Regenerative Ranching: Analyzing the impact of specific variation in rotational grazing practices on pasture health and biodiversity.

A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
(School for Environment and Sustainability)
University of Michigan
April 2024

Thesis Committee:
Dr. Sheila Schueller, Chair
Dr. Ivette Perfect, Co-advisor

Table of Contents:

Abstract:

Rotational grazing, or paddock grazing, is a form of regenerative agriculture where livestock are regularly moved among pastures. In a time of increased environmental degradation and agricultural expansion, it has the potential to be a sustainable alternative to the destructive overgrazing commonly found in industrial livestock rearing. While studies have suggested that implementing intense short-period grazing with prolonged periods of rest can increase plant diversity and biomass, the efficiency of this practice has been argued by practitioners in the United States for about seventy years. This study aimed to address how rotational grazing farmers' management decisions, such as time left between grazes, impact groundcover and arthropod communities on a small scale. The study included data collected from two ranches in southeast Michigan implementing intensive rotational grazing, meaning moving the herds daily. Through sweep net and pitfall sampling, pastures were monitored pre- and post-grazing over an entire grazing season. This was collected along with quadrat sampling of vegetation height, diversity, and groundcover percentage to paint a fuller picture of ecological impact. From this information, how pasture recovery is affected by time since last graze, grazing frequency, and livestock type (cattle, sheep, or chicken) was analyzed. There was a significant increase in several vegetation and arthropod measures in response to increasing time since last grazed as well as a significant farm-specific effect, which could be attributable to factors such as soil type or site history. Faster recovery at the farm with the longer grazing history suggests that long-term implementation of rotational grazing as continued disturbance through grazing could be correlated with increased pasture resilience. Other variations in grazing management including grazing frequency and livestock type were found to significantly influence vegetation communities. This underscores the complexity of rotational grazing management and the necessity for a nuanced understanding of its effects on pasture health. These findings have implications for new farmers considering adopting rotational grazing. Specifically, with prolonged adoption of rotational grazing there appears a possibility to sustain larger livestock populations on more compact acreage while decreasing reliance on supplemental hay. All of these outcomes have the potential to help offset the initial cost and effort of transition to rotational grazing and could act as an encouragement for potential farms.

Introduction:

Livestock accounts for over half of the globe's agricultural gross domestic product (Herrero et al., 2016) and occupies about one-third of the earth's ice-free surface (Erb et al., 2016). The global livestock industry is responsible for approximately 14.5% of all human-induced greenhouse gas emissions (Gerber & FAO, 2013) and was estimated to contribute to 19% of the total anthropogenic warming of 0.81°C in 2010 (Reisinger & Clark, 2018). This significant global impact underscores the need to expand research on the ecological effects of alternative livestock-rearing methods. While some argue that large-scale livestock rearing is entirely incompatible with conservation goals (Steinfeld et al., 2006), others contend that the ecological impact of the industry could be mitigated or even improved with alternative management practices (Briske et al., 2011)

Currently, there are three primary categories of grazing systems within the formal livestock rearing industry that range from less to more restriction on livestock movement: continuous grazing, simple rotational grazing, and intensive rotational grazing (Armstrong & Heins, 2021; Table 1). In the United States, continuous grazing is the most common practice due to its low maintenance and simplicity (James, 2011), making up 60% of current livestock management plans (Whitt & Wallander, 2022). Continuous grazing permits livestock to graze an area with minimal restriction. In contrast, in rotational grazing systems, livestock are moved and deliberately restricted from areas to enable periods of land recovery between grazing events (Armstrong & Heins, 2021). Depending on the size of the paddocks and the frequency of their rotation, rotational grazing practices vary from simple to intensive. Livestock in intensive rotational grazing systems are more tightly controlled regarding time and space, using smaller and more frequently shifted paddocks, which allows for longer pasture recovery times.

Rotational grazing and even intensive rotational grazing act as larger umbrella terms that can cover a wide variety of practices based on industry type, land and water constraints, and labor availability. For example, rotational grazing can be used in both meat and dairy farming, but dairy operations face unique challenges, such as the need for close access to milking stations, leading to distinct management decisions compared to meat production. Out of the 40% of US farmers who use some form of rotational grazing, only 40% employ intensive rotational grazing (Whitt & Wallander, 2022). Even among those practicing intensive rotational grazing, there is considerable diversity in the management decisions (Badgery et al., 2017). Depending on management goals, livestock may be moved between paddocks with a frequency that varies from every few days to every couple of months. This choice aims to balance livestock production needs with forage availability and plant health in pastures. Variation in the number of days since the last grazing on a paddock, the duration of grazing in each area, and the overall grazing frequency could all affect the health of the pasture and the success of the grazing strategy.

In addition to decisions related to the frequency of livestock movement, grazing outcomes can also depend on other metrics, such as stocking rate (Table 1). The stocking rate, defined as the number of livestock units per acre, is critical in standardizing grazing intensity across different livestock species and ensuring that the grazing pressure on the pasture is sustainable. The term 'livestock units' is used as a reference for the forage demand by different types of livestock and is essential for accurately measuring and comparing the impact of grazing practices across various species and farming operations.

