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Effect of Herbage Density, Height and Age on Nutrient and Invertebrate Generalist Predator Abundance in Permanent and Temporary Pastures

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Abstract: The aim of this research was to assess differences in the quantity and quality of herbage and invertebrate generalist predator abundance among permanent and temporary pastures. Two permanent pastures and four temporary ley pastures (either one year or two years since being sown) were monitored weekly for 10 weeks in the spring. Permanent pastures included a diverse range of native UK grass species, and temporary ley pastures were predominantly perennial ryegrass (*Lolium perenne*) with or without white clover (*Trifolium repens*). Weekly measurements of herbage height (in centimeters), herbage cover (fresh and dry matter in kg per hectare) and herbage density (fresh and dry matter in kg per hectare per centimeter) were obtained for each field, along with lycosid spider and carabid beetle abundance. Weekly pasture samples were used to obtain nutrient concentrations of dry matter, crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF), ash, oil, sugars, digestible organic matter in the dry matter (DOMD) and metabolisable energy (ME) in the herbage as a measure of forage quality for grazing or harvesting. A linear mixed model was used to assess the effect of sward age, herbage density and height on herbage production, nutrient concentrations and invertebrate abundance. Although this study showed that permanent pastures were associated with lower nutrient concentrations of crude protein, ash, oil and ME compared to younger and predominantly perennial ryegrass pastures, the older pastures were associated with higher carabid numbers. Furthermore, permanent pastures had a higher density of dry matter herbage compared to younger pastures, and more dense and taller swards were associated with higher lycosid numbers. The study suggests that within pastures of 3 to 20 cm height, increasing the height and density of swards increases both ME and oil concentrations in herbage, therefore enhancing forage nutrient quality. Older and more permanent pastures can be beneficial for plant and invertebrate generalist predator populations, and still provide a useful source of nutrients for forage production.

Keywords: grasslands; pasture type; biodiversity; technology; management

1. Introduction

Humankind relies on domesticated herbivorous mammals, such as ruminants, to produce edible food (e.g., meat and milk), fiber and labour. Ruminants are efficient convertors of non-human edible plant material into edible energy and protein food products for humans. Some 37% of the world's terrestrial land area is grassland, which provides a source of nutrients for animals if managed sustainably [1]. The role of grassland in the rural landscape and its contribution to livestock production are both important for food production and environmental management [2]. In a temperate climate such as the UK, grassland is the dominant agricultural land type with 12.3 million hectares [3,4], with forage estimated to contribute 50% to 60% of the diet for dairy cows, 80% to 85% for beef cattle and 90% to 95% for sheep [5].

In the UK, grassland area can be subdivided into two main groups: uncultivated grassland, including rough and hill grazing (representing 5.1 million ha), and more managed grassland, including permanent and temporary leys (5.1 and 1.4 million ha respectively) [4,6]. Temporary leys are replaced within five years of sowing and are often part of an arable rotation to help restore soil fertility and reduce weed, pest and disease problems, whereas permanent pastures are grasslands of more than five years old [5]. Permanent pasture swards generally host a more diverse range of native species, which in the UK include perennial ryegrass (*Lolium perenne*), bents (*Agrostis* spp.), meadow grasses (*Poa* spp.), timothy (*Phleum pratense*), Yorkshire fog (*Holcus lanatus*) and cocksfoot (*Dactylis glomerata*) [7]. In comparison, perennial ryegrass is often the main grass species in temporary leys and sown with white clover [5]. The use of legumes rich in protein are often used in temporary grassland swards to help fix atmospheric nitrogen into soils to aid plant growth. Furthermore, in recent years varieties of ryegrass with high growth vigour and high sugar content have become popular for temporary ley swards used for forage production [8,9]. The nutrient quality of permanent pastures is poorly understood and how it compares to temporary ley swards. Gibon [2] identified a lack of scientific knowledge in the area of grassland management for production and non-production attributes.

