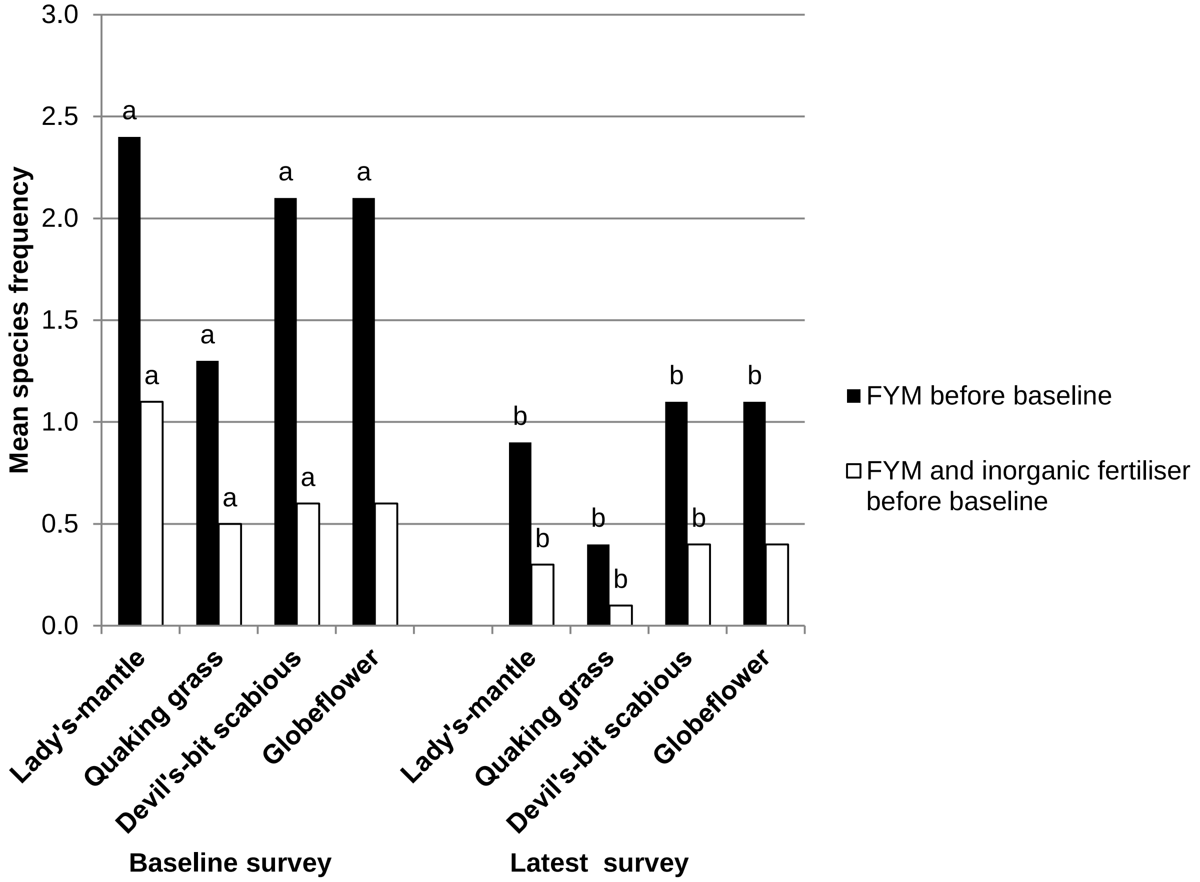

Figure 13. Mean species frequency and different historic fertiliser groups. The differences between historic fertiliser groups and changes over time in mean frequency of Lady's-mantle, quaking grass, devil's-bit scabious and globeflower; between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before the baseline period. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

6.6 Fertility and historic fertiliser inputs

There is an association between historic inorganic fertiliser inputs and fertility scores.

The findings suggest that in the baseline survey period, Upper Teesdale SSSI meadows that only had FYM additions before the survey were less fertile than those that have received both FYM and inorganic fertiliser applications; Ellenberg fertility index and SS-Nutrient score were all significantly lower (Table 8). Over time, Ellenberg fertility index and SS-Nutrient score increased in both historic fertiliser groups (Table 9, Figure 14). In the latest surveys, Ellenberg fertility index and SS-Nutrient scores remain significantly lower in meadows that only had FYM additions before the baseline period compared to meadows that have received both FYM and inorganic fertiliser applications (Table 8).

Figure 15 shows phosphorous levels (ppm) for 43 Upper Teesdale meadows that have had soil samples taken recently (over the last 10 years). Phosphorous levels (ppm) are significantly lower in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period ($F_{1,42}$=5.47, p=0.024) (Figure 15). Potassium (K), magnesium (M) and nitrogen (N) were not significantly different (K: 119; 127, M: 175; 197, N: 0.77; 0.84, FYM only; FYM and inorganic fertiliser respectively).

The findings suggest that in the baseline survey period, meadows that only had FYM additions before the baseline survey period were wetter than those that received both FYM and inorganic fertiliser applications; SS-Moisture scores and Ellenberg moisture index (M) were all significantly higher (Table 8). Over time, Ellenberg moisture index has increased in meadows that only had FYM additions before the baseline survey period (Table 9). In the latest surveys, Ellenberg moisture index and SS-Moisture scores remain significantly higher in meadows that only had FYM additions before the baseline period compared to meadows that have received both FYM and inorganic fertiliser applications (Table 8).

Ellenberg pH index was not significantly different between the historic fertiliser groups in both baseline and latest surveys. The findings suggest that meadows got less acidic over time where they had received FYM and inorganic fertiliser additions before the baseline survey period: Ellenberg pH index slightly increased (Table 9). The pH results from the 43 Upper Teesdale meadows that have had soil samples taken recently (over the last 10 years) have shown no significant differences between the groups and relate closely to the Ellenberg pH index (pH 5.7 and 5.7 in each group).

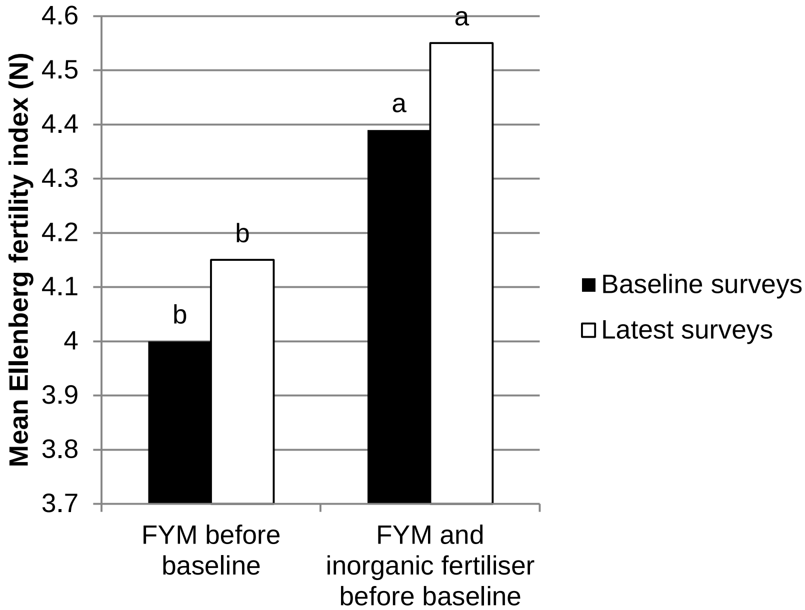

Figure 14. Ellenberg fertility index (N) in different historic fertiliser groups. The differences between historic fertiliser groups and changes over time in mean Ellenberg fertility index (N) between meadows that only had FYM additions before the baseline survey period and meadows that had FYM and inorganic fertiliser additions before this period. Both differences between groups and changes over time are significantly different. In this figure, statistically significant differences are shown between the different groups only, not between the baseline and the latest survey: a = the highest value, b = the lowest value.

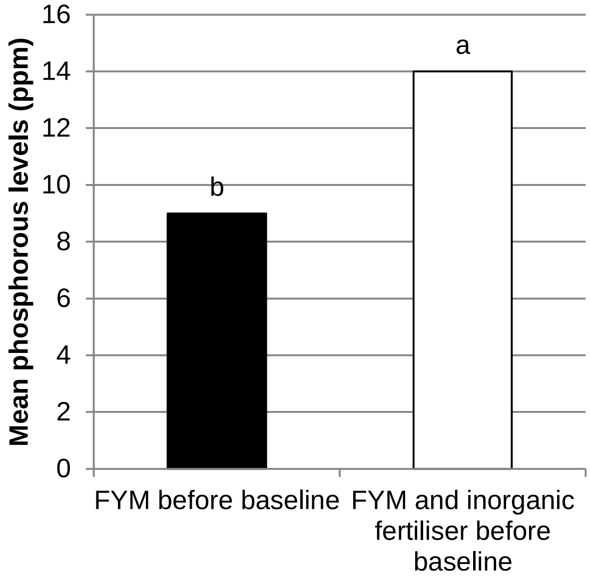

Figure 15. Phosphorous levels (ppm) in different historic fertiliser groups. The differences in the mean phosphorous levels (ppm) between Upper Teesdale meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before this period (a total of 43 meadows, soil samples taken from 2002 - present). 9 ppm = Index 0.9; 14 ppm = Index 1.7. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value ($F_{1,42}$=5.47, p=0.024).

Table 8. SS species scores, Ellenberg indices and best fit to NVC in different historic fertiliser groups. The differences in SS species scores, Ellenberg indices and best fit to NVC between meadows that have only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before the baseline period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Historical fertiliser inputs before the baseline survey period		
SS Species score, Ellenberg indices and NVC	**Survey type**	**FYM before Baseline period**	**FYM and inorganic fertiliser input before baseline period**	**Significant difference**
SS-Nutrient Scores	**Baseline**	**-0.85 a**	**-0.40 b**	**$F_{1,97}$=23.97,p<0.001*** **
	Latest	**-0.61 a**	**-0.30 b**	**$F_{1,97}$=14.28,p<0.001*** **
SS-Moisture Scores	**Baseline**	**0.57 a**	**0.33 b**	**$F_{1,97}$=6.26,p=0.021** **
	Latest	**0.63 a**	**0.32 b**	**$F_{1,97}$=12.99,p=0.011** **
Ellenberg Fertility Index (N)	**Baseline**	**4.00 b**	**4.39 a**	**$F_{1,97}$=28.65,p<0.001*** **
	Latest	**4.15 b**	**4.55 a**	**$F_{1,97}$=21.11,p<0.001*** **
Ellenberg Moisture Index (M)	**Baseline**	**5.99 a**	**5.82 b**	**$F_{1,97}$=3.24,p=0.075* **
	Latest	**6.14 a**	**5.82 b**	**$F_{1,97}$=13.98,p<0.001*** **
Ellenberg pH Index (R)	**Baseline**	**5.7**	**5.7**	N.S
	Latest	**5.66**	**5.74**	N.S
MG8 Best Fit	**Baseline**	**29**	**33**	N.S
	Latest	**35 b**	**42 a**	**$F_{1,97}$=3.81,p=0.054* **
MG3b Best Fit	**Baseline**	**49 a**	**43 b**	**$F_{1,97}$=3.19,p=0.077* **
	Latest	**44**	**41**	N.S

Table 9. SS species scores, Ellenberg indices and best fit to NVC in baseline and latest surveys. The changes in SS species scores, Ellenberg indices and best fit to NVC between baseline and latest surveys; grouped by meadows that only had FYM additions before the baseline survey period compared to meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Historical fertiliser inputs before the baseline survey period					
	FYM before baseline period			**FYM and inorganic fertiliser input before baseline period**		
SS Species score, Ellenberg indices and NVC	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
SS-Nutrient Scores	**-0.85 a**	**-0.61 b**	**T=-3.29,p=0.003*** **	**-0.40 a**	**-0.30 b**	**T=-3.05,p=0.003*** **
SS-Moisture Scores	**0.57**	**0.63**	N.S	**0.33**	**0.32**	N.S
Ellenberg Fertility Index (N)	**4.00 b**	**4.15 a**	**T=-3.13,p=0.004*** **	**4.39 b**	**4.55 a**	**T=-4.41,p<0.001*** **
Ellenberg Moisture Index (M)	**5.99 b**	**6.14 a**	**T=-3.54,p<0.001*** **	**5.82**	**5.82**	N.S
Ellenberg pH Index (R)	**5.7**	**5.66**	N.S	**5.7**	**5.74**	**T=-1.99,p=0.051**
MG8 Best Fit	**29**	**35**	N.S	**33 b**	**42 a**	**T=-4.21,p<0.001*** **
MG3b Best Fit	**49 a**	**44 b**	**T=2.43,p=0.022** **	**43**	**41**	N.S

6.7 Botanical quality and fertiliser categories

There is a positive association between the length of time that inorganic fertilisers have been added to meadows (fertiliser categories) and declining botanical quality.

The five fertiliser categories have been worked out by grouping meadows by the number of years they have received inorganic fertilisers, rather than categorisation based on exact measurements of rates of inputs (as these have not been documented). This has meant that there are likely to be overlaps from one category to the next; there were few significant differences between each individual category. All significant differences have been explained comprehensively in Appendix 6 and the clear patterns are described in this section.

In the baseline and latest surveys, the 1st and 2nd category had higher positive indicator species scores and higher total meadows scores than 4th and 5th categories. The 1st category had fewer grasses than 5th category. This pattern shows an association between the number of years that inorganic fertilisers have been applied, and a reduction in botanical quality. Between the baseline and latest survey, Shannon diversity index, positive indicator species score (Figure 16) and total meadow score all significantly declined in Upper Teesdale meadows, in all fertiliser categories (Appendix Table P and Q).

Generally, key negative indicator species were common in all fertiliser categories. Four key negative indicator species declined over time in 1st category where only FYM has been added: Yorkshire fog, sharp-flowered rush (Figure 17), perennial rye-grass and white clover. Three key negative indicator species have increased in 5th category, where meadows have received inorganic fertilisers for over 20 years: Yorkshire fog, perennial rye-grass and creeping buttercup (see Appendix Table T and U).

Generally, key positive indicators with a score of +1 or +2 were common in all fertiliser categories. Between the baseline and latest surveys, five species showed a decline over time in some categories: marsh marigold, pignut, meadowsweet, meadow buttercup and self-heal. Four species showed a preference for meadows that have had inorganic fertiliser inputs over fewer years: marsh marigold, eyebright, hay rattle (Figure 18) and lesser trefoil were more frequently found in 1st or 2nd categories, in comparison to 4th or 5th categories. Eyebright, hay rattle and lesser trefoil have significantly increased in 5th category, even where inorganic fertilisers have been added for over 20 years, however the frequencies of these species still remain lower than 1st or 2nd category (Figure 18) (see Appendix Table V, W).

The majority of key positive indicator species with a score of +3 were found infrequently in Upper Teesdale meadows. Nine of these species declined in more than one category between the baseline and latest surveys: Lady's-mantle, bugle, quaking grass, common knapweed, rough hawkbit, wood crane's-bill, great burnet, devil's-bit scabious and globeflower. In the latest surveys, Lady's-mantle had significantly higher frequencies only in 1st category compared to other categories, suggesting this species cannot tolerate inorganic fertiliser use (Figure 19). Bugle, quaking grass, common knapweed, rough hawkbit, great burnet, devil's-bit scabious (Figure 20) and globeflower showed a preference to meadows that have had fewer nutrient inputs over time (Appendix Table X and Y).

A number of species were found in greater frequencies in 2nd category in the baseline and latest surveys. Four species are wet loving species and suggest these meadows are wetter: ragged robin, marsh marigold, sharp-flowered rush and creeping buttercup (Figure 24, Table 28). This pattern was not confirmed by the fit to MG8 which is a reflection of the inconsistencies of MG8 species in the NVC rather than a reflection on the Upper Teesdale data, although the Ellenberg moisture index and SS-moisture scores increased in this category (Appendix Figure E, Appendix Table R and S) (see Appendix 6 for comprehensive descriptions of all meadow scores and species declines with differences between groups).

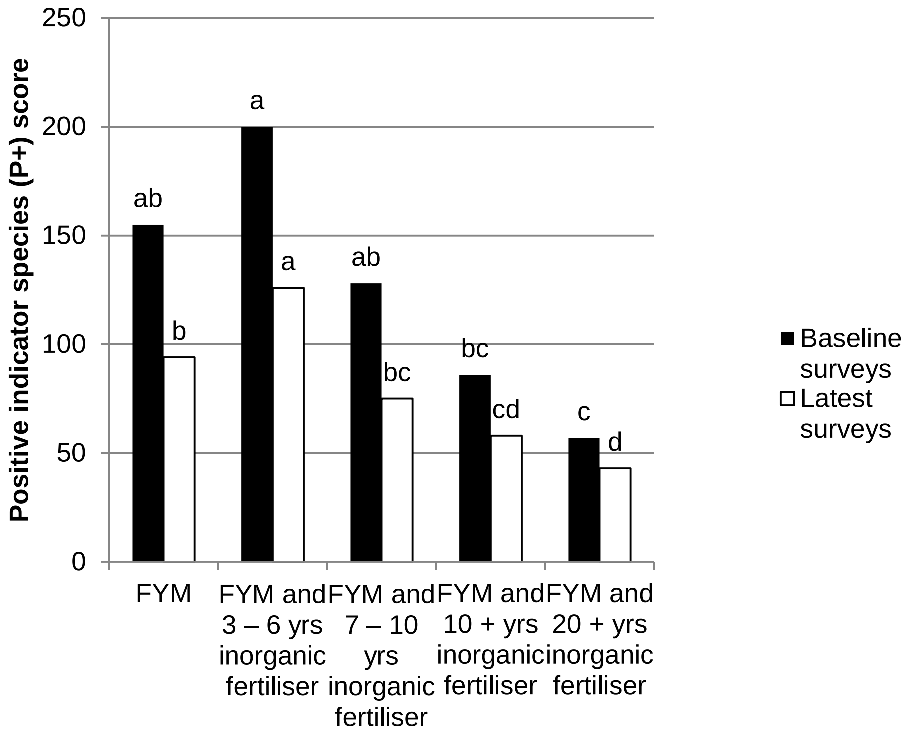

Figure 16. Positive indicator species scores and fertiliser categories. The differences between fertiliser categories and changes over time in positive indicator species (P+) scores in Upper Teesdale meadows. Both differences between groups and changes over time are significantly different. Statistically significant differences are shown between the different groups: a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

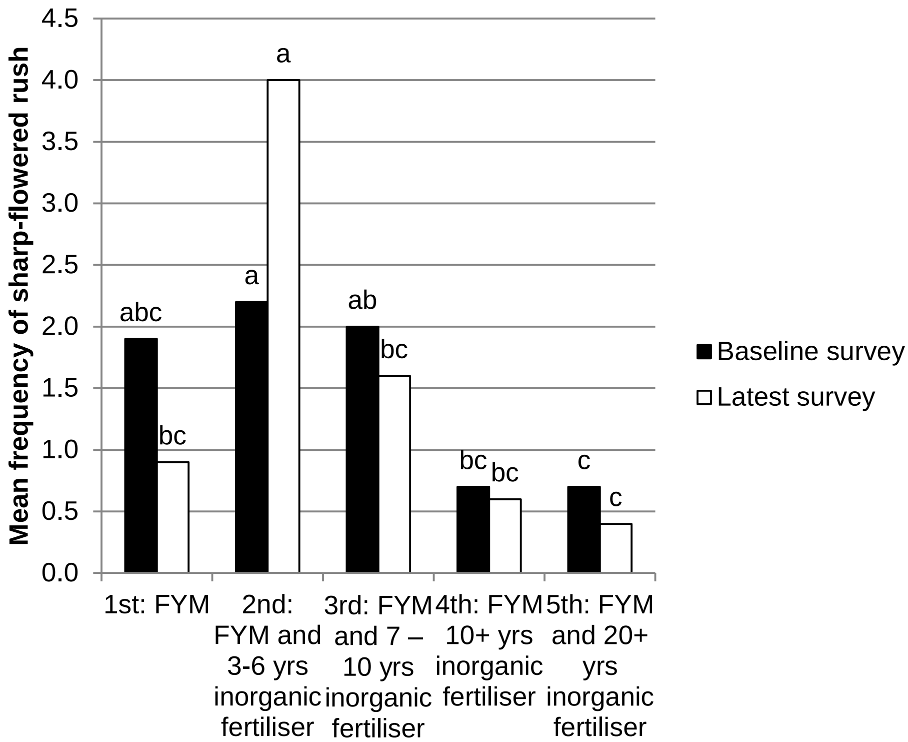

Figure 17. Sharp-flowered rush and fertiliser categories. The differences between fertiliser categories and changes over time in mean frequency of sharp-flowered rush in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, c = the lowest value: those groups with the same letter are not significantly different.

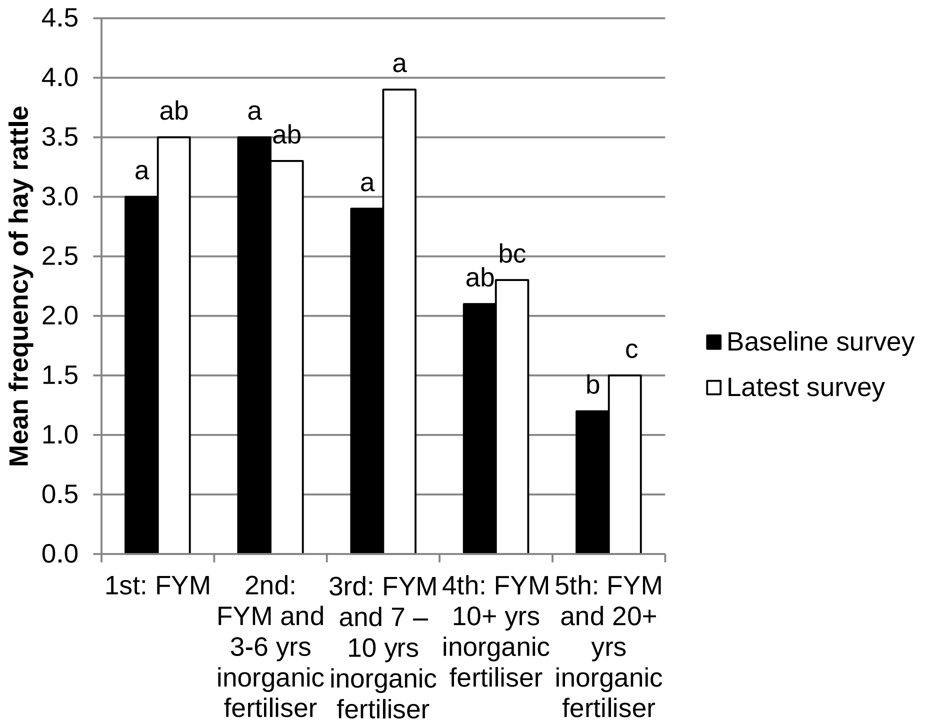

Figure 18. Hay rattle and fertiliser categories. The differences between fertiliser categories and changes over time in mean frequency of hay rattle in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, c = the lowest value: those groups with the same letter are not significantly different.