Rotational grazing is a highly adaptable management approach that can be tailored to the specific objectives and constraints of each farm operation. Adjusting the rotational frequency, stocking rates, and grazing durations can help manage pasture conditions effectively, improve forage utilization, and potentially benefit both the environment and animal welfare (University of Minnesota Extension, 2023). Farmers typically adhere to recommended grazing intervals of 10 to 15 or 30 to 40 days based on pasture species composition (Undersander et al., 2014; Smith et al., 2011; Williams, 1996) to allow for regrowth. However, these guidelines are generalized and do not account for the variability in the decisions that may affect recovery rates of pastures. A deeper understanding of rotational grazing dynamics is key to enhancing livestock production and agricultural sustainability.

Table 1. Key terms for grazing management (USDA, n.d; University of Minnesota Extension, 2023; and Oklahoma State University Extension, 2021)

	Term	Definition
Grazing areas	Livestock	Domesticated animals, such as cattle or sheep, raised in order to provide labor and/or produce diversified products for consumption.
	Paddock	A small field or enclosure that restrict livestock movement. These can be permanent structures or made using moveable electric fencing.
	Pasture	Land use type having vegetation cover comprised primarily of introduced or enhanced native forage species that are used for livestock grazing.
Grazing strategies	Continuous Grazing	Livestock is left in a singular area for a prolonged period of grazing with little to no moving over the grazing season.
	Rotational Grazing	Livestock is moved around a grazing area or pasture occasionally, typically every 10 to 90 days.
	Intensive Rotational Grazing	Livestock is moved to a new grazing area at a rapid pace usually ranging between being moved every couple of days to daily movement.
Specific management decisions	Days since last grazed	Number of days that have passed since livestock was removed from a grazing area
	Grazing duration	Number of days that livestock is left in a restricted area for grazing.
	Grazing frequency	Number of times livestock have returned to a particular area during a grazing season.
	Stocking Rate	Number of animal units per area. A way to standardize grazing intensity over multiple livestock species. Animal units accounts for forage demand by livestock which allows for a standardized unit for different species, variety, or life stages of livestock

Research on the ecological effects of rotational grazing is limited but suggests it can support sensitive species and enhance grassland health. The implementation of rotational grazing practices has been linked to increases in plant biomass and biodiversity (Gonzalez-Hernandez et al., 2020). For example, specific studies associate rotational grazing regimes with elevated amphibian populations and a spike in rare species richness due to increased vegetation cover (Pulsford et al., 2019). Pollinators, such as butterflies, also show a boost in both richness and abundance under rotational grazing (Farruggia et al., 2012), indicating the practice's potential benefit to grassland ecosystems and to supporting sensitive species intrinsic to ecosystem function.

Despite existing evidence of the ecological benefits of rotational grazing, the research community has not fully endorsed it as a more regenerative alternative to continuous grazing, partly due to a lack of comprehensive data on specific grazing decision outcomes (Roche et al., 2015). Conflicting research suggests that adverse effects, such as small mammal population declines and minor changes in plant community composition, may occur in areas practicing rotational grazing (Barry & Huntsinger, 2021; Schieltz & Rubenstein, 2016). On the other hand, surveys of farmers document that the reason that they implement these practices is due to their overall positive effects on the environment (Roche et al., 2015). Even the two farms within this study define themselves as "regenerative" ranches, based on their intentions and visible changes that they see within their land. The ecological impacts of rotational grazing, including variables like stocking rate, paddock count, and grazing frequency, lack holistic research for definitive conclusions (Badgery et al., 2017). Moreover, studies often overlook key experimental design factors, such as livestock species, leading to oversimplifications by clustering sheep and cattle impacts together, despite their distinct grazing behaviors (Jansen & Healey, 2003). Variation in outcomes across management decisions may explain variable results across studies and between the observations of researchers and farmers.

This study aims to improve our understanding of how fine-scale variations in rotational grazing management decisions affect ecological outcomes. Examining the ecological effects of specific grazing management decisions can guide the identification of rotational grazing practices that best support biodiversity and raise awareness of the potential for rotational grazing to aid grassland recovery and regeneration. To this end, we assessed recovery not only in terms of vegetation, but also arthropod communities. Arthropods serve as well-documented indicator species due to their sensitivity to environmental changes and their ability to reflect broader biological trends (Solascasas et al., 2022), and insects are one of the taxa most threatened by anthropogenic disturbances globally (Sánchez-Bayo & Wyckhuys, 2021). Specifically, we studied how variation in three key grazing management decisions - days since last grazed, livestock type, and frequency of return to pasture - relate to (1) vegetative growth (height and percent cover) and composition (forb diversity) and (2) arthropod abundance and diversity. Our approach allowed us to investigate specific research questions to inform practice, including:

- Do vegetative and arthropod communities respond differently to increasing intervals of days since last grazing (1-15 days, 16-40, 41-60, greater than a year)?
- How do repeated visits to the same pasture affect vegetative and arthropod communities?
- How do cattle, sheep, and chicken differ in their ecological impact in rotational grazing?
- How are pasture responses also influenced by environmental variables (precipitation and soil compaction) and other site differences?

Methodology:

Study Sites:

We studied two farms in Washtenaw County, Southeast Michigan. While Michigan is not a major meat-producing state, it is one of the top five dairy-producing states in the United States, with an estimated 1.14 million cattle as of 2016 (USDA, 2014; USDA, 2016). The average climate in the study area ranges from 3.55°C to 15.17°C, with an annual average precipitation of approximately 972 mm (38.26 inches; NOAA, 2020). Data were collected from March to August 2023 to cover the majority of the livestock grazing season.