New tools and sources of information for biomass and nutrient composition measurements are being developed to help quantify temporal and spatial changes in herbage in real-time to provide more timely information for enhanced land management [10–12]. For perishable plant material, such as grass, the implementation of real-time near-infrared spectroscopy (NIRS) is beneficial given that changes in nutrient concentrations can occur within 24 h of harvesting [13]. Bell et al. [12] used real-time NIRS combined with a measure of herbage production (e.g., herbage per hectare and its height) to show that grazing pastures of a mean height of below seven centimetres result in a significantly reduced concentration of crude protein and digestibility, which may be detrimental to the productivity of grazing animals.

Naturally occurring generalist predators, such as ground carabid beetles and lycosid spiders, are ubiquitously present in agricultural systems. Their persistence within agricultural landscapes has been the focus of both empirical and theoretical studies and there is strong evidence to suggest that the persistence of these species is influenced both by the physical composition of the landscape and by how it is managed [14–18]. Generalist predators such as these are valuable for agricultural systems as they contribute to the fundamental ecosystem service of biological control of insect crop pests [19,20]. The current study explores the association between herbage production metrics (i.e., herbage density, height and nutrient composition), sward age and the presence of grassland generalist predator invertebrates.

The objective of the current study was to investigate the differences in herbage production, nutrient composition and invertebrate generalist predator abundance for pastures of different ages to explore the balance between productivity and the presence of two different types of generalist predator groups—lycosids and carabids. During this study, two permanent pastures and four temporary ley fields (either one or two years old) were monitored each week for 10 weeks in spring.

2. Materials and Methods

2.1. Field Data

The study was carried out at the University of Nottingham farm at Sutton Bonington (52.5°N, 1.3°W) over a 10-week period from February to April 2019. This period was studied as it covered the transition between winter (when grass is rested from grazing and harvest) and more productive spring grass growth (when productivity is high and grass is utilized for forage) as ambient temperatures increase (Figure 1). Weather data (total daily rainfall and average daily values for temperature, windspeed, relative humidity and irradiance), were recorded at the site above ground level throughout the study. During the study, the month of February had the lowest amount of rainfall (30 mm) and was cooler on average (7 °C) than other months (Figure 1). March had the highest amount of rainfall (57 mm) and April was the warmest month (8 °C). Noticeably, the average daily temperature for February and March during the study were higher than the average temperature for the same months during the previous 10 years from 2009 to 2018. Total rainfall was also noticeably higher during March of the study, whereas February and April were drier compared to the previous 10 years.

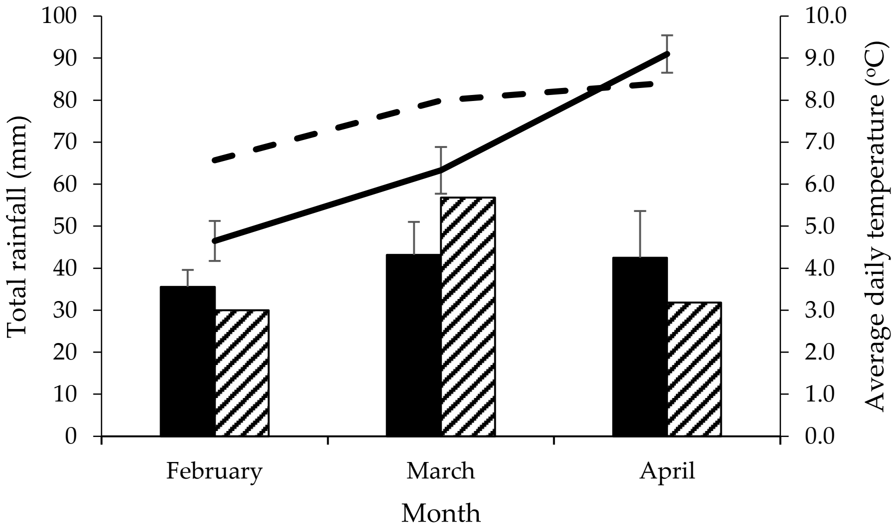

Figure 1. Monthly total rainfall and average daily temperatures during the years 2009 to 2018 (solid column and solid line, respectively) and during the study period in 2019 (dashed column and dashed line, respectively). Standard error bars are shown for months during years 2009 to 2018.