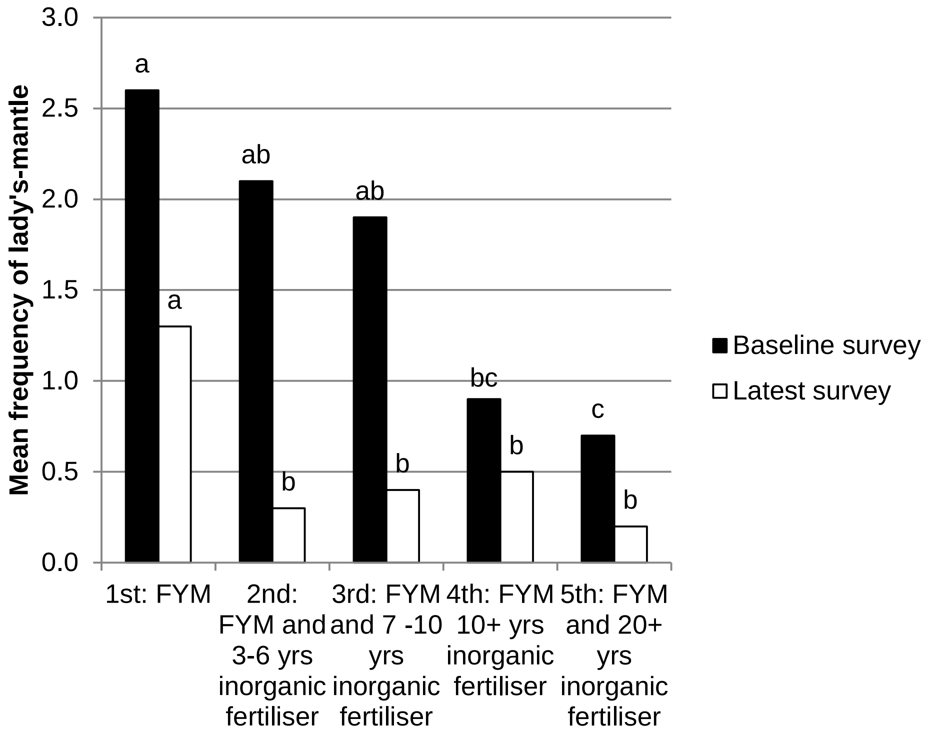

Figure 19. Lady's-mantle and fertiliser categories. The differences between fertiliser categories and changes over time in mean frequency of Lady's-mantle in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, c = the lowest value; those groups with the same letter are not significantly different.

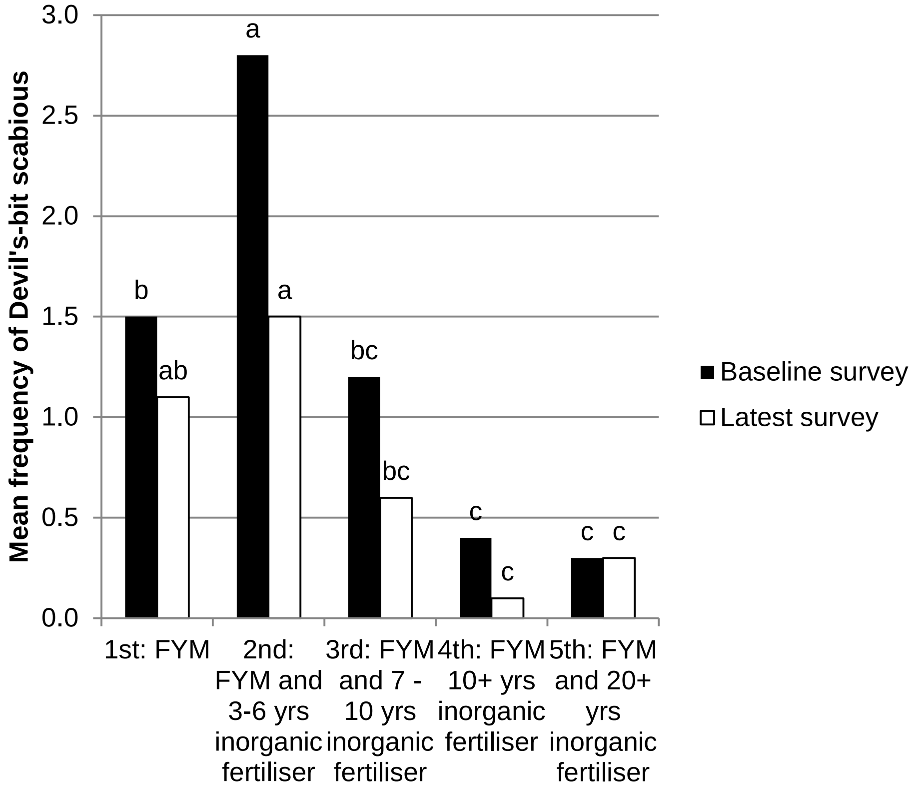

Figure 20. Devil's-bit scabious and fertiliser categories. The differences between fertiliser categories and changes over time in mean frequency of devil's-bit scabious in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, c = the lowest value; those groups with the same letter are not significantly different.

6.8 Fertility and fertiliser categories

There is a positive association between the length of time that inorganic fertilisers have been added to meadows and increasing fertility scores.

The findings suggest that in the baseline survey period, Upper Teesdale meadows that received inorganic fertilisers before the baseline survey period, were more fertile than meadows than had only received FYM additions before this period; SS-Nutrient score was significantly lower in 1st category compared to 4th and 5th categories; and 2nd, 3rd and 4th categories were intermediate (Figure 21); Ellenberg fertility index (N) was significantly lower in 1st, 2nd and 3rd categories and significantly higher in 4th and 5th categories (Appendix Table R).

The pattern suggests that over time, the majority of meadows have become more fertile; SS-Nutrient scores increased in 1st, 2nd and 4th categories (Figure 21) and Ellenberg fertility index (N) significantly increased in all five fertiliser categories (Appendix Table S).

In the latest surveys, the results suggest that meadows that received inorganic fertilisers for longer than ten years were more fertile than meadows that received inorganic fertilisers for less than 10 years: Ellenberg fertility index (N) and SS-Nutrient scores were lower in the first three categories compared to 4th and 5th categories (Appendix Table R) (see Appendix 6 for further descriptions of Ellenberg fertility, plus moisture and pH scores).

Figure 22 shows phosphorous levels (ppm) for 43 Upper Teesdale meadows that have had soil samples taken recently (over the last 10 years). Fertiliser categories had to be reduced to just three categories as there were a smaller number of meadows. The findings show that meadows that have had inorganic fertiliser inputs the longest number of years, also have the highest phosphorous levels: 1st category (meadows that have received up to 6 years of inorganic fertiliser) was significantly lower than 3rd category (inorganic fertilisers for over 20 years); The 2nd category (7 – 19 years of inorganic fertiliser inputs) was intermediate ($F_{2,42}$=3.41, p=0.043). Potassium (K), magnesium (M) nitrogen (N) and pH were not significantly different.

Figure 23 shows a correlation between total meadow score and Ellenberg fertility index (N). As Ellenberg fertility index (N) increases, total meadow score decreases. Figure 24 shows an association between phosphorous levels (ppm) and Ellenberg fertility index (N). When phosphorous levels increase, so does Ellenberg fertility index (N). This infers a relationship between the calculated Ellenberg fertility index (N) and the recorded nutrient conditions of the soils in the Upper Teesdale dataset.

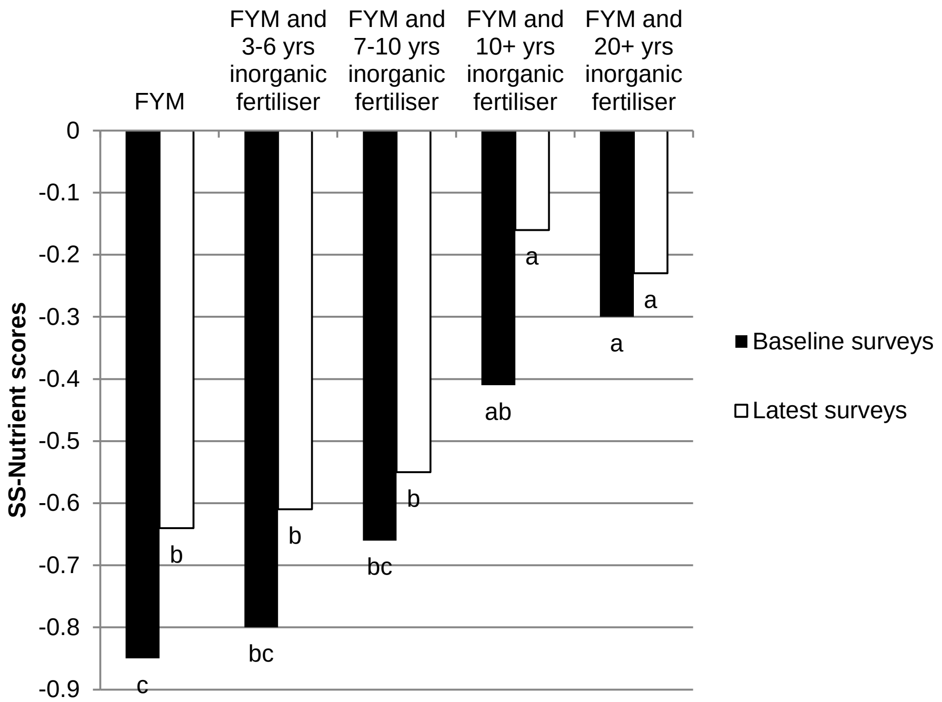

Figure 21. SS-Nutrient scores and fertiliser categories. The differences between fertiliser categories and changes over time in mean SS-Nutrient scores; meadows categorised by number of years they have received inorganic fertiliser inputs. Both differences between groups and changes over time are significantly different. Statistically significant differences are shown between the different groups: a = the highest value, c = the lowest value; those groups with the same letter are not significantly different.

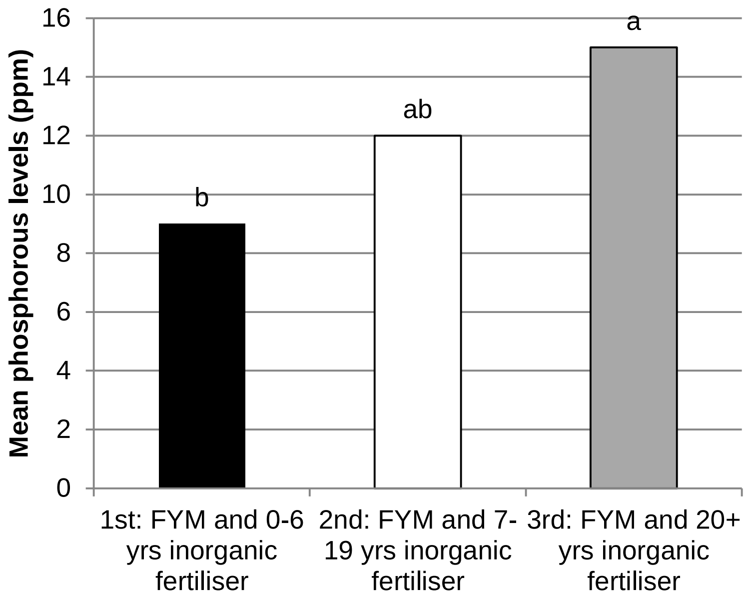

Figure 22. Phosphorous levels (ppm) and fertiliser categories. The differences in mean phosphorous levels (ppm) between 43 Upper Teesdale meadows (soil samples taken from 2002 – present); categorised by number of years they have received inorganic fertiliser inputs. 9 ppm = Index 0.9; 12 ppm = Index 1.4; 15 ppm = Index 1.9. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value; those groups with the same letter are not significantly different. ($F_{2,42}$=3.41, p=0.043).

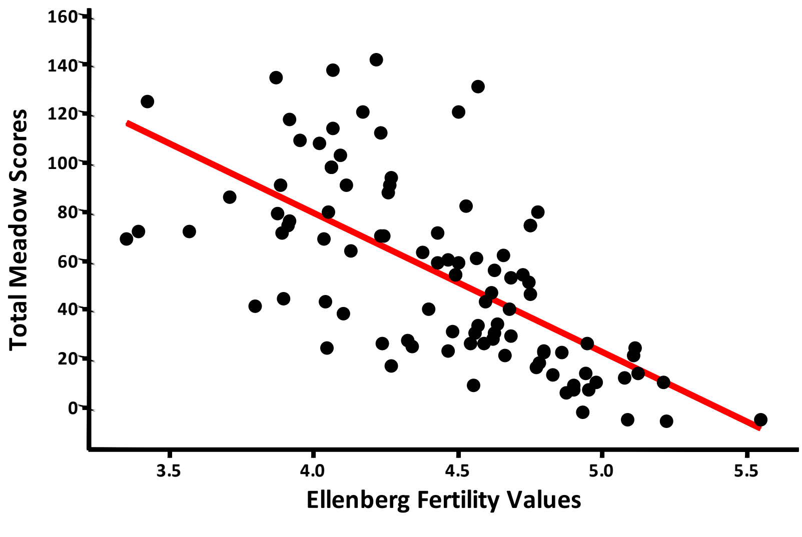

Figure 23. The relationship between total meadow score and Ellenberg fertility index (N). $F_{1, 97}$ = 73.87, p< 0.001, R-Sq=43.5%. As Ellenberg fertility score increases, total meadow score decreases.

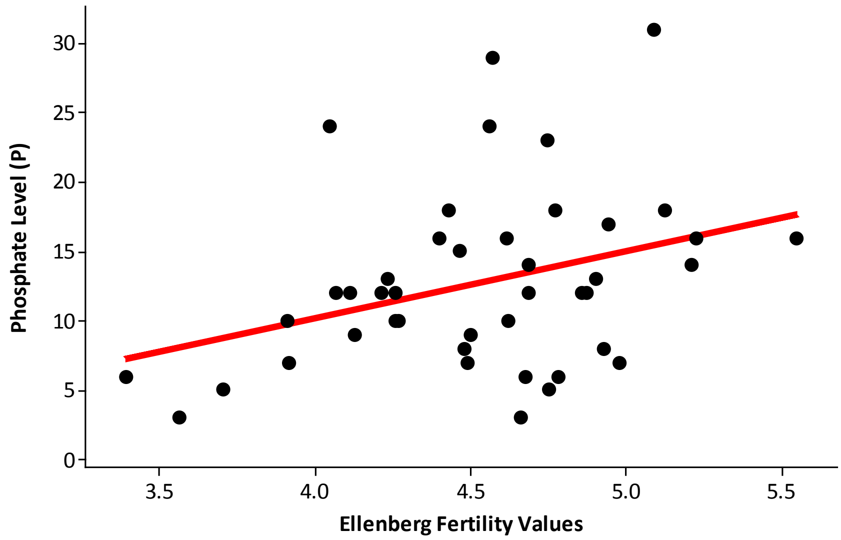

Figure 24. The relationship between phosphate levels and Ellenberg fertility index (N). $F_{1, 42}$=5.39, p= 0.025, R-Sq = 11.6%. As phosphate levels increase, so does Ellenberg fertility index (N).

6.9 Redundancy Analysis (RDA)

Redundancy analysis shows declining botanical quality over time is associated with increasing fertility scores.

Figure 25 shows a bi-plot from a Redundancy Analysis (RDA) conducted using the modeling program CANOCO, using the full dataset of 98 matched pairs of Upper Teesdale upland hay meadows. The lengths of gradient were under 4 so the data was linear. In a bi-plot, the lines that are closest together are the most closely related and the lines that are opposite each other are not related, i.e. opposite environmental conditions. The longer the lines, the more the species or management category is related to the area it is pointing to.

1st and 3rd categories were found in bottom right of bi-plot, 2nd category was found to far right of bi-plot, and 4th and 5th categories were found in far left side of bi-plot. There were very few species on left side of bi-plot, the majority of species being found on right side. Fertility scores, latest surveys, non SSSI meadows (Tier 1), meadows managed as ESA Tier 1 (ESA), meadows that have received inorganic fertiliser inputs before baseline survey period (Hist Fert), fit to MG8 and negative indicator species score point to left of bi-plot. Number of grasses point to the top of the bi-plot where grass species were also found, i.e. perennial rye-grass, Yorkshire fog, smooth meadow-grass (*Poa pratensis*) and red rescue (*Festuca rubra*). Moisture scores, baseline surveys, SSSI meadows and those that have been in a management agreement (WES), meadows that only received FYM before the baseline survey period (No Hisfer), number of species (Sp rich), Shannon diversity index, number of wildflowers, positive indicator species score (P+), total meadow score (TM) and fit to MG3b point to right side of bi-plot. Table 10 shows the results from Monte Carlo permutation tests whilst partitioning the variance: historic fertiliser input was not significant but all other groups were and interactions accounted for highest percentage of variance (22%) within the data.

The bi-plot pattern suggests that the left to right axis is a fertility axis. As the previous results have shown, the 2nd category had the highest species and meadow scores which have drawn this group to far right of bi-plot, along with the majority of plant species. 1st and 3rd categories were found in the same area of bi-plot with 4th and 5th categories on the opposite side. As the latest surveys and fertility scores point to the left of the bi-plot where there were very few species, it would suggest that over time the meadows have become more fertile and the species and meadow scores have declined. The diversity of sedges (*Carex* sp.) and orchids (*Dactylorhiza* sp.) have particularly declined over time, along with the key indicator species mentioned previously. Other species to note from right side of bi-plot include: smooth hawk's-beard (*Crepis capillaris)* and marsh hawk's-beard (*Crepis paludosa*), marsh valerian (*Valerian dioica)*, water avens *(Geum rivale*), cats-ear *(Hypochaeris radicata)* and wood anemone (*Anemone nemorosa).*

Table 10. Monte Carlo permutation tests for each management group. Each group has been partitioned and analysed separately in CANOCO. Only historic fertiliser inputs are not significant.

Management Groups	%	F-ratio	p-value
Baseline: Latest	**2**	**4.4**	**0.002**
SSSI: Tier1	**0.8**	**1.84**	**0.036**
WES: ESA	**1.6**	**3.56**	**0.002**
Hist Fert: No HistBa	**0.5**	**1.08**	**0.32**
Fertiliser categories	**5.7**	**3.11**	**0.002**
Interactions	**22**	**2.34**	**0.002**
Total inertia	**32.6**	**16.33**	**0.002**

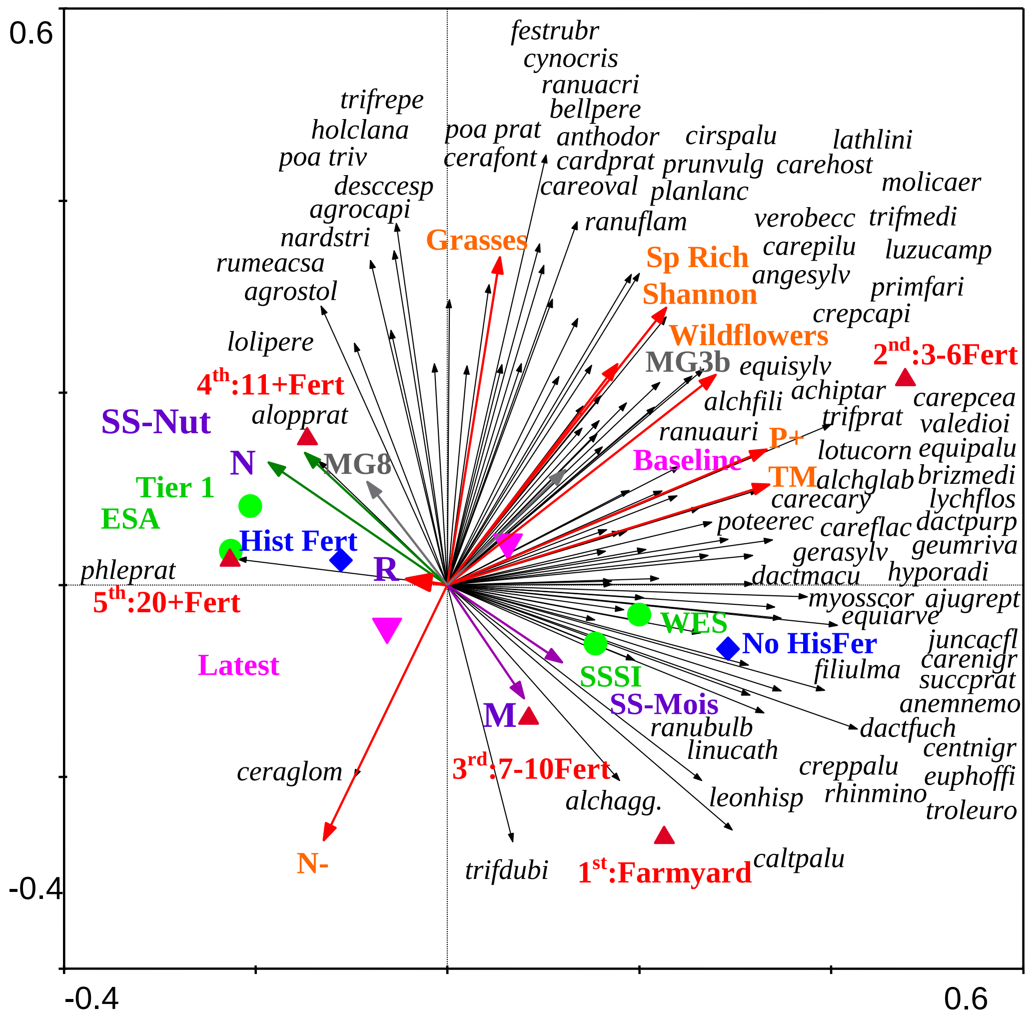

Figure 25. Redundancy Analysis (RDA). A RDA bi-plot created in CANOCO, using the botanical data from 98 matched pairs of baseline and latest surveys from upland hay meadows in Upper Teesdale. Management groups and fertiliser categories are shown by this key: Baseline = baseline surveys, Latest = latest surveys with pink triangles; Hist Fert = inorganic fertiliser additions before baseline survey period, and No HisFer = no historical fertiliser additions before baseline survey period with blue squares; 1st:Farmyard = 1st category, FYM only, 2nd:3-6Fert = 3rd category, FYM plus 3 – 6 years fertiliser, 3rd:7-10Fert = 3rd category, 7 – 10 years inorganic fertiliser, 4th:11+Fert = 4th category, 11+ years inorganic fertiliser and 5th:20+Fert = 5th category, 20+ years inorganic fertiliser with red triangles; WES = meadows in a management agreement, ESA = meadows managed as ESA Tier 1; SSSI = SSSI meadows, and Tier 1 = non SSSI meadows with green circles; N = Ellenberg Fertility Index; SS-Nut = SS-Nutrient scores; M = Ellenberg Moisture Index; SS-Mois = SS-Moisture scores; R = Ellenberg pH Index. Fertility scores with green lines, moisture scores with purple lines. Sp Rich = Numbers of species; Shannon = Shannon Diversity Index; grasses = numbers of grasses and rushes and flowers = numbers of wildflowers and sedges with red lines. MG8 and MG3b – best fit to the NVC classification with grey lines.