Both farms implemented intensive rotational grazing, although their specific practices varied. They differed in several key aspects of grazing practices, including the species of livestock, stocking rates, days left between grazing sessions, and the duration of each grazing period.

Whitney Farm is a regenerative ranching and maple syrup operation with 105 acres of grazing land that has used an intensive rotational grazing system for both sheep and cattle raised primarily for meat production, with daily herd movements for nearly a decade. While both sheep and cattle are raised in close proximity, they never graze on the same land. Whitney Farm is situated on land with primarily loam soil type (Figure 1). For approximately the past 125 years, the land has seen a variety of agricultural uses, mainly cash crops in rotation, contributing to a rich mosaic of land use history.

Shining Light Farm is considerably smaller at 14 acres of actively grazed land and is now in its second year of transitioning to regenerative homestead operations on loamy sand soil—moving from exclusive corn and soy cultivation to intensive rotational grazing (Figure 1). This farm manages cattle for meat and chickens for both meat and egg production. Similar to Whitney Farm, Shining Light does not practice multispecies grazing, so the two species are never in the same pastures. With limited land available for rotation, Shining Light also employs a “sacrificial pasture” approach, allowing cattle to graze in a designated area while other pastures recover. The land history of Shining Light is not as well documented as Whitney Farm's. However, it has recently been used to grow soy and corn.

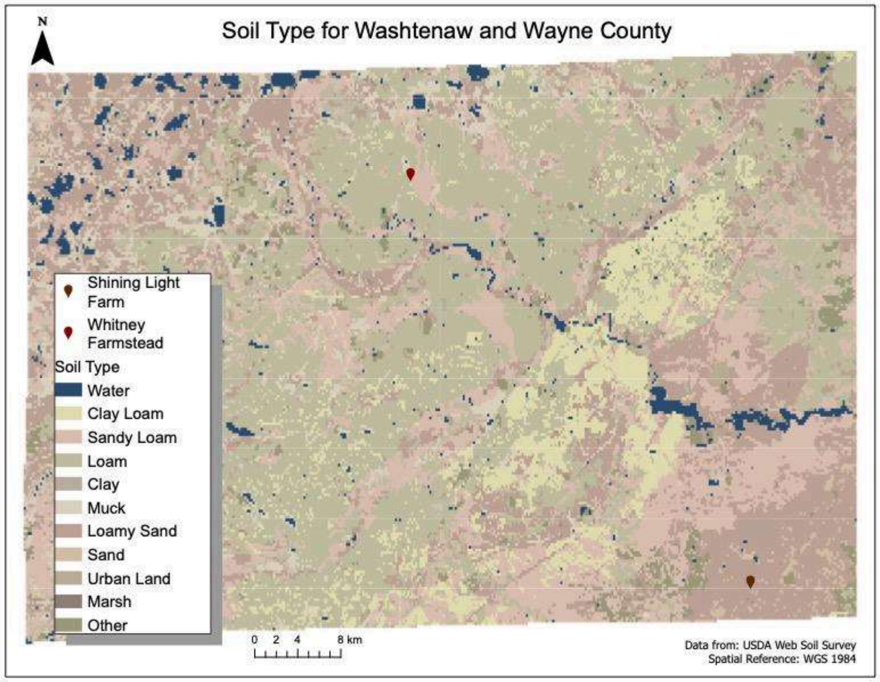

Figure 1. Map of soil types in Washtenaw and Wayne County in Michigan, United States.

Management Decisions:

In order to assess the ecological effect of specific practices, we first needed to determine which practices varied enough between or within farms to allow for analysis of how that variation impacts grazing outcomes. To do this we recorded a broad array of management information each time we assessed a paddock after grazing across a whole grazing season: herd size (number of animals), paddock size, grazing duration (number of days livestock had been in a particular paddock), livestock type (sheep, cattle, or chickens), and the date of the last graze. From this, we also calculated the stocking rate (defined as the number of animal units per acre), the number of days since the last grazing event, and grazing frequency (number of times livestock had returned to the same paddock during the season).

Certain management practices were consistent across the two study areas, particularly grazing duration and stocking rate. Specifically, each paddock was grazed for approximately 24 hours, and the average stocking rate was maintained at roughly 0.03 animal units per acre in both farming locations. Since the stocking rate already accounts for the influence of both herd size and paddock size, these variables were not considered relevant for this study. Therefore, we omitted grazing duration, stocking rate, paddock size, and herd size from our analysis.

The management decision variables that did vary enough both between and within the two farms to allow for analysis were: livestock type (cattle, chicken, sheep), days since last graze and grazing frequency. Variation in the grazing frequency relates to variations in land availability, with Whitney having significantly more pasture available for rotational grazing than Shining Light's. The criteria for determining the timing of herd reintroduction, or grazing frequency of return to pasture, also differed between the farms. Whitney followed a consistent rotational system, which completed its cycle in approximately one month, before livestock returned to a previously grazed pasture. In contrast, Shining Light made decisions based on observing vegetation regrowth, resulting in less consistent recovery periods between grazing events.