Grassland at the farm consisted of permanent and temporary ley pastures used for sheep grazing and/or silage production. Six fields were selected for this study (Figure 2), with two being ancient permanent pastures (fields C and D), two temporary ley pastures that had been established for one year (fields E and F) and two temporary ley pastures (fields A, B) that had been established for two years (Table 1). The permanent pasture fields had never been cultivated and contained a diverse botanical composition of native UK grass species of perennial ryegrass (*Lolium perenne*), timothy (*Phleum pratense*), Yorkshire fog (*Holcus lanatus*), cocksfoot (*Dactylis glomerata*), common bent (*Agrostis capillaris*) and meadow grass (*Poa annua*). The temporary ley pastures were part of a crop rotation and are cultivated after two to three years of production. The temporary leys consisted of predominantly perennial ryegrass (field B) and white clover (*Trifolium repens*, fields A, E and F). In the majority of cases, the fields studied were bordered by either a road, railway, tarmac footpath, waterway or arable field. Arable fields (south and east of fields C and D, and south of field F) included winter wheat, which received a single application of herbicide and inorganic fertilizer during the study period.

Prior to commencement of the study all six fields were rested for four or more weeks, as fields were intermittently grazed by sheep over the winter months. During this period all fields received an application of inorganic fertilizer. The temporary ley fields (A, B, E and F) received dirty water, which is produced after removing solid organic material from cattle slurry (the amount of nutrient inputs are shown in Table 1). During the study, ewes and lambs intermittently grazed fields B, C and D.

Soil samples were taken in weeks three, seven and ten. A core soil sample was taken to a depth of 30 cm and 2 cm diameter from the middle of each ring where grass samples were taken. The subsequent five soil samples were combined for each field to produce six samples for both sampling weeks for further analysis. Soil samples were stored at 4 °C overnight before being sent for laboratory analysis (NRM Laboratories, Cambridge, UK) to determine amounts of dry matter (g/kg) and total available nitrogen (kg N/ha). During the study the permanent pastures had on average a lower soil dry matter content compared to temporary leys. The soil available nitrogen was highest at the start of the study in each field, and then declined.

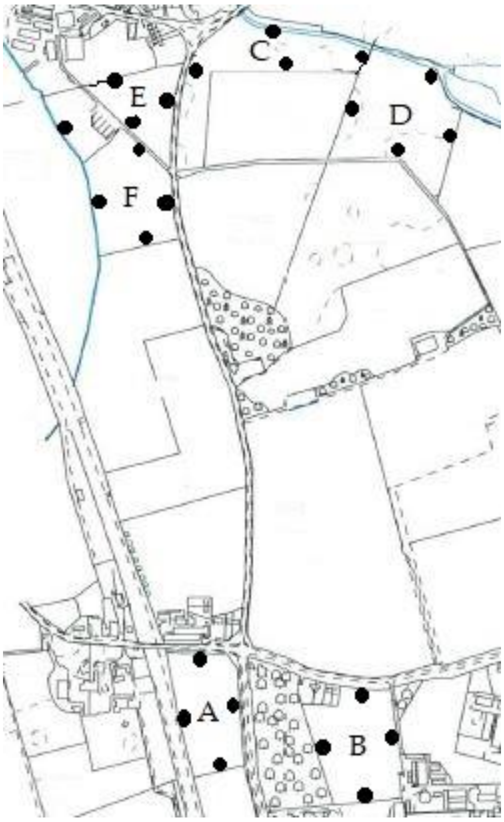

Figure 2. Map showing the temporary ley pastures (fields A, B, E and F) and permanent pasture studied (C and D). Pitfall traps in each field boundary are shown (•).

Table 1. Description of fields assessed in the study.