Key:
ceraglom=*Cerastium glomeratum*, phleprat=*Phleum pratense*, aloprat=*Alopecurus pratensis*, lolipere=*Lolium perenne*, agrostol=*Agrostis stolonifera*, rumeacsa=*Rumex acetosa*, nardstri=*Nardus stricta*, agrocapi=*Agrostis capillaris*, desccesp=*Deschampsia cespitosa*, poa triv=*Poa trivialis*, holclana=*Holcus lanatus*, trifrepe=*Trifolium repens*, cerafont=*Cerastium fontanum*, festrubr=*Festuca rubra*, cynocris=*Cynosurus cristatus*, ranuacri=*Ranunculus acris*, bellpere=*Bellis perennis*, anthodor=*Anthoxanthum odoratum*, cardprat=*Cardamine pratensis*, careoval=*Carex ovalis*, ranuflam=*Ranunculus flammula*, cirspalu=*Cirsium palustre*, prunvulg=*Prunella vulgaris*, planlanc=*Plantago lanceolata*, carehost=*Carex hostiana*, lathlini=*Lathyrus linifolius*, molicaer=*Molinia caerulea*, verobecc=*Veronica beccabunga*, trifmedi=*Trifolium medium*, carepilu=*Carex pilulifera*, luzucamp=*Luzula campestris*, angesylv=*Angelica sylvestris*, primfari=*Primula farinosa*, crepcapi=*Crepis capillaris*, equisylv=*Equisetum sylvaticum*, alchfili=*Alchemilla filicaulis*, achiptar=*Achillea ptarmica*, carepcea=*Carex panicea*, ranuauri=*Ranunculus auricomus*, trifprat=*Trifolium pratense*, valedioi=*Valerium dioica*, lotucorn=*Lotus corniculus*, equipalu=*Equisetum palustre*, alch glab=*Alchemilla*

glabra, brizmedi=*Briza media*, carecary=*Carex caryophyllea*, dactpurp=*Dactylorhiza purpurella*, careflac=*Carex flacca*, gerasylv=*Geranium sylvaticum*, dactmacu= *Dactylorhiza maculata*, hyporadi=*Hypochaeris radicata*, myosscor=*Myosotis scorpioides*, ajugrept=*Ajuga reptans*, equiarve=*Equisetum arvense*, juncacut=*Juncus acutiflorus*, carenigr=*Carex nigra*, filiulma=*Filipendula ulmaria*, succprat=*Succisa pratensis*, anemnemo=*Anemone nemorosa*, dactfuch= *Dactylorhiza fuchii*, centnigr=*Centaurea nigra*, euphoffi=*Euphrasia arctica*, troleuro=*Trollius europaeus*, creppalu=*Crepis paludosa*, rhinmino=*Rhinanthus minor*, ranubulb=*Ranunculus bulbosus*, linucalt=*Linum caltharticum*, leonhisp=*Leontodon hispidus*, caltpalu=*Caltha palustris*, alchagg.=*Alchemilla sp.*, trifdubi=*Trifolium dubium*.

6.10 RDA and soil samples

Redundancy analysis shows an association between poor botanical quality, higher phosphate levels and long-term inorganic fertiliser use.

Figure 26 shows a bi-plot from a Redundancy Analysis (RDA) conducted using the modeling program CANOCO, using data from the 43 meadows in Upper Teesdale that have had soil samples taken recently (over the last ten years). The lengths of gradient were 2.909 so the data was linear. 1st category was found in far right of bi-plot, 2nd and 3rd categories were found in left of bi-plot. 3rd category, phosphate levels (ppm), magnesium (Mag), fertility scores, non SSSI meadows (Tier 1) and meadows managed as ESA Tier 1 (ESA) point to bottom left of bi-plot. 2nd category, meadows that have received inorganic fertiliser inputs before baseline survey period (Hist Fert), fit to MG8 and number of grasses point to top left of bi-plot. Number of species (Sp rich), number of wildflowers, Shannon diversity index and fit to MG3b point to top of bi-plot. 1st category, moisture scores, SSSI meadows and those that have been in a management agreement (WES), positive indicator species scores (P+) and total meadow score (TM) point to right/top right of bi-plot. The meadows that only received FYM before baseline survey period (No FertBa) and negative indicator species score point to the bottom right of the bi-plot. Table 11 shows results from Monte Carlo permutation tests whilst partitioning the variance: SSSI compared to non SSSI meadows and differences in type of management agreement were not significant but historic fertiliser input was and 1st category was significantly different to 3rd category. The interactions accounted for highest percentage (25.3%) of variance within the data.

The bi-plot pattern suggests that the bottom left to the top right axis is a fertility axis. The species associated with high phosphate levels, Ellenberg fertility index and 3rd category were: soft brome, perennial rye-grass and meadow foxtail (*Alopecurus pratensis)*, directly opposite these grass species were the species: eyebright, globeflower, common knapweed, hay rattle, bugle, sharp-flowered rush, carnation sedge (C*arex panicea),* common sedge *(Carex nigra*), devil's-bit scabious, rough hawkbit, marsh marigold and meadowsweet. A number of species noted in the description of Figure 25, plus the less common sedges (*Carex* sp.) and orchids (*Dactylorhiza* sp.) are no longer found in this bi-plot, suggesting that they are no longer a key component of the meadows in these later surveys.

Table 11. Monte Carlo permutation tests for each management group using soils data. Each group has been partitioned and analysed separately in CANOCO. SSSI: Tier 1 and WES: ESA are not significant, whereas historic fertiliser inputs and fertiliser categories are significant, and the interactions are significant.

Management Groups	%	F-ratio	p-value
SSSI: Tier1	**2.3**	**1.05**	**0.348**
WES: ESA	**2.9**	**1.37**	**0.134**
Hist Fert: No HistBa	**4.5**	**2.13**	**0.012**
Fertiliser categories	**3.5**	**1.67**	**0.054**
Interactions	**25.3**	**1.7**	**0.002**
Total inertia	**32.6**	**7.92**	**0.002**

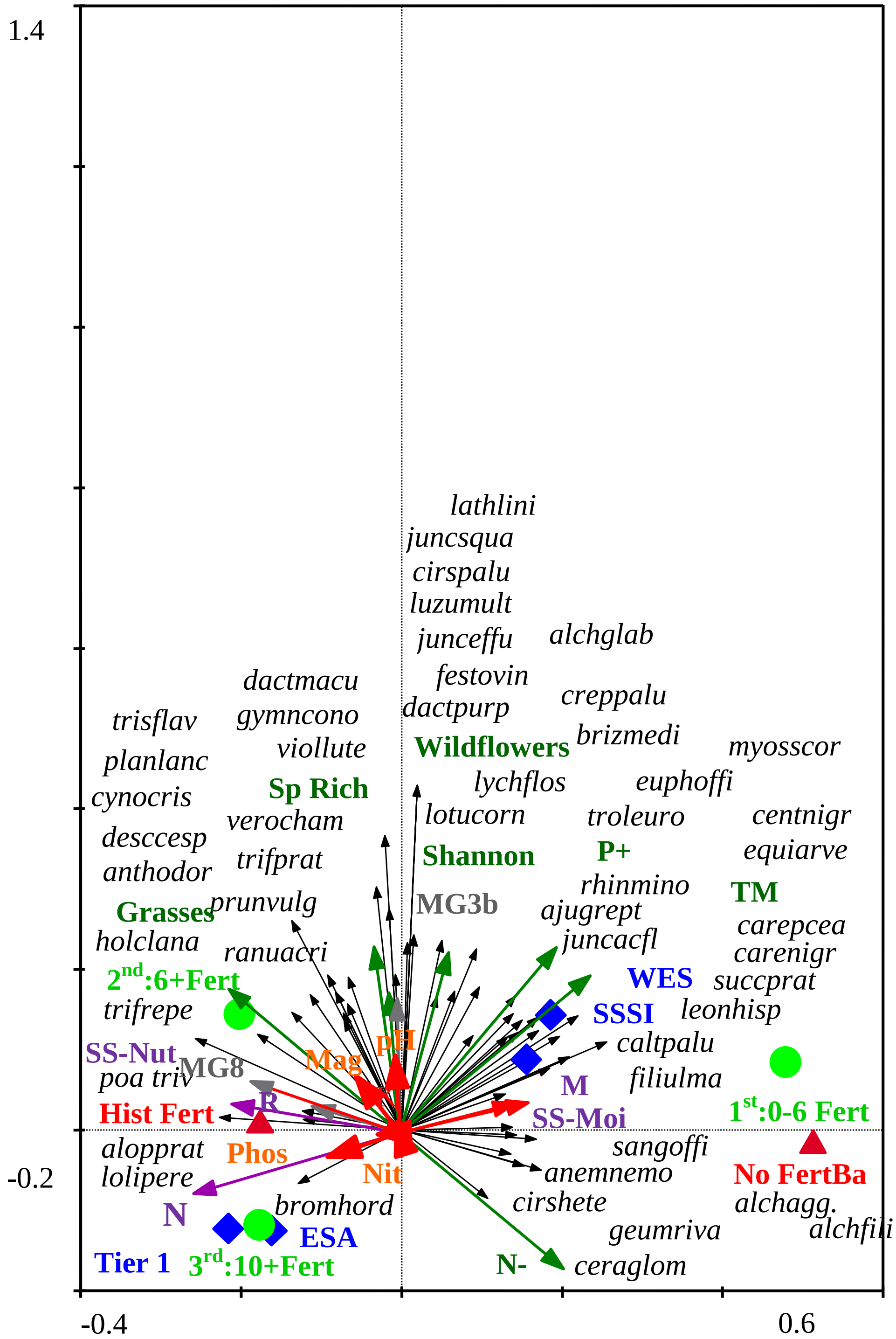

Figure 26. RDA and soils data. RDA bi-plot created in CANOCO using botanical and soils data from 43 Upper Teesdale meadows, showing 53 species. Categories are grouped as: Hist Fert = inorganic fertiliser additions before baseline surveys, and No HisFer = no historical fertiliser additions before baseline surveys, red triangles: 1st:0-6 Fert = 1st category: small amounts of fertiliser inputs; 2nd:6+Fert = 2nd category; 6+ yrs inorganic fertiliser use; 3rd:10+Fert = 3rd category; 10+ yrs inorganic fertiliser use; green circles: WES = SSSI in management agreement, ESA = meadows managed as ESA Tier 1, SSSI = SSSI meadows, and Tier 1 = non SSSI meadows, blue squares. N = Ellenberg fertility index; SS-Nut = SS-Nutrient score; M = Ellenberg moisture index; SS-Moi = SS-Moisture scores; R = Ellenberg pH index. Fertility scores with purple lines, moisture scores with red lines. Phos = phosphate levels (ppm); Nit = nitrogen; Mag = magnesium; pH = pH. Sp Rich = numbers of species; Shannon = Shannon Diversity Index; grasses = numbers of grasses and Wildflowers = numbers of wildflowers, green lines. MG8 and MG3b – best fit to the NVC classification, with grey lines.

Key:
bromhord=*Bromus hordeaceus*, lolipere=*Lolium perenne*, aloprat=*Alopecurus pratensis*, poa triv=*Poa trivialis*, trifrepe=*Trifolium repens*, holclana=*Holcus lanatus*, ranuacri=*Ranunculus acris*, prunvulg=*Prunella vulgaris*, anthodor=*Anthoxanthum odoratum*, trifprat=*Trifolium pratense*, desccesp=*Deschampsia cespitosa*, verocham=*Veronica chamaedrys*, cynocris=*Cynosurus cristatus*, planlanc=*Plantago lanceolata*, trisflav=*Trisetum flavescens,* gymncono=*Gymnadenia conopsea*, viollute=*Viola lutea*, dactmacu= *Dactylorhiza maculata*, lathlini=*Lathyrus linifolius*, juncsqua=*Juncus squarrosus*, cirspalu=*Cirsium palustre*, luzumult=*Luzula multiflora*, junceffu=*Juncus effusus*, festovin=*Festuca ovina*, dactpurp=*Dactylorhiza purpurella*, creppalu=*Crepis paludosa*, brizmedi=*Briza media*, myosscor=*Myosotis scorpioides, lychflos=Lychnis flos-cuculi,* euphoffi=*Euphrasia arctica*, lotucorn=*Lotus corniculus*, troleuro=*Trollius europaeus*, centnigr=*Centaurea nigra*, equiarve=*Equisetum arvense*, rhinmino=*Rhinanthus minor*, ajugrept=*Ajuga reptans*, juncacut=*Juncus acutiflorus*, carepcea=*Carex panicea*, carenigr=*Carex nigra*, succprat=*Succisa pratensis*, leonhisp= *Leontodon hispidus*, caltpalu=*Caltha palustris*, filiulma=*Filipendula ulmaria*, sangoffi=Sanguisorba officinalis, anemnemo=*Anemone nemorosa*, alchagg.=*Alchemilla* sp., alchfili=*Alchemilla filicaulis*, cirshete=*Cirsium heterophyllum*, geumriva=*Geum rivale*, ceraglom=*Cerastium glomeratum.*

7. Discussion

Upper Teesdale meadows and botanical quality

1) Have Upper Teesdale upland hay meadows declined in botanical quality over time?

The results presented in this report for Upper Teesdale upland hay meadows show a decline of 40% in the botanical quality (referring to positive indicator species score and total meadow score) of upland hay meadows over the last 20 to 30 years and these declines follow a consistent pattern across different types of datasets. Sixty-four percent of meadows have declined, 15% of meadows remained the same whilst the remaining 21% increased in botanical quality. Number of species, Shannon diversity index (H'), positive indicator species score (P+) and total meadow score (TM) have all declined, whilst Ellenberg fertility index (N) and SS-nutrient scores, have increased. A number of MG3 indicator species have declined: Lady's-mantle, pignut, wood crane's-bill and great burnet, along with the rarer MG3b/MG8 plants: bugle, quaking grass, common knapweed, meadowsweet, rough hawkbit, devil's-bit scabious and globeflower, whilst other mesotrophic grassland species have increased: Yorkshire fog, soft rush, creeping buttercup, hay rattle and lesser trefoil.

The results presented in this report follow a similar pattern to that shown by Petit and Pacha (2008) in the Yorkshire Dales National Park, where a decline in habitat quality, increased fragmentation and intensive management practices have led to a loss of wood crane's-bill in 40% of upland hay meadows. The work of John O'Reilly (2010a; 2010b) looking at upland hay meadows across the North Pennines, has also demonstrated a decline in the botanical quality of MG3b upland hay meadows since the mid-1980s with an increase in perennial rye-grass, hay rattle and lesser trefoil (O'Reilly 2010a; 2010b).

Eyebright, hay rattle and lesser trefoil are generally increasing in upland hay meadows in Upper Teesdale. O'Reilly has suggested that these species are annuals and flower earlier, so can cope with the earlier cutting times and faster hay-making associated with modern machinery (O'Reilly 2010a). Furthermore, as the positive indicator species with a score of +3 are showing the greatest declines over time, the special MG3/MG8 meadows are becoming rarer and the MG6 meadows are becoming more common. Rodwell (1992) states that with an increase in fertility, species-rich MG3b meadows can convert to improved, productive mesotrophic meadows, firstly MG6, followed by *Lolium perenne* (MG7) grassland. This appears to be happening in Upper Teesdale: the following MG3/MG8 species are declining; Lady's-mantle, bugle, quaking grass, wood crane's-bill, devil's-bit scabious, great burnet and globeflower; and the following MG6 species are common or increasing; sweet vernal grass, crested dog's-tail, eyebright, perennial rye-grass, Yorkshire fog, creeping buttercup, meadow buttercup, hay rattle, lesser trefoil and red clover.

The data gathered for this project has found no significant evidence from the changes in plant communities to suggest that Upper Teesdale upland hay meadows have generally become wetter or more acidic over time: although some meadows have become wetter or more acidic, other meadows have become drier or less acidic. Sharp-flowered rush is found in higher frequencies in the wetter meadows with a lower Ellenberg fertility index (generally the 2nd category of the fertiliser categories where both the SS-moisture scores and Ellenberg moisture index (M) have increased) (Hill *et al.* 1999). There is a perception that soft rush and sharp-flowered rush is spreading into Upper Teesdale meadows as the meadows are becoming wetter (per comms; O'Reilly 2010a; 2010b). Soft rush has shown increases (in the overall dataset and in the 1st fertiliser category) but the increases are very small (an increase in frequency of 0.2), whereas there are no significant increases in sharp-flowered rush. Creeping buttercup is not only found in wet meadows but is also a competitive species which has increased in the meadows that have had the highest inorganic fertiliser inputs. This species has been shown to be increasing in other upland hay meadows in the North Pennines (O'Reilly 2010a; 2010b).

The data gathered for this report has found no significant evidence to show what may have caused the improvement in botanical quality found in 21% of meadows. However, these meadows consistently had a low positive indicator species score in the baseline surveys (an average of 41 P) and a low positive indicator species score in the latest surveys (an average of 59 P) compared to the overall averages, suggesting that improvements have been from a low base. There were an equal number of SSSI meadows compared to ESA Tier 1 meadows that showed an increase in botanical quality and an equal number of meadows showed a decline in Ellenberg fertility indices or increase in Ellenberg moisture indices. The majority of these meadows did have historical fertiliser inputs before the baseline surveys were undertaken, and this might explain why the positive indicator scores are lower than the overall averages. The meadows that improved in botanical quality were not found on a particular farm or in a particular area, rather they were distributed across farms in Upper Teesdale. A number of these meadows had increases in lesser trefoil, eyebright and yellow rattle suggesting that modern farming methods may be favoring these species and driving an improvement in botanical diversity in some cases, as suggested by O'Reilly (2010a; 2010b). In addition, Critchley *et al.* (2007) found evidence of some improvements in botanical quality in species-poor upland hay meadows in the North Pennines. These improvements were related to later cutting dates and a reduction in spring grazing (Critchley *et al*. 2007).

Agri-environment schemes and botanical quality

2) *Have agri-environment schemes maintained the botanical quality of Upper Teesdale upland hay meadows?*

The management prescribed for meadows in Upper Teesdale, whether this was MA, WES or ESA Tier 1 has not maintained botanical quality over time. The number of grasses, number of species, Shannon diversity index, positive indicator species score and total meadow score have declined, along with the species, Lady's-mantle, bugle, quaking grass, meadowsweet, wood crane's-bill and great burnet, in the majority of both SSSI meadows managed in a MA or WES *and* meadows managed as ESA Tier 1. In meadows managed as ESA Tier 1, creeping buttercup and Yorkshire fog increased over time.

In both the baseline and the latest surveys, Upper Teesdale SSSI meadows managed through a MA or WES had higher botanical quality (positive indicator species score and total meadow score) than meadows managed as ESA Tier 1. A large number of species were found in greater frequencies in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1: bugle, Lady's-mantle, quaking grass, marsh marigold, common knapweed, crested dog's-tail, eyebright, meadowsweet, wood crane's-bill, rough hawkbit, ragged robin, self-heal, hay rattle, great burnet, devil's-bit scabious, red clover and globeflower. Many of the MG3/MG8 indicator species are found in extremely low frequencies in meadows managed as ESA Tier 1.

These results suggest that in the past, the decision-making process that allocated MA or WES agreements to particular SSSI meadows worked, and gave better protection to the top meadows. Although the meadows have declined, SSSI meadows are still of higher quality in terms of numbers of wildflowers, positive indicator species scores and total meadow scores than the other meadows. SSSI meadows that were managed in a MA or WES are now the remaining remnants of good MG3/MG8 upland hay meadows. It has been shown that it is most cost-effective to spend agri-environment money on sites with the highest biodiversity (Kleijn *et al.* 2009); perhaps priority conservation efforts should be focused on SSSI meadows in Upper Teesdale? However, an additional priority should be to understand why these special meadows are still deteriorating and to halt and reverse the decline.

What may have caused this decline? Studies have shown that agricultural practices may act in combination with one another and as a consequence it is difficult to implicate any one individual management practice. Intensive spring grazing for long periods of time can reduce species richness and diversity; a shift from hay making to silage production can quickly reduce wildflowers and increase the number of grasses; earlier cutting times can reduce the abundance of later flowering plants; use of inorganic fertilisers can increase the hay yield to the detriment of botanical quality, sowing grass seeds changes the botanical composition. In combination these practices can rapidly reduce botanical quality (Smith and Jones 1991; Smith *et al.* 1996a; 1996b; 2008; Jefferson 2005; Critchley *et al.* 2007; Pacha and Petit 2008; Kirkham *et al.* 2008; in press). Agri-environment schemes aim to encourage farmers to adhere to traditional management practices: hay making is preferred; later cutting dates are implemented; inorganic fertiliser use is restricted; stocking densities are controlled and closing dates are brought forward (DEFRA 2002; Critchley *et al.* 2007).

Critchley *et al.* (2003) investigated lowland grasslands in agri-environment schemes and concluded that the schemes were effective in maintaining floristic diversity. However, they did find deterioration in botanical quality resulting from the use of inorganic fertilisers and changes in cutting time. This study was repeated, looking specifically at northern upland hay meadows. The study showed a decline in the botanical quality of upland hay meadows in agri-environment schemes, with a corresponding increase in Ellenberg fertility index, similar to the patterns presented in this report. However, Critchley *et al.* 2007 were able to investigate interactions between different management regimes: in the absence of spring grazing but without any change in nutrient inputs, they found that wildflower diversity increased whilst Ellenberg fertility index decreased. They also found a negative relationship between wildflower diversity, intensive grazing, nutrient levels and Ellenberg fertility index. The overall conclusion was that intensive spring grazing should be avoided, inorganic fertiliser restricted and cutting dates should be after the 22nd July (Critchley *et al.,* 2007).