Vegetation Measures:

To assess plant productivity and diversity, vegetation metrics were collected by subsampling paddocks across the farm before and after grazing events using several 1 square meter quadrats (Figure 2). To capture variation across the paddock and to reduce edge effects, sampling began with two quadrats haphazardly (by tossing without facing the field) placed at least 5 meters away from each of the two corners at one end of the paddock. Subsequently, a third quadrat was sampled approximately 10 meters from the midpoint between the first two quadrats. This corner-to-center pattern continued sequentially until the opposite end of the paddock was reached. Each sampled paddock was subjected to a minimum of five samples using this pattern to ensure adequate representation of the area, with additional quadrats included for larger paddocks. Due to variations in paddock size between farms, the number of samples per paddock ranged from five to nine, with an average spacing of about 13 meters between samples. Within each quadrat, we assessed percent ground cover (the proportion of the soil surface covered by vegetation), vegetation height, and forb diversity (the variety of broadleaf herbaceous plants).

Figure 2. Sampling methods in relation to cattle movement at Whitney Farmstead. White dots indicate the locations where temporary paddocks were established. The green dashed lines outline the boundaries of these paddocks. Within these borders, sampling sites are marked with yellow X's, denoting areas where samples were taken both before and after grazing events. The yellow perimeters highlight pastures that have been grouped together due to their similar vegetation characteristics and topographical conditions.

Ground cover in each pasture was quantified using the smartphone application Canopeo, developed by the University of Oklahoma. This tool has been validated as an effective tool for quantifying pasture green cover—a key indicator of productivity in livestock pastures (Jáuregui et al., 2019). A detailed visual assessment of each quadrat also provided a compositional breakdown of the ground cover into categories, including manure, bare ground, dead/trampled grasses, forbs, and living/untrampled grasses.

Grass height was measured to assess vegetation growth and dry matter production, a crucial part of livestock nutrition and long-term productivity (Ganche et al., 2015). This variable was collected due to the fact that a pasture's ability to produce more aboveground biomass can influence future grazing management decisions such as herd size, the need for supplemental feed, and stocking rate. Within each quadrat, we recorded minimum, maximum, and most commonly observed grass heights. The 'most common height' or vegetation height, was determined by noting the height that appeared most frequently among a systematic selection of ten measurements within the quadrat taken in a grid pattern of alternating offset rows of three and two. All measurements were taken approximately six centimeters from the quadrat's boundary. Finally, forb diversity was determined by counting the total number of different forb species within the quadrat, which provided insight into the biodiversity component of the pasture's ecological response. We identified which forb species were present on each farm, not by sample.

Insect Surveying:

To investigate the responses of insect communities to grazing, two distinct sampling methods were implemented within the same quadrats used for vegetation assessment: pitfall traps and sweep netting. These methods were chosen to mitigate the inherent sampling bias that may arise when relying on a single technique, as different methods may be variably effective for different species (Batáry et al., 2007; Hohbein & Conway, 2018). For example, pitfall traps may be less effective at capturing highly mobile species, such as grasshoppers, locusts, and crickets, which are more effectively sampled using sweep netting.

Sweep netting involved performing a series of six consecutive sweeps with a standard 38cm-diameter sweep net within the one-square-meter quadrat boundaries. Arthropod abundance for each sample was recorded as the total number of individuals, and arthropod diversity was estimated as the total number of morphospecies—organisms that appeared morphologically distinct in the field.

Pitfall traps were constructed using 50 mL centrifuge tubes, 30mm in diameter and 115mm in depth, which were buried so that the top of the tube was level with the ground. The traps were left in the field for an average duration of twenty-four hours before collection, each containing approximately 30 mL of water and soap mixture as an attractant and trapping medium. Captured specimens were subsequently preserved in alcohol for future sorting and identification (Ascensio-Álvarez et al., 2015). The diversity and abundance of arthropods from the pitfall traps were identified to the level of order or family, including Acari (mites and ticks), Araneae (spiders), Coleoptera (beetles), Formicidae (ants), and Orthoptera (grasshoppers and crickets).

Abiotic Variables:

In an effort to account for potential confounding abiotic factors that may influence ecological responses, we also recorded environmental parameters for each data collection event. Data from a local weather station provided the average temperature corresponding to the deployment of the pitfall traps. The average amount of precipitation (mm) for the week prior to the installation of each pitfall trap was collected using the same weather database.

Alongside these climate-related measures, we used an AMS pocket penetrometer to quantify soil compaction (tons/sq. ft) within each sampling quadrat. The average soil compaction was determined from four systematically placed measurements within the quadrat boundary, each six centimeters away from the corners. Multiple measurements were taken to account for the significant variability observed within each quadrat. Given the differences in soil type and compaction between the farms, soil compaction was considered an explanatory variable rather than an outcome of grazing.

Data Analysis:

For all data analyses, we used the program RStudio Version 2023.09.1+494.

Factor Reducing Methods - Cluster Analysis and PCA

Due to multiple correlated response variables, a hierarchical cluster analysis and PCA were used to minimize the number of variables included in subsequent multivariate models and generalized linear models testing the relationship between management decisions and ecological responses. By identifying related clusters and variables, we could select a subset of response variables that most representatively captured the effects of different management practices on the ecosystem.

Before constructing the hierarchical cluster, it was necessary to standardize the data to account for the variation in measurements. This standardization was performed in RStudio using the scale() function, which centers the data (by subtracting the mean) and scales it (by dividing by the standard deviation). Subsequently, the dist() function was employed to compute the Euclidean distances between each pair of observations in the dataset. The Euclidean distance metric was chosen because it measures the shortest path between two points, highlighting the similarities among ecological response variables. The resulting distance matrix was then used as the input for clustering, carried out using the hclust() function. The hierarchical clustering result was visualized with a dendrogram, elucidating the relationships between clusters.