Field	Soil Type	Pasture Type	Predominant Pasture Species	Use	Nutrient Applications	Average Soil Dry Matter (min–max) g/kg	Average Soil Available Nitrogen (min–max) kg/ha
A	Sandy loam	Temporary ley (2 years old)	Perennial ryegrass and white clover	To be harvested for silage	Inorganic fertilizer (70 kg of ammonium nitrate of 34.5% N: 0% P:0% K) plus 1 × 30 m^3/ha (0.7 kg N/m^3) of dirty water	823 (806–847)	39.9 (18.5–82.1)
B	Sandy loam		Perennial ryegrass	Sheep grazing		815 (800–840)	30.5 (12.9–60.3)
C	Sandy loam	Permanent and never cultivated	Perennial ryegrass, timothy, Yorkshire fog, cocksfoot, common bent, meadow grass	Sheep grazing	Inorganic fertilizer (70 kg of ammonium nitrate of 34.5% N: 0% P:0% K)	763 (729–808)	35.8 (16.7–56.6)
D	Sandy loam					802 (773–851)	28.0 (9.4–51.4)
E	Sandy loam	Temporary ley (1 year old)	Perennial ryegrass, White clover	To be harvested for silage	Inorganic fertilizer (70 kg of ammonium nitrate of 34.5% N: 0% P:0% K) plus 1 × 30 m^3/ha (0.7 kg N/m^3) of dirty water	820 (798–846)	22.9 (11.0–42.7)
F	Sandy loam					845 (827–875)	29.1 (13.5–58.6)

2.2. Herbage and Invertebrate Measurements

Field measurements were conducted every Monday during the study. The herbage height, fresh and dry matter herbage cover and nutrient concentrations of each field were measured. Grass measurements avoided dung, urine and dense weed patches when taken. In each field five grass samples were cut to ground level within a 36 cm diameter wire ring (0.1 m^2) placed on the ground at each point of a W-pattern walked across the field. The W-pattern ensured representative coverage of each field. The total weight (grams) of grass within the ring was multiplied by 100 (i.e., 1 hectare = 10,000 m^2) to estimate the fresh herbage cover (kg fresh weight/hectare). The fresh pasture cover value was then multiplied by the percentage of dry matter measured by NIRS to derive the dry matter herbage cover (kg DM/hectare). The average fresh and dry matter herbage cover was divided by the sward height to derive the density of herbage in kg FW/ha/cm and kg DM/ha/cm.

A rising plate meter (F400; Farmworks Precision Farming Systems Ltd, Feilding, NZ) was used to measure sward height. The pasture height of each field was estimated from the average of 30 'spot' measurements taken in a W-pattern across the field. A mobile NIRS device (NIR4; Aunir, Towcester, UK) was used to scan cut pasture samples for their nutrient concentrations. The NIR4 takes five replicate scans, consisting of a spectrum of infrared energy reflected from the pasture sample illuminated by the scanner, from which nutrient concentrations are estimated from the average of the five scans. The scan results were uploaded to a tablet and secure server for further analysis. The nutrient concentrations measured were: dry matter, crude protein, neutral detergent fibre (NDF), acid detergent fibre (ADF), sugars, oil, ash, digestible organic matter in the dry matter (DOMD) (all expressed as grams per kilogram of dry matter) and metabolisable energy (ME, megajoules per kilogram of dry matter). The average concentration for each field and week of the study was used in the analysis.

As a measure of generalist predators, the number of adult and juvenile lycosids and carabids counted in a pitfall trap (Figure 3) were recorded for each field each week. Lycosids were identified using the guides of Roberts [21] and Bee et al. [22] and carabids using [23].