For this report there was insufficient information available on length of spring grazing, grazing intensity, cutting times, silage making or rates of FYM and inorganic fertiliser applications to enable these factors to be investigated. Interactions between these factors are likely to have played a part in the decline of the meadows in Upper Teesdale but the data does not exist to demonstrate their relative importance. The only management data available for this project were differences in management agreements and the length of time inorganic fertilisers had been applied. The Ellenberg fertility index and SS-Nutrient scores have been found to be increasing in the majority of meadows, regardless of their management agreement, suggesting that either grazing intensity is too great or too many nutrients are being applied (or a combination of these factors) on both SSSIs and ESA Tier 1, thus reducing wildflower diversity (Smith *et al.* 2008; Critchley *et al.,* 2007).

Fertility in upland hay meadows

3) *Is there any evidence to suggest that inorganic fertiliser use is an acceptable management option for Upper Teesdale upland hay meadows in order to maintain and sustain botanical quality?*

This correlative study suggests that long-term inorganic fertiliser use is not an acceptable management option for Upper Teesdale upland hay meadows if the aim is to maintain and sustain botanical quality.

Inorganic fertiliser started being used in the UK during the 20th century. It is unclear when inorganic fertiliser use started in Upper Teesdale but Olff and Bakker (1991) claim that its use was prevalent in the Netherlands in the 1920s and Ratcliffe (1978) claims that meadows had declined in Upper Teesdale due to inorganic fertiliser use from as early as the 1960s. Bradshaw and Hedley (2003) refer to inorganic fertiliser use over the last 40 years in the book 'The Natural History of Upper Teesdale', so it is clear that inorganic fertilisers were used in Upper Teesdale from at least 1965 onwards. Therefore, upland hay meadows that received inorganic fertiliser additions before the baseline survey period could have had those additions for up to 20 years.

Upper Teesdale meadows that only had FYM additions before the baseline survey period had higher botanical quality, with lower Ellenberg fertility index and SS-Nutrient scores, in comparison to the meadows that had FYM and inorganic fertiliser additions before this period. The following species were found in higher frequencies in the meadows that only had FYM in the past: Lady's-mantle, bugle, quaking grass, marsh marigold, common knapweed, eyebright, meadowsweet, rough hawkbit, ragged robin, hay rattle, devil's-bit scabious, red clover and globeflower. Over time, botanical quality has declined in both groups, whilst fertility indices have increased. Phosphorous levels are much higher in the meadows that have received historical inorganic fertiliser applications compared to meadows that only had FYM additions before the baseline survey period. Perennial rye-grass, Yorkshire fog and creeping buttercup have increased, whereas many positive indicator species have declined, in meadows that received historic additions of inorganic fertiliser compared to meadows that only had FYM additions before the baseline survey period.

In the baseline surveys, in both meadows managed as ESA Tier 1 and those meadows that had historic inorganic fertiliser inputs, botanical quality was less than SSSI meadows and those meadows that only received FYM additions. This suggests that either botanical quality had already declined before the baseline survey period, or these meadows were always of lower botanical quality. Considering that the majority of the key positive indicator species with a score of +3 have declined over the last 20+ years there is a strong suggestion that declines in botanical quality began in Upper Teesdale meadows long before the baseline surveys were undertaken.

The five categories of inorganic fertiliser use have been crudely grouped based on the number of years inorganic fertiliser has been added. As the available data does not include information on the rates of nutrient application, there is likely to be significant overlap in the rates of nutrients applied, and the distinctions between the categories were mixed. However, even with these limitations, a general correlative pattern is indicated by the results: there is a positive association between the number of years that inorganic fertilisers have been applied and a reduction in botanical quality.

As discussed in the previous paragraphs, past inorganic fertiliser use before the baseline survey period could have led to a decline in the botanical quality of meadows in the past. A number of species were already found in greater frequencies the 1st and 2nd categories compared to the 4th and 5th categories: Lady's-mantle, bugle, marsh marigold, common knapweed, eyebright, meadowsweet, hay rattle, red clover, devil's-bit scabious and globeflower.

The Shannon diversity index (H'), positive indicator species score (P+) and total meadow score (TM) declined in all fertiliser categories and the number of species declined in all apart from the last category where inorganic fertilisers had been added for a long time (number of species was already low in this category). Conversely, the Ellenberg fertility index (N) increased in all categories and the SS-Nutrient score increased in the majority. Many species declined in more than one category: Lady's-mantle, bugle, quaking grass, marsh marigold, pignut, meadowsweet, self-heal, common knapweed, rough hawkbit, meadow buttercup, wood crane's-bill, great burnet, devil's-bit scabious and globeflower

By the latest surveys, the fertility indices remained higher in meadows that had over ten years of inorganic fertiliser applications and the phosphorous levels were also higher in the meadows that had received inorganic fertilisers for the greatest number of years. In contrast, positive indicator species score and total meadow score was lower in the meadows that had received inorganic fertilisers for over ten years. The species showing the closest association (negative) with the application of inorganic fertilisers is Lady's-mantle which is now restricted to meadows that have only received FYM applications. Other species showing a preference for meadows with fewer years of inputs were bugle, quaking grass, sharp-flowered rush, common knapweed, rough hawkbit, great burnet, devil's-bit scabious and globeflower. This pattern was also supported by the RDA bi-plots in Figure 25 and 26, where indicators of botanical quality pointed away from inorganic fertiliser use for over ten years. In addition to the species mentioned previously, the differences between the two RDAs highlighted that the diversity of sedges and orchids have declined over time, and smooth hawk's-beard, marsh hawk's-beard, marsh valerian, water avens, cats-ear and wood anemone are more associated with meadows that have had inorganic fertiliser additions for fewer years. Orchids, sedges, marsh valerian, cats-ear, quaking grass, rough hawkbit, devil's-bit scabious and sharp-flowered rush all have low Ellenberg fertility scores (Appendix Table A).

Is the increase in Ellenberg fertility index and SS-Nutrient scores a good indicator for increases in nutrients? The Ellenberg fertility index is accepted amongst ecologists to be a good proxy measure of the nutrient status of soils and is well regarded as an indicator of grassland fertility levels (Ersten *et al.* 1998; Schaffers and Sykora, 2000; Duru *et al.* 2010). Other intensive management practices can reduce wildflower diversity and increase Ellenberg fertility indices such as intensive spring grazing and silage production (Smith *et al*. 2008; Critchley *et al.* 2007). Figure 24 shows a significant correlation between Ellenberg fertility index and phosphorous levels (ppm) in the Upper Teesdale dataset, although the R^2 suggests a range of other factors are also influential. If we are to assume that there has been an increase in nutrients in the meadows, shown by the fertility indices increasing, there are a number of potential explanations for this increase:

1) Inorganic fertiliser use has become commonplace in agriculture. The use of inorganic fertiliser has been shown by many studies to reduce botanical quality in lowland and upland grasslands. Nutrient input encourages the growth of competitive fast-growing grasses and wildflowers, increasing the hay yield. Over time, the larger grasses and wildflowers out-compete the smaller, slower-growing grasses and wildflowers. This lowers the number of species found and botanical quality is reduced in lowland and upland grasslands (Thurston 1969; Mountford *et al.* 1993; Marrs 1993; Janssens *et al.* 1998; Jones and Hayes 1999; Smith *et al.* 1996a; 1996b; 2000; 2008; Stevens *et al.* 2004; Critchley *et al.* 2003; 2007; Kirkham *et al.,* 2008; in press). Fast-growing species include perennial rye-grass, creeping buttercup and Yorkshire fog which have been increasing in Upper Teesdale meadows that have received long-term inorganic fertiliser inputs. Perennial rye-grass and creeping buttercup have high Ellenberg fertility values (Appendix Table A).

2) FYM has a high nutrient content and is added to most of the meadows (Smith *et al.* 1998; 2008). SSSI meadows that have been in a MA or WES have received little in the way of inorganic fertilisers, if these meadows have increased in fertility it may be due to the high nutrient content of FYM (Smith *et al.* 1998; 2008 Kirkham *et al.* 2008; Kirkham *et al.* in press). Kirkham *et al.* (in press) have shown that FYM application rates of 12t/ ha^{-1}/ year have sustained MG3b upland hay meadows whereas rates of 24t/ ha^{-1}/ year have reduced species richness and positive indicator species of MG3b, however, lower rates of 6t/ ha^{-1}/ year enhanced botanical quality (Kirkham *et al.* 2008; in press). Within the Pennine Dales ESA, rates of FYM application were limited to 12.5t/ ha^{-1}/ year. The ratio of N:P is smaller in FYM than in inorganic fertilisers (2 to 6:1 compared to 7 to 11:1 respectively). This level of phosphorous is more than plants require and large applications can result in a steady build-up of phosphorous in the soil over time (Smith *et al.* 1998).

Smith *et al.* 1998; 2008 and Kirkham *et al.* (2008; in press) have shown that FYM and inorganic fertilisers are broadly equivalent; both add nutrients and levels need to be controlled to prevent nutrient enrichment. A ‘light dressing of FYM’ which should only cover part of a meadow (and be equivalent to 12.5t/ ha^{-1}/ year) is rarely witnessed, whereas ‘heavy dressings of FYM’ have been regularly reported (NP AONB per comms). The commonly held view that FYM is better for upland hay meadows has possibly led to it being added in too high a quantity as farmers are not aware how much phosphorous it contains (Smith *et al.* 1998; Kirkham *et al.* in press).

Kirkham *et al.* (in press) had to readjust their FYM measurements from their previous experiment (Kirkham *et al.* 2008) to bring them in line with new methods for measuring FYM nutrient levels (Smith *et al.* 1998). The original experiment of Smith *et al.* (1996b) only included a ‘fertiliser to no fertiliser’ treatment and did not look at FYM until later. Once FYM was added as a treatment, this also reduced species diversity along with the inorganic fertiliser treatment (Smith *et al.* 2008). The HLS prescriptions for HK6 and HK7 meadows now (since 2009) recommend that FYM application rates are only 12.5t/ ha^{-1}/ year *every other year* or every three years. These prescriptions appear appropriate but the application rates need to be monitored.

3) Atmospheric nitrogen deposition has been shown to be increasing globally (Olff and Bakker 1991; Holland *et al.* 1999; Stevens *et al.* 2004). Upper Teesdale has an average nitrogen deposition rate compared to the rest of Europe (20 kg N/ ha^{-1}/ year compared to the highest at 40 kg N/ ha^{-1}/ year) (Holland *et al.* 1999). At these rates, some reduction in botanical quality would be expected (Holland *et al.* 1999). Stevens *et al.* (2004) showed a correlation between nitrogen deposition and botanical grassland quality and suggested that inorganic fertiliser use needed to be reduced as nitrogen deposition was increasing. However, Olff and Bakker (1991) have shown that the cessation of inorganic fertiliser applications has led to increased species richness, despite background nitrogen deposition. In addition, phosphorous limitation has been found to be more important than nitrogen in grassland plants that are classed as ‘endangered’ from the Red List of endangered species of the Netherlands (Wassen *et al.* 2005). This suggests that direct nutrient applications to the soil (through the use of an inorganic fertiliser containing phosphorous or FYM) are more likely to cause greater changes to the plant species composition than nitrogen deposition.

8. Conclusion

Upper Teesdale upland hay meadows have declined in botanical quality over time. Agri-environment schemes have not maintained the botanical quality of Upper Teesdale upland hay meadows. The findings of this correlative study suggest that the declines in botanical quality may be associated with increases in soil fertility, as indicated by significant increases in Ellenberg fertility index and SS-nutrient scores between the baseline and recent surveys for the majority of meadows. As a consequence a precautionary approach should be applied to nutrient additions, either FYM or inorganic fertiliser in order to maintain and enhance botanical quality. The priority for conservation management action should be the SSSI meadows that have been in past MA or WES agreements and these meadows should receive very low nutrient inputs - no inorganic fertilisers and very low applications of FYM.

Experiments looking at high altitude upland hay meadows (Smith *et al.* 1996a; 1996b, 1998; 2008; Critchley *et al.* 2007; Kirkham *et al.* in press) have shown that traditional upland hay meadow management is important in maintaining botanical quality. Timing of cutting, intensity of spring grazing, silage production, reseeding, the use of modern farm machinery that reduces time of cutting and drying and increases soil compaction, are all important. However, it is when these changes take place in combination with increases in soil fertility that the most serious declines in plant species-diversity take place. This report highlights issues concerning the use of inorganic fertilisers for long periods of time and has shown major declines in botanical quality. Clearly, changes in farm management have taken place that are now affecting one of the last remaining strongholds of upland hay meadows in the UK.

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Appendix 1: Key indicator species lists

Appendix Table A. Key indicator species list for Upper Teesdale report. The 28 key indicator species chosen for this report from the Upper Teesdale data, with their corresponding indicator score, Ellenberg fertility, moisture and pH values.

Key plant species	Indicator Score	Ellenberg fertility index (N)	Ellenberg moisture index (F)	Ellenberg pH index (R)
Soft brome	-2	4	4	7
Yorkshire fog	0	5	6	6
Sharp-flowered rush	-1	2	8	4
Soft rush	-1	4	7	4
Perennial rye-grass	-1	6	5	6
Creeping buttercup	-2	7	7	6
White clover	-1	6	5	6
Sweet vernal grass	1	3	6	4
Marsh marigold	2	4	9	6
Pignut	2	5	5	5
Crested dog's-tail	1	4	5	6
Eyebright	2	4	5	6
Meadowsweet	2	5	8	6
Self-heal	2	4	5	6
Meadow buttercup	1	4	6	6
Hay rattle	2	4	5	6
Lesser trefoil	1	5	4	6
Red clover	1	5	5	7
Lady’s-mantle	3	4	6	6
Bugle	3	5	7	5
Quaking grass	3	3	5	7
Common knapweed	3	5	5	6
Wood crane's-bill	3	5	5	6
Rough hawkbit	3	3	4	7
Ragged robin	3	4	9	6
Great burnet	3	5	7	6
Devil's-bit scabious	3	2	7	5
Globeflower	3	4	7	6

Appendix Table B. SSSI indicator species list, drawn from Natural England SSSI conditions assessments (2000 – 2010).

SSSI indicator species	Latin name	Common name
Positive species	*Alchemilla* spp.	Lady's-mantles
	Achillea ptarmica	Sneezewort
	Ajuga reptans	Bugle
	Caltha palustris	Marsh marigold
	Centaurea nigra	Common knapweed
	Cirsium heterophyllum	Melancholy thistle
	Conopodium majus	Pignut
	Crepis paludosa	Marsh hawk's-beard
	Euphrasia spp.	Eyebright
	Filipendula ulmaria	Meadowsweet
	Geranium sylvaticum	Wood crane's-bill
	Geum rivale	Water avens
	Lathyrus pratensis	Meadow vetchling
	Leontodon spp.	Hawkbits
	Lotus corniculatus	Birds-foot trefoil
	Lychnis flos-cuculi	Ragged robin
	Orchidaceae spp.	Orchids
	Persicaria bistorta	Bistort
	Potentilla erecta	Tormentil
	Rhinanthus minor	Hay rattle
	Sanguisorba officinalis	Great burnet
	Serratula tinctoria	Saw-wort
	Succisa pratensis	Devils-bit scabious
	Trollius europaeus	Globeflower
	Valeriana dioica	Marsh valerian
	Carex spp.	Blue green sedges
Negative species	*Anthriscus sylvestris*	Cow parsley
	Cirsium arvense	Creeping thistle
	Cirsium vulgare	Spear thistle
	Rumex crispus	Curly dock
	Rumex obtusifolius	Broad leaved dock
	Urtica dioica	Nettle
	Juncus spp.	Rushes
	Deschampsia cespitosa	Tufted hair-grass
Often recorded by surveyor:	*Equisetum* spp.	Horsetails
	Cardamine pratensis	Cuckooflower
	Myosotis spp.	Forget-me-nots
	Prunella vulgaris	Self-heal
	Ranunculus repens	Creeping buttercup
	Rumex acetosa	Common sorrel
	Trifolium dubium	Lesser trefoil
	Trifolium pratense	Red clover
	Trifolium repens	White clover

Appendix 2: Model for calculating Shannon Diversity Index (H')

$H' = - \sum p_i \ln p_i$

Where p_i = the individual cover of each species divided by the total cover for the survey. The natural log of p_i was calculated and the total sum of $p_i \ln p_i$ equals the Shannon diversity index (H') for each survey (Shannon and Weaver 1949).

Appendix 3: Comparison of different datasets

Appendix Table C shows the general trends in Upper Teesdale upland hay meadows, depending on the type of survey. Both the group of meadows which had the most comprehensive botanical survey data and the group of meadows which just had key indicator surveys showed the same trends as the entire dataset of 98 pairs. However, when just the ESA monitoring surveys were looked at, these changes were not significant. Only the decline in total meadow score was significant, from a score of 29 to a score of 24 ($T=2.09$, $p=0.047$). However, the ESA monitoring surveys from the outset had significantly lower positive indicator species score ($F_{2,97}=24.60$, $p<0.001$ baseline surveys) and significantly lower total meadow scores ($F_{2,97}=18.14$, $p<0.001$ baseline surveys), with a significantly higher Ellenberg fertility index ($F_{2,97}=5.92$, $p=0.004$ baseline surveys) in comparison to the other types of surveys.

Appendix Table C. General trends across Upper Teesdale upland hay meadows. The first column shows the entire dataset of 98 pairs comparing the baseline surveys to the latest surveys. The second column shows the changes over time in the meadows which had the most comprehensive botanical survey data. The third column shows the changes over time in the meadows which just had key indicator surveys and column four shows the changes over time in the meadows which were part of the ESA monitoring surveys. Statistically significant differences are shown between the baseline and latest surveys: a = the highest value, b = the lowest value.

		Different datasets			
Derived Variables	**Survey Type**	**Entire 98 Meadow pairs compared**	**Comparison between the best data set**	**Comparison with key indicator data set only**	**Comparison with ESA data set only**
Number of Species	**Baseline**	**37 a**	**51 a**	**23 a**	**34**
	Latest	**31 b**	**39 b**	**21 b**	**32**
Shannon Diversity Index (H')	**Baseline**	**3.37 a**	**3.76 a**	**2.92 a**	**3.4**
	Latest	**3.2 b**	**3.47 b**	**2.8 b**	**3.34**
Positive Indicator Species Score (P+)	**Baseline**	**107 a**	**177 a**	**79 a**	**42**
	Latest	**69 b**	**95 b**	**65 b**	**38**
Total Meadow Score (TM)	**Baseline**	**90 a**	**150 a**	**69 a**	**29 a**
	Latest	**54 b**	**73 b**	**56 b**	**24 b**
Ellenberg Fertility Index (N)	**Baseline**	**4.28 b**	**4.28 b**	**4.08 b**	**4.55**
	Latest	**4.44 a**	**4.59 a**	**4.25 a**	**4.61**

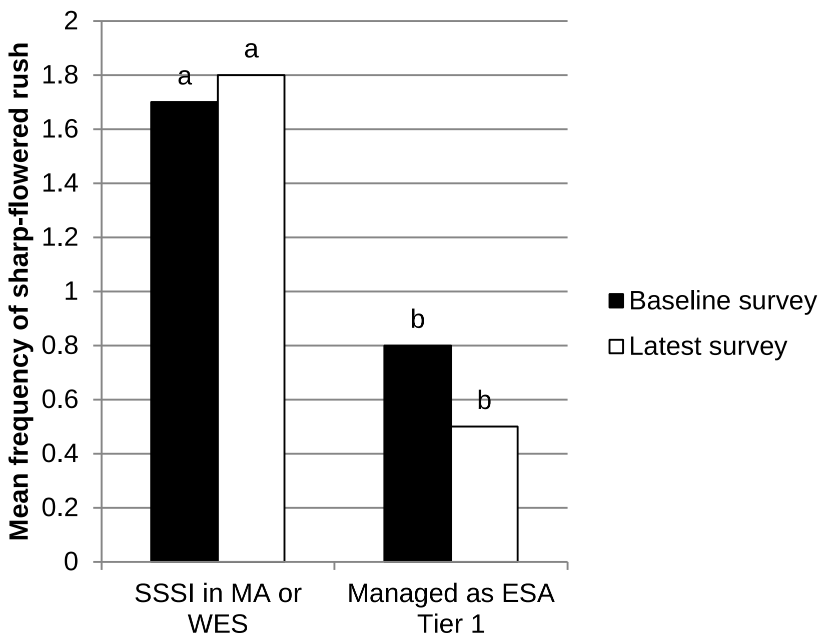
Appendix 4: Key Indicator species in Upper Teesdale SSSI and ESA Tier 1 meadows

a) Key negative indicator species

The changes in key negative indicator species: differences between SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1.

In both the baseline and latest surveys there were no significant differences in the frequency of soft brome, Yorkshire fog, soft rush, perennial rye-grass, creeping buttercup or white clover between SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1 (Appendix Table D). Over time, soft rush frequency significantly increased in SSSI meadows that have been in a MA or WES but not in meadows managed as ESA Tier 1. Soft brome frequency significantly declined in SSSI meadows that have been in a MA or WES but not in meadows managed as ESA Tier 1. Both Yorkshire fog and creeping buttercup increased in meadows managed as ESA Tier 1 but not in SSSI meadows that have been in a MA or WES (Appendix Table E). However, although there have been significant changes over time, they were not large enough to lead to significant differences between the management groups in the latest surveys (Appendix Table D).

The exception is sharp flowered rush. In both baseline and latest surveys, sharp-flowered rush frequency was significantly greater in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1. However, there were no significant changes over time in this species (Appendix Figure A).