After identifying clusters, a correlation matrix was constructed for all response variables using the cor() function in R. Subsequently, principal components were generated with the princomp() function. The variables that contributed most to each principal component were identified, focusing on those that accounted for the largest proportion of variance in the dataset.

Regression models and ANOVAs

To investigate the relationship between the ecological response variables identified from the previous dimensionality reduction process and the explanatory variables, multiple linear regression models and ANOVAs were used. The variable “farm” was consistently included in the linear models as a covariate to account for variance attributable to differences between farms. Due to limitations in sample size and concerns about statistical power, each variable—selected from the dimensionality reduction—was modeled individually in conjunction with "farm."

The first research question addressed through these models examined the responses of vegetative and arthropod communities to increasing time since last grazing. Days since last grazing was treated as a categorical variable using four intervals: 1-15 days, 16-40, 41-60, and greater than a year. The selected intervals correspond with the grazing regimens typically recommended for practical farm management (Undersander et al., 2014; Smith et al., 2011; Williams, 1996), so that the results could be compared with current management prescriptions. Models were set up using the lm function in R with the categorical variable days since last grazing as the explanatory variable and run separately for each of the selected response variables.

The same type of linear model was used to answer the second research question: how do repeated visits to the same pasture affect vegetative and arthropod communities? In this model, the variable grazing frequency, representing the number of times livestock grazed in the same area over the season, was used as the explanatory variable.

To investigate the impact of livestock type on each ecological response variable, an Analysis of Variance (ANOVA) was conducted using the aov function in R to compare means across different livestock categories: cattle, sheep, and chickens. Post-hoc tests using Tukey's Honest Significant Difference were applied when ANOVA results indicated significant differences.

For understanding the influence of external environmental variables, such as precipitation and soil compaction, on pasture responses, a multivariate analysis was performed, using these environmental factors as the explanatory variables. To distinguish the effects of these variables, both individually and in combination, both precipitation and soil compaction as well as all response variables were incorporated into a single multimetric model using the lm function. Farm was not included as a factor, aiming to isolate the effects of the environmental variables independent of farm-specific management practices.

Results:

Cluster Analysis Results

Initial hierarchical cluster analysis divided the dataset into five distinct clusters (Figure 3). Cluster one included only the variable average soil compaction, underscoring their potential as a unique explanatory variable for further analysis. Vegetative measures (average and maximum vegetation height, forb diversity, and forb and total ground cover percentages) defined cluster two, in addition to one management-related variable, days since last graze. Cluster three was characterized by the minimum vegetation heights and invertebrate data including the abundance of pitfall-captured total arthropods and Formicidae. Temperature data variations were the sole focus of cluster four, distinguished from others by their specific environmental factor. The fifth cluster was an assemblage of various variables including the remaining variables, a mix of management decision, environmental, and ecological response variables.

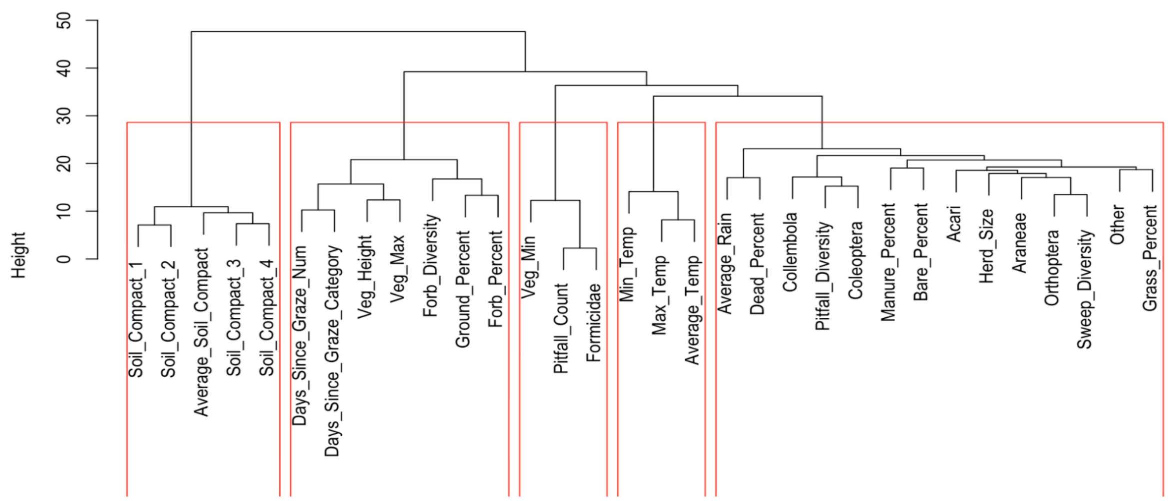

Figure 3. Dendrogram depicting five clusters in red brackets, using Euclidean distances to illustrate the similarities and distinctions, based on cluster analysis of all collected variables — both independent and dependent.