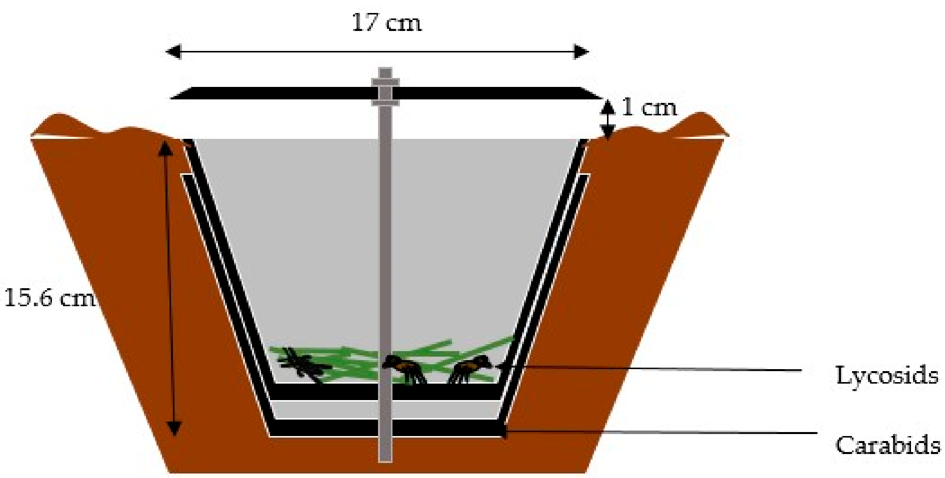

Figure 3. Pitfall trap used to monitor lycosid and carabid numbers.

Each field had four pitfall traps, placed approximately in the middle of each side of a field within the field margin to reduce the chance of damage and disturbance from field activities. The trap was composed of two plastic plant pots (diameter = 17 cm and depth = 15.6 cm) covered by a plastic bowl (diameter = 17 cm) connected to the ground with a metal bar. Some blades of grass and leaves were placed in the pot to provide some cover for lycosids. The use of two pots aided the collection and separation of lycosids and carabids, as the lycosids gathered in the upper pot and carabids preferred the darkness of the lower pot, as highlighted in Figure 3. The average number of lycosids and carabids per pot for each field and week of the study were used in the analysis.

2.3. Statistical Analysis

For the analysis there were a total of 60 weekly records for all fields (10 weeks × 6 fields). Data were analysed using a linear mixed model in Genstat software (version 19.1; Lawes Agricultural Trust, 2012). Equation (1) was used to assess the effects of sward age, herbage dry matter density and height on herbage nutrient concentrations, lycosid and carabid numbers as:

$$Y_{ijk} = \mu + A_i + b_1 D \times b_2 H + F_j + W_k + e_{ijk} \quad (1)$$

where Y_{ijk} is the dependent variable of average herbage nutrient concentration, lycosid or carabid specimen numbers per pot for each field; μ = overall mean; A_i = fixed effect of age of sward (i = 1 year, 2 years or permanent); b_1D = linear regression of Y on dry herbage density; b_2H = linear regression of Y on herbage height; F_j = random effect of field (j = A to F); W_k = random effect of week of study (k = 1 to 10); e_{ijk} = random error term. In the multivariate model, residual variance estimates were allowed to differ among fields. To assess differences in herbage height, herbage cover (fresh matter and dry matter) and herbage density (fresh and dry matter) among different aged swards Equation (1) was fitted without the effects of herbage density and height (i.e., $b_1D \times b_2H$). Significance was attributed at $P < 0.05$.

3. Results

3.1. Variability Among Fields Studied

There is considerable variability in fresh herbage cover and dry herbage cover among fields, with coefficients of variation of 53% and 52%, respectively (Table 2). The coefficient of variation in herbage height is also high at 50%, which results in coefficients of variation in fresh herbage density of 24% and dry matter herbage density of 25%. The variability in herbage nutrient concentrations is highest for dry matter with a coefficient of variation of 21%, with other nutrients ranging from 2% for DOMD to 10% for oil. The current study also finds considerable variability in lycosid numbers (65%) and carabid numbers (70%) among fields studied.

Table 2. Average herbage production, herbage nutrient concentrations and invertebrate numbers across fields studied.

Variable	Units	Mean (s.d)	Range	Coefficient of Variation (%)
Herbage production				
Height	cm	8.6 (4.3)	3.1–19.9	50
Fresh weight	kg FW/ha	7613 (4021)	1861–18494	53
Dry matter	kg DM/ha	1370 (718)	462–3253	52
Fresh density	kg FW/ha/cm	867 (205)	412–1401	24
Dry density	kg DM/ha/cm	173 (43)	106–296	25
Herbage nutrients				
Dry matter	g/kg	204 (34)	160–301	21
Crude protein	g/kg DM	129 (6)	117–141	5
Neutral detergent fibre	g/kg DM	410 (26)	373–483	6
Acid detergent fibre	g/kg DM	219 (11)	187–239	5
Sugars	g/kg DM	139 (13)	98–158	9
Ash	g/kg DM	85 (5)	71–95	6
Digestible organic matter	g/kg DM	706 (12)	672–722	2
Oil	g/kg DM	21 (2)	17–24	10
Metabolisable energy	MJ/kg DM	10.4 (0.3)	9.6–10.8	3
Invertebrate numbers				
Lycosids	No. per pot	1.7 (1.1)	0–5.23	65
Carabids	No. per pot	2.0 (1.4)	0–7.3	70

3.2. Effect of Sward Age

The predicted mean herbage height are higher for the one year old sward compared to older swards (P < 0.01) (Table 3). There is no difference in fresh herbage cover, dry matter herbage cover or fresh herbage density between different aged swards, however, permanent pastures have a higher dry matter density compared to temporary ley pastures (P < 0.01) and carabid numbers increase with age of the sward (P < 0.01). Permanent pastures have higher nutrient concentrations of dry matter and NDF (both P < 0.001), but lower concentrations of ash, ME (both P < 0.001), crude protein and oil (both P < 0.01) compared to younger pastures. The sugar concentration varies among different aged swards (P < 0.01) and DOMD is lower for the 2 year old sward (P < 0.05). There is no difference in ADF among different aged swards.

Table 3. Predicted mean[1] herbage production, herbage nutrient concentrations and invertebrate numbers for different aged swards.

		Age of Sward[2]					
Variable	**Units**	**1 Year**	**2 Years**	**Permanent**	**SED**	**F-Statistic**	**P Value**
Herbage production							
Height	cm	11.7^a	7.6^b	8.1^b	0.7	9.2	<0.01
Fresh weight	kg FW/ha	9859	6005	6974	1090	6.8	0.077
Dry matter	kg DM/ha	1743	1118	1558	162	7.9	0.064
Fresh density	kg FW/ha/cm	867	882	871	39.6	0.1	0.919
Dry density	kg DM/ha/cm	152^a	157^a	196^b	9.8	8.8	<0.01
Herbage nutrients							
Dry matter	g/kg	173^a	196^b	244^c	7.5	41.3	<0.001
Crude protein	g/kg DM	131^a	132^a	127^b	1.6	5.9	<0.01
NDF[2]	g/kg DM	391^a	404^b	423^c	4.8	18.2	<0.001
ADF[2]	g/kg DM	224	221	218	2.6	2.1	0.148
Ash	g/kg DM	86.2^a	87.4^a	83.2^b	1.4	12.7	<0.001
Oil	g/kg DM	21.7^a	21.8^a	20.5^b	0.4	7.5	<0.01
Sugars	g/kg DM	143^{ab}	147^b	140^a	2.8	6.2	<0.01
DOMD[2]	g/kg DM	712^a	702^b	706^a	2.4	5.5	<0.05
ME[2]	MJ/kg DM	10.6^a	10.5^a	10.3^b	0.05	10.5	<0.001
Invertebrate numbers							
Lycosids	No. per pot	1.3	2.0	1.9	0.4	2.8	0.082
Carabids	No. per pot	0.9^a	1.6^b	2.8^c	0.4	7.6	<0.01

[1] Linear mixed model with field and week of study added as random effects and covariates centred to a zero mean.
[2] Means within a row with different superscript letters (i.e., a,b,c) differ significantly and attributed at P < 0.05. SED means standard errors of differences; ADF is Acid detergent fibre, NDF is neutral detergent fibre, DOMD is digestible organic matter in the dry matter and ME is metabolisable energy.

3.3. Effect of Herbage Height and Density

Increasing dry matter herbage density increases dry matter, NDF (both P < 0.001), ME (P < 0.01) and oil (P < 0.05), but reduces ash (P < 0.001) and crude protein (P < 0.01) nutrient concentrations (Table 4). Increasing herbage height increases ADF, ME (both P < 0.001) and oil (P < 0.05) nutrient concentrations. There is a significant interaction between herbage density and height for nutrients of ADF (P < 0.001), sugars (P < 0.01) and DOMD (P < 0.05). With increasing herbage density and herbage height, lycosid numbers increase, whereas carabid numbers are unaffected by herbage density and height.

Table 4. Effect of dry herbage density and herbage height [1] on herbage nutrient concentrations and invertebrate numbers across fields studied.

Variable	Units	Effect (s.e) d.f. = 1			F-Statistic			P Value		
		Density	Height	Density × Height	Density	Height	Density × Height	Density	Height	Density × Height
Herbage nutrients										
Dry matter	g/kg	0.14 (0.08)	−0.09 (1.0)	−0.10 (0.02)	79.8	1.4	1.8	<0.001	0.250	0.189
Crude protein	g/kg DM	−0.008 (0.018)	0.38 (0.2)	0.004 (0.005)	8.2	3.8	0.1	<0.01	0.059	0.815
NDF	g/kg DM	0.02 (0.06)	0.06 (0.6)	−0.04 (0.02)	19.2	3.3	0	<0.001	0.078	0.954
ADF	g/kg DM	0.05 (0.03)	1.05 (0.3)	−0.01 (0.01)	2.8	24.6	15.4	0.107	<0.001	<0.001
Ash	g/kg DM	−0.02 (0.01)	0.04 (0.2)	0.01 (0.003)	24.6	3.9	0.7	<0.001	0.058	0.426
Oil	g/kg DM	0.0004 (0.004)	0.07 (0.05)	0.002 (0.001)	6.6	4.7	0.04	<0.05	<0.05	0.840
Sugars	g/kg DM	0.07 (0.03)	0.70 (0.4)	0.03 (0.01)	1.5	1.1	12.7	0.231	0.299	<0.01
DOMD	g/kg DM	−0.002 (0.02)	−0.49 (0.30)	0.02 (0.01)	0.3	0.1	4.9	0.574	0.716	<0.05
ME	MJ/kg DM	0.0005 (0.001)	0.03 (0.01)	0.0002 (0.0002)	11.9	64.8	0.1	<0.01	<0.001	0.772
Invertebrate numbers										
Lycosids	No. per pot	0.01 (0.004)	0.10 (0.03)	0.0002 (0.001)	11.3	7.7	1.1	<0.01	<0.05	0.305
Carabids	No. per pot	−0.001 (0.005)	0.001 (0.04)	−0.002 (0.001)	4.1	0	0	0.052	0.972	0.965

[1] Linear mixed model with field and week of study added as random effects and covariates centred to a zero mean.

4. Discussion

In our study we show that older and more permanent pastures can be beneficial for animals, plants and invertebrate populations. Grasslands used for grazing or forage production have several benefits for agricultural systems, such as preventing soil erosion, building soil fertility [24] and conserving plant species. These areas are also known to be an important habitat for conserving invertebrate populations, some of which provide important ecosystem services such as predation upon pest species, to adjacent farmed areas [2]. In this study, we present data on both the productivity and the presence of invertebrates of such a system through measuring the biological properties of pastureland of different ages and at the same time recording the abundance of two predatory groups of invertebrate, namely lycosids and carabids.

Several studies have shown that variability in pasture biomass and changes in nutrient concentrations are important to the productivity of grazing animals and forage production generally [24–26]. Factors that influence properties of the plant biomass (e.g., yield and nutrient content) include maturity, season [5,27,28], plant species, soil properties [5] and sward management [29,30]. Management of grassland (e.g., nutrient inputs and grazing/harvesting management) can modify the functioning of the terrestrial ecosystem by altering soil conditions and also the plant community composition [31]. Younger and genetically superior temporary pastures, as in the current study, tend to include less plant species of predominantly ryegrass species which are considered more productive, with better nutrient qualities and greater persistency than older pastures [25,32]. The permanent pastures studied were found to have higher nutrient concentrations of dry matter and NDF, but lower concentrations of ash, ME, crude protein and oil compared to younger pastures. This would support the general finding of lower nutrient quality [5]. The most valued nutrients in pastures are crude protein content, sugar content and the digestibility of organic or dry matter [24,29], reflected by the popularity of high sugar perennial ryegrass pastures in recent years. As observed in the current study, Bell et al. [12] found that sugar and DOMD content of temporary ley pastures are not necessarily superior to more diverse and permanent pastures. Changes in herbage density and herbage height affect pasture nutrients, and reflect changes in botanical composition, maturity and tillering. When short and leafy, a grass plant tends to be rich in protein and highly digestible. However, during its growth to maturity, the proportion of cell wall material increases and the proportion of cell contents decreases. The consequence is an increase in the percentage of fibre (i.e., NDF and ADF) and a decrease in the percentage of crude protein, which often results in decreased digestibility and ME [7]. Additionally, during grass growth the sugar content increases as the stem to leaf ratio increases, with sugars mainly stored in the stem of the grass plant [7].