Appendix Figure A. Sharp-flowered rush and different management agreements. The differences between management groups and changes over time in the frequency of sharp-flowered rush between SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Only differences between groups are significant, not changes over time. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Appendix Table D. Key negative indicator species and different management agreements. The differences in mean frequency of key negative indicator species between SSSI meadows that have been in a MA or WES those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Management group		
Key Negative Indicator Species	**Survey Type**	**SSSI in MA or WES (mean species frequency)**	**Managed as ESA Tier 1 (mean species frequency)**	**Significant difference**
Soft Brome	**Baseline**	**1.2**	**1.1**	N.S
Soft Brome	**Latest**	**0.6**	**0.9**	N.S
Yorkshire fog	**Baseline**	**1.8**	**1.7**	N.S
Yorkshire fog	**Latest**	**2.2**	**2.1**	N.S
Sharp-flowered rush	**Baseline**	**1.7 a**	**0.8 b**	**$F_{1,97}$=7.85,p=0.006*** **
Sharp-flowered rush	**Latest**	**1.8 a**	**0.5 b**	**$F_{1,97}$=12.31,p=0.001*** **
Soft rush	**Baseline**	**0.2**	**0.3**	N.S
Soft rush	**Latest**	**0.5**	**0.3**	N.S
Perennial rye-grass	**Baseline**	**1.6**	**1.6**	N.S
Perennial rye-grass	**Latest**	**1.4**	**1.8**	N.S
Creeping buttercup	**Baseline**	**2.1**	**2**	N.S
Creeping buttercup	**Latest**	**2.4**	**2.3**	N.S
White clover	**Baseline**	**2.0**	**2.2**	N.S
White clover	**Latest**	**1.8**	**2.2**	N.S

Appendix Table E. Key negative indicator species in baseline and latest surveys. The changes in the mean frequency of key negative indicator species between baseline and latest surveys; grouped by meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = he highest value, b = the lowest value.

	Management group					
	SSSI in MA or WES			**Managed as ESA Tier 1**		
Key Negative Indicator Species	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Soft Brome	**1.2 a**	**0.6 b**	**T=3.01,p=0.004*** **	**1.1**	**0.9**	N.S
Yorkshire fog	**1.8**	**2.2**	N.S	**1.7 b**	**2.1 a**	**T=-2.23,p=0.03***
Sharp-flowered rush	**1.7**	**1.8**	N.S	**0.8**	**0.5**	N.S
Soft rush	**0.2 b**	**0.5 a**	**T=-1.97,p=0.054***	**0.3**	**0.3**	N.S
Perennial rye-grass	**1.6**	**1.4**	N.S	**1.6**	**1.8**	N.S
Creeping buttercup	**2.1**	**2.4**	N.S	**2 b**	**2.3 a**	**T=-1.94,p=0.058***
White clover	**2.0**	**1.8**	N.S	**2.2**	**2.2**	N.S

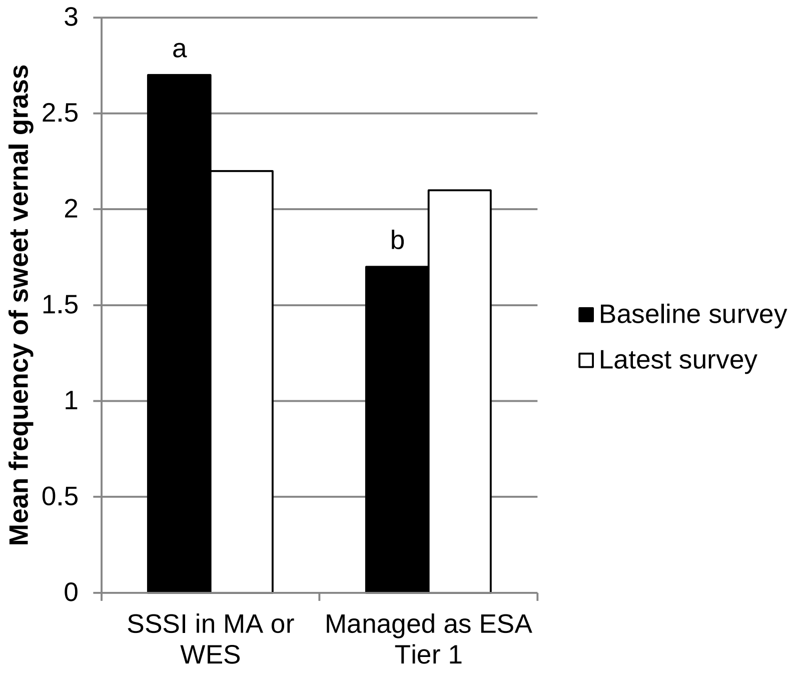
b) Key positive indicator species with a score of +1 or +2

The changes in key positive indicator species with a score of +1 or +2: differences between SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1.

In both the baseline and latest surveys, seven species with a positive indicator score of +1 or +2 had greater frequency in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1: marsh marigold, crested dog's-tail, eyebright, meadowsweet, self-heal, hay rattle and red clover (Appendix Table F). Of these seven, only meadowsweet declined in both of the management groups and eyebright increased in the meadows that have been managed as ESA Tier 1 between the baseline and latest surveys (Appendix Table G).

In the baseline surveys, sweet vernal grass and pignut were found in significantly higher frequencies in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1. These species declined in SSSI meadows that have been in a MA or WES so there were no differences between the management groups in the latest surveys (Appendix Figure B; Appendix Table F and G).

In the baseline surveys, lesser trefoil was found in only low frequencies in the SSSI meadows that have been in a MA or WES and not at all in meadows managed as ESA Tier 1. This species has increased in frequency in both management groups so there is still a significant difference between the management groups in the latest surveys (Appendix Table F and G).



Appendix Figure B. Sweet vernal grass and different management agreements. The differences between management groups and changes over time in frequency of sweet vernal grass between SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Appendix Table F. Key positive indicator species with a score of +1 or +2 and different management agreements. The differences in the mean frequency of key positive indicator species with a score of +1 or +2 between Upper Teesdale SSSI meadows that have been in a management agreement and Upper Teesdale meadows that haven't been in a management agreement. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Management group		
Key Positive indicators with a score of +1 or +2	**Survey Type**	**SSSI in MA or WES (mean species frequency)**	**Managed as ESA Tier 1 (mean species frequency)**	**Significant difference**
Sweet vernal grass	**Baseline**	**2.7 a**	**1.7 b**	**$F_{1,97}$=6.54,p=0.012****
Sweet vernal grass	**Latest**	**2.2**	**2.1**	N.S
Marsh marigold	**Baseline**	**3. a**	**1.6 b**	**$F_{1,97}$=15.06,p<0.001*****
Marsh marigold	**Latest**	**2.9 a**	**1.8 b**	**$F_{1,97}$=8.99,p=0.003*****
Pignut	**Baseline**	**1.8 a**	**0.7 b**	**$F_{1,97}$=14.24,p<0.001*****
Pignut	**Latest**	**1.2**	**0.8**	N.S
Crested dog's-tail	**Baseline**	**2.6 a**	**1.8 b**	**$F_{1,97}$=4.46,p=0.037****
Crested dog's-tail	**Latest**	**2.6 a**	**1.5 b**	**$F_{1,97}$=8.58,p=0.004*****
Eyebright	**Baseline**	**2.4 a**	**0.3 b**	**$F_{1,97}$=60.03,p<0.001*****
Eyebright	**Latest**	**2.4 a**	**0.8 b**	**$F_{1,97}$=36.56,p<0.001*****
Meadowsweet	**Baseline**	**1.9 a**	**0.8 b**	**$F_{1,97}$=14.39,p<0.001*****
Meadowsweet	**Latest**	**1.4 a**	**0.5 b**	**$F_{1,97}$=37.15,p<0.001*****
Self-heal	**Baseline**	**1.1 a**	**0.7 b**	**$F_{1,97}$=3.37,p=0.069***
Self-heal	**Latest**	**1. a**	**0.4 b**	**$F_{1,97}$=5.97,p<0.016****
Meadow buttercup	**Baseline**	**2.6**	**1.9**	N.S
Meadow buttercup	**Latest**	**2.3**	**1.7**	N.S
Hay rattle	**Baseline**	**3.1 a**	**1.2 b**	**$F_{1,97}$=40.53,p<0.001*****
Hay rattle	**Latest**	**3.5 a**	**1.5 b**	**$F_{1,97}$=42.60,p<0.001*****
Lesser trefoil	**Baseline**	**0.1**	**0.0**	N.S
Lesser trefoil	**Latest**	**0.5 a**	**0.1 b**	**$F_{1,97}$=5.84,p=0.018****
Red clover	**Baseline**	**2.5 a**	**1.1 b**	**$F_{1,97}$=24.48,p<0.001*****
Red clover	**Latest**	**2.4 a**	**1.3 b**	**$F_{1,97}$=14.74,p<0.001*****

Appendix Table G. Key positive indicator species with a score of +1 or +2 in baseline and latest surveys. The changes in mean frequency of key positive indicator species with a score of +1 or +2 between the baseline and latest surveys; grouped by SSSI meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Management group					
	SSSI in MA or WES			**Managed as ESA Tier 1**		
Key Positive indicators with a score of +1 or +2	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Sweet vernal grass	**2.7 a**	**2.2 b**	**T=2.02,p=0.049***	**1.7 b**	**2.1 a**	**T=-2.12,p=0.039****
Marsh marigold	**3.0**	**2.9**	N.S	**1.6**	**1.8**	N.S
Pignut	**1.8 a**	**1.2 b**	**T=2.70,p=0.009*****	**0.7**	**0.8**	N.S
Crested dog's-tail	**2.6**	**2.6**	N.S	**1.8**	**1.5**	N.S
Eyebright	**2.4**	**2.4**	N.S	**0.3 b**	**0.8 a**	**T=-3.58,p=0.001*****
Meadowsweet	**1.9 a**	**1.4 b**	**T=2.45,p=0.018****	**0.8 a**	**0.5 b**	**T=2,p=0.052***
Self-heal	**1.1**	**1.0**	N.S	**0.7**	**0.4**	N.S
Meadow buttercup	**2.6**	**2.3**	N.S	**1.9**	**1.7**	N.S
Hay rattle	**3.1**	**3.5**	N.S	**1.2**	**1.5**	N.S
Lesser trefoil	**0.1 a**	**0.5 b**	**T=-2.75,p=0.008*****	**0 b**	**0.1 a**	**T=-2.07,p=0.044***
Red clover	**2.5**	**2.4**	**N.S**	**1.1**	**1.3**	N.S

c) Key positive indicator species with a score of +3

The changes in key positive indicator species with a score of +3; differences between SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1.

In both the baseline and latest survey, all ten key indicator species with a positive score of +3 had greater frequency in SSSI meadows that have been in a MA or WES compared to meadows managed as ESA Tier 1: bugle, Lady's-mantle, quaking grass, common knapweed, wood crane's-bill, rough hawkbit, ragged robin, great burnet, devil's-bit scabious and globeflower (Appendix Table H).

Between the baseline survey and latest survey, five species significantly declined in both management groups: Lady's-mantle, bugle, quaking grass, wood crane's-bill and great burnet (Figure 9). Devil's-bit scabious and globeflower only significantly declined in meadows that have been in a MA or WES; though bear in mind the frequency of these species was already very low in the meadows managed as ESA Tier 1 (0.3 and 0.2 frequency respectively). Common knapweed and ragged robin significantly declined in only meadows managed as ESA Tier 1 (Appendix Table I).

In the latest surveys of meadows managed as ESA Tier 1, five species are found in such low frequencies that they would be classed as extremely rare (0 – 0.1 frequency): bugle, quaking grass, wood crane's-bill and great burnet; and two species are rare (0.2): Lady's-mantle and globeflower. In the latest surveys of the SSSI meadows that have been in a MA or WES, quaking grass, wood crane's-bill and great burnet are found at low frequencies (0.3; 0.4 and 0.4 respectively); however, rough hawkbit, common knapweed, ragged robin, devil's-bit scabious and globeflower are found in frequencies above 0.9 (Appendix Table H).

Appendix Table H. Key positive indicator species with a score of +3 in different management agreements. The differences in the mean frequency of key positive indicator species with a score of +3 between SSSI meadows that have been in a MA or WES and those meadows managed as a ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant): a = the highest value, b = the lowest value.

		Management group		
Key Positive indicators with a score of +3	**Survey Type**	**SSSI in MA or WES (mean species frequency)**	**Managed as ESA Tier 1 (mean species frequency)**	**Significant difference**
Lady's-mantle	**Baseline**	**2.1 a**	**0.7 b**	**$F_{1,97}$=33.50,p<0.001*** **
Lady's-mantle	**Latest**	**0.7 a**	**0.2 b**	**$F_{1,97}$=14.86,p<0.001*** **
Bugle	**Baseline**	**1.2 a**	**0.4 b**	**$F_{1,97}$=15.26,p<0.001*** **
Bugle	**Latest**	**0.8 a**	**0.2 b**	**$F_{1,97}$=20.09,p<0.001*** **
Quaking grass	**Baseline**	**1.1 a**	**0.4 b**	**$F_{1,97}$=9.60,p=0.003*** **
Quaking grass	**Latest**	**0.3 a**	**0.1 b**	**$F_{1,97}$=8.66,p=0.004*** **
Common knapweed	**Baseline**	**1.4 a**	**0.5 b**	**$F_{1,97}$=15.30,p<0.001*** **
Common knapweed	**Latest**	**1.1 a**	**0.3 b**	**$F_{1,97}$=24.38,p<0.001*** **
Wood crane's-bill	**Baseline**	**1.1 a**	**0.4 b**	**$F_{1,97}$=8.29,p<0.005*** **
Wood crane's-bill	**Latest**	**0.4 a**	**0.1 b**	**$F_{1,97}$=6.32,p=0.014** **
Rough hawkbit	**Baseline**	**1.9 a**	**0.9 b**	**$F_{1,97}$=17.29,p<0.001*** **
Rough hawkbit	**Latest**	**1.7 a**	**0.5 b**	**$F_{1,97}$=25.01,p<0.001*** **
Ragged robin	**Baseline**	**0.8 a**	**0.3 b**	**$F_{1,97}$=4.29,p=0.041* **
Ragged robin	**Latest**	**1. a**	**0.3 b**	**$F_{1,97}$=4.29,p=0.041* **
Great burnet	**Baseline**	**0.9 a**	**0.2 b**	**$F_{1,97}$=24.39,p<0.001*** **
Great burnet	**Latest**	**0.3 a**	**0 b**	**$F_{1,97}$=8.36,p=0.005*** **
Devil's-bit scabious	**Baseline**	**1.7 a**	**0.3 b**	**$F_{1,97}$=14.39,p<0.001*** **
Devil's-bit scabious	**Latest**	**0.9 a**	**0.3 b**	**$F_{1,97}$=10.04,p=0.002*** **
Globeflower	**Baseline**	**1.8 a**	**0.2 b**	**$F_{1,97}$=35.00,p<0.001*** **
Globeflower	**Latest**	**0.9 a**	**0.2 b**	**$F_{1,97}$=14.60,p<0.001*** **

Appendix Table I. Key positive indicator species with a score of +3 in baseline and latest surveys. The changes in the mean frequency of key positive indicator species with a score of +3 between the baseline and latest surveys; grouped by meadows that have been in a MA or WES and those meadows managed as ESA Tier 1. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant a = the highest value, b = the lowest value.

	Management group					
	SSSI in MA or WES			**Managed as ESA Tier 1**		
Key Positive indicators with a score of +3	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Lady's-mantle	**2.1 a**	**0.7 b**	**T=7.31,p<0.001*** **	**0.7 a**	**0.2 b**	**T=3.44,p=0.001*** **
Bugle	**1.2 a**	**0.8 b**	**T=2.57,p=0.013** **	**0.4 a**	**0.1 b**	**T=2.20,p=0.003*** **
Quaking grass	**1.1 a**	**0.3 b**	**T=4.70,p<0.001*** **	**0.4 a**	**0.1 b**	**T=3.29,p=0.002*** **
Common knapweed	**1.4**	**1.1**	N.S	**0.5 a**	**0.3 b**	**T=2.54,p=0.015** **
Wood crane's-bill	**1.1 a**	**0.4 b**	**T=3.70,p=0.001*** **	**0.4 a**	**0.1 b**	**T=1.85,p=0.07* **
Rough hawkbit	**1.9**	**1.7**	N.S	**0.9 a**	**0.5 b**	**T=2.48,p=0.017** **
Ragged robin	**0.8**	**1.0**	N.S	**0.3**	**0.3**	N.S
Great burnet	**0.9 a**	**0.4 b**	**T=2.94,p=0.005*** **	**0.2 a**	**0 b**	**T=2.23,p=0.031** **
Devil's-bit scabious	**1.7 a**	**0.9 b**	**T=3.50,p=0.001*** **	**0.3**	**0.3**	N.S
Globeflower	**1.8 a**	**0.9 b**	**T=4.15,p<0.001*** **	**0.2**	**0.2**	N.S

Appendix 5: Key indicator species and historic fertiliser inputs

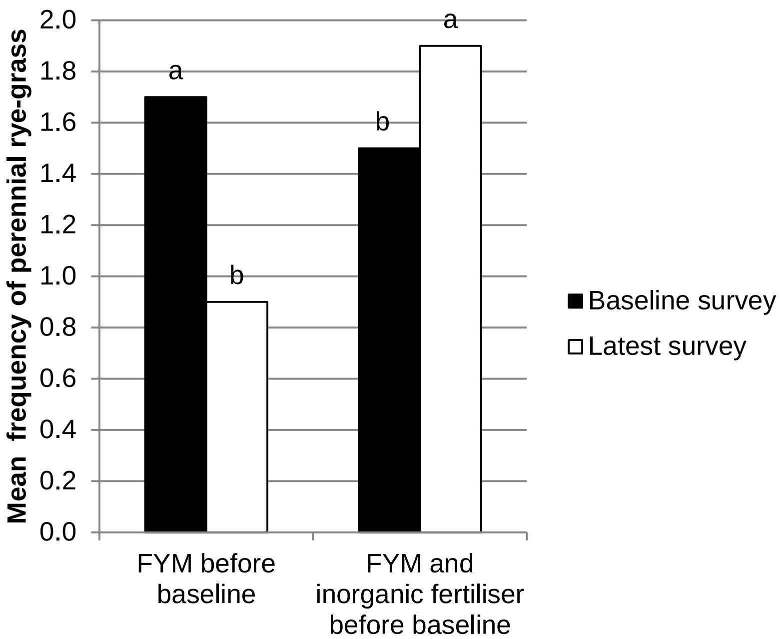
a) Key negative indicator species

Changes in key negative indicator species: differences between meadows that only had FYM applications before the baseline survey period and meadows that received FYM and inorganic fertilisers before this period.

In both baseline and latest surveys, sharp-flowered rush was the only negative indicator species found in greater frequencies in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period (Appendix Table J).

Between the baseline and latest surveys, the frequency of perennial rye-grass significantly declined in meadows that only had FYM additions before the baseline survey period, yet increased in meadows that had FYM and inorganic fertiliser additions before the baseline survey period. In the latest surveys, the frequency of perennial rye-grass is higher in the meadows that have had FYM and inorganic fertiliser (Appendix Figure C; Appendix Table K).

Between the baseline and the latest survey, soft rush significantly increased whereas soft brome significantly decreased in meadows that only had FYM additions before the baseline survey period. Conversely, Yorkshire fog and creeping buttercup significantly increased in the meadows that had FYM and inorganic fertiliser additions before the baseline survey period (Appendix Table K).



Appendix Figure C. Perennial rye-grass and historic fertiliser groups. The differences between historic fertiliser groups and changes over time in mean frequency of perennial rye-grass between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences are shown between the baseline and latest surveys: a = the highest value, b = the lowest value.

Appendix Table I. Key negative indicator species and historic fertiliser groups. The differences in mean frequency of key negative indicator species between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before the baseline survey. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Historical fertiliser inputs before baseline survey period		
Negative indicator species	**Survey type**	**FYM (mean species frequency)**	**FYM and inorganic fertiliser (mean species frequency)**	**Significant difference**
Soft Brome	**Baseline**	**1.2**	**1.1**	N.S
Soft Brome	**Latest**	**0.4**	**0.9**	N.S
Yorkshire fog	**Baseline**	**1.8**	**1.7**	N.S
Yorkshire fog	**Latest**	**1.8**	**2.3**	N.S
Sharp-flowered rush	**Baseline**	**2. a**	**1.1 b**	**$F_{1,97}$=6.87,p=0.010****
Sharp-flowered rush	**Latest**	**2.3 a**	**0.8 b**	**$F_{1,97}$=16.62,p<0.001*****
Soft rush	**Baseline**	**0.2**	**0.3**	N.S
Soft rush	**Latest**	**0.5**	**0.4**	N.S
Perennial rye-grass	**Baseline**	**1.7**	**1.5**	N.S
Perennial rye-grass	**Latest**	**0.9 b**	**1.9 a**	**$F_{1,97}$=7.62,p=0.007*****
Creeping buttercup	**Baseline**	**2.2**	**2.0**	N.S
Creeping buttercup	**Latest**	**2.4**	**2.3**	N.S
White clover	**Baseline**	**2.0**	**2.1**	N.S
White clover	**Latest**	**2.0**	**2.1**	N.S

Appendix Table J. Key negative indicator species in baseline and latest surveys. The changes in mean frequency of key negative indicator species between the baseline and latest surveys; grouped by meadows that only had FYM additions before the baseline survey period compared to meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Historical fertiliser inputs before the baseline survey period					
	FYM before baseline period			FYM and inorganic fertiliser input before baseline period		
Key negative indicator species	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Soft Brome	**1.2 a**	**0.4 b**	**T=2.64,p=0.014****	**1.1**	**0.9**	N.S
Yorkshire fog	**1.8**	**1.8**	N.S	**1.7 b**	**2.3 a**	**T=-3.22,p=0.001*****
Sharp-flowered rush	**2.0**	**2.3**	N.S	**1.1**	**0.8**	N.S
Soft rush	**0.2 b**	**0.5 a**	**T=-2.13,p=0.043***	**0.3**	**0.4**	N.S
Perennial rye-grass	**1.7 a**	**0.9 b**	**T=3.09,p=0.005*****	**1.5 b**	**1.9 a**	**T=-2.05,p=0.044***
Creeping buttercup	**2.2**	**2.4**	N.S	**2 b**	**2.3 a**	**T=-1.91,p=0.06***
White clover	**2.0**	**2.0**	N.S	**2.1**	**2.1**	N.S

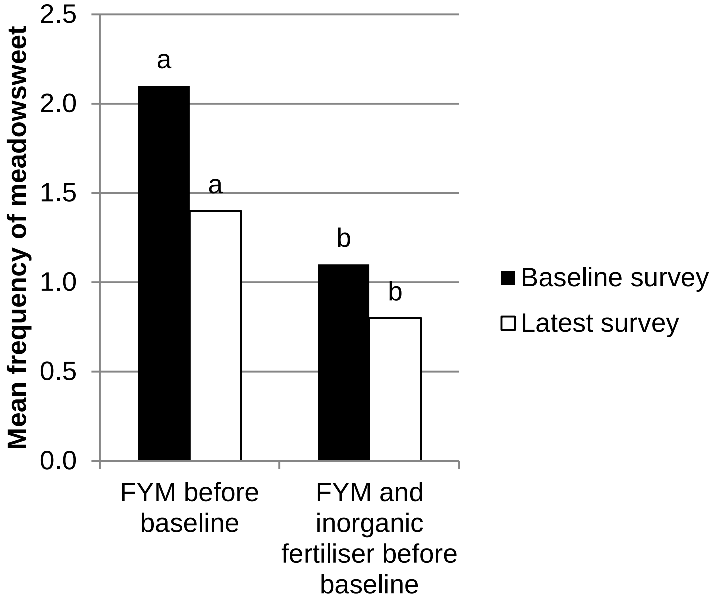
b) Key positive indicator species with a score of +1 or +2

Changes in key positive indicator species with a score of +1 or +2: differences between meadows that only had FYM applications before the baseline survey period and meadows that received FYM and inorganic fertilisers before this period.

In the baseline surveys, six species had significantly higher frequency in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period: self-heal, marsh marigold, eyebright, meadowsweet, hay rattle and red clover (Appendix Table L). Of these species, meadowsweet, hay rattle and self-heal changed in frequency between the baseline and latest survey period (Appendix Table M): meadowsweet significantly decreased in both groups over time (Appendix Figure D); hay rattle significantly increased in meadows that had FYM and inorganic fertiliser additions before the baseline period and self-heal significantly declined in meadows that only had FYM applications before the baseline period. In the latest surveys, these species, bar self-heal, remained with greater frequency in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period (Appendix Table L).

Lesser trefoil was rare in the baseline surveys and significantly increased in meadows that only had FYM additions before the baseline survey period, so that in the latest surveys, the frequency was greater in meadows that only had FYM additions before the baseline period, in comparison to meadows that had FYM and inorganic fertiliser additions before the baseline period (Appendix Table L and M).

There were no significant differences in the frequency of sweet vernal grass, pignut, crested dog's-tail and meadow buttercup between meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period (Appendix Table L) and none of these species changed in frequency over time (Appendix Table M).



Appendix Figure D. Meadowsweet and historic fertiliser groups. The differences between historic fertiliser groups and the changes over time in mean frequency of meadowsweet between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before the baseline period. Both differences between groups and changes over time are significantly different. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Appendix Table K. Key positive indicator species with a score of +1 or +2 and historic fertiliser groups. The differences in mean frequency of key positive indicator species with a score of +1 or +2 between meadows that only had FYM additions before the baseline survey period and meadows that have had FYM and inorganic fertiliser additions before the baseline period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Historical fertiliser inputs before the baseline survey		
Key Positive indicators with a score of +1 or +2	**Survey Type**	**FYM (mean species frequency)**	**FYM and inorganic fertiliser (mean species frequency)**	**Significant difference**
Sweet vernal grass	**Baseline**	**2.6**	**2.1**	N.S
Sweet vernal grass	**Latest**	**2.7**	**2.0**	N.S
Marsh marigold	**Baseline**	**3.3 a**	**2 b**	**$F_{1,97}$=10.94,p=0.001*** **
Marsh marigold	**Latest**	**3.2 a**	**2 b**	**$F_{1,97}$=8.91,p=0.004*** **
Pignut	**Baseline**	**1.7**	**1.2**	N.S
Pignut	**Latest**	**1.1**	**1.0**	N.S
Crested dog's-tail	**Baseline**	**2.6**	**2.1**	N.S
Crested dog's-tail	**Latest**	**2.4**	**1.9**	N.S
Eyebright	**Baseline**	**2.4 a**	**1 b**	**$F_{1,97}$=17.13,p<0.001*** **
Eyebright	**Latest**	**2.6 a**	**1.3 b**	**$F_{1,97}$=14.53,p<0.001*** **
Meadowsweet	**Baseline**	**2.1 a**	**1.1 b**	**$F_{1,97}$=10.5,p=0.002*** **
Meadowsweet	**Latest**	**1.4 a**	**0.8 b**	**$F_{1,97}$=7.47,p=0.007*** **
Self-heal	**Baseline**	**1.3 a**	**0.7 b**	**$F_{1,97}$=5.29,p=0.024** **
Self-heal	**Latest**	**0.4**	**0.7**	N.S
Meadow buttercup	**Baseline**	**2.3**	**2.2**	N.S
Meadow buttercup	**Latest**	**2.1**	**2.0**	N.S
Hay rattle	**Baseline**	**3. a**	**1.9 b**	**$F_{1,97}$=9.19,p=0.003*** **
Hay rattle	**Latest**	**3.5 a**	**2.2 b**	**$F_{1,97}$=11.63,p=0.001*** **
Lesser trefoil	**Baseline**	**0.0**	**0.1**	N.S
Lesser trefoil	**Latest**	**0.7 a**	**0.2 b**	**$F_{1,97}$=11.02,p=0.001*** **
Red clover	**Baseline**	**2.4 a**	**1.6 b**	**$F_{1,97}$=5.49,p=0.021** **
Red clover	**Latest**	**2.4 a**	**1.7 b**	**$F_{1,97}$=4.56,p=0.035** **

Appendix Table L. Key positive indicator species with a score of +1 or +2 in baseline and latest surveys. The changes in mean frequency of key positive indicator species with a score of +1 or +2 between baseline and latest surveys; grouped by meadows that only had FYM additions before the baseline survey period compared to meadows that had FYM and inorganic fertiliser additions before the baseline period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Historical fertiliser inputs before the baseline survey period					
	Only FYM before baseline period			FYM and inorganic fertiliser input before baseline period		
Key Positive indicators with a score of +1 or +2	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys : mean frequency**	**Significant difference**
Sweet vernal grass	**2.6**	**2.7**	N.S	**2.1**	**2.0**	N.S
Marsh marigold	**3.3**	**3.2**	N.S	**2.0**	**2.0**	N.S
Pignut	**1.7**	**1.1**	N.S	**1.2**	**1.0**	N.S
Crested dog's-tail	**2.6**	**2.4**	N.S	**2.1**	**1.9**	N.S
Eyebright	**2.4**	**2.6**	N.S	**1.0**	**1.3**	N.S
Meadowsweet	**2.1 a**	**1.5 b**	**T=2.70,p=0.012****	**1.1 a**	**0.8 b**	**T=2.32,p=0.023****
Self-heal	**1.3 a**	**0.4 b**	**T=1.89,p=0.07***	**0.7**	**0.7**	N.S
Meadow buttercup	**2.3**	**2.1**	N.S	**2.2**	**2.0**	N.S
Hay rattle	**3.0**	**3.5**	N.S	**1.9 b**	**2.2 a**	**T=-1.85,p=0.069***
Lesser trefoil	**0. b**	**0.7 a**	**T=-2.86,p=0.008*****	**0.0**	**0.2**	N.S
Red clover	**2.4**	**2.4**	N.S	**1.6**	**1.7**	N.S

c) Key positive indicator species with a score of +3

The changes in key positive indicator species with a score of +3: differences between meadows that only had FYM applications before the baseline survey period and meadows that received FYM and inorganic fertilisers before this period.

In the baseline surveys there were eight key positive indicator species with a score of +3 that were found in significantly higher frequencies in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period: Lady's-mantle, bugle, quaking grass, common knapweed, rough hawkbit, ragged robin, devil's-bit scabious and globeflower (Appendix Table N). Of these eight species, three species declined in both groups between the baseline and the latest surveys: Lady's-mantle, quaking grass and globeflower. Two species declined in meadows that only had FYM additions before the baseline survey period: bugle and devil's-bit scabious and two species declined in meadows that had FYM and inorganic fertiliser additions before the baseline period: common knapweed and rough hawkbit. Ragged robin did not change over time (Appendix Table O). In the latest surveys, these eight species remained with greater frequency in meadows that only had FYM additions before the baseline survey period, in comparison to meadows that had FYM and inorganic fertiliser additions before this period (Appendix Table N; Figure 13).

In the baseline surveys, there was no significant difference in the frequency of great burnet between meadows that only had FYM additions before the baseline survey period in comparison to meadows that had FYM and inorganic fertiliser additions before the baseline period (Appendix Table N). Over time, the frequency significantly declined in meadows that had FYM and inorganic fertiliser additions before the baseline survey period, so that by the latest survey, great burnet was found in significantly higher frequencies in the meadows that only had FYM additions before the baseline period. The frequency of wood crane's-bill was not significantly different between the historic fertiliser groups in the baseline and the latest surveys, however, over time, the frequency declined in both groups (Appendix Table N and O).

In the latest surveys, Lady's-mantle, bugle, quaking grass, wood crane's-bill, great burnet, devil's-bit scabious and globeflower are found in extremely low frequencies in meadows that had FYM and inorganic fertiliser additions before the baseline survey period (0.1 - 0.4). Only five species: common knapweed, rough hawkbit, ragged robin, devil's-bit scabious and globeflower are found in frequencies above 1 in the latest surveys, and this is in meadows that only had FYM additions before the baseline survey period (Appendix Table N; Figure 13).

Appendix Table M. Key positive indicator species with a score of +3 and historic fertiliser groups. The differences in mean frequency of key positive indicator species with a score of +3 between Upper Teesdale meadows that have only had FYM additions before the baseline survey period and Upper Teesdale meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

		Historical fertiliser inputs before the baseline survey		
Key Positive indicators with a score of +3	**Survey Type**	**FYM (mean species frequency)**	**FYM and inorganic fertiliser (mean species frequency)**	**Significant difference**
Lady's-mantle	**Baseline**	**2.4 a**	**1.1 b**	**$F_{1,97}$=21.60,p<0.001*** **
Lady's-mantle	**Latest**	**0.9 a**	**0.3 b**	**$F_{1,97}$=16.68,p<0.001*** **
Bugle	**Baseline**	**1.7 a**	**0.5 b**	**$F_{1,97}$=27.62,p<0.001*** **
Bugle	**Latest**	**0.7 a**	**0.4 b**	**$F_{1,97}$=4.06,p=0.047* **
Quaking grass	**Baseline**	**1.3 a**	**0.5 b**	**$F_{1,97}$=11.27,p=0.001*** **
Quaking grass	**Latest**	**0.4 a**	**0.1 b**	**$F_{1,97}$=9.31,p=0.001*** **
Common knapweed	**Baseline**	**1.7 a**	**0.7 b**	**$F_{1,97}$=18.24,p<0.001*** **
Common knapweed	**Latest**	**1.5 a**	**0.4 b**	**$F_{1,97}$=31.87,p<0.001*** **
Wood crane's-bill	**Baseline**	**1.0**	**0.6**	N.S
Wood crane's-bill	**Latest**	**0.4**	**0.2**	N.S
Rough hawkbit	**Baseline**	**2.1 a**	**1.2 b**	**$F_{1,97}$=10.04,p=0.002*** **
Rough hawkbit	**Latest**	**1.8 a**	**0.9 b**	**$F_{1,97}$=11.86,p=0.001*** **
Ragged robin	**Baseline**	**1.1 a**	**0.4 b**	**$F_{1,97}$=9.29,p=0.003*** **
Ragged robin	**Latest**	**1.2 a**	**0.5 b**	**$F_{1,97}$=9.07,p=0.003*** **
Great burnet	**Baseline**	**0.7**	**0.5**	N.S
Great burnet	**Latest**	**0.4 a**	**0.1 b**	**$F_{1,97}$=8.02,p=0.006*** **
Devil's-bit scabious	**Baseline**	**2.1 a**	**0.6 b**	**$F_{1,97}$=26.69,p<0.001*** **
Devil's-bit scabious	**Latest**	**1.1 a**	**0.4 b**	**$F_{1,97}$=14.70,p<0.001*** **
Globeflower	**Baseline**	**2.1 a**	**0.6 b**	**$F_{1,97}$=20.38,p<0.001*** **
Globeflower	**Latest**	**1.1 a**	**0.4 b**	**$F_{1,97}$=11.48,p<0.001*** **

Appendix Table N. Key positive indicator species with a score of +3 in baseline and latest surveys. The changes in mean frequency of key positive indicator species with a score of +3 between baseline and latest surveys in Upper Teesdale meadows; separated by meadows that have only had FYM additions before the baseline survey period compared to Upper Teesdale meadows that have had FYM and inorganic fertiliser additions before this period. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, b = the lowest value.

	Historical fertiliser inputs before the baseline survey period					
	Only FYM before baseline period			**FYM and inorganic fertiliser input before baseline period**		
Key Positive indicators with a score of +3	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Lady's-mantle	**2.4 a**	**0.9 b**	**T=5.74,p<0.001*** **	**1.1 a**	**0.3 b**	**T=5.39,p<0.001*** **
Bugle	**1.7 a**	**0.7 b**	**T=3.48,p=0.002*** **	**0.5**	**0.4**	N.S
Quaking grass	**1.3 a**	**0.4 b**	**T=3.51,p=0.002*** **	**0.5 a**	**0.1 b**	**T=4.15,p<0.001*** **
Common knapweed	**1.7**	**1.5**	N.S	**0.7 a**	**0.4 b**	**T=2.59,p=0.012** **
Wood crane's-bill	**1.1 a**	**0.4 b**	**T=2.70,p=0.012** **	**0.6 a**	**0.2 b**	**T=3.08,p=0.003*** **
Rough hawkbit	**2.1**	**1.8**	N.S	**1.2 a**	**0.9 b**	**T=2.05,p=0.044* **
Ragged robin	**1.1**	**1.2**	N.S	**0.4**	**0.5**	N.S
Great burnet	**0.7**	**0.4**	N.S	**0.5 a**	**0.1 b**	**T=1.91,p=0.061* **
Devil's-bit scabious	**2.1 a**	**1.1 b**	**T=2.84,p=0.009*** **	**0.6**	**0.4**	N.S
Globeflower	**2.1 a**	**1.1 b**	**T=3.12,p=0.004*** **	**0.6 a**	**0.4 b**	**T=2.09,p=0.041* **

Appendix 6: Long-term fertiliser inputs (fertiliser categories)

a) Number of species, diversity and meadow scores

In the baseline surveys, positive indicator species score was significantly higher in 2nd category, in comparison to 4th and 5th categories, and 1st and 3rd categories were higher than 5th category (Figure 16). Total meadow score was significantly higher in 2nd category, in comparison to 3rd, 4th and 5th categories; 1st category was significantly higher than 4th and 5th categories; 3rd category was significantly higher than 5th category. Number of wildflowers was significantly higher in 2nd category, in comparison to 4th and 5th categories, and 1st and 3rd categories were intermediate. Number of species was significantly higher in 2nd category in comparison to 5th category, and 1st, 3rd and 4th categories were intermediate. In the baseline surveys, there were no significant differences between fertiliser categories in numbers of grasses, Shannon diversity index or negative indicator species scores (Appendix Table P).

In the baseline surveys, 1st and 2nd categories should be identical as these meadows have not yet received any additions of inorganic fertiliser. Third, 4th and 5th categories should be identical as they have received additions of inorganic fertilisers before the baseline surveys. Second category is not identical to 1st category and has inadvertently got higher numbers of wildflowers, species and positive indicators and this gives the meadows in this category higher total meadow scores. However, in 1st and 2nd categories, total meadow scores were higher than 4th and 5th categories, and positive indicator scores were higher than 5th category indicating that meadows with the longest number of years of inorganic fertiliser additions are lower in botanical quality (Appendix Table P).

Between baseline and latest survey, Shannon diversity index, positive indicator species score and total meadow score all significantly declined in Upper Teesdale meadows, in all categories. Number of grasses significantly declined in all categories, apart from 2nd category. Number of wildflowers significantly declined in 2nd and 3rd categories but not in 1st, 4th or 5th. Number of species significantly declined in all categories, apart from 5th category where numbers of species was already low. Negative indicator species score improved (i.e. decreased) in 1st and 3rd categories (Appendix Table Q).

By the latest surveys, positive indicator species score was significantly higher in 2nd category compared to all of the other categories; 1st category was significantly higher than 4th and 5th categories, and 3rd category was significantly higher than 5th category (Figure 16). Total meadow score was significantly higher in 2nd category compared to 3rd, 4th and 5th categories; 1st category was significantly higher than 4th and 5th categories and 3rd category was significantly higher than 5th category. This pattern shows an association between the number of years that inorganic fertilisers have been applied, and a reduction in botanical quality (Appendix Table P).

In the latest surveys there were other significant differences between fertiliser categories, although these differences do not follow a logical pattern in association with length of time of inorganic fertiliser input. Numbers of grasses: 1st category had fewer numbers of grasses than 2nd and 5th categories, with 3rd and 4th categories intermediate. Number of wildflowers remained significantly higher in 2nd category, whereas both 3rd and 5th categories had lower number of wildflowers, with 1st and 4th categories intermediate. Number of species remained significantly higher in 2nd category but was significantly lower in 3rd category, with 1st, 4th and 5th categories intermediate. Shannon diversity index was significantly higher in 2nd category compared to 3rd category, with 1st, 4th and 5th categories intermediate. Negative indicator species scores was lower in the 1st category compared to the 2nd category, with 3rd, 4th and 5th categories intermediate (Appendix Table P).

Appendix Table O. Number of species, diversity and meadow scores in different fertiliser categories. Differences in number of species, diversity and meadow scores between fertiliser categories in Upper Teesdale meadows. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

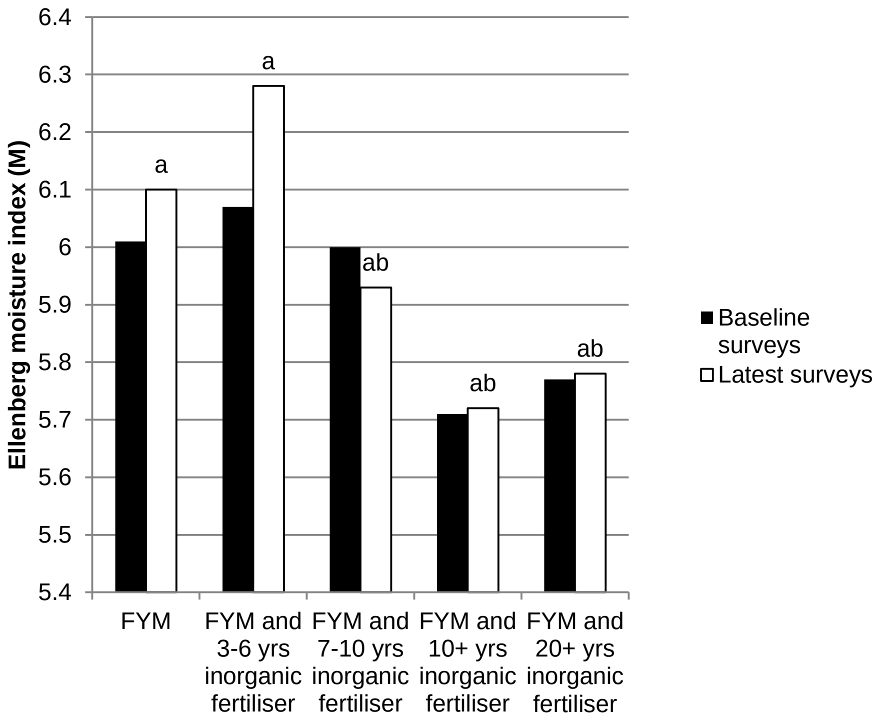
		Fertiliser categories					
		1st Category	2nd Category	3rd Category	4th Category	5th Category	
Number of species, diversity and meadow scores	**Survey type**	**FYM**	**FYM and 3 – 6 yrs inorganic Fertiliser**	**FYM and 7 – 10 yrs inorganic Fertiliser**	**FYM and 10 + yrs inorganic Fertiliser**	**FYM and 20 + yrs inorganic Fertiliser**	**Significant difference**
Number of grasses	Baseline	8	13	8	12	12	N.S
	Latest	6 c	11 ab	6 bc	9 abc	11. a	$F_{4,97}$=5.43,p=0.001***
Number of wildflowers	Baseline	28 ab	38 a	26 ab	25 b	21 b	$F_{4,97}$=4.80,p=0.001***
	Latest	25 ab	30 a	18 b	21 ab	20 b	$F_{4,97}$=4.22,p=0.003***
Number of species	Baseline	36 ab	51 a	35 ab	37 ab	33 b	$F_{4,97}$=2.74,p=0.033**
	Latest	30 ab	40 a	24 b	30 ab	30 ab	$F_{4,97}$=3.12,p=0.019**
Shannon diversity index (H')	Baseline	3.34	3.74	3.25	3.45	3.28	N.S
	Latest	3.18 ab	3.49 a	2.94 b	3.25 ab	3.21 ab	$F_{4,97}$=2.58,p=0.042*
Positive indicator species (P+) score	Baseline	155 ab	200 a	128 ab	86 bc	57 c	$F_{4,97}$=12.66,p<0.001***
	Latest	94 b	126 a	75 bc	58 cd	43 d	$F_{4,97}$=25.91,p<0.001***
Negative indicator species (N-) score	Baseline	-18	-18.5	-20	-17	-15	N.S
	Latest	-11 a	-21 b	-13 ab	-18 ab	-14.5 ab	$F_{4,97}$=3.02,p=0.022**
Total meadow score (TM)	Baseline	137 ab	181 a	108 bc	69 cd	41 d	$F_{4,97}$=15.10,p<0.001***
	Latest	82.5 ab	105 a	62 bc	40 cd	29 d	$F_{4,97}$=28.08,p<0.001***

Appendix Table P. Number of species, diversity and meadow scores in baseline and latest surveys. Changes in number of species, diversity and meadow scores between baseline and latest surveys in Upper Teesdale meadows grouped by fertiliser category. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

	Fertiliser categories														
	1st. FYM			2nd. FYM and 3 – 6 yrs inorganic fertiliser after baseline			3rd. FYM and 7 – 10 yrs inorganic fertiliser			4th. FYM and 10 + yrs inorganic fertiliser			5th. FYM and 20 + yrs inorganic fertiliser		
Number of species, diversity and meadow scores	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
Number of grasses	**8. a**	**6. b**	**T=2.67, p=0.018****	**13**	**11**	N.S	**8. a**	**6 b**	**T=3.40, p=0.004*****	**12a**	**9 b**	**T=2.83, p=0.013****	**12. a**	**11 b**	**T=2.39, p=0.022****
Number of wildflowers	**28**	**25**	N.S	**38 a**	**30 b**	**T=2.53, p=0.027****	**26 a**	**18 b**	**T=2.33, p=0.034****	**25**	**21**	N.S	**21**	**20**	N.S
Number of species	**36 a**	**31 b**	**T=2.23, p=0.042***	**51 a**	**40.5 b**	**T=2.59, p=0.024****	**35 a**	**24 b**	**T=2.75, p=0.034****	**36.5 a**	**30.5 b**	**T=2.34, p=0.034****	**33**	**31**	N.S
Shannon diversity index (H')	**3.34 a**	**3.18 b**	**T=2.03, p=0.062***	**3.74 a**	**3.49 b**	**T=3.00, p=0.011****	**3.25 a**	**2.94 b**	**T=2.54, p=0.015****	**3.45 a**	**3.25 b**	**T=3.26, p=0.005*****	**3.28 a**	**3.21 b**	**T=1.83, p=0.076***
Positive indicator species (P+) score	**155 a**	**94 b**	**T=2.90, p=0.012****	**200 a**	**126 b**	**T=3.62, p=0.004*****	**128 a**	**75 b**	**T=2.80, p=0.013****	**86 a**	**58 b**	**T=2.02, p=0.062***	**57 a**	**43 b**	**T=2.35, p=0.024****
Negative indicator species (N-) score	**-18 b**	**-11 a**	**T=-2.33, p=0.035****	**-19**	**-21**	N.S	**-20 b**	**- 13 a**	**T=-2.43, p=0.028****	**-17**	**-18**	N.S	**-15**	**-15**	N.S
Total meadow score (TM)	**137 a**	**82.5 b**	**T=2.81, p=0.014****	**181 a**	**105 b**	**T=4.14, p=0.001*****	**108 a**	**62 b**	**T=2.61, p=0.02****	**69 a**	**40 b**	**T=2.37, p=0.031****	**41 a**	**29 b**	**T=2.45, p=0.019****

b) Moisture and pH scores

In the baseline survey period, there were no differences between moisture or pH scores in the fertiliser categories (Appendix Table R). Over time, SS-Moisture index and Ellenberg moisture index significantly increased in 2nd category, suggesting that these meadows have become wetter (Appendix Figure E). Ellenberg pH index increased in 4th category (Appendix Table S). By the latest surveys, SS-Moisture scores, Ellenberg moisture index and Ellenberg pH index showed differences between the categories, however, there was not a logical pattern except in the Ellenberg moisture index. SS-Moisture scores were much higher in 2nd category compared to 4th and 5th categories; 3rd category was higher than 5th category, and 1st category was intermediate. Ellenberg moisture index (M) was significantly higher in 1st and 2nd categories in comparison to 4th and 5th categories and 3rd category was intermediate (showing an association with meadows receiving less nutrient inputs). Ellenberg pH index (R) was significantly lower in 2nd category in comparison to 3rd and 4th categories, with 1st and 5th categories intermediate. These scores suggest that meadows in 2nd category have increased in wetness and become more acidic, although there is no clear association with 2nd category having a higher fit to the MG8 NVC (Appendix Table R).



Appendix Figure E. Ellenberg moisture index and fertiliser categories. The differences between fertiliser categories and changes over time in mean Ellenberg moisture index (M) in Upper Teesdale meadows categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Appendix Table Q. SS species scores, Ellenberg indices and best fit to NVC in different fertiliser categories. The differences in SS species scores, Ellenberg indices and best fit to NVC between meadows categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

		Fertiliser categories					
		1st Category	2nd Category	3rd Category	4th Category	5th Category	
SS Species score, Ellenberg indices and NVC	**Survey type**	**FYM**	**FYM and 3 – 6 yrs inorganic fertiliser**	**FYM and 7 – 10 yrs inorganic fertiliser**	**FYM and 10 + yrs inorganic fertiliser**	**FYM and 20 + yrs inorganic fertiliser**	**Significant difference**
SS-Nutrient score	**Baseline**	**-0.85 c**	**-0.80 bc**	**-0.66 bc**	**-0.41 ab**	**-0.30 a**	**$F_{4,97}$=7.81,p<0.001*** **
	Latest	**-0.64 b**	**-0.61 b**	**-0.55 b**	**-0.16 a**	**-0.23 a**	**$F_{4,97}$=11.70,p<0.001*** **
SS-Moisture score	**Baseline**	**0.56 ab**	**0.60 a**	**0.60 a**	**0.24 b**	**0.23 b**	**$F_{4,97}$=4.33,p=0.031** **
	Latest	**0.49 abc**	**0.78 a**	**0.56 ab**	**0.3 bc**	**0.22 c**	**$F_{4,97}$=7.49,p<0.001*** **
Ellenberg fertility index (N)	**Baseline**	**4.03 b**	**3.89 b**	**4.12 b**	**4.53 a**	**4.49 a**	**$F_{4,97}$=9.94,p<0.001*** **
	Latest	**4.18 b**	**4.05 b**	**4.28 b**	**4.77 a**	**4.60 a**	**$F_{4,97}$=11.70,p<0.001*** **
Ellenberg moisture index (M)	**Baseline**	**6.01**	**6.07**	**6**	**5.71**	**5.77**	N.S
	Latest	**6.10 a**	**6.28 a**	**5.93 ab**	**5.72 b**	**5.78 b**	**$F_{4,97}$=6.52,p<0.001*** **
Ellenberg pH index (R)	**Baseline**	**5.78**	**5.55**	**5.74**	**5.72**	**5.7**	N.S
	Latest	**5.73 ab**	**5.52 b**	**5.77 a**	**5.83 a**	**5.7 ab**	**$F_{4,97}$=4.15,p=0.004*** **
MG8 best bit	**Baseline**	**30**	**29**	**29**	**32**	**35**	N.S
	Latest	**26 c**	**45 ab**	**39 abc**	**52 a**	**39 b**	**$F_{4,97}$=7.28,p<0.001*** **
MG3b best fit	**Baseline**	**47**	**48**	**49**	**48**	**39**	N.S
	Latest	**46**	**42**	**45**	**42**	**39**	N.S

Appendix Table R. SS species scores, Ellenberg indices and best fit to NVC in baseline and latest surveys. The changes in SS species scores, Ellenberg indices and best fit to NVC between baseline and latest surveys in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant: a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

	Fertiliser categories														
	1st. FYM			2nd. FYM and 3 – 6 yrs inorganic fertiliser			3rd. FYM and 7 – 10 yrs inorganic fertiliser			4th. FYM and 10 + yrs inorganic fertiliser			5th. FYM and 20 + yrs inorganic fertiliser		
SS Species score, Ellenberg indices and NVC	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**	**Baseline surveys**	**Latest surveys**	**Significant difference**
SS-Nutrient score	**-0.85 a**	**-0.64 b**	**T=-1.99, p=0.066***	**-0.80 a**	**-0.61 b**	**T=-2.11, p=0.057***	**-0.66**	**-0.55**	N.S	**-0.41 a**	**-0.16 b**	**T=-3.44, p=0.004***	**-0.3**	**-0.23**	N.S
SS-Moisture score	**0.56**	**0.49**	N.S	**0.60 b**	**0.78 a**	**T=-1.89, p=0.083***	**0.60**	**0.56**	N.S	**0.24**	**0.3**	N.S	**0.23**	**0.22**	N.S
Ellenberg fertility score (N)	**4.03 b**	**4.18 a**	**T=-2.21, p=0.044***	**3.89 b**	**4.05 a**	**T=-1.93, p=0.078***	**4.12 b**	**4.28 a**	**T=-2, p=0.064***	**4.53 b**	**4.77 a**	**T=-3.44, p=0.004***	**4.49 b**	**4.60 a**	**T=-2.56, p=0.015**
Ellenberg moisture index (M)	**6.01**	**6.1**	N.S	**6.07 b**	**6.28 a**	**T=-2.91, p=0.013**	**6**	**5.93**	N.S	**5.71**	**5.72**	N.S	**5.77**	**5.78**	N.S
Ellenberg pH index (R)	**5.78**	**5.73**	N.S	**5.55**	**5.52**	N.S	**5.74**	**5.77**	N.S	**5.72 b**	**5.83 a**	**T=-2.87, p=0.012**	**5.7**	**5.7**	N.S
MG8 best fit	**30**	**26**	N.S	**29 b**	**45 a**	**T=-3.15, p=0.008***	**29 b**	**39 a**	**T=-1.92, p=0.075***	**32**	**52**	**T=-4.17, p=0.001***	**35 b**	**39 a**	N.S
MG3b best fit	**47**	**46**	N.S	**48**	**42**	N.S	**49**	**45**	N.S	**48**	**42**	N.S	**39**	**39**	N.S

c) Key negative indicator species

In the baseline surveys, the only key negative indicator species to show any significant differences between fertiliser categories was sharp-flowered rush. The frequency of sharp-flowered rush was much higher in 2nd category, in comparison to 4th and 5th categories; 3rd category was significantly higher than 5th category, whilst 1st category was intermediate (Figure 17). All key negative indicator species were commonly found in the majority of Upper Teesdale meadows, apart from soft rush which was found in low frequencies (Appendix Table T).

Overall, four key negative indicator species have declined over time in Upper Teesdale meadows in 1st category where only FYM has been added to the meadows: Yorkshire fog, sharp-flowered rush, perennial rye-grass and white clover. Three key negative indicator species have increased in 5th category, where meadows have received inorganic fertilisers for over 20 years: Yorkshire fog, perennial rye-grass and creeping buttercup. Two species have increased in 2nd category: sharp-flowered rush and creeping buttercup, suggesting that these meadows have become wetter (Appendix Table U).

By the latest surveys, sharp-flowered rush, perennial rye-grass and creeping buttercup were found in lower frequencies in 1st category which has only received FYM, in comparison to 2nd category which has received 3 – 6 years inorganic fertiliser. Soft rush has remained in low frequencies, despite an increase in 1st category. In 2nd category, sharp-flowered rush and creeping buttercup were found in greater frequencies, suggesting these meadows have become wetter. In 4th category, which has received inorganic fertiliser additions for over ten years, white clover and perennial rye-grass were found in higher frequencies than 1st category. In 5th category, which has received inorganic fertiliser additions for over twenty years, sharp-flowered rush was found in lower frequencies than 2nd and 3rd categories, and white clover was significantly higher than 1st category (Appendix Table T).

Appendix Table S. Key negative indicator species in different fertiliser categories. The differences in mean frequency of key negative indicator species between fertiliser categories in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

		Fertiliser categories					
		1st Category	2nd Category	3rd Category	4th Category	5th Category	
Negative Indicator Species	**Survey Type**	**FYM (mean frequency)**	**FYM and 3 – 6 yrs inorganic fertiliser (mean frequency)**	**FYM and 7 – 10 yrs inorganic fertiliser (mean frequency)**	**FYM and 10 + yrs inorganic fertiliser (mean frequency)**	**FYM and 20 + yrs inorganic fertiliser (mean frequency)**	**Significant difference**
Soft brome	**Baseline**	**1.2**	**0.8**	**1.8**	**0.8**	**1.2**	N.S
Soft brome	**Latest**	**0.6**	**0.2**	**0.6**	**0.9**	**1.0**	N.S
Yorkshire fog	**Baseline**	**1.4**	**2.4**	**1.4**	**2.4**	**1.5**	N.S
Yorkshire fog	**Latest**	**0.8 b**	**3. a**	**1.9 ab**	**3.3 a**	**2.1 ab**	**$F_{4,97}$=4.75,p=0.002*** **
Sharp-flowered rush	**Baseline**	**1.9 abc**	**2.2 a**	**2 ab**	**0.7 bc**	**0.7 c**	**$F_{4,97}$=4.91,p=0.001*** **
Sharp-flowered rush	**Latest**	**0.9 bc**	**4. a**	**1.6 b**	**0.6 bc**	**0.4 c**	**$F_{4,97}$=17.66,p<0.001*** **
Soft rush	**Baseline**	**0.0**	**0.6**	**0.2**	**0.3**	**0.2**	N.S
Soft rush	**Latest**	**0.4**	**0.8**	**0.6**	**0.2**	**0.3**	N.S
Perennial rye-grass	**Baseline**	**1.7**	**1.6**	**1.3**	**1.8**	**1.5**	N.S
Perennial rye-grass	**Latest**	**0.8 b**	**1.1 ab**	**1.1 ab**	**2.4 a**	**1.9 ab**	**$F_{4,97}$=3.23,p=0.016** **
Creeping buttercup	**Baseline**	**2.3**	**2.0**	**2.4**	**2.0**	**1.8**	N.S
Creeping buttercup	**Latest**	**1.6 b**	**3.5 a**	**2.3 ab**	**2.6 ab**	**2.1 ab**	**$F_{4,97}$=2.96,p=0.024** **
White clover	**Baseline**	**1.7**	**2.6**	**1.9**	**2.1**	**2.1**	N.S
White clover	**Latest**	**0.3 b**	**3.1 a**	**1.6 ab**	**2.5 a**	**2.1 a**	**$F_{4,97}$=6.59,p<0.001*** **

Appendix Table T. Key negative indicator species in baseline and latest surveys. The changes in mean frequency of key negative indicator species between baseline and latest surveys in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

	Fertiliser categories														
	1st FYM			2nd FYM and 3 – 6 yrs inorganic fertiliser after baseline			3rd FYM and 7 – 10 yrs inorganic fertiliser			4th FYM plus 10 + yrs Inorganic Fertiliser			5th FYM plus 20 + yrs inorganic fertiliser		
Key Negative Indicator Species	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Soft brome	**1.2**	**0.6**	N.S	**0.8**	**0.2**	N.S	**1.8 a**	**0.6 b**	**T=3.05, p=0.008*** **	**0.8**	**0.9**	N.S	**1.2**	**1.0**	N.S
Yorkshire fog	**1.4 a**	**0.8 b**	**T=2.07, p=0.057***	**2.4**	**3.0**	N.S	**1.4**	**1.9**	N.S	**2.4**	**3.3**	N.S	**1.5 b**	**2.1 a**	**T=-2.55, p=0.001*** **
Sharp-flowered rush	**1.9 a**	**0.9 b**	**T=-2.20, p=0.042***	**2.2 b**	**4. a**	**T=-2.41, p=0.033** **	**2.0**	**1.6**	N.S	**0.7**	**0.6**	N.S	**0.7 a**	**0.4 b**	**T=2.01, p=0.051***
Soft rush	**0 b**	**0.4 a**	**T=-2.45, p=0.028** **	**0.6**	**0.8**	N.S	**0.2**	**0.6**	N.S	**0.3**	**0.2**	N.S	**0.2**	**0.3**	N.S
Perennial rye-grass	**1.7 a**	**0.8 b**	**T=2.16, p=0.048***	**1.6**	**1.1**	N.S	**1.3**	**1.1**	N.S	**1.8**	**2.4**	N.S	**1.5 b**	**1.9 a**	**T=-1.96, p=0.058***
Creeping buttercup	**2.3**	**1.6**	N.S	**2. b**	**3.5 a**	**T=-2.16, p=0.052***	**2.4**	**2.3**	N.S	**2.0**	**2.6**	N.S	**1.8 b**	**2.1 a**	**T=-1.88, p=0.049***
White clover	**1.7 a**	**0.3 b**	**T=2.77, p=0.015** **	**2.6**	**3.1**	N.S	**1.9**	**1.6**	N.S	**2.1**	**2.5**	N.S	**2.1**	**2.1**	N.S

d) Key positive indicator species with a score of +1 or +2

In the baseline surveys, nine of the eleven key positive indicator species with a score of +1 or +2, showed differences between fertiliser categories, although there is not a consistent pattern: sweet vernal grass had significantly higher frequency in 2nd category compared to 1st, 3rd and 5th categories, with 4th category intermediate; marsh marigold had significantly higher frequency in 1st, 2nd and 3rd categories, compared to 4th and 5th (Appendix Figure F); pignut had significantly higher frequency in 3rd category, compared to 5th category, with 1st, 2nd and 4th categories intermediate; crested dog's-tail had significantly higher frequency in 2nd category, compared to 1st and 5th category, with 3rd and 4th category intermediate; eyebright had significantly higher frequency in 2nd category, compared to 4th and 5th category, with 1st, 3rd and 4th categories higher than 5th; meadowsweet had significantly higher frequency in 1st and 2nd category, compared to 5th category, with 3rd and 4th categories intermediate; self-heal had significantly higher frequency in 2nd category, compared to 5th category, with 1st, 3rd and 4th category intermediate; hay rattle and red clover had significantly higher frequency in 1st, 2nd and 3rd categories, compared to 5th category, with 4th category intermediate. Meadow buttercup and lesser trefoil showed no differences in the categories in the baseline surveys (Appendix Table V).

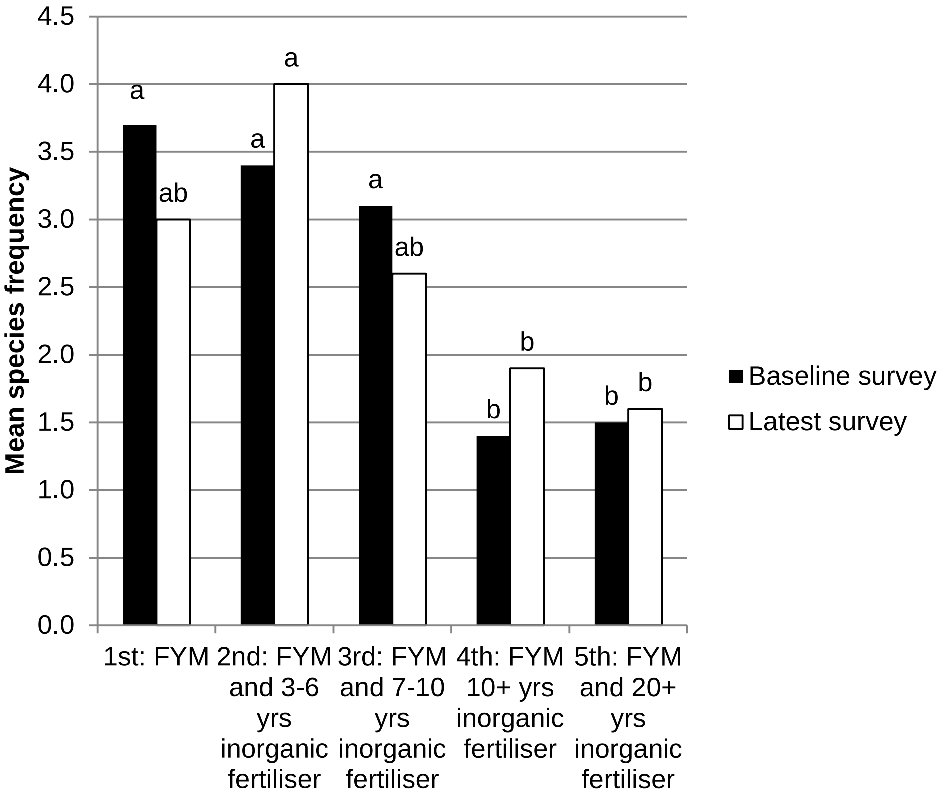
Between the baseline and latest surveys, five species showed a decline in some categories: marsh marigold, pignut, meadowsweet, meadow buttercup and self-heal. Marsh marigold significantly declined in 1st category, but remained the same in other categories (Appendix Figure F); pignut significantly declined in 2nd and 3rd categories; meadowsweet significantly declined in 1st, 2nd and 5th categories; self-heal and meadow buttercup significantly declined in 1st category (self-heal declined from 0.9 to 0.1). Three species showed an increase over time: eyebright and hay rattle significantly increased in 5th category and remained the same in other categories; lesser trefoil significantly increased in 1st, 3rd and 5th categories. Only three species showed no change: sweet vernal grass, crested dog's-tail and red clover (Appendix Table W).

In the latest surveys, ten species have shown differences between different categories, but the responses vary. Sweet vernal grass has significantly higher frequency in 2nd category compared to all other categories. Marsh marigold has significantly higher frequency in 2nd category, compared to 4th and 5th, with the 1st and 3rd category intermediate. Crested dog's-tail has significantly higher frequency in 2nd category, compared to 1st and 5th category, with 4th category also significantly higher than 5th category and 3rd category intermediate. Eyebright has remained with the same pattern: the frequency is significantly higher in 2nd category, compared to 4th and 5th category, with the 1st, 3rd and 4th categories higher than 5th. Meadowsweet has significantly higher frequency in 1st category, compared to 5th category, with 2nd, 3rd and 4th categories intermediate. Self-heal has significantly higher frequency in 2nd category, compared to 1st and 5th, with 3rd category intermediate, plus 1st category is also much lower than 4th. Hay rattle has significantly higher frequency in 1st, 2nd and 3rd categories, compared to 5th category, plus 3rd category is also higher than 4th and 5th category. Lesser trefoil has higher frequency in 1st category compared to other categories. Red clover has significantly higher frequency in 2nd category, compared to 5th category, with 1st, 4th and 5th category intermediate. Pignut showed no differences in the categories in the latest surveys (Appendix Table V).

Over time, the differences between 1st and 2nd categories have become more apparent. Sweet vernal grass, crested dog's-tail, self-heal and meadow buttercup have higher frequencies in 2nd category, compared to 1st category, whereas, meadowsweet and lesser trefoil have higher frequencies in 1st category compared to 2nd category. Sweet vernal grass was also higher in 2nd category compared to 3rd, 4th and 5th, otherwise there were no other differences between 2nd and 3rd categories. Hay rattle has higher frequency in 3rd category compared to 4th category, otherwise there were no other differences between 3rd and 4th categories. Similarly, there were no differences between 4th and 5th category (Appendix Table V).

However, there were a few species which were found in greater frequencies in meadows that haven't had much inorganic fertiliser applications compared to meadows that have had inorganic fertiliser applications for more years. Marsh marigold, eyebright, hay rattle and lesser trefoil were more frequently found in 1st or 2nd categories, in comparison to 4th or 5th categories. Although the trends are quite different for each species, generally, meadowsweet is declining over time, whereas lesser trefoil is increasing over time (Appendix Table V).

It is finally worth pointing out that these positive indicator species with a score of +1 or +2 are commonly found in Upper Teesdale meadows, irrespective of any differences in each category, with the exception of eyebright, pignut, self-heal and lesser trefoil. These four species were sometimes found in low frequencies (0.1 – 0.9) but all the other species had frequencies above 1 and ranged up to a frequency of 4 ((Appendix Table V).



Appendix Figure F. Marsh marigold in different fertiliser categories. The differences between fertiliser categories and changes over time in mean frequency of marsh marigold in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences are shown between the different groups: a = the highest value, b = the lowest value.

Appendix Table U. Key positive indicator species with a score of +1 or +2 in different fertiliser categories. The differences in mean frequency of key positive indicator species with a score of +1 or +2 between Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant) a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

		Fertiliser categories					
		1st Category	**2nd Category**	**3rd Category**	**4th Category**	**5th Category**	
Positive indicators with a score of +1 or +2	**Survey Type**	**FYM (mean frequency)**	**FYM and 3 – 6 yrs inorganic fertiliser (mean frequency)**	**FYM and 7 – 10 yrs inorganic fertiliser (mean frequency)**	**FYM and 10 + yrs inorganic fertiliser (mean frequency)**	**FYM and 20 + yrs inorganic fertiliser (mean frequency)**	**Significant difference**
Sweet vernal grass	**Baseline**	**1.9 b**	**3.8 a**	**2 b**	**2.8 ab**	**1.7 b**	$F_{1,97}$**=4.27,p=0.003*** **
Sweet vernal grass	**Latest**	**1.8 b**	**3.8 a**	**1.8 b**	**1.9 b**	**2 b**	$F_{1,97}$**=3.46,p=0.011** **
Marsh marigold	**Baseline**	**3.7 a**	**3.4 a**	**3.1 a**	**1.4 b**	**1.5 b**	$F_{4,97}$**=8.60,p<0.001*** **
Marsh marigold	**Latest**	**3 ab**	**4. a**	**2.6 ab**	**1.9 b**	**1.6 b**	$F_{4,97}$**=5.94,p<0.001*** **
Pignut	**Baseline**	**1.5 ab**	**1.6 ab**	**2.2 a**	**1.3 ab**	**0.8 b**	$F_{4,97}$**=2.76,p=0.032** **
Pignut	**Latest**	**1.5**	**0.5**	**1.1**	**0.9**	**1.0**	N.S
Crested dog's-tail	**Baseline**	**1.8 b**	**3.8 a**	**2.3 ab**	**2.6 ab**	**1.7 b**	$F_{4,97}$**=3.78,p=0.007*** **
Crested dog's-tail	**Latest**	**1.5 bc**	**3.5 a**	**1.9 abc**	**3.1 ab**	**1.4 c**	$F_{4,97}$**=5.82,p<0.001*** **
Eyebright	**Baseline**	**2.3 ab**	**2.9 a**	**2.2 ab**	**1.2 bc**	**0.3 c**	$F_{4,97}$**=13.49,p<0.001*** **
Eyebright	**Latest**	**2.3 ab**	**3.1 a**	**2.4 ab**	**1.4 bc**	**0.7 c**	$F_{4,97}$**=10.94,p<0.001*** **
Meadowsweet	**Baseline**	**2.4 a**	**2.2 a**	**1.4 ab**	**1.1 ab**	**0.8 b**	$F_{4,97}$**=4.88,p=0.001*** **
Meadowsweet	**Latest**	**1.7 a**	**1.2 ab**	**1.3 ab**	**0.9 ab**	**0.5 b**	$F_{4,97}$**=4.11,p=0.004*** **
Self-heal	**Baseline**	**0.9 ab**	**1.8 a**	**0.9 ab**	**0.9 ab**	**0.6 b**	$F_{4,97}$**=2.50,p=0.048* **
Self-heal	**Latest**	**0.1 c**	**1.7 a**	**0.7 abc**	**1.3 ab**	**0.4 bc**	$F_{4,97}$**=5.95,p<0.001*** **
Meadow buttercup	**Baseline**	**1.9**	**3.2**	**2.4**	**2.6**	**1.9**	N.S
Meadow buttercup	**Latest**	**1.4 b**	**3.5 a**	**2.1 ab**	**2.5 ab**	**1.6 b**	$F_{4,97}$**=3.74,p=0.007*** **
Hay rattle	**Baseline**	**3. a**	**3.5 a**	**2.9 a**	**2.1 ab**	**1.2 b**	$F_{4,97}$**=8.14,p<0.001*** **
Hay rattle	**Latest**	**3.5 ab**	**3.3 ab**	**3.9 a**	**2.3 bc**	**1.5 c**	$F_{4,97}$**=10.51,p<0.001*** **
Lesser trefoil	**Baseline**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	N.S
Lesser trefoil	**Latest**	**1.1 a**	**0.2 b**	**0.3 b**	**0.1 b**	**0.1 b**	$F_{4,97}$**=5.37,p=0.001*** **
Red clover	**Baseline**	**2.3 a**	**2.5 a**	**2.4 a**	**2 ab**	**1 b**	$F_{1,97}$**=4.80,p=0.001*** **
Red clover	**Latest**	**1.9 ab**	**3.2 a**	**2.2 ab**	**1.9 ab**	**1.3 b**	$F_{1,97}$**=4.84,p=0.001*** **

Appendix Table V. Key positive indicator species with a score of +1 or +2 in baseline and latest surveys. The changes in mean frequency of key positive indicator species with a score of +1 or +2 between baseline and latest surveys in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

	Fertiliser categories														
	1st FYM			2nd FYM and 3 – 6 yrs inorganic fertiliser after baseline			3rd FYM and 7 – 10 yrs inorganic fertiliser			4th FYM and 10 + yrs inorganic fertiliser			5th FYM and 20 + yrs inorganic fertiliser		
Key Positive indicators with a score of +1 or +2	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Sweet vernal grass	**1.9**	**1.8**	N.S	**3.8**	**3.8**	N.S	**2.0**	**1.8**	N.S	**2.8**	**1.9**	N.S	**1.7**	**2.0**	N.S
Marsh marigold	**3.7 a**	**3 b**	**T=2.20, p=0.045***	**3.4**	**4.0**	N.S	**3.1**	**2.6**	N.S	**1.4**	**1.9**	N.S	**1.5**	**1.6**	N.S
Pignut	**1.5**	**1.5**	N.S	**1.6 a**	**0.5 b**	**T=2.56, p=0.025****	**2.2 a**	**1.1 b**	**T=2.42, p=0.029****	**1.3**	**0.9**	N.S	**0.8**	**1.0**	N.S
Crested dog's-tail	**1.8**	**1.5**	N.S	**3.8**	**3.5**	N.S	**2.3**	**1.9**	N.S	**2.6**	**3.1**	N.S	**1.7**	**1.4**	N.S
Eyebright	**2.3**	**2.3**	N.S	**2.9**	**3.1**	N.S	**2.2**	**2.4**	N.S	**1.2**	**1.4**	N.S	**0.3 b**	**0.7 a**	**T=-3.58, p=0.001*****
Meadowsweet	**2.4 a**	**1.7 b**	**T=1.98, p=0.068***	**2.2 a**	**1.2 b**	**T=2.05, p=0.063***	**1.4**	**1.3**	N.S	**1.1**	**0.9**	N.S	**0.8 a**	**0.5 b**	**T=1.81, p=0.078***
Self-heal	**0.9 a**	**0.1 b**	**T=2.48, p=0.027****	**1.8**	**1.7**	N.S	**0.9**	**0.7**	N.S	**0.9**	**1.3**	N.S	**0.6**	**0.4**	N.S
Meadow buttercup	**1.9 a**	**1.4 b**	**T=2.43, p=0.029****	**3.2**	**3.5**	N.S	**2.4**	**2.1**	N.S	**2.6**	**2.5**	N.S	**1.9**	**1.6**	N.S
Hay rattle	**3.0**	**3.5**	N.S	**3.5**	**3.3**	N.S	**2.9**	**3.9**	N.S	**2.1**	**2.3**	N.S	**1.2 b**	**1.5 a**	**T=-1.88, p=0.068***
Lesser trefoil	**0.0**	**1.1**	**T=-2.61, p=0.021****	**0.2**	**0.2**	N.S	**0 b**	**0.3 a**	**T=-2.08, p=0.018****	**0.0**	**0.1**	N.S	**0 b**	**0.1 a**	**T=-2.09, p=0.044***
Red clover	**2.3**	**1.9**	N.S	**2.5**	**3.2**	N.S	**2.4**	**2.2**	N.S	**2.0**	**1.9**	N.S	**1.0**	**1.3**	N.S

e) Key positive indicator species with a score of +3

In the baseline survey period, eight of the ten key positive indicator species with a score of +3, showed differences between fertiliser categories. Lady's-mantle had significantly higher frequency in 1^{st} category compared to 4^{th} and 5^{th} categories, with 2^{nd} and 3^{rd} categories significantly higher than 5^{th} category (Figure 19). Bugle had significantly higher frequency in 2^{nd} category, compared to all other categories, plus 1^{st} category was significantly higher than 5^{th} category, with 3^{rd} and 4^{th} intermediate. Quaking grass had significantly higher frequency in 2^{nd} category, compared to 4^{th} and 5^{th} categories, with 1^{st} and 3^{rd} categories intermediate. Common knapweed had significantly higher frequency in 1^{st} category, compared to 4^{th} and 5^{th} category, and 2^{nd} category was higher than 5^{th} category, with 3^{rd} and 4^{th} categories intermediate. Rough hawkbit had significantly higher frequency in 1^{st} category, compared to 3^{rd} and 5^{th} category, with 2^{nd} and 4^{th} categories intermediate. Ragged robin had significantly higher frequency in 2^{nd} category, compared to 3^{rd}, 4^{th} and 5^{th} categories, with 1^{st} category intermediate. Devil's-bit scabious had significantly higher frequency in 2^{nd} category, compared to other categories, and 1^{st} category had significantly higher frequency than 4^{th} and 5^{th} categories, with 3^{rd} intermediate (Figure 20). Globeflower had significantly higher frequency in 1^{st} and 2^{nd} categories compared to 4^{th} and 5^{th} categories and 3^{rd} category was intermediate. Two species showed no significant differences between the categories: Wood crane's-bill and Great burnet (Appendix Table X).

These patterns are showing that generally 1^{st} and 2^{nd} categories where only FYM had been added before the baseline survey period had higher frequencies of key positive indicator species with a score of +3, compared to 4^{th} and 5^{th} categories, where inorganic fertilisers had been added before the baseline survey period, especially the species Devil's-bit scabious and Globeflower. Lady's-mantle, Bugle and Common knapweed were also higher in the 1^{st} and 2^{nd} categories, compared to the 5^{th} category (Appendix Table X).

Between the baseline and latest surveys, nine species showed a decline in some categories. Lady's-mantle significantly declined in all categories, declining by more than half of the frequency found in the baseline surveys. In 2^{nd} category, the frequency of Lady's-mantle declined from 2.1 to 0.3 (Figure 27). Bugle significantly declined in 2^{nd} and 4^{th} categories, almost disappearing in 4^{th} category (0.8 to 0.1). Quaking grass significantly declined in 1^{st}, 2^{nd}, 3^{rd} and 5^{th} categories, almost disappearing in 3^{rd} and 5^{th} categories (0.9 to 0.1; 0.4 to 0.1 respectively, and was at a frequency of 0.1 in 4^{th} category). Common knapweed significantly declined in 5^{th} category. Wood crane's-bill significantly declined in 1^{st}, 3^{rd} and 5^{th} categories, almost disappearing in 3^{rd} and 5^{th} categories (1 to 0.1; 0.5 to 0.2 respectively). Rough hawkbit significantly declined in 4^{th} and 5^{th} categories. Great burnet significantly declined in 3^{rd} and 5^{th} categories, almost disappearing in both (1.1 to 0.1, 0.2 to 0.1 respectively). Devil's-bit scabious significantly declined in 2^{nd} and 3^{rd} categories, almost halving in frequency in both (Figure 28). Globeflower significantly declined in 1^{st} and 3^{rd} categories by over half the frequency found in baseline surveys and was already found in low frequencies in 4^{th} and 5^{th} categories (Appendix Table Y).

In the latest surveys, nine species showed differences between fertiliser categories, with the majority showing a preference to meadows that have received inorganic fertiliser inputs the least number of years. Lady's-mantle had significantly higher frequencies only in 1^{st} category compared to other categories. These results suggest that this species cannot tolerate inorganic fertiliser use and has declined to very low frequencies in 2^{nd}, 3^{rd}, 4^{th} and 5^{th} categories (Figure 19). Bugle had significantly higher frequency in 1^{st}, 2^{nd} and 3^{rd} categories, compared to 5^{th} category, plus 1^{st} and 3^{rd} categories were higher than 4^{th} category. Quaking grass had significantly higher frequency in 2^{nd} category, compared to other categories but it had declined so that its frequency is very low across all categories. Common knapweed had significantly higher frequency in 1^{st} and 2^{nd} categories, compared to 4^{th} and 5^{th} categories, and 3^{rd} category was intermediate. Rough hawkbit had significantly higher frequency in 1^{st} category, compared to 4th and 5th category, with 3rd category significantly higher than 5th category and 2nd intermediate. Ragged robin had significantly higher frequency in 2nd category, compared to other categories. Great burnet was higher in 1st category compared to 2nd, 3rd and 5th categories, although frequency of this species is very low across all categories. Devil's-bit scabious had significantly higher frequency in 1st and 2nd categories, compared 4th and 5th categories, plus 2nd category was higher than 3rd category (Figure 20). Globeflower had significantly higher frequency in 1st and 2nd categories compared to 5th category and 2nd category was significantly higher than 3rd and 4th category. Only one species showed no significant differences between the categories: wood crane's-bill. However, this species has declined over time and is found in low frequencies in all types of meadows (Appendix Table X).

There were only a few differences between one category and the next: Lady's-mantle and great burnet were found in higher frequencies in 1st category compared to 2nd category; ragged robin was found in higher frequencies in 2nd category compared to 1st category; quaking grass, devil's-bit scabious and globeflower was found in higher frequencies in 2nd category, compared to 3rd category; bugle was found in higher frequency in 3rd category compared to 4th category and there are no differences between 4th and 5th category (Appendix Table X).

In summary, all positive indicator species with a score of +3 have shown some sort of decline in upland hay meadows in Upper Teesdale from the baseline to the latest survey period. Lady's-mantle has consistently declined in Upper Teesdale and is now rare in meadows that have had any inorganic fertiliser use. A number of species show a preference to meadows that have less nutrient inputs over time: Lady's-mantle, bugle, common knapweed, rough hawkbit, devil's-bit scabious, great burnet and globeflower. Common knapweed, devil's-bit scabious and globeflower are mainly found in 1st and 2nd categories and are very rare in 4th and 5th categories. Rough hawkbit primarily occurs in 1st category and is found in low frequencies in 4th and 5th categories and bugle is now rare in 4th and 5th categories.

Appendix Table W. Key positive indicator species with a score of +3 in different fertiliser categories. The differences in mean frequency of key positive indicator species with a score of +3, between Upper Teesdale meadows categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

		Fertiliser categories					
		1st Category	2nd Category	3rd Category	4th Category	5th Category	
Positive indicators with a score of +3	**Survey Type**	**FYM (mean frequency)**	**FYM and 3 – 6 yrs inorganic fertiliser (mean frequency)**	**FYM and 7 – 10 yrs inorganic fertiliser (mean frequency)**	**FYM and 10 + yrs inorganic fertiliser (mean frequency)**	**FYM and 20 + yrs inorganic fertiliser (mean frequency)**	**Significant difference**
Lady's-mantle	**Baseline**	**2.6 a**	**2.1 ab**	**1.9 ab**	**0.9 bc**	**0.7 c**	**$F_{4,97}$=9.51,p<0.001*** **
Lady's-mantle	**Latest**	**1.3 a**	**0.3 b**	**0.4 b**	**0.5 b**	**0.2 b**	**$F_{4,97}$=10.40,p<0.001*** **
Bugle	**Baseline**	**1.2 b**	**2.3 a**	**0.7 bc**	**0.8 bc**	**0.3 c**	**$F_{4,97}$=11.70,p<0.001*** **
Bugle	**Latest**	**0.9 a**	**0.8 ab**	**0.8 a**	**0.1 bc**	**0.2 c**	**$F_{4,97}$=6.69,p<0.001*** **
Quaking grass	**Baseline**	**1.3 ab**	**1.5 a**	**0.9 ab**	**0.3 b**	**0.4 b**	**$F_{4,97}$=4.58,p=0.002*** **
Quaking grass	**Latest**	**0.3 ab**	**0.6 a**	**0.1 b**	**0.1 b**	**0.1 b**	**$F_{4,97}$=6.56,p<0.001*** **
Common knapweed	**Baseline**	**1.8 a**	**1.6 ab**	**1.1 abc**	**0.6 bc**	**0.5 c**	**$F_{4,97}$=5.17,p=0.001*** **
Common knapweed	**Latest**	**1.5 a**	**1.5 a**	**0.8 ab**	**0.3 b**	**0.3 b**	**$F_{4,97}$=11.56,p<0.001*** **
Wood crane's-bill	**Baseline**	**1.1**	**0.9**	**1.0**	**0.7**	**0.5**	N.S
Wood crane's-bill	**Latest**	**0.5**	**0.3**	**0.1**	**0.4**	**0.2**	N.S
Rough hawkbit	**Baseline**	**2.6 a**	**1.4 ab**	**1.4 b**	**1.5 ab**	**1 b**	**$F_{4,97}$=4.91,p=0.001*** **
Rough hawkbit	**Latest**	**2.2 a**	**1.4 abc**	**1.7 ab**	**0.6 bc**	**0.6 c**	**$F_{4,97}$=7.24,p<0.001*** **
Ragged robin	**Baseline**	**0.7 ab**	**1.7 a**	**0.5 b**	**0.3 b**	**0.3 b**	**$F_{4,97}$=5.13,p=0.001*** **
Ragged robin	**Latest**	**0.7 b**	**2.1 a**	**0.9 b**	**0.3 b**	**0.2 b**	**$F_{4,97}$=10.87,p<0.001*** **
Great burnet	**Baseline**	**1.0**	**0.2**	**1.1**	**0.8**	**0.2**	N.S
Great burnet	**Latest**	**0.7 a**	**0.1 b**	**0.1 b**	**0.3 ab**	**0 b**	**$F_{4,97}$=6.09,p<0.001*** **
Devil's-bit scabious	**Baseline**	**1.5 b**	**2.8 a**	**1.2 bc**	**0.4 c**	**0.3 c**	**$F_{4,97}$=15.16,p<0.001*** **
Devil's-bit scabious	**Latest**	**1.1 ab**	**1.5 a**	**0.6 bc**	**0.1 c**	**0.3 c**	**$F_{4,97}$=8.40,p<0.001*** **
Globeflower	**Baseline**	**2.3 a**	**2.3 a**	**1.6 ab**	**0.4 bc**	**0.2 c**	**$F_{4,97}$=11.97,p<0.001*** **
Globeflower	**Latest**	**1. ab**	**1.6 a**	**0.6 bc**	**0.3 bc**	**0.2 c**	**$F_{4,97}$=7.78,p<0.001*** **

Appendix Table X. Key positive indicator species with a score of +3 in baseline and latest surveys. The changes in mean frequency of key positive indicator species with a score of +3 between baseline and latest surveys in Upper Teesdale meadows; categorised by number of years they have received inorganic fertiliser inputs. Statistically significant differences were graded from * = ≤ 0.05 (slightly significant),** = ≤ 0.04 (significant), *** = ≤ 0.001 (highly significant). a = the highest value, d = the lowest value; those groups with the same letter are not significantly different.

	Fertiliser categories														
	1st FYM			2nd FYM and 3 – 6 yrs inorganic fertiliser			3rd FYM and 7 – 10 yrs inorganic fertiliser			4th FYM and 10 + yrs inorganic fertiliser			5th FYM and 20 + yrs inorganic fertiliser		
Key Positive indicators with a score of +3	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**	**Baseline surveys: mean frequency**	**Latest surveys: mean frequency**	**Significant difference**
Lady's-mantle	**2.6 a**	**1.3 b**	**T=4.01, p=0.001*** **	**2.1 a**	**0.3 b**	**T=4.48, p=0.001*** **	**1.9 a**	**0.4 b**	**T=4.28, p=0.001*** **	**0.9 a**	**0.5 b**	**T=2.41, p=0.029** **	**0.7 a**	**0.2 b**	**T=2.91, p=0.005*** **
Bugle	**1.2**	**0.9**	N.S	**2.3 a**	**0.8 b**	**T=3.33, p=0.006*** **	**0.7**	**0.8**	N.S	**0.8 a**	**0.1 b**	**T=3.10, p=0.007*** **	**0.3**	**0.2**	N.S
Quaking grass	**1.3 a**	**0.3 b**	**T=2.18, p=0.046***	**1.5 a**	**0.6 b**	**T=3.49, p=0.004*** **	**0.9 a**	**0.1 b**	**T=2.67, p=0.018** **	**0.3**	**0.1**	N.S	**0.4 a**	**0.1 b**	**T=2.92, p=0.006*** **
Common knapweed	**1.8**	**1.5**	N.S	**1.6**	**1.5**	N.S	**1.1**	**0.8**	N.S	**0.6**	**0.3**	N.S	**0.5 a**	**0.3 b**	**T=2.52, p=0.016** **
Wood crane's-bill	**1.1 a**	**0.5 b**	**T=2.07, p=0.057***	**0.9**	**0.3**	N.S	**1. a**	**0.1 b**	**T=2.57, p=0.021** **	**0.7**	**0.4**	N.S	**0.5 a**	**0.2 b**	**T=2.09, p=0.04***
Rough hawkbit	**2.6**	**2.2**	N.S	**1.4**	**1.4**	N.S	**1.4**	**1.7**	N.S	**1.5 a**	**0.6 b**	**T=3.22, p=0.006*** **	**1. a**	**0.6 b**	**T=2.11, p=0.04***
Ragged robin	**0.7**	**0.7**	N.S	**1.7**	**2.1**	N.S	**0.5**	**0.9**	N.S	**0.3**	**0.3**	N.S	**0.3**	**0.2**	N.S
Great burnet	**1.0**	**0.7**	N.S	**0.2**	**0.1**	N.S	**1.1 a**	**0.1 b**	**T=2.51, p=0.024** **	**0.8**	**0.3**	N.S	**0.2 a**	**0.1 b**	**T=1.78, p=0.083***
Devil's-bit scabious	**1.5**	**1.1**	N.S	**2.8 a**	**1.5 b**	**T=2.77, p=0.017** **	**1.2 a**	**0.6 b**	**T=2.08, p=0.05***	**0.4**	**0.1**	N.S	**0.3**	**0.3**	N.S
Globeflower	**2.3 a**	**1 b**	**T=2.81, p=0.012** **	**2.3**	**1.6**	N.S	**1.6 a**	**0.6 b**	**T=2.27, p=0.038** **	**0.4**	**0.3**	N.S	**0.2**	**0.2**	N.S