In developing multivariate models, additional subdivisions of clusters were taken into consideration, adhering to the methodological guideline of 1 to 10 events per variable as recommended by Peduzzi et al. (1996), to ensure the construction of robust models. Refining the clustering for analytical precision as demonstrated in Figure 4, we subdivided the initial clusters. This led to the segregation of ground cover percentage and forb-related variables into an independent sub-cluster derived from cluster two. The substantial fifth cluster was further divided into five subclusters: 1) average rainfall and dead plant cover percentage; 2) a collection of arthropod-related metrics; 3) manure and bare ground percentages; 4) a mix of Acari, herd size, specific arthropods (Araneae, Orthoptera), and sweep net diversity; and 5) the remaining variables (Figure 4).

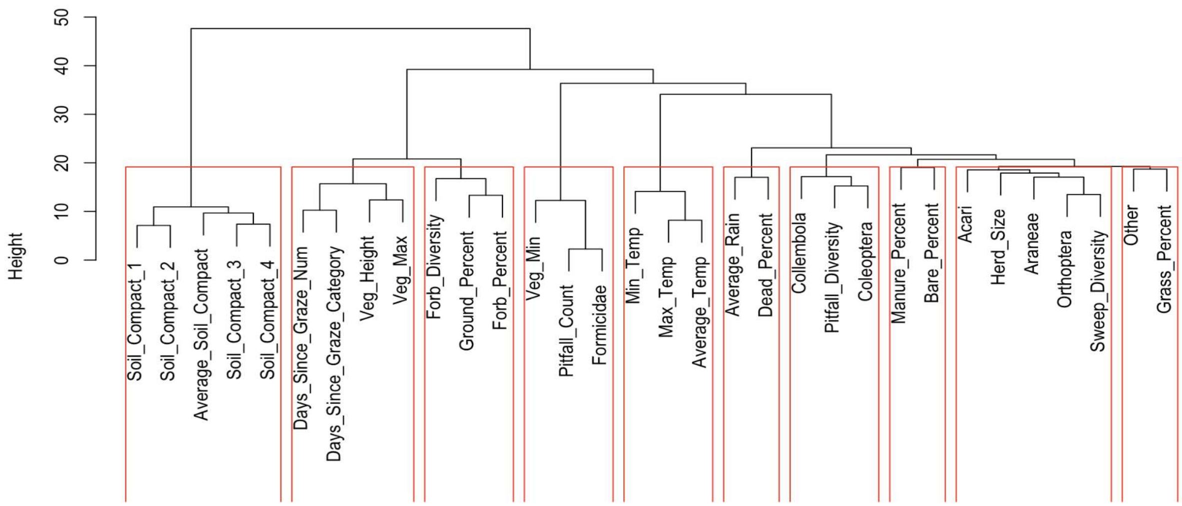

Figure 4. Refined sub-division of the initial clusters into ten distinct groups, providing a detailed framework for subsequent multivariate analysis. This breakdown is essential for identifying inter-variable relationships and selecting variables that best represent the ecological and management factors under study.

The PCA results, shown in Figure 5, guided the narrowing of ecological response variables from 21 to 9 variables for inclusion in future models. These included six vegetation community measures (vegetation height, percent ground cover, percent bare ground, percent dead/trampled vegetation, percent grass, percent manure, and forb diversity) and three arthropod community measures (arthropod diversity from pitfall traps and sweepnets, and arthropod abundance from pitfall traps). Variables were selected for their significant loadings on both the first and second principal components, indicating that they account for a substantial proportion of the data variance. Additionally, the selected variables represent the distinct clusters identified in both the PCA and cluster analysis, ensuring comprehensive coverage of the data's inherent structure in the reduced variable set.

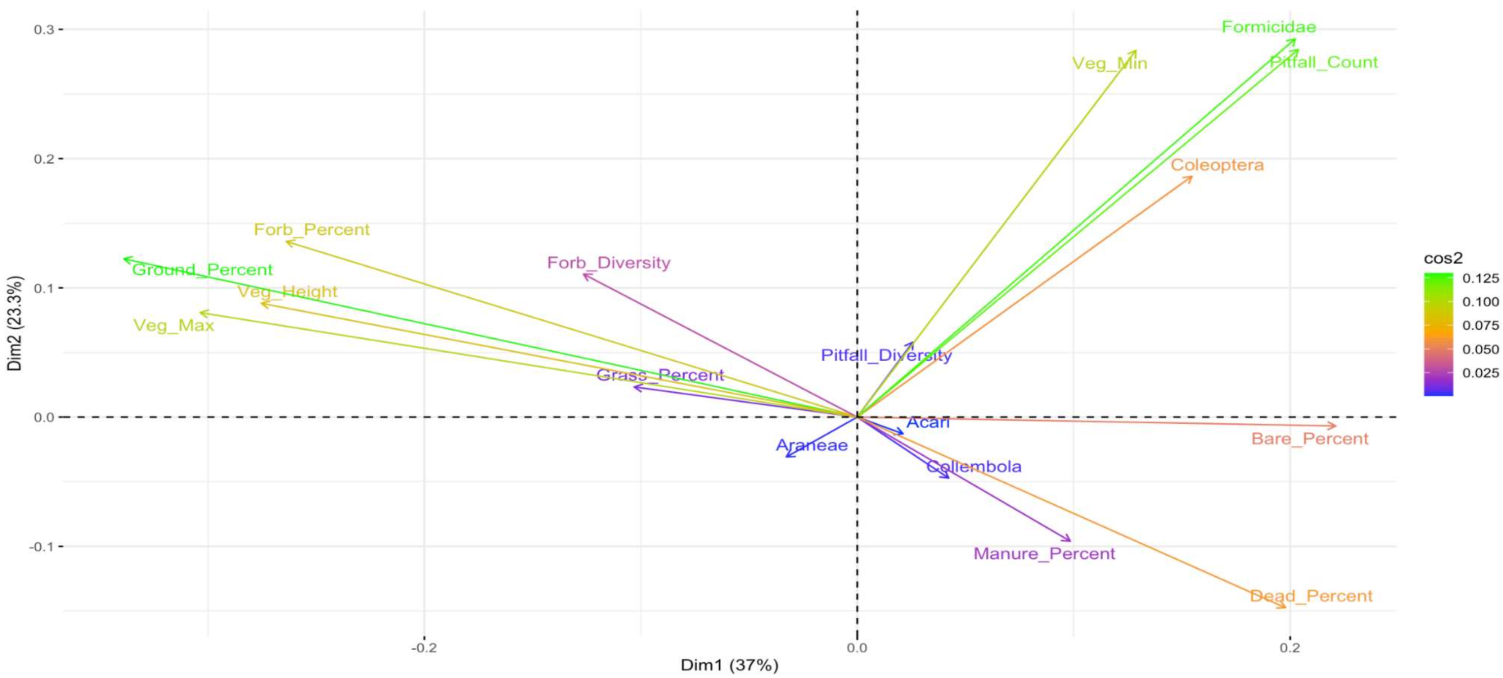

Figure 5. PCA visualization of relationships between all ecological variables considered for factor minimization.

Response to management decisions:

Days since last grazed

Several measures of pasture recovery significantly increased with the increasing intervals of the number of days since last grazing. Vegetation height ($\beta = 0.0427$, $t = 10.164$, $p < 2e-16$), overall percent ground cover ($\beta = 0.0193$, $t = 8.313$, $p < 2e-16$), forb diversity ($\beta = 0.1558$, $t = 4.981$, $p < 1e-06$), and percent grass cover ($\beta = 0.0127$, $t = 3.861$, $p = 0.0002$) all showed an increase over time (Figure 6). The elapsed time since grazing explained a relatively high amount of variation in vegetation height (39%) and ground cover (32%). Conversely, the percent of dead material cover significantly decreased with more days since last grazing ($\beta = -0.0247$, $t = 11.791$, $p < 2e-16$, $R^2 = 0.4738$) (Figure 6).

Farms had a significant effect on the relationship between interval since last graze and percent groundcover ($p = 0.00112$). This is reflected in the difference in ground cover among intervals for each farm (Fig. 6a), with Whitney Farm exhibiting a quicker recovery of ground cover, achieving over 75% in the 16-40 day period, whereas Shining Light Farm reached this level in the 41-60 day interval (Fig. 6a). Other ecological response variables also had a significant effect of farm on the relationship with days since last graze: forb diversity ($p = 1.56e-07$), dead percent ($p = 1.73e-07$) and grass percent ($p = 0.000423$)

Two of the three arthropod community measures increased significantly with days since graze: diversity measured by sweep netting ($\beta = 0.0420$, $t = 2.753$, $p = 0.0065$) and diversity from pitfall trap samples ($\beta = 0.2146$, $t = 2.957$, $p = 0.0036$; Figure 7a and 7c), while arthropod abundance from pitfall traps had a similar but non-significant trend ($t = 0.674$, $p = 0.501$; Figure 7b). However, in contrast to the patterns observed for vegetation measures, these arthropod diversity metrics did not exhibit a significant effect of farm.

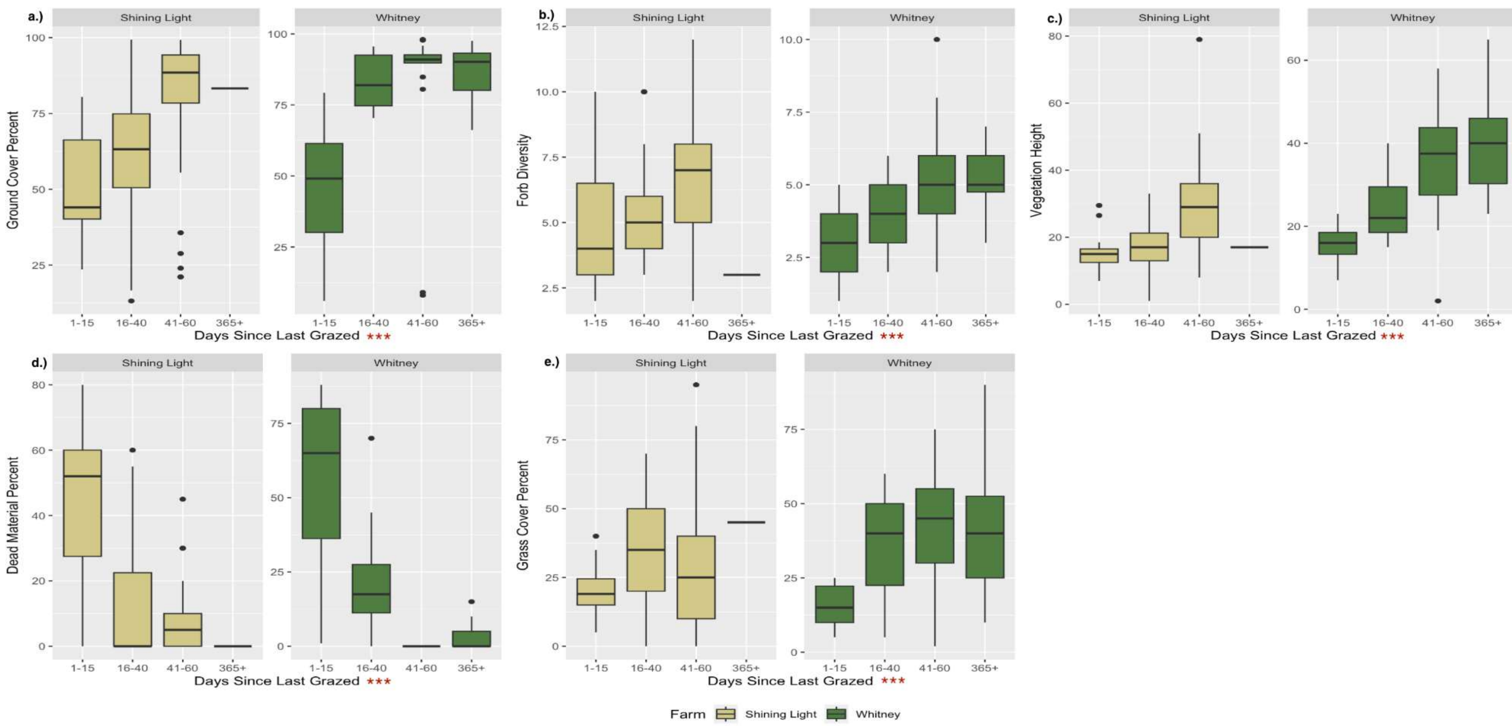

Figure 6. Relationship between the management decision days since last graze as a category (1-15, 16-40, 41-60 days, and greater than 1 year) and vegetative responses : a) overall ground cover percentage, as measured using Canopeo, b) forb diversity, c) most common vegetation height, d) dead/trampled vegetation cover percentage, e) grass cover percentage.

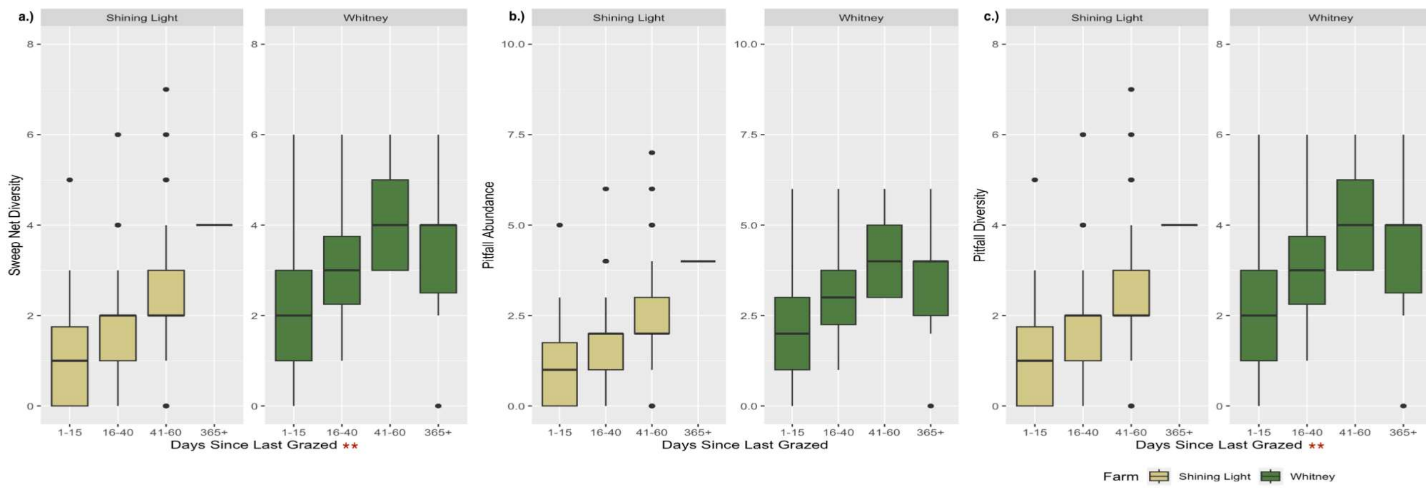

Figure 7. Relationship between the management decision of days since last graze and arthropod community responses: a) arthropod diversity found with sweep net, b) arthropod abundance from pitfall traps, c) arthropod diversity from pitfall traps.

Livestock type

When examining the ecological impact of different livestock species, five response variables showed signs of significant relationships: vegetation height, ground cover percent, forb diversity, manure percent, and grass percent. Vegetation measurements indicated that areas grazed by sheep were associated with taller vegetation (cattle: diff = 11.9772, $p < 0.001$; chickens: diff = 16.2339, $p < 0.001$; Figure 8a) and greater ground cover (cattle: diff = 14.6788, p = 0.0399; chickens: diff = 20.8927, p = 0.0094) compared to both cattle and chickens (Figure 8b). Areas grazed by sheep (diff = 2.1569, p = 0.0005) and cattle (diff = -2.6648, $p < 0.001$) both had higher forb diversