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SID 5 Research Project Final Report

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Project identification

1. Defra Project code: BD5207
2. Project title: Utility of lenient grazing of agricultural grassland to promote in-field structural heterogeneity, invertebrates and bird foraging
3. Contractor organisation(s): Royal Society for the Protection of Birds (RSPB)
   CABI
   ADAS
4. Total Defra project costs (agreed fixed price): £ 291,738
5. Project: start date .... 01 April 2011
   end date .... 31 March 2013

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Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

1. A major obstacle to reversing long-term declines in farmland bird populations is the provision of invertebrate-rich habitats that are required to successfully raise chicks. This is particularly true of livestock-rearing areas dominated by intensively managed grassland, which lacks invertebrate resources; especially larger-bodied groups like grasshoppers and caterpillars (Lepidoptera and sawflies), which are important dietary components for farmland birds.

2. Modern grazing management aims to maximise utilisation of grass at a young, vegetative stage though frequent and thorough defoliation of all parts of grasslands; resulting in uniform, fast-growing, species-poor swards. These conditions are hostile to a broad range of grassland invertebrates, which require swards to be heterogeneous in structure and composition, thereby providing the full range of required niches, including patches of vegetation left undisturbed by grazing (avoiding disruption of vulnerable stages in life cycles).

3. The general aim of this study was to optimise management prescriptions for extensively grazed cattle pastures to provide invertebrate-rich foraging habitat for breeding farmland birds. Specific objectives were: (1) to investigate the effects of reduced cattle grazing intensity on fine-scale structural heterogeneity in the sward; (2) to measure the effects on sward composition, invertebrate communities and utility to foraging birds; (3) to measure the agronomic and economic costs of the grazing treatments and (4) to recommend lenient grazing options for inclusion in Natural England's agri-environment schemes.

4. Grazing treatments were established for 3 years on a split-plot design across six semi-improved grass fields in South Devon. The sites were in localities known to support populations of priority farmland birds (buntings, finches and skylarks). Two extensification treatments were tested: continuous and intermittent (rotational) cattle grazing at reduced (lenient) intensity, maintaining a sward surface height of 9-12 cm throughout the grazing season (compared to 6-8 cm on control plots). The treatments aimed to improve the performance of extensification measures developed in project BD1454: specifically by increasing the intensity and duration of grazing to reduce agronomic costs, increase structural heterogeneity in grass swards and increase usage by buntings. Intermittent grazing was predicted to further increase structural heterogeneity. Increased structural heterogeneity was expected to increase the availability of niches needed by invertebrates and the length of tall grass-short grass interfaces, where foraging birds obtain access to abundant invertebrate prey in tall patches.

5. Lenient grazing was associated with immediate changes in structural heterogeneity: increasing the quantity of tall grass-short grass interfaces, but also reducing the availability of short grass patches. Intermittent lenient grazing did not enhance sward structure any more than continuous lenient grazing. Lenient grazing also resulted in increased dominance by grasses (particularly Yorkshire fog) and reduced clover cover.

6. In the first year of the study, lenient grazing doubled the densities of the subset of invertebrate taxa that are preyed upon by birds, though the combined densities of all invertebrates were unaffected. The effects of intermittent lenient grazing were the same as those of continuous lenient grazing. Invertebrate numbers generally fell in subsequent years and there was no apparent benefit from reduced grazing pressure in the third year. The invertebrate groups benefiting most from lenient grazing were forb and grass-feeding species, including Chrysomelid beetles and certain Auchenorrhyncha.

7. Lenient grazing increased the frequency of foraging visits by buntings and skylarks. Skylarks also

foraged more frequently on continuously grazed paddocks. Buntings did not distinguish between continuously and intermittently grazed paddocks and only preferentially used leniently grazed paddocks in the second half of the breeding season. Buntings and skylarks foraged more often on paddocks with high structural heterogeneity (more tall-short interfaces), taller swards and lower accessibility (fewer short grass patches). Only skylark responded to higher invertebrate densities, selecting paddocks with higher densities of large-bodied invertebrates (caterpillars and Orthoptera). Obligate seed-eating finches used the paddocks infrequently (perhaps because of local absences of favoured foodplants) and did not exhibit strong preferences for lenient grazing.

8. Weather had a strong influence on the results: 2010 and 2011 were dry years, while rainfall was unusually high in 2012. None of the apparent benefits of lenient grazing observed in 2010 and 2011 were detectable in 2012, largely because stronger grass growth resulted in taller, more heterogeneous swards on control paddocks, which more closely resembled the leniently grazed paddocks. The seven years of combined data from BD1454 and this study showed that high rainfall generally depressed grassland invertebrate populations (particularly Coleoptera and Auchenorrhyncha) and this masked any benefits of lenient grazing in 2012.

9. Economic costs of lenient grazing measures were substantially lower than the BD1454 Lenient treatment, but it was not possible to assess whether yields fell with time, due to the effects of highly variable weather. The agronomic costs of the lenient grazing were low in the first two years, when drought conditions generally depressed grass and cattle productivity. In 2012, greater grass growth increased the relative outputs so that continuous lenient grazing resulted in lost live weight production of £139 ha^{-1} (compared to a loss of £37 ha^{-1} in 2011). Intermittent lenient grazing was less costly, but the difference may be due to cattle grazing intermittently on other, higher quality fields. Daily growth rates of individual cattle were generally good on leniently grazed paddocks (0.70 – 0.83 kg/d).

10. No injurious weed problems developed during the study although weed cover was greater on leniently grazed paddocks. Lenient grazing apparently helped suppress creeping thistle infestations present on some sites at the start of the study.

11. The recommended approach for an extensive cattle grazing measure is to graze throughout the grazing season (April to October), maintaining an average sward surface height of 9-12 cm. This sward target may also be expressed as maintain at least 20% of the sward below 10 cm and at least 20% of the sward above 10 cm. This study shows that both continuous and intermittent (rotational) grazing have similar beneficial impacts on invertebrates and bird usage. The approach was tested on fields with zero fertiliser inputs, though low application rates can probably be tolerated (recommended maximum: 5 t/yr of manure). Topping should not take place, to retain sward heterogeneity (unless required for localised weed control). This approach meets the study objectives: enhancing the utility of grass swards to foraging birds (particularly buntings) and reducing costs relative to measures recommended previously (BD1454).

Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

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1. Objectives

This experiment tested extensive cattle grazing techniques designed to optimise the trade off between the utility of pastures to farmland birds, invertebrate populations and agricultural outputs. The treatments were based on the results of project BD1454 and aimed to improve utility to buntings and reduce agricultural impacts, while retaining the benefits resulting from the best BD1454 treatments, which included enhanced invertebrate densities and utility to skylarks. Both continuous and intermittent lenient grazing were tested, with the latter predicted to further enhance structural heterogeneity in grass swards. The formal objectives of the project were:

Objective 1: To assess the biodiversity benefits and agronomic costs of continuous and intermittent lenient cattle grazing of agricultural grassland, and specifically to assess:
(a) the effects of lenient grazing on fine-scale structural sward heterogeneity;
(b) the effects of lenient grazing and the subsequent changes in sward structure on invertebrate abundance and community structure;
(c) the responses of foraging birds to changes in sward structure and invertebrate communities.

Objective 2: To recommend lenient grazing options suitable for inclusion in Natural England's Entry Level or Higher Level agri-environment Schemes.

The first year of the study was funded separately as project BD5206 and continued for two years as project BD5207. This report covers the full three-year study (2010 to 2012 grazing seasons).

2. Methods

2.1. Study sites and treatments

Three treatments were imposed in a split-paddock design on three 1ha paddocks, formed by dividing single fields with fences. The set of three treatments was replicated across six fields previously engaged in BD1454 (five from Experiment 1 and one from the Experiment 2 - Devon Extension; Peach *et al*. 2010). All sites were known to support breeding populations of the priority declining farmland birds: yellowhammer *Emberiza citrinella* L., cirl bunting *E. cirlus* L. and skylark *Alauda arvensis* L. The fields were permanent grass fields, spread across South Devon (between Plymouth and Dartmouth), with a history of grazing by beef cattle and inorganic fertilizer inputs below 50 kg N/ha/year. The trial fields averaged 2.8 ha in area (range 2.3-3.3 ha) and were selected so that the three split-paddock paddocks had equal area and similar aspect, slope and boundary characteristics.

The following treatments were imposed from April 2010 to September 2012 (i.e. three grazing seasons).

Continuous Lenient grazing (CL): Paddocks were grazed continuously to a target sward height (TSH) of 9-12cm between April and the end of the grazing season (typically early October). Livestock density was manipulated with the aim of maintaining a constant sward height of 10-11cm.

Intermittent Lenient grazing (IL): Paddocks were grazed to the same average TSH as the Continuous Lenient treatment but they were grazed rotationally, with alternating periods of grazing and resting. Paddocks were grazed till sward heights fell to a TSH of 8-9cm and then the sward was rested (no grazing) until it grew back to 12-13cm, when grazing resumed. Stocking rates during grazing periods were initially set at double the rate on the adjacent Continuous Lenient paddock and were then adjusted so that the grazing periods were no shorter than two weeks in duration. This approach aimed to implement grazing and rest periods of equal duration and to equalise total grazing days on the Continuous and Intermittent Lenient paddocks in each trial field.

Control (continuous intensive grazing): Paddocks were continuously grazed to a TSH of 6-8cm between April and the end of the grazing season.

Target sward heights were achieved by manipulating stocking rates: adding cattle from a reservoir of animals on a neighbouring Overflow Field or moving excess cattle to the Overflow Field. Stocking rates were guided by mean sward heights, which were measured frequently (at least weekly) using a standard HFRO sward stick (Barthram 1986). On each occasion, 40 measurements were collected along a W-shaped transect, recording the sward surface (the highest point of contact with live vegetation, excluding inflorescences). Stocking rates on each paddock were recorded daily, to measure the cumulative number of grazing-days for each paddock. The Overflow Fields were not kept under experimental control, though farmers were asked not to fertilise these fields and to aim to keep sward heights in the range 9-12cm.

The fences and paddocks were established during the BD1454 study. The following measures were taken to prevent the preceding BD1454 treatments from affecting the new study (as carry-over effects). All trial paddocks were grazed to a sward height of less than 7cm by sheep during the winter of 2009/10. Where sheep rejected tussocks, the paddocks were also topped or grazed by cattle. The new CL treatment followed the BD1454 Moderate treatment on three of the trial fields, and the new IL treatment followed the BD1454 Moderate treatment on the other three trial fields (resulting in a cross-over design). The new Control treatment always followed the preceding BD1454 Control treatment. Two trial fields were withdrawn from the experiment at the end of 2010, but one new trial field (previously managed as a normal cattle pasture) was added as a replacement in 2011.

Cattle body size seems to have a greater influence on grazing behaviour and sward impacts than cattle breed (BD1443, Rook *et al*. 2004, Stewart & Pullin 2008) so all grazing of the trial paddocks was carried out by cattle aged 12-18 months. Cattle breeds were allowed to vary between sites but not between trial paddocks within sites.

None of the treatment paddocks received fertilizers. Weed control (herbicide spot-spraying or topping) was only permitted if severe problems developed, but this option was not used during the study.

The aims of both leniently-grazed treatments were to generate fine-scale structural heterogeneity; to simultaneously enhance invertebrate abundance throughout the avian breeding season and provide access for foraging birds. The purpose of the IL treatment was to test whether intermittent grazing enhanced sward structure and biodiversity benefits (especially bird usage) above and beyond the CL treatment. It was predicted that rest periods would enhance structural heterogeneity by polarising selective grazing: initially-rejected patches of grass would become more mature and less palatable to cattle, while a plentiful supply of palatable, young, vegetative regrowth would develop on initially-selected (grazed) patches.

2.2. Sward assessments

The main objective of these measurements was to simultaneously quantify sward structure and invertebrate densities at the same sampling locations on a sampling grid, to contrast their relative importance to foraging birds and to test for treatment effects. Additional aims were to understand how the trophic chain operates and monitor for the development of weed problems.

2.2.1. Sward measurements

Sward structure was measured on two occasions each year, in early June and late July, coinciding with early and late nesting attempts by buntings. Measurements were taken on a sampling grid of 10 permanently marked sampling locations in each trial paddock and each Overflow Field. The sampling locations were arranged on a rectangular grid with two locations 30m apart at 3 m, 10 m, 20 m, 30 m and 40 m from the field boundary.

Sward structure was assessed using a drop disk (Stewart 2001) with a 30 g disk 12cm in diameter: a similar size and weight to a foraging yellowhammer. At each sampling grid location, 64 spatially-referenced drop disk measurements were collected in an 8x8 rectangular array, with points spaced 20 cm apart. At each point, vegetation height and the dominant functional group (grasses or forbs) was recorded. The sward height arrays were used to quantify fine-scale structural heterogeneity (Section 2.5.1).

Botanical composition was recorded on the same sampling occasions within four, permanently marked 1x1m quadrats on each trial paddock (plus the Overflow Fields). The fixed quadrats were located at the four corners of the sampling grid (i.e. 30 m apart, at 3 m and 40 m into the paddock). Percentage ground cover was measured for each plant species and functional group (grasses, forbs, clover, bryophytes, dung, leaf litter and bare ground). Additionally, at four randomly selected sampling grid locations in each paddock, the number of plants and percentage cover of injurious weeds was measured within a 10 m radius.

Drop disk measurements were calibrated against the standard HFRO sward stick measurements, by pairing HFRO measurements with a subset of drop disk measurements in the four sampling grid locations used to measure botanical composition. The additional HFRO sward stick measurements were collected at ten of the 64 drop disk measurement points during all sampling rounds (2011 – 2012).

2.2.2. Invertebrate abundance measurements

Invertebrate densities were measured at the same ten sampling grid locations and on the same dates as the sward structure measurements (see above). At each sampling location, the invertebrate community was sampled by two complimentary techniques: Vortis suction sampling and sweep netting. The Vortis suction sampler (Burkhard, Rickmansworth, UK) measures total invertebrate abundance in a defined area (here 0.19 m^2 per sample location) (Arnold, 1994; Brook *et al*., 2008). Ten pooled suction samples, each of 15 s duration, constituted a single Vortis sample. Sweep nets were used to sample invertebrate groups that are not well represented in Vortis samples (Orthoptera and larvae of Symphyta and Lepidoptera). Each sweep net sample comprised 20 double sweeps with a 46 cm diameter, circular sweep net (Watkins & Doncaster, Hawkhurst, UK). The positions of the sward structure, Vortis and sweep net measurements at each sampling location were offset so that they did not compromise each other. The insects in the Vortis samples were preserved in ethanol and retained, but those from sweep samples were identified, counted and released at the time of capture.

Invertebrates were identified to Order and selected groups were subdivided further (e.g. splitting the Hemiptera into Heteroptera, Auchenorrhyncha and Sternorrhyncha). Identification excluded any individuals <2mm long as these were judged to be unprofitable as bird food (Peach *et al*., 2010). The sorted invertebrates >2mm were assigned to age classes (adults or larvae) and into three body size classes (2-5 mm, 5-10 mm or >10 mm) and the number of each group in each size class was recorded. Body length is a useful predictor of invertebrate body mass both within and between taxonomic groups (e.g. Rogers *et al*., 1976; Jarosik, 1989) and several studies have demonstrated clear impacts of grassland management on invertebrate body size distributions (e.g. Blake *et al*. 1994; Blake & Foster 1998). Counts of invertebrate groups known to be potential bird food (including beetles and their larvae, spiders, true bugs, flies and larval Symphyta or Lepidoptera; Wilson *et al.*, 1999) were pooled within samples for use as covariates in analyses of bird usage. Further species-level identification was conducted on Auchenorrhyncha, Carabidae, Curculionoidea and Chrysomelids for July samples, excluding overflow paddocks (2010–2012).

2.3. Bird usage measurements

Standardised timed watches were used to quantify paddock usage by all bird species. Timed watches lasted 45 minutes and took place in the morning or late afternoon, when foraging activity was highest. The number of foraging visits to the paddock was counted, subdivided by the species and the foraging location (field centre or headland, within 10m of the field boundary). Each timed watch was followed by a flush count, in which the observer walked to within 25 m of all points in the paddock, to count foraging birds that were hidden from view. Timed watches were performed on all three treatments on each site visit. Bird usage was measured on each site 16 to 27 times per season (mean 20) between 19 April and 13 September (encompassing the chick provisioning period for breeding buntings and larks).

Sward structure was measured at each bunting foraging patch and at a paired, unused control location constrained to be the same distance into the field from the field boundary (the hedgerow, not the internal dividing fences). Grassland foraging sites of yellowhammers and cirl buntings were identified during timed watches and focal nest watches plus any opportunistic observations in or around the study fields. Focal watches were undertaken on yellowhammer and cirl bunting nests found within foraging range (200 m) of the trial fields. Bunting foraging sites on the trial paddocks were paired with unused control locations on the same paddock. Foraging sites on other nearby grasslands were compared with unused control locations on the CL paddock, to test whether buntings selected foraging patches with features not provided by that treatment. Sward structure at foraging/control sites was quantified using the same approach employed for sward measurements (see section 2.2.1), but with 10x10 drop disk arrays centred on the foraging/control locations.

2.4. Agronomy measurements

Annual live weight production from each trial paddock was estimated using the product of the number of grazing-days and the mean daily weight gain of core cattle. Three core animals were used to measure daily live weight gains and remained on their allotted paddock whenever it was grazed (i.e. non-core cattle were the first to be removed from a paddock when stocking rates had to be reduced). Cattle were weighed at two sites where scales were available and live weight was estimated visually by an expert (D Chapple, ADAS) on all sites (allowing a calibration exercise). Comparisons of measured and estimated animal weights collected during BD1454 showed that these visual estimates were accurate (r^2 = 91%, 95% and 95% for 2007-2009 respectively). Core cattle weights were measured/estimated on three occasions during each grazing season: at turnout in May, during mid-summer (mid August) and at the end of the grazing season (mid-late October).

Forage quality was measured using pluck samples collected from locations where animals were actively grazing. Six separate pluck samples were collected from each trial paddock and overflow field on two occasions per year (early June and mid August). Laboratory measurements on these samples included crude protein, modified acid detergent fibre (MADF), and sugars, plus derived measurements of digestibility (D-value) and metabolisable energy (ME).

The mean growth rates of core cattle were influenced by the amount of time they spent on the Overflow Fields, as sward conditions there differed from those on trial paddocks. For example, if forage quality were higher on the Overflow field than on the IL treatment paddock, we would expect the observed weight gain data to overestimate true rates of weight gain for cattle on the IL treatment. It was not possible to weigh core cattle every time they moved between their trial paddocks and Overflow Fields in order to partition live weight gains to specific paddocks. The time spent by each core animal on its Overflow Field and the sward conditions there (sward height and forage quality) were recorded to aid interpretation of mean growth rate measurements.

Soil nutrient status was measured once, towards the end of the study (April 2012). Five to ten surface soil cores (to a depth of 7.5 cm) were collected from each treatment paddock or Overflow Field and bulked prior to laboratory analysis. The following properties were measured on the bulked sample: pH and concentrations of available phosphorus, potassium, magnesium, soil moisture, nitrate N, ammonium N, total nitrogen and derived soil mineral nitrogen. The same measurements were collected on the paddocks in April 2009, during the preceding BD1454 study.

2.5. Analysis

2.5.1. Derivation of sward structure metrics

The primary aim of the sward structure metrics was to quantify the features in the fine-scale structural patchiness that were relevant to birds foraging for invertebrates. The metrics either describe accessibility for foraging alone (bare ground or short grass availability) or the size of the foraging habitat resource. The foraging habitat resource was described by the length of tall grass-short grass interfaces. We hypothesized that tall-short interfaces combined the tall patches harbouring the invertebrate prey with the short patches around them, which provided access to foraging birds. The following metrics were calculated for each sward height array:

(i) Transition density: the number of pairs of adjacent points in the array that straddle a tall grass-short grass transition (range 0-112). To qualify as a tall-short transition, sward heights at adjacent measurement points had to differ by more than a minimum gap size, one point had to be accessible to foraging buntings (sward height < accessibility threshold) and the other tall/inaccessible (sward height ≥ accessibility threshold).

(ii) Accessible point density: the number of array points that were judged accessible to foraging buntings by sward height < accessibility threshold (range 0-64).

(iii) Bare ground cover: the number of array points where bare ground was present under the drop disc (range 0-64).

The accessibility thresholds and minimum gap sizes required by foraging birds were not known in advance. Likely ranges of values were estimated to test whether bird and invertebrate responses were dependent on these values. Two values of accessibility threshold were selected (6 cm and 8 cm) and two values of minimum gap size (3 cm and 5 cm). More extreme values were discarded, as the resulting transitions density scores were not sensitive to variation between sward height arrays (high proportions of observed arrays being assigned either zero or maximum scores).

Sward structure metrics are abbreviated with the following shorthand: A6 = accessible points density for a 6 cm accessibility threshold; T8G5 = transitions density for a 8 cm accessibility threshold and a 5 cm minimum sward height gap.

2.5.2. Statistical methods

Treatment responses (sward condition, invertebrate, bird usage and agronomy data) were modelled using GLMs or GLMMs. Treatment response models generally included year (as a categorical effect) along with year*treatment interactions, though the experimental design could not distinguish the longitudinal effects of treatments from year-specific effects that were independent of treatment (such as weather). Sampling period (June or July sward samples) was also used as an explanatory variable, with bird usage and grazing data divided into comparable periods (early = up to 19 June; late = 20 June onwards). Sward and invertebrate data were modelled at the sampling point scale in normal errors GLMMs, with distance from the edge of the field as a random effect, nested within paddock and site (Eschen *et al.* 2012). Percentage cover data of the six injurious weed species were first centred around the means and ranked prior to analysis, to normalise the strongly non-Gaussian distribution. Bird usage and agronomy data were modelled at the paddock scale in GLMs with site as a fixed effect. Bird usage data (counts of foraging visits) were modelled with negative binomial errors, to account for non-independence in foraging behaviour (clustering of visits due to flocking or learning). Where necessary, data from paddocks where treatments were not adequately implemented were censored from analyses of treatment effects. Bird usage treatment models only used data from sites where the species concerned was recorded foraging on at least one trial paddock. Additional paddock-level covariates tested in bird usage models included presence of cattle and an enclosure index (a mean boundary height score; Buckingham at al. 2006).

Treatment effects on vegetation and invertebrate community composition were analysed using Principal Response Curves (van den Brink & Ter Braak 1999). Data were $\log_{10}$-transformed where required to meet the assumption of a Gaussian data distribution.

Separate models were fitted to test relationships between sward, invertebrate and bird usage data. Invertebrate data were modelled at the sampling point scale in GLMMs, with sward condition measurements as explanatory variables. Bird usage data were modelled at the paddock scale in GLMs, with sward condition and invertebrate density data as explanatory variables. Bird usage data within each period were modelled as probabilities of occurrence (number of timed watches when foraging took place / number of timed watches) in binomial trials GLMs.

Fine-scale foraging patch selection by birds was modelled as the probability of a patch being selected (1 = foraging site; 0 = control) in log-linear GLMs. The fixed effects comprised a categorical variable to identify each foraging patch-control location pair, plus the explanatory covariates. Only sward structure measurements were available as covariates at this scale.

All statistical analyses were carried out in R (3.11.0; R Development Core Team 2011) with the additional package 'vegan' (Oksanen 2013) and SAS (9.2; SAS Institute Inc. 2008).

2.5.3. Long-term trends on Control paddocks

The management of Control paddocks and the measurements taken on them were the same throughout the seven years of the BD1454 and BD5206-07 studies. This allowed underlying trends to be estimated and related to locally-sourced weather data from both the Hadley centre (HadUKP; Alexander & Jones, 2001) and Met Office Integrated Data Archive System (MIDAS). Invertebrate and vegetation data collected in the July sampling rounds and agricultural yield data were examined in this way. GLMs were fitted to invertebrate and sward data to model the effects of weather, including time-lagged effects of weather in preceding seasons (see Appendix 4 for descriptions of the weather variables).

3. Results

3.1. Treatment delivery

The quality of treatment delivery (maintenance of target sward heights, grazing continuity and treatment separation) was generally good in the second half of the grazing season (20 June onwards), but was poorer in the early season (Appendix 1 Table A1.1.1). Only one paddock (in one year) had to be excluded from treatment response analyses, due to inadequate treatment delivery. The treatments were easiest to implement when there was sufficient grass growth to feed the cattle on the paddocks. Consequently, treatment delivery was best in 2012, when plentiful rain supported strong grass growth. In 2010 and 2011, periods of drought limited grass growth resulting in cattle having to be removed from all trial paddocks when forage ran out. The resulting grazing interruptions weakened the distinction between the CL and IL treatments. Examples of ideal treatment implementation and poor delivery during a drought year are presented in Appendix 1 (Figs. A1.1 & A1.2).

The IL and CL treatments supported similar numbers of grazing-days in all years. On average, IL paddocks supported 11% more grazing-days than the CL paddocks on the same fields (range: 13% fewer grazing days to 36% more). It was rarely possible to graze paddocks continuously so the IL and CL treatments differed principally in the length of time when cattle were excluded from the paddocks. In the late season, IL and CL treatments were clearly differentiated and IL paddocks were grazed for around half of the time when grazing was possible on CL paddocks (Table A1.1.2). In the early season (particularly in 2010), separation of the IL and CL treatments was less distinct. On IL paddocks, rest periods were generally longer than the intervening grazing periods (1.1 to 2.6 times longer; mean 1.8).

3.2. Sward structure, botanical composition and injurious weeds

Sward heights were significantly higher on both leniently-grazed treatments compared to Control paddocks in 2010 and 2011, but not in 2012 when sward heights and transition densities on Control paddocks increased ($F_{2,14} = 9.883$, $P = 0.002$; Fig. 3.2.1). A separate calibration exercise confirmed that these drop disk measurements conformed to the treatment specifications, which were based on HFRO sward stick measurements (Appendix 1 A1.1 to A1.3). Transition densities showed the same patterns as sward height but accessible point densities were significantly lower on the leniently-grazed treatments in the first two years, but not in 2012 (all $P < 0.05$; Fig.3.2.1; Appendix 2 Fig. A2.3 & Table A2.1). A strong negative correlation between mean sward height and accessible point density was found (Spearman Rank Correlation: $S = 7841184$, $P < 0.001$, $r = -0.97$), resulting from the use of sward height to define accessible points. Sward heights, accessible point and transition densities did not differ between IL and CL paddocks.

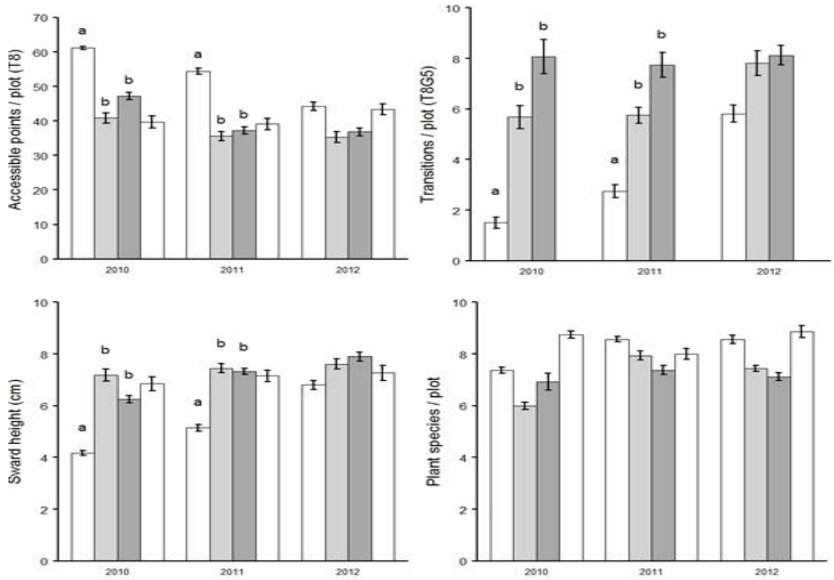


Figure 3.2.1. Treatment effects on accessible point density, sward height (as measured using a drop disc) and the number of higher plant species per paddock in July 2010-2012. White, light grey and dark grey bars indicate means (± 1 SE) for Control (and Overflow, to right), IL and CL treatments. Overflow fields are only included for reference and were omitted from the analyses. Letters indicate significant (P < 0.05) within-year differences between treatments in post hoc tests.

The treatments had no impact on plant species number (Fig.3.2.1Figure 3.2.). Figure 3.2.2 shows that the CL treatment had the largest impact on vegetation composition with grasses being dominant and suppressing forbs e.g. clovers (*Trifolium* spp.). Of the functional plant groups, only the agricultural clovers responded significantly to the treatments ($F_{2,14}$=4.695, P=0.028; Appendix 2 Table A2.2 & Fig. A2.5); of these, *Trifolium repens* was the most abundant. The cover of agricultural clovers in both leniently grazed treatments was less than half that in Control paddocks (pairwise t-tests: P < 0.001). The treatment effects were stronger in July than in June (significant treatment * month interaction). Amongst the grasses, the cover of *Holcus lanatus* was increased and *Lolium perenne* was suppressed by lenient grazing (Fig.3.2.3). Only *Lolium perenne* showed a significant treatment*year interaction, though this appeared to describe higher losses on Control plots in 2012, rather than deterioration caused by the leniently-grazed treatments.

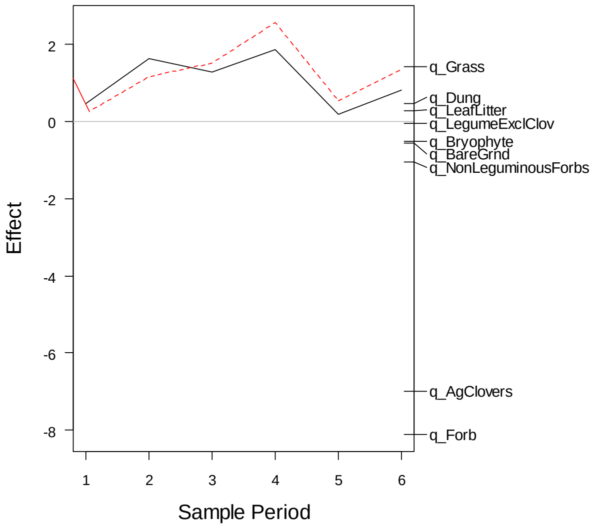


Figure 3.2.2. Principal response curves showing the vegetation composition in the CL and IL paddocks (solid black and red dashed lines respectively) relative to the Control paddocks which is represented as a grey line through Y=0

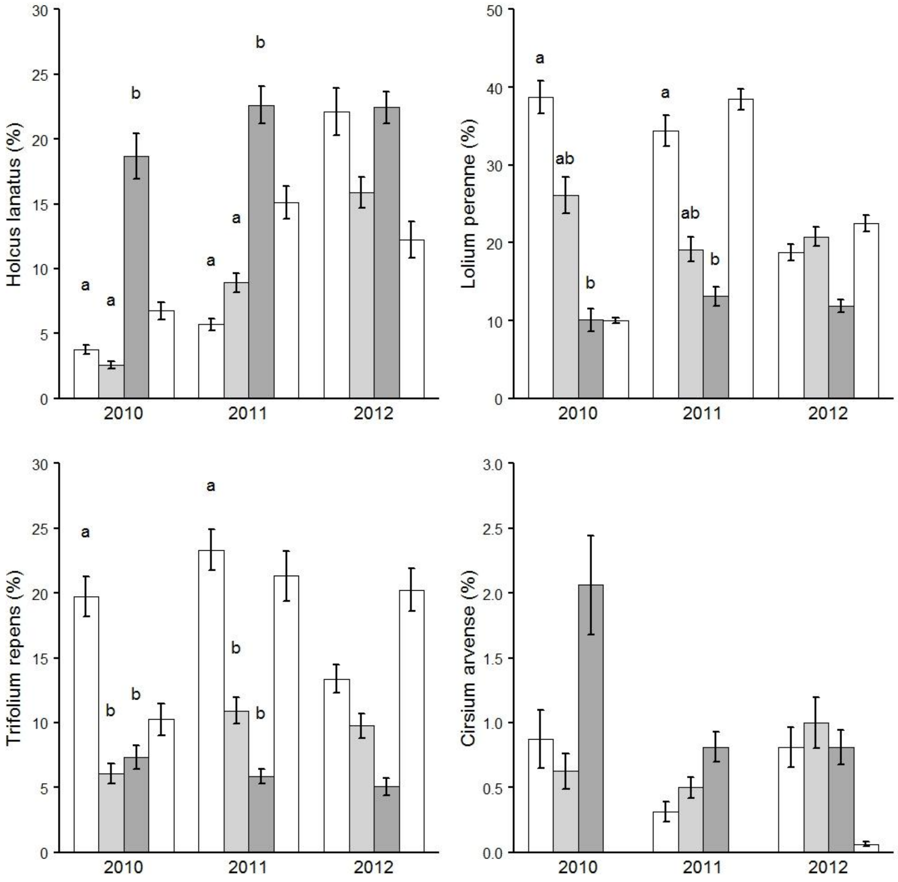


Figure 3.2.3. July treatment effects on the abundance of key plant species that were responsive to the treatments in BD1454. White, light grey and dark grey bars indicate means (± 1 SE) for Control (and overflow to the right), IL and CL treatments. Overflow fields are included for reference and were omitted from the analyses. Letters indicate significant ($P < 0.05$) within-year differences between treatments in post hoc tests.

Significant treatment*year interactions were found for three weed species: *Cirsium arvense*, *C. vulgare* and *Urtica dioica* (Appendix 2 Fig. A2.6 & Table A2.3). These results have to be interpreted cautiously due to the highly non-normal data, but indicated that in some years the average percentage cover of these species was higher in the CL paddocks, but the pattern was different across species and the mean percentage cover did not exceed 2.5%. Higher cover was recorded for the most abundant weed *Cirsium arvense* in 2010 (Fig. 3.2.3). We suggest that this was the result of the excessive disturbance due to intensive sheep grazing during 2009-10 winter, and cover of *C. arvense* was much lower in 2011 and 2012.

3.3. Invertebrate abundance and community composition

3.3.1. Treatment and sward effects on invertebrate abundance

The mean number of birdfood invertebrates was higher on leniently-grazed paddocks than on Control paddocks (Fig. 3.3.1.1, pairwise t-tests: $P < 0.05$; Appendix 2 Table A2.4 & Fig. A2.7). However, there was a lot of variation in the differences between treatments, and between sampling periods. These patterns were similar for small and medium-sized birdfood invertebrates, but no treatment effect was evident for the largest birdfood invertebrates. The number of birdfood invertebrates in the summer samples declined during the study with the overall abundance lower in 2012 than in previous years; possibly due to weather (see section 3.5 & Appendix 4).

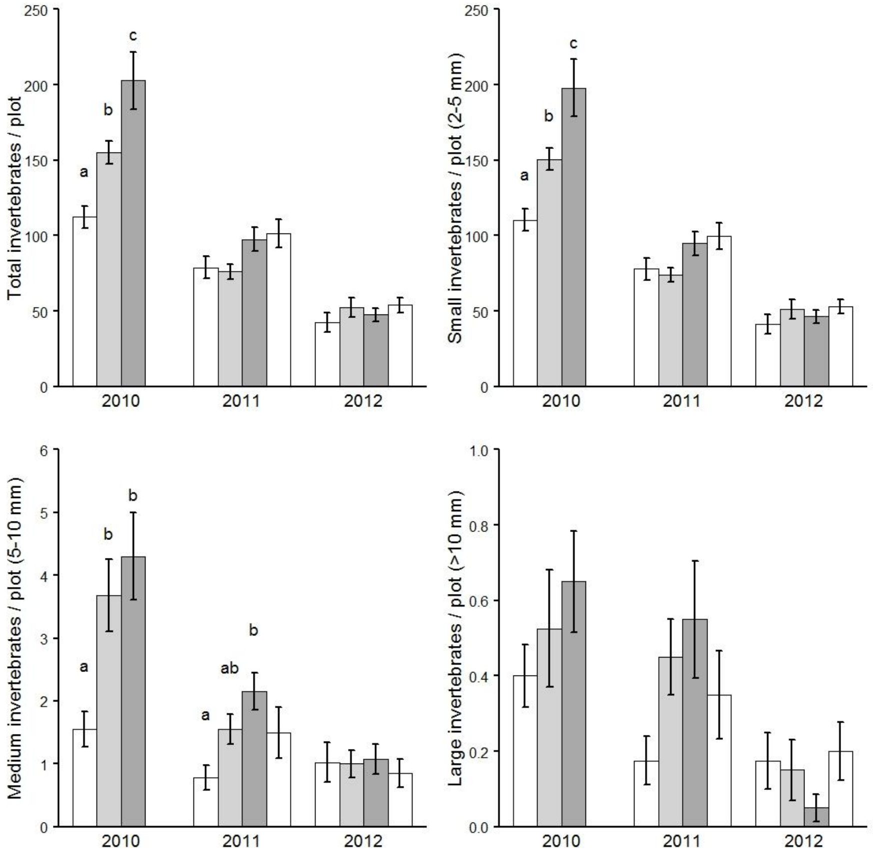


Figure 3.3.1.1. Treatment effects on the abundance of birdfood invertebrates in July 2010-2012: means (± 1 SE) of total birdfood invertebrates, small (2-5mm), medium (5-10mm) and large (>10mm) birdfood invertebrates. White, light grey and dark grey bars indicate means for Control, IL and CL treatments. Letters indicate significant ($P < 0.05$) within-year differences between treatments in post hoc tests.

The different invertebrate orders within the birdfood group exhibited different phenology, in terms of abundance in each month: e.g. Auchenorrhyncha being most abundant in June, and Diptera and Coleoptera in July (Fig. 3.3.1.2). The differing phenology within these invertebrate groups depended on the size class: for example medium-sized Coleoptera were most abundant in June versus July, and vice versa for small Coleoptera (Appendix 2 Figs A2.8 & A2.9 respectively; Table A2.5). Generally, there was a decline in the abundance of all the taxa throughout the experiment, except for Diptera. Significant treatment effects on Diptera abundance were most evident in June and for the medium size class where abundance was significantly higher in the CL during all three years of the study.(Appendix 2 Fig. A2.8).

Small (2-5mm) Auchenorrhyncha were significantly more abundant on leniently-grazed treatments in 2010 although there was no such difference in 2011 and 2012 (Fig. 3.3.1.2; Appendix 2 Figs. A2.8 & A2.9; Table A2.5). The larger Auchenorrhyncha (5-10 mm) were much less abundant and showed no consistent treatment effects (Appendix 2). Abundance of small Coleoptera was significantly higher in both leniently-grazed treatments in July 2010, and in just the CL treatment in July 2011 (Fig. 3.3.1.2; Appendix 2 Fig. A2.9 & Table A2.5).

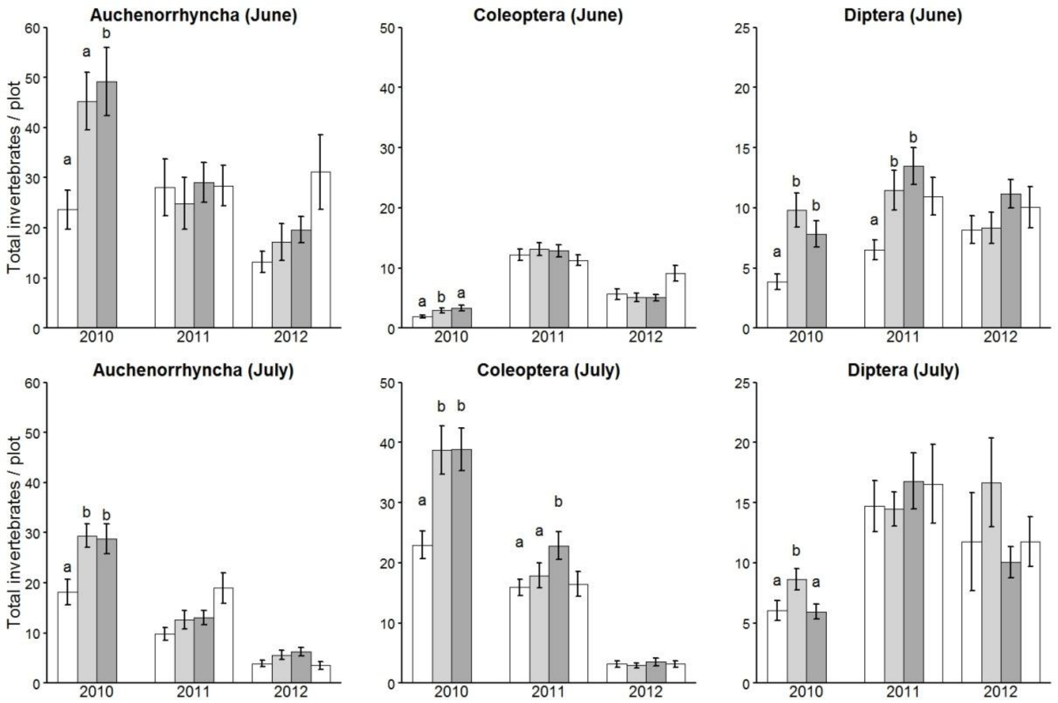


Figure 3.3.1.2. Treatment effects on the abundance of invertebrates (size 2-5 mm) over the period 2010 – 2012. Shown are a subset of the numerically dominant invertebrate groups, top = June and bottom = July. Control = white bars, light grey = IL, dark grey = CL. Bars indicate means (abundance / $0.19m^2$ ± 1 SE). Letters indicate significant ($P < 0.05$) within-year differences between treatments in post hoc tests. For further details of invertebrates divided into size classes within these Orders see Appendix 2 Figs A2.9, A2.9 & A2.14 and Table A2.5.

As in BD1454 (Eschen *et al*. 2012), sward height was a strong explanatory variable for the abundance of birdfood. However, the slope of the positive relationship was different (flatter) in the CL paddocks (sward height * treatment interaction: $F_{3,862} = 2.89$, $P < 0.05$; Fig. 3.3.1.3). A positive relationship was found between the number of small birdfood invertebrates and transition densities (T8G5) in July ($F_{1,18} = 26.71$, $P < 0.001$; Fig. 3.3.1.3). The relationship was significant and similar in 2010 and 2012, but not in 2011 (treatment * year interaction: $F_{2,18} = 4.68$, $P = 0.023$).

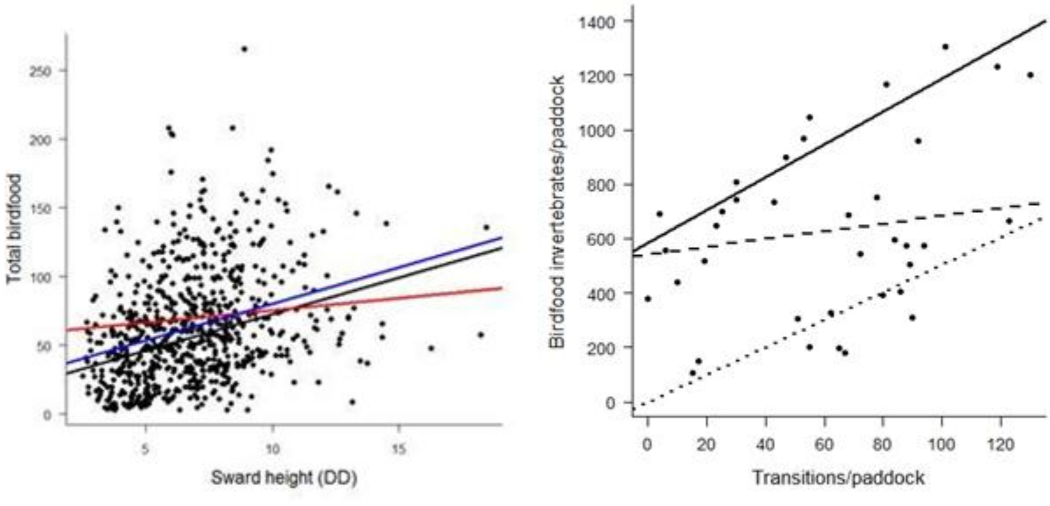


Figure 3.3.1.3. Relationship between sward height (as measured using drop discs) and total birdfood invertebrate abundance per sampling location (left). The black and blue lines indicate the relationship for Control and IL paddocks and the red line indicates the relationship for CL paddocks. The relationship between the number of transitions T8G5 and total birdfood invertebrates (per paddock, right). Solid, dashed and dotted lines indicate the relationships for 2010, 2011 and 2012, respectively. The relationship for 2011 was not significant ($P = 0.370$).

3.3.2. Treatment effects on invertebrate community composition

A total of 6,254 invertebrates from samples taken in July 2010-2012 were identified to species level. The large majority were adult Auchenorrhyncha and Chrysomelid beetles. There were significant treatment effects on the community composition of Auchenorrhyncha (Fig. 3.3.2.1; $P < 0.01$). The differences in Auchenorrhyncha community composition was mainly due to higher abundances of *Streptanus sordidus* (Zetterstedt 1828), *Javesella dubia* (Kirschbaum 1868), *Arthaldeus pascuellus* (Fallen 1826) and *Macrosteles viridigriseus* (Edwards 1924), and lower abundance of *Deltocephalus pulicaris* (Fallen 1806) and *Psammotettix confinis* (Dahlbom 1850) in leniently-grazed paddocks, compared to Control paddocks. There were also significant community responses by the Chrysomelidae and Curculionoidea (Appendix 3 Figs A3.2 & A3.3). Significantly higher numbers of forb- and grass-feeding Chrysomelids and Auchenorrhyncha were found in leniently-grazed paddocks compared to Control paddocks (Appendix 3 Table A3.1). These treatment differences were strongest in 2010 and were minimal or absent in 2012 (grass-feeding species only).

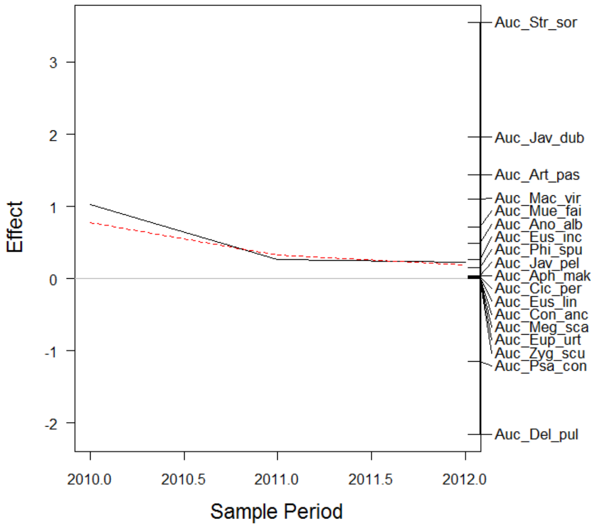


Figure 3.3.2.1. Principal response curves (PRC) showing Auchenorrhyncha community responses to the grazing treatments in July samples of the years 2010-2012. CL and IL paddocks are shown with solid black and red dashed lines respectively, and are relative to the Control paddocks which is represented as a grey line through Y=0. See Appendix 3 for full species names to abbreviations.

3.4. Long-term trends on Control paddocks

There was no significant relationship between sward height and the climate variables (rainfall, temperature and sunshine) as the sward was actively managed to achieve a target height (6-8 cm). Forb cover was found to be significantly negatively related to rainfall (P = 0.011; $F_{1,5}$ = 15.57; R^2 = 0.708). In particular, this was found for agricultural clovers (P = 0.018; $F_{1,5}$ = 12.06; R^2 = 0.648), non-leguminous forbs (P = 0.014; $F_{1,5}$ = 13.76; R^2 = 0.680) (Appendix 4 Fig. A4.2a) and *Ranunculus repens* (P = 0.032; $F_{1,5}$ = 8.72; R^2 = 0.563). Grass cover was not significantly related to the climate variables. However, the abundance of some individual species such as *Dactylis glomerata* was positively related to growing degree days (>10^{o}C; P = 0.027; $F_{1,5}$ = 15.57; R^2 = 0.591) (Appendix 4 Fig. A4.2b). Likewise, *Holcus lanatus* cover showed a significant positive relationship with spring and summer rainfall (P = 0.046; $F_{1,5}$ = 6.99; R^2 = 0.499). In addition, *H. lanatus* showed a significant negative relationship with sunshine-hours (P = 0.007; $F_{1,5}$ = 18.78; R^2 = 0.748). There were no significant climate relationships with other grass species, including *Lolium perenne*. However, there was a significant negative relationship between the percentage cover of *Lolium perenne* and *Holcus lanatus* (P = 0.025; $F_{1,5}$ = 10.08; R^2 = 0.602).

The overall abundance of invertebrates was not significantly related to any of the climate variables (Appendix 4; Table 2). The invertebrate groups considered included abundant groups such as Collembola that were excluded from the “birdfood” groups. Birdfood invertebrate numbers showed a significant negative relationship with spring and summer rainfall (P = 0.011; $F_{1,5}$ = 15.61; R^2 = 0.709; Fig. 3.4.1). Within the birdfood grouping, two numerically dominant groups showed significant negative relationships with rainfall: the Coleoptera (P = 0.01; $F_{1,5}$ = 16.36; R^2 = 0.719) and Auchenorrhyncha (P = 0.044; $F_{1,5}$ = 7.12; R^2 = 0.505) (Appendix 4 Fig. A4.3a & Table A4.2). Removing these two groups from birdfood resulted in a non-significant relationship between the remaining taxa and spring and summer rainfall (P = 0.254; $F_{1,5}$ = 1.66; R^2 = 0.099). Coleoptera and Auchenorrhyncha also responded positively to spring and summer sunshine (Appendix 4 Table A4.2).

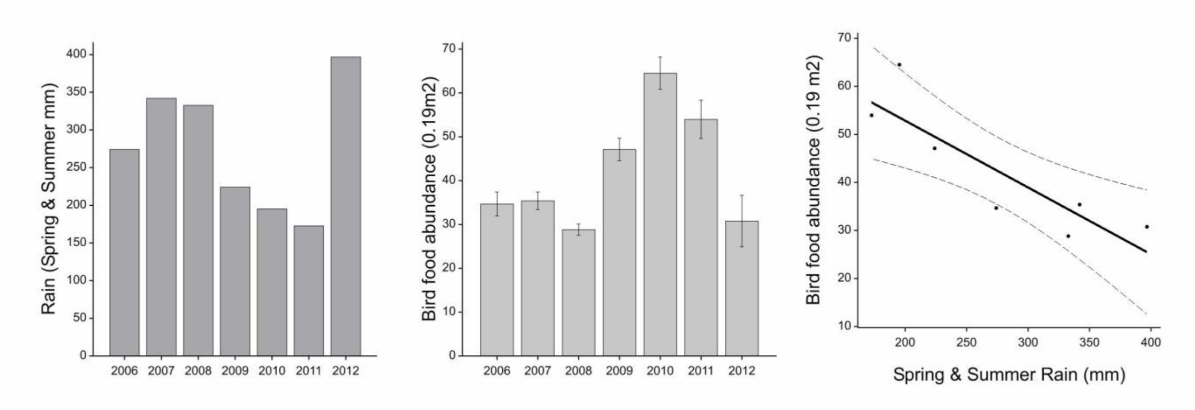


Figure 3.4.1. Left = spring and summer rainfall for the South West, middle = mean Birdfood (subset of invertebrates >2mm deemed potential bird food groups); right = regression paddocks of invertebrate groups and spring and summer rain (March–June, mm). Error bars = 1 SE and dashed lines = 95% confidence intervals.

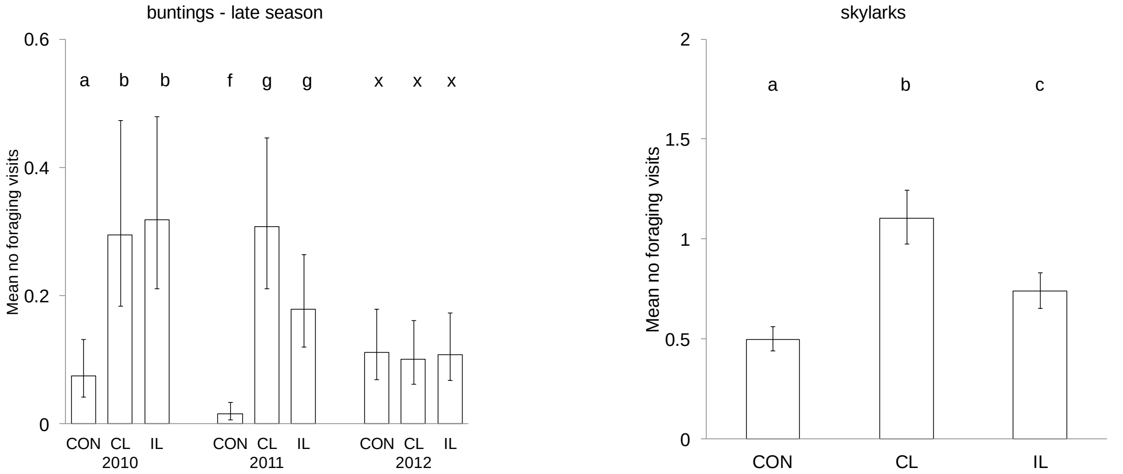
All available agronomy data were used to examine trends on the Controls as only one site provided agronomy data in all years. These data indicated that total live weight outputs were positively related to annual rainfall, but the relationship was not significant (Appendix 4 Fig. A4.4). Forage quality in areas where cattle grazed (pluck samples) remained constant throughout the study.

3.5. Bird usage

Results are presented for the three groups of conservation-dependent passerine species that were expected to benefit from improved densities of seeds and sward-dwelling invertebrates (Appendix 5 Table A5.3): the buntings (yellowhammer and cirl bunting), skylark and obligate seed eaters (linnet *Carduelis cannabina* L. and goldfinch *C. carduelis* L. which predominantly feed their chicks on seeds). Sample sizes for timed watches and foraging patch observations are summarised in Appendix 5.

3.5.1. Effects of experimental treatments on bird usage

In the first two years, buntings significantly preferred the two leniently-grazed treatments in the second half of the breeding season, but did not distinguish between the IL and CL treatments (Fig. 3.5.1.1). However, in 2012, buntings used all three treatments equally. There were no significant treatment preferences in the early season. Buntings also significantly preferred paddocks with high enclosure indices and this was controlled for in the model. The final model was further improved by adding a variable describing a significant positive association with the presence of cattle (foraging visits were 2.4 times more frequent when cattle present; P = 0.003). Data from the IL and CL paddocks were reanalysed without the Control paddocks, to test whether a small preference was being obscured by stronger avoidance of Control paddocks. This found no evidence for a preference between the IL and CL treatments.



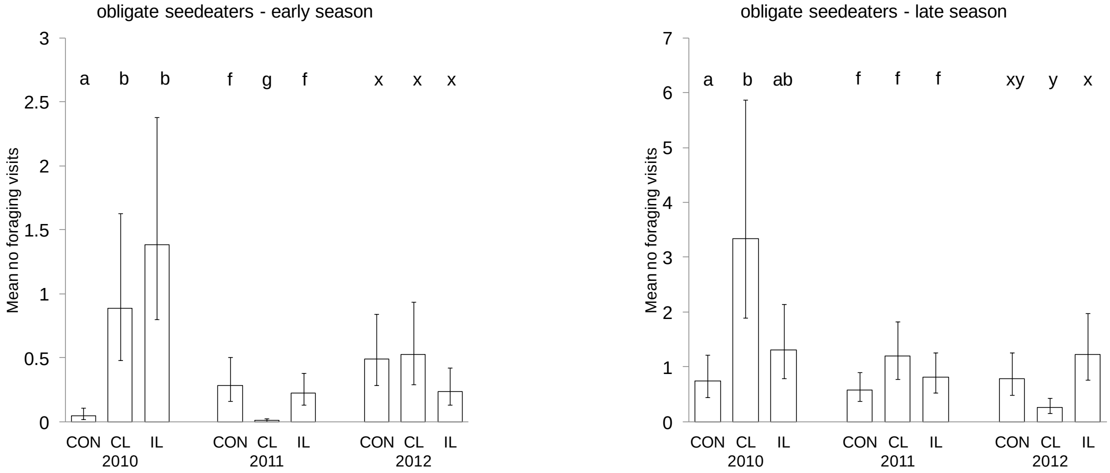
model: site + treatment*year*period + enclosure (AIC 1048.92)

model: site + treatment + year + period (AIC 2537.73)

Figure 3.5.1.1. Treatment preferences of foraging buntings and skylarks. Bunting preferences in the second half of the breeding season are presented (≥June 20; prior to this, buntings showed no preference). Fitted mean numbers of foraging visits per three-hour timed watch are plotted (± 1 SE); letters above each bar show which values differed significantly (P < 0.05).

Skylarks significantly preferred CL paddocks to IL paddocks and Controls (Fig. 3.5.1.1). The IL treatment was also preferred to Controls. Neither paddock enclosure nor presence significantly influenced skylark usage.

The obligate seedeaters (linnet and goldfinch) used the paddocks infrequently and, on rare occasions, visited in larger flocks, when favoured food plants were producing seed (primarily common sorrel *Rumex acetosa* and hawkbits *Leontodon/Scorzoneroides*). There was no consistent pattern in the results, beyond a significant preference for the two leniently-grazed treatments at the start of the experiment, followed by a weak preference for IL and Control paddocks over CL in subsequent years (Fig.3.5.1.2). The sparse, highly skewed foraging data biased the results. A single feeding flock on one visit caused the significant treatment preference observed in late 2010. If this flock were excluded, there was no treatment preference in this period. The other significant preference results were more plausible, as they reflected foraging patterns across more than one site or on multiple occasions and remained significant if the largest flocks were censored.



model: site + treatment*year*period (AIC 1781.49)

Figure 3.5.1.2. Treatment preferences of foraging obligate seedeaters in the early and late breeding season. Fitted mean numbers of foraging visits per three-hour timed watch are plotted. Expected means (± 1 SE) are plotted; letters above each bar show which values differ significantly ($P < 0.05$).

There was no evidence that the preceding BD1454 treatment affected bird usage (Appendix 5).

3.5.2. Paddock level effects of vegetation and prey density on bird usage

Sward structure was the only factor influencing paddock choice by foraging Buntings; there were no significant relationships with invertebrate prey density variables (Appendix 5 Table A5.4). The probability that a paddock was used by foraging buntings was positively related to structural heterogeneity (transition densities) and mean sward height, but negatively related to accessibility.

Foraging skylarks exhibited the same preferences for sward structure covariates as buntings, but heterogeneity (transition densities) was only influential in the late season and accessibility was more influential in 2011 and 2012 (Appendix 5 Table A5.5). The probability that a paddock was used by foraging skylarks was also positively related to the density of large-bodied invertebrate prey, primarily in the late breeding season and the first two years of the study (but not in 2012). This preference was largely due to selection of paddocks with higher densities of caterpillars, though there was also a weak positive association with grasshopper densities.

No relationships were found between sward condition variables (including cover scores of key food plant species) and paddock selection by the obligate seedeaters.

3.5.3. Selection of foraging patches

Yellowhammer foraging patches on the experimental paddocks were the most numerous and were analysed fully. There were too few cirl bunting or skylark foraging patches to demonstrate significant selection responses.

Univariate tests showed that yellowhammers preferred to forage in patches with greater accessibility (positive effects of bare ground cover and accessible point density; negative effect of average sward height) and greater structural heterogeneity (positive effects of transition densities and sward height CV) (Appendix 5 Table A5.8). The sward structure metrics were highly correlated, so a multivariate model was fitted by stepwise addition, adding the most influential (significant) terms at each step. The final model retained bare ground cover (positive effect) and sward height CV (a quadratic effect, but positive over the observed range of CV values). Thus, accessibility and structural heterogeneity were both required within yellowhammer foraging patches. Fitting year*covariate interactions to the univariate models showed that the measures of accessibility (bare ground, accessible point density and average sward height) had significantly stronger effects on foraging patch selection in 2010, compared to 2011 and 2012.

Yellowhammer foraging patches on nearby fields were less numerous and only one significant selection response was found. On this subset of foraging patches, accessible point density had a negative effect on patch selection; the opposite of the effect observed on the experimental paddocks.

3.6. Effects of grazing treatments on agronomic measures

Mean grazing day data for both the four sites common to each year and for all five sites are presented in Appendix 6 (Table A6.1 & Fig. A6.1). An analysis of the whole season grazing day data for the four sites (fields) that were common to all three years highlighted differences between years and sites ($P < 0.001$) but significant differences between treatments were not observed. Overall stock carrying capacity on the trial paddocks was influenced strongly by grass growing conditions. In 2010 difficult conditions in early and mid-season lead to cattle being removed from the Control and CL paddocks for significant periods of time (averaging approximately 40% of the grazing season). Conditions were slightly better in 2011 but poor grass growth meant that cattle were removed from the continuously grazed treatments for significant periods at some sites. In contrast grass growth in 2012 was better at all sites and occupancy of the continuously grazed treatment paddocks was high at around 90%.

Mean growth rates of core cattle are summarised in Appendix 6 (Table A6.2 & Fig. A6.2). Values shown are the means of raw data for individual animals recorded in each year. Cattle growth rates differed between sites ($P < 0.001$) but no significant differences between treatments or years were found. Mean cattle growth rates (across the four sites in the study for all three years) were in the range 0.70 – 0.83 kg/d across the trial period, although individual performance varied widely on some sites. Industry recommendations (EBLEX – Action For Profit) suggest target growth rates of 0.8 – 0.9 kg/day for continental cross steers and heifers on grass, achieved through a combination of good pasture management and supplementary feeding in late season if necessary.

Mean cattle live weight output, is shown below in Figure 3.6.1. An analysis of the four sites that were common to each year highlighted significant differences between sites and years. Significant differences were not observed between treatments, although output on the CL treatment was the lowest in each year.

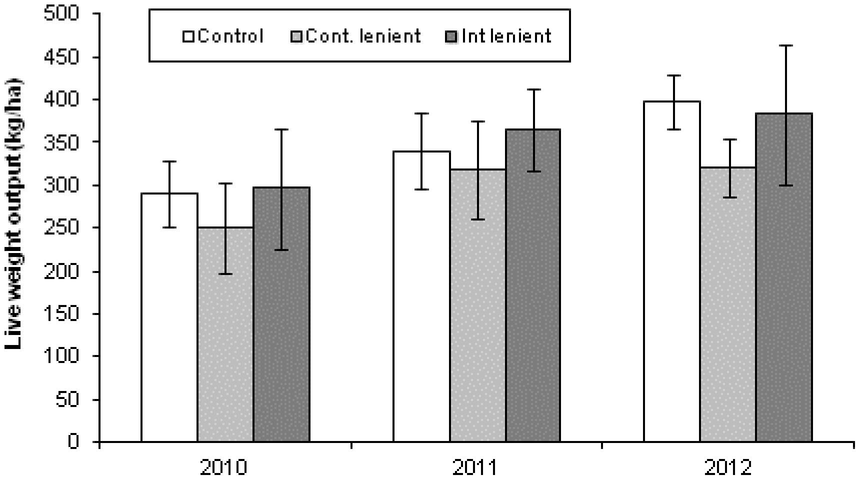


Figure 3.6.1. Annual mean livestock output (kg/ha) based on total number of grazing days and the growth rates of core animals at each site. Confidence intervals shown are ±1 SE.

Live weight outputs were valued using a representative price per unit weight (£1.80 kg^{-1}; May 2013) (Table 3.6.1). Figures relating to the four sites common to each year are shown below and for all five sites in Appendix 6 (Table A6.3). Relative to Control paddocks, the economic output of IL paddocks varied between £46 greater than Control paddocks (2011) to £26 less (2012). The economic output of the CL paddocks relative to the Controls ranged from £37 lower (2011) to £139 lower (2012). Animals using the IL paddocks spent more time on the Overflow fields, where the forage quality was typically higher and this may have boosted the overall live weight output associated with the IL treatment.

Table 3.6.1. Mean cattle live weight output (kg/ha (SE)) and economic output (£/ha) for the four sites studied in all three years.

Year	Control		Continuous Lenient		Intermittent Lenient	
	(kg/ha)	£/ha	(kg/ha)	£/ha	(kg/ha)	£/ha
2010	290 (39)	522	251 (52)	451	297 (70)	535
2011	340 (44)	611	319 (57)	574	365 (49)	657
2012	398 (32)	716	321 (34)	577	383 (82)	690

Forage quality

Analysis of the herbage pluck sample data identified significant interactions for the majority of the measures involving site, treatment, month and year, making interpretation difficult. The significance of each of the model terms can be found in Appendix 6 (Table A6.4).

Metabolisable energy (ME) levels in the Control swards were significantly higher than those in CL and IL swards, in both June and August of 2010 and 2011 and in June of 2012 (Fig. 3.6.2). ME of the CL and IL swards did not differ significantly at any time. The Overflow fields produced significantly higher quality grass, in terms of energy, than the leniently-grazed paddocks and were similar to Control paddocks. August 2012 was the one exception: with the energy levels on all treatment paddocks and Overflow fields being similar. Improved grass growing conditions in 2012 probably increased the quantity of young leafy herbage available on the CL and IL paddocks during August, compared with that in 2010 and 2011. Although the data shows significant treatment effects, the mean differences were less than 0.15 MJ (approximately equivalent to 1 D value unit) and are likely to be of limited agronomic significance.

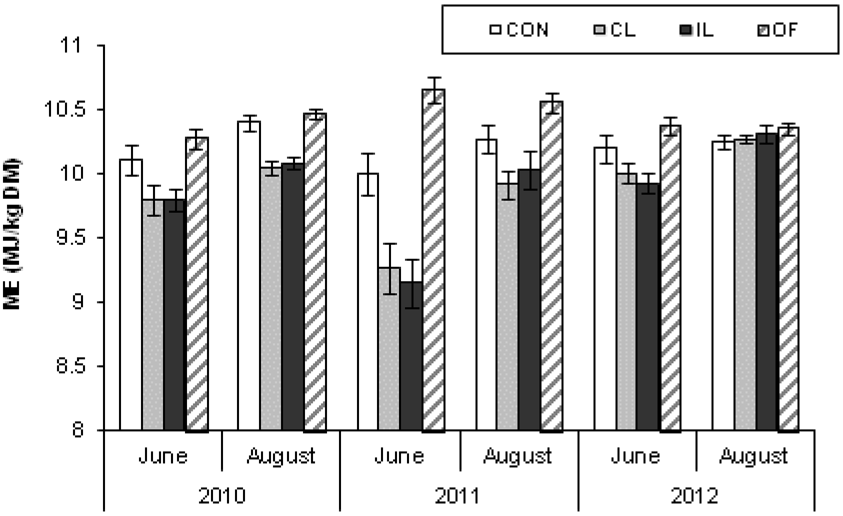


Figure 3.6.2. Mean ME (+/- SE) from pluck samples for different months, year and treatments for the four sites where fields were common across all three years.

Overall, crude protein levels in pluck samples did not differ between treatments, but were significantly higher on Overflow fields (18.2 %, compared to the trial field mean of 17.3 %). Significant differences were evident between sites, years and month. Protein levels are linked to grass growth stage so it is perhaps not surprising that treatment differences were not evident as sampling aims to select the younger leafier grass that cattle selectively graze. Sugar levels also did not differ between treatments or month, although significant differences were seen for site and year.

3.7. Carry-over effects from BD1454 treatments

The preceding BD1454 treatments were significantly associated with some response measurements, notably the cover of certain plant species and bird usage (Appendices 2 & 5). These associations do not appear to have affected the observed responses to the new BD5206-07 treatment. In most cases, the restorative management (winter 2009-10) removed preceding treatment effects or the new BD5206-07 treatments took effect immediately in 2010. The BD1454 treatments initially affected botanical composition (e.g. cover of *Lolium perenne*) but these effects faded over time. The effects of the new and old treatments on bird usage were confounded: with the main differences being between the Controls and the leniently-grazed BD5206-07 treatments, which were on the same paddocks as the two (preferred) BD1454 early-closure treatments. Also, the effects of BD1454 treatments on bird usage increased over time, indicating responses to new, unrelated influences (notably weather) rather than carry-over effects, which should weaken over time.

4. Discussion

4.1. Costs and benefits of lenient grazing

In the preceding BD1454 study, the grazing extensification treatment that provided the greatest biodiversity benefits had a number of shortcomings, which presented obstacles to its use as an agri-environment measure. The BD1454 Lenient treatment combined very low grazing intensity (12-14 cm target sward heights) with early closure (exclusion of cattle from mid July). This measure unexpectedly reduced structural heterogeneity in the sward (limiting its utility to a key target group of birds, the buntings) and led to high agricultural losses that increased over time. The current study tested the BD1454 prediction that a lower (intermediate) target sward height and season-long grazing could correct these problems without compromising biodiversity benefits that depended on taller swards (increased invertebrate densities and high usage by foraging skylarks). The second (new) prediction was that grazing leniently, but intermittently rather than continuously, would further enhance structural heterogeneity and result in greater biodiversity benefits.

Whole-season lenient grazing successfully addressed the short-term problems associated with the BD1454 Lenient treatment. Whole-season lenient grazing enhanced structural heterogeneity, densities of prey invertebrates and the frequency of foraging visits by both buntings and skylarks, relative to conventionally-grazed control paddocks. These differences appeared immediately, in the first year of the study and persisted into the second year. During this period there was no yield penalty associated with the whole-season lenient grazing measures. Furthermore, individual daily growth rates of cattle were respectable and close to levels typically achieved on more intensively managed pastures.

In the third year, all biodiversity-related differences between the leniently-grazed and control paddocks disappeared, though structural heterogeneity remained high on the leniently-grazed paddocks and showed no signs of the medium-term decline seen in BD1454. Agricultural yields on leniently-grazed paddocks fell in the third year, though losses were much lower than the equivalent third-year losses on BD1454 Lenient treatment plots (£ 139 ha^{-1} on the Continuous Lenient treatment, compared to £ 607 ha^{-1}, based on 2013 prices). Vegetation composition had started to change in the same way as deteriorating swards in BD1454 (*Holcus lanatus* increasing; clover and *Lolium perenne* decreasing, Appendix 2 Fig.A2.15), but cover of weeds and litter remained low and stable. The disappearance of benefits in the third year appeared to be caused by extreme weather (exceptionally high rainfall), rather than by cumulative impacts of the treatments (the evidence for this interpretation is discussed in the following sections). It is possible that the biodiversity benefits observed in the first two years would persist for longer in the absence of extreme weather conditions, as structural heterogeneity remained favourable to invertebrates and foraging birds, while sward deterioration was relatively slow, compared to the BD1454 treatments. Given the uncertainty regarding medium-term development of leniently grazed grasslands in this study and BD1454, it would be prudent to allow for some form of corrective management after the second year, should this be required. The option to continue lenient grazing if biodiversity benefits persist (or accumulate, e.g. Auchenorrhyncha densities in BD1454, Eschen *et al*. 2012) should be retained.

Contrary to expectations, the Intermittent Lenient treatment did not result in greater fine-scale structural heterogeneity and provided similar biodiversity benefits to the Continuous Lenient treatment. Foraging skylarks were the only target group to distinguish between the two treatments; preferring continuous grazing. In practice, all paddocks were grazed intermittently, but a relative distinction between intermittent and continuous grazing was maintained, when there was sufficient grass growth to support grazing cattle. The practical consequence of this result is that whole-season lenient grazing allows some flexibility within grazing regimes and works equally well with continuous and intermittent (rotational) stocking.

4.2. Influence of weather and carry-over effects on the results

The pervasive effect of weather on grassland plant and invertebrate communities was clearly illustrated by the seven-year time series of data collected on Control paddocks, which were managed consistently throughout BD1454 and the current study. Rainfall had particularly strong, largely negative effects across many taxonomic groups. Sensitivity to high rainfall helped account for the divergent results of the study in 2012, which was the second wettest in the last 100 years (UK Meteorological Office, 2012).

High spring rainfall had a consistent negative effect on the cover of the main forb species present in Control paddock swards. In addition to superfluous soil moisture, high spring rainfall was associated with more prolonged cloud cover and lower temperatures, which together reduce plant growth of some species (Pitt & Heady 1978). Forbs that are tolerant of waterlogging, such as *Ranunculus repens* (Gibson 1996; Bond *et al.* 2007a) may have been negatively affected by the low temperatures associated with high spring rainfall. In contrast, the grass *Holcus lanatus* benefitted from high spring and summer rainfall as it is adapted to water-logged soils (Bond *et al*. 2007c; Watt & Haggar 1980) and also starts to grow early in the season at low temperatures (Grime *et. al*., 1988). Competition from *Holcus lanatus* may account for the negative impact of cold, wet springs on the cover of *Lolium perenne* (which was negatively correlated with *Holcus* cover) and *Trifolium repens*, both of which also begin growing in spring. *Trifolium repens* tolerates heavy grazing (Grime *et. al*. 1988), but can be outcompeted in swards dominated by grass species including *Holcus lanatus* and *Agrostis capillaris* (Bond *et al*. 2007b).

Sensitivity to weather varies considerably across invertebrate taxa and may include indirect effects on host plants as well as direct impacts. Thus the effect of weather is specific to the invertebrate community being studied. In this study, the main observed pattern was a negative effect of rainfall on the subset of invertebrates that are preyed upon by birds (the opposite of the effect on invertebrate communities in pea crops, Frampton *et al*. 2000). Collectively, this group declined steeply in abundance during the three years of the current study, having increased in more favourable weather conditions during BD1454. This community effect was driven by the Coleoptera and Auchenorrhyncha and may reflect the sensitivity of immature stages to adverse weather. Within the Coleoptera, the larval stages of weevils are known to be sensitive to soil water logging (Murray & Clement 1995). The clover-feeding genus *Sitona* is particularly sensitive to waterlogged soils, in addition to being affected by the loss of its foodplant in wet weather. The early nymphal stages of Auchenorrhyncha can be drowned by excessive rainfall, which also inhibits the flight of macropterous forms (May 1978).

The longer run of data from the Control plots showed that weather had a strong influence on plant and invertebrate communities during the three years of this study. The two drought years (2010 and 2011) followed by the exceptionally wet 2012 season acted to change sward composition in ways consistent with grazing extensification (BD1454 results; Eschen et al. 2012) and generally reduced densities of bird prey invertebrates. The strong, year-specific weather effects are likely to have confounded or obscured medium-term, cumulative effects of treatments, requiring careful interpretation of the results.

Measures taken to reduce the influence of carry-over effects from the preceding BD1454 treatments appear to have succeeded, as in most cases (see following sections), strong effects of the new BD5206-07 treatments appeared immediately, in the first year. In some cases, the BD1454 early closure treatments (Lenient and Moderate) and the BD5206-07 lenient grazing explained similar amounts of variation in the data but this probably reflects the strong and largely confounded effects of early closure (BD1454) and lenient grazing (BD5206-07) treatments in the study design (i.e. lenient grazing treatments always followed early closure treatments and the differences between the two lenient treatments, and between the two early closure treatments, were relatively small). In the few cases where these pairs of treatments did differ, randomisation of treatment allocation should have controlled for the possibility of carry-over effects. Carry-over effects were most apparent in the vegetation composition results, but these diminished over time as the influence of the new treatments came to predominate.

4.3. Effects of lenient grazing on sward structure and composition

Fine-scale structural heterogeneity on leniently grazed paddocks changed immediately in the first year, then remained stable throughout the three years of the study. Transition densities (tall grass-short grass interfaces) increased but accessible point densities (short grass providing foraging birds with access) decreased, relative to Control paddocks. In contrast, heterogeneity fell over time on BD1454 Lenient treatment plots. A different metric was used to quantify heterogeneity in BD1454 (a combination of sward height CV and accessible point densities) but this was comparable to transition densities as it described the admixture of tall and short grass patches. Whole-season lenient grazing avoided the medium-term decline in structural heterogeneity observed in BD1454 by preventing the accumulation of rejected vegetation and litter. Heterogeneity on Control paddocks differed significantly from the leniently-grazed paddocks in 2010 and 2011, but there were no differences in 2012. In 2012 transition densities increased and accessible point densities fell on Control paddocks, while levels on the leniently-grazed paddocks remained unchanged. The structural changes in Control paddock swards in 2012 were caused by rapid grass growth, resulting in taller sward heights and a reduced differential between treatments.

Whole-season lenient grazing increased the cover of *Holcus lanatus* while suppressing *Trifolium repens* and *Lolium perenne*. These changes were new effects of the lenient grazing treatments separate from the general weather-related trends (Section 4.2) and carry-over effects of the preceding BD1454 treatments. The preceding BD1454 Lenient and Moderate treatments both caused similar changes to sward composition, leaving a legacy of low *Trifolium/Lolium* cover and high *Holcus* cover. Consequently, the BD1454 carry-over effects were confounded with the effects of the new lenient-grazing treatments, but the carry-over effects weakened over time as the effects of the new treatments accumulated. The switch from *Lolium/Trifolium* to *Holcus* (along with *Agrostis stolonifera, Dactylis glomerata* and *Ranunculus repens*) in response to extensive grazing occurred in both BD1454 and this study and was associated with reduced agricultural yields (sward deterioration) in both studies. However, sward deterioration was less marked under whole-season lenient grazing, as there was no increase in weed cover or accumulation of litter; both of which increased under the BD1454 extensification treatments.

The sward composition on Intermittent Lenient paddocks was more similar to Controls than the Continuous Lenient paddocks, suggesting that grazing intermittently at higher stocking rates retained more forbs (particularly *Trifolium repens*), compared to the Continuous Lenient treatment. The Intermittent Lenient treatment also apparently reduced a *Cirsium arvense* infestation that followed intensive winter sheep grazing at the start of the study. However, the statistical results for weeds need to be interpreted cautiously, because of the sparse and highly aggregated distribution of weed patches.

4.4. Effects of lenient grazing on invertebrate communities

The leniently-grazed treatments initially increased densities of the subset of invertebrate taxa that are preyed upon by birds, but differences between treatments disappeared over time. Continuous Lenient grazing increased bird prey invertebrate densities by 70% in the first year (compared to a 50% increase on the Lenient treatment in the first year of BD1454). Lenient grazing had no effect on the combined density of all invertebrate groups, as individual groups responded to the treatments in different ways, masking the bird prey invertebrate response. A general decline in invertebrate densities affected all the treatments and appeared to be caused by weather patterns (see section 4.2) rather than by cumulative effects of the treatments. Densities had fallen so low by 2012 that treatment differences could no longer be detected.

Densities of bird prey invertebrates were generally higher where swards were taller and fine-scale structural heterogeneity (transition densities) was greater, both in this study and BD1454 (Eschen *et al*. 2012). The initial grazing-related increases in bird prey taxa were largely due to fluctuations in the numbers of small and medium-sized individuals and in Coleoptera and Auchenorrhyncha. Larger invertebrates remained too scarce for treatment responses to be detected. Species-level information for these groups helped identify the probable mechanisms underlying the treatment impacts. The strongest Auchenorrhyncha responses to the grazing treatments can be explained by a combination of sward structure and food plant preferences. *Streptanus sordidus* exhibits several traits that explain its association with the leniently grazed treatments: they prefer taller grass stands, with relatively humid microclimates and are also strongly associated with *Agrostis* spp. In contrast, *Psammotettix confinis* and *Deltocephalus pulicaris* are typical species of intensively managed, improved and often eutrophic grasslands (Nickel, 2003). They prefer short swards compared to the majority of grassland inhabiting Auchenorrhyncha, which tend to build up higher densities in taller swards (Waloff & Solomon 1973; Maczey 2005). However, both short-grass species often develop on *Agrostis* spp. or, in the case of *P. confinis*, on *Holcus* spp. (Waloff & Solomon 1973; Prestidge & McNeill 1983, Nickel 2003). The Chrysomelid beetle community responses were mainly driven by the foodplant preferences of the abundant flea-beetle *Longitarsus luridus*. This species feeds on a range of forb species, including *Ranunculus repens*, *Cirsium* spp. and *Urtica dioica*, all of which were more abundant in the leniently-gazed paddocks.

4.5. Effects of lenient grazing on bird usage

Reducing the target sward height to improve heterogeneity (for foraging buntings) risked reducing invertebrate prey densities to levels that would be unattractive to foraging birds and particularly to skylarks which also preferred taller swards. The results showed that this trade-off was judged correctly: buntings and skylarks preferred the new leniently-grazed treatments and the frequency of foraging visits by both was high, compared to levels in BD1454. As in BD1454, buntings only preferred leniently grazed paddocks in the second half of the breeding season, but had no preference in the early part of the season. Buntings feed on different prey taxa at these times (e.g. Evans *et al*. 1997) and probably require different foraging habitats. The early closure treatment tested in BD1454 aimed to provide early season bunting foraging habitat but did not succeed. Unmanaged grass field margins (albeit on arable fields) are the only conservation measures with proven efficacy at this time of year (Douglas *et al*. 2009).

In this study, structural heterogeneity was quantified in ways believed to be directly relevant to how birds foraged in heterogeneous swards: distinguishing the amount of foraging resource (transition densities) from general accessibility (accessible point densities). These structural features were readily manipulated by grazing to target sward heights and transition densities were also positively associated with densities of invertebrate prey. The sward structure requirements of foraging birds were scale-dependent. Buntings and skylarks chose to forage in paddocks with high transition densities, but at this scale accessibility was less important and paddocks with higher accessibility were avoided. Thus paddocks selected for high transition densities had, by inference, higher prey densities and more opportunities for birds to catch their prey. Only skylarks showed direct foraging preferences for higher densities of invertebrate prey, preferring large-bodied prey taxa (primarily caterpillars, but also grasshoppers). Fine-scale foraging patch selection could only be measured for yellowhammers. Having selected food-rich paddocks with complex sward structure, yellowhammers primarily selected foraging patches offering maximum accessibility – the opposite requirement to that observed at the paddock scale. In 2012, foraging buntings did not distinguish between the treatments because there were no longer any measureable treatment differences in structural heterogeneity (transition densities) or invertebrate prey densities.

Intermittent and continuous lenient grazing were equally attractive to buntings, but skylarks preferred continuous grazing. Skylarks also prefer larger fields, which are likely to be easier to graze continuously. Sward heights were difficult to control in the small paddocks used in this study, as the addition of a single cow had a larger effect on the average sward height.

The remaining target group of birds, the obligate seed-eaters (linnet and goldfinch), did not use the study paddocks sufficiently frequently to determine whether they benefited from lenient grazing. Most foraging took place on a small numbers of paddocks that supported the favoured foodplants, which were scarce on all other paddocks. There were indications of a weak preference for leniently-grazed plots, in the early season, when dandelions (*Taraxacum* agg., the most widespread early-season foodplant) were flowering. The BD1454 early closure treatments enhanced densities of seedheads in autumn, indicating that lenient grazing measures might increase seed abundance by reducing grazing pressure.

4.6. Effects of lenient grazing on agricultural outputs

The costs of whole-season lenient grazing measures are uncertain due to problems with extreme weather and limited replication. The main uncertainty is the speed and extent of sward deterioration and falling live weight yields. During 2010 and 2011 the livestock output from lenient grazing was the same or better than control sites, but yields (and differences between treatments) were generally depressed, due to poor grass growth in drought conditions. Yield losses on leniently grazed treatments increased in 2012 when wet weather generally increased grass growth and livestock outputs; possibly magnifying yield differences between treatments. The 2012 yield loss (£139 ha^{-1} for the Continuous Lenient treatment) is likely to be the worse-case scenario for losses in a third year of whole-season lenient grazing and the figure is likely to be lower in years with less extreme weather. The value of the 2012 yield loss is relatively low compared to agri-environment payments offered by the Entry Level Scheme and is only 23% of the third year loss caused by the BD1454 Lenient treatment. Even allowing for uncertainty over yield measurements, the Continuous Lenient treatment appears to have substantially slowed the decline in yield losses, compared to the best BD1454 measures. The yield losses from Intermittent Lenient grazing appear to be lower, but these were not measured directly and may be inflated by cattle having access to higher quality forage on the Overflow fields.

There are few published studies that describe whole-season yield penalties for raised target sward heights in the range used by this study. Wright & Whyte (1989) found that whole-season liveweight yield peaked on 9 cm swards (588 kg yr^{-1} on 9 cm swards compared to 346 kg yr^{-1} on 11 cm swards), but these measurements were based on cows and calves (rather than the beef cattle used in this study) and they did not measure how yields changed over time. Their yields were higher than those on the Control paddocks of this study (398 kg ha^{-1} yr^{-1}, in year 3), but indicate that yield losses of the order of 242 kg ha^{-1} yr^{-1} (£436 yr^{-1} by 2013 prices) may be possible (9 cm vs 11 cm swards) for Continuous Lenient treatment on more productive land. Daily growth rate figures for beef cattle from other studies indicate that growth rates on the Continuous Lenient paddocks were comparable with the best unimproved and semi-improved grasslands (typically less than 1 kg d^{-1}, due to practical constraints: Peel and Jefferson 2000; Tallowin 1997). This suggests that the figures from this study may be more representative of yield costs where these measures are likely to be applied.

The whole-season lenient grazing treatments resulted in some sward deterioration, but this was evidently less rapid and severe than in BD1454, suggesting that the new treatments could be maintained for longer, before costs became too great. As in BD1454 there was a shift from productive species such as *Lolium perenne* and *Trifolium repens* to unproductive *Holcus lanatus* swards. In contrast, there was no accumulation of plant litter or dense mats of *Holcus/Agrostis*, which exacerbated sward deterioration under the BD1454 early closure treatments.

4.7. Conservation recommendations

The recommended approach for an extensive cattle grazing measure is:

(1) Graze with cattle throughout the grazing season (April to October)

(2) Maintain an average sward surface height of 9-12 cm. This sward target can also be expressed as: maintain at least 20% of the sward below 10 cm and at least 20% of the sward above 10 cm.

(3) The field may be continuously or intermittently (rotationally) stocked. If the field is rotationally stocked , the average sward should not fall below 9 cm and at least 20% of the sward should be above 10 cm at all times. The proportion of the sward below 10 cm may be allowed to fall briefly below 20% during rest periods, but this situation must only be temporary

(4) Do not apply artificial fertilisers, but light applications of well-rotted farmyard manure (maximum 5 tonnes ha^{-1}) are acceptable.

(5) Lime applications are acceptable.

(6) Do not roll or harrow during the skylark nesting season (the vulnerable period is mid April to mid August).

(7) Where necessary weed control by spot-spraying, weed-wiper or topping is acceptable, provided that the control measures are strictly limited to the patches of weeds.

(8) No winter grazing or feeding livestock on the field over winter

This approach was tested on fields with zero fertiliser inputs. The results from BD1454 Experiment 2 (including the Devon Extension) indicated that the BD1454 grazing extensification measures resulted in bird and invertebrate benefits even when moderate fertiliser inputs (up to 50 kg N ha^{-1}) were permitted.

The benefits of restricting topping and herbicide use were not tested in this study. Topping would destroy the sward structure features that this measure seeks to produce and there are observations of topping resulting in an immediate cessation of foraging by yellowhammers (Buckingham 2006). It is possible that topping higher above the ground is less damaging: grasshoppers can remain numerous after topping at heights above 20 cm, which would still allow flowering stems of tall grassland weeds to be controlled (D. Buckingham pers.obs.). The numerical importance of forb-feeding invertebrates in the leniently grazed treatments provides clearer evidence that the extent of herbicide use should be restricted as much as possible (Appendix 3). Wintering seed eating birds are significantly less likely to use grass fields treated by spot-spraying (Buckingham et al. 2006).

Because of the influence of extreme weather, this study was unable to measure the medium-term impacts of maintaining this measure on the same field for multiple years. BD1454 found that the biodiversity benefits of extensification were cumulative over time (Eschen et al. 2012) but that agricultural outputs fell. This is likely to be true for the measure proposed here, though any reductions in agricultural output were evidently less severe than those under the BD1454 treatments. We predict that the greatest biodiversity benefits will accrue from maintaining this management package on the same field for as long as is practically possible. However, the flexibility to cease and return to conventional management would allow problems such as sward deterioration, weed infestations or falling yields to be rectified. In these circumstances the measure could be moved to another field. The results of this study and BD1454 suggest that this management package should remain in place for at least three years before the option can be moved to another field.

4.8. Further research

The main uncertainty regarding lenient grazing is the medium-term effect of the measure (from the third year onwards). It is likely that biodiversity benefits will accumulate over time (BD1454, Eschen *et al*. 2012) and that agricultural yields will fall (Section 4.6). The rate at which these changes take place and the point at which the cost-benefit trade-off becomes unacceptable could not be determined in this study. The design of this study was too simple and short to distinguish weather effects from cumulative treatment effects in the medium-term. This would require a more complex experimental study with greater replication, including the simultaneous provision of paddocks with treatments at a number of different ages. A further, related research aim would be to develop practical techniques for prolonging the useful life of a leniently grazed paddock, by slowing sward deterioration or identifying corrective management fixes. Alternatively, the costs and benefits of such an approach could be compared with rotating the measure to a new field every few years.

The benefits to birds were not investigated fully in BD5206-07. This study only measured foraging preferences and did not quantify the consequences for breeding performance or population demography. Performance and demographic measurements are more directly relevant to conservation planning but are onerous to measure. They are, however, of particular relevance to the design of agri-environment schemes to guide the key decisions: how much of a measure is required and where it should be located? This subject area is understood far better in arable farmland, facilitating the design of the Farmland Bird Package (Winspear *et al*. 2010), but the evidence base available related to livestock systems is relatively weak. A landscape-level trial of grassland and livestock biodiversity conservation measures, along the lines of the arable Hillesden Experiment, is needed to address this knowledge gap (Woodcock *et al*. 2010).

It is likely that seed-eating birds will benefit from reduced grazing pressure on grasslands where their foodplants still occur, but reduced grazing pressure may not be conducive to maintaining populations of these plants. Further research on this issue would be of particular practical relevance to the conservation of twite *Carduelis flavirostris* (in addition to linnets), for which late breeding season foraging habitat may be limiting (after species rich hayfields have been harvested).

Further research priorities include measuring the costs and benefits of extensive sheep grazing and grass-field margin management measures to provide spring invertebrate prey sources for buntings. The recommendations from this project relate specifically to cattle grazing. Sheep exhibit qualitatively different patterns of selective grazing, compared to cattle and the economic cost-benefit trade-off for extensification will be different. There are still unexplored suggestions for the management of hay/silage field margins to provide greater benefit to foraging buntings in spring.

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References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.