The higher dry matter density associated with permanent pastures may provide a resilient sward compared to temporary pastures [33,34]. The permanent pastures studied also had higher soil moisture than fields with temporary pastures (Table 1). The effect of increasing dry matter herbage density is found to increase dry matter, NDF, ME and oil, but reduce ash and crude protein nutrient concentrations in the swards studied. Increasing herbage height resulted in an increased ADF, ME and oil nutrient concentration in swards. Furthermore, the older permanent pastures studied, that had a higher dry matter density, less disturbance due to lack of cultivation and more diverse plant species, had higher numbers of carabids. Taller and denser pastures also had greater abundance of lycosids, a finding that is not unexpected given previous work on associations between the physical structure (e.g., open vegetation and reduced sward height due to grazing) and lycosid specimen number (reviewed in Bell et al. [16] and Petillon et al [35]). Nonetheless, the fields and period studied show considerable variability both in terms of lycosid numbers (65%), carabid numbers (70%), herbage height (50%), density (24% for fresh and 25% for dry plant matter) and herbage nutrient concentrations (ranging from 2% for DOMD to 21% for dry matter). The effect of sward age on carabid numbers, but not on lycosids, might potentially indicate that the former are, on average, less likely to disperse than the latter, but it should be noted that there is heterogeneity even within these different invertebrate groups in their dispersal ability, and therefore dispersal might be only one contributing factor. The nutrient content of pastures are typically not monitored but doing so may help land managers improve how effectively they use forage and improve grazing management whilst maintaining plant and invertebrate diversity. Perhaps one of the most valuable insights gained from this study is the heterogeneity amongst sites, even when factors such as sward age or height are accounted for. This may indicate a patchiness in distribution that is driven by local factors that are as yet not measured. Local versus landscape arguments about what matters for these beneficial invertebrates, many of which are capable of dispersing over large distances, with the ability to rapidly colonise new areas, remain incompletely understood [36]. The findings in our study here indicate that, as has been found by other authors, small scale patches may be important, notwithstanding ongoing processes at much larger scales [37]. Furthermore, the life cycle of lycosids and carabids are not the same. In early spring, male lycosids are more active than females, and females become more active towards the end of the spring [38]. For carabids, there are spring breeders that reproduce in spring or early summer, and autumn breeders that reproduce in summer or autumn [39]. Therefore, the timing of the current study would likely sample the lycosids and carabids that are more active in early spring. Pitfall traps are useful for assessing the relative abundance of ground dwelling lycosids and carabids to compare different areas over a short period [40], as in the current study. While the location of the pitfall traps in the margins of each field helped avoid damage and disturbance from field activities (vehicles and animals), it may have influenced the abundance of invertebrates recorded. Sampling of neighbouring fields would have helped determine if sampling the margins of fields biased the results. The presence of waterways, railway, roads and pathways next to fields studied would hopefully create a barrier from neighbouring areas. Additional years of sampling and during other periods of the year, rather than just 10-weeks in spring as in the current study, would help to confirm that the results are consistent over a longer time period.

5. Conclusions

This study assessed the relationship between pasture characteristics and invertebrate generalist predator abundance over a ten week period. Although newer pastures of predominantly perennial ryegrass may provide higher concentrations of nutrients such as crude protein, ash, oil and ME compared to older pastures, the older and more dense pastures had higher carabid and lycosid numbers. Older and more permanent pastures can be beneficial for plant and invertebrate abundance, and still provide a useful source of nutrients for forage production.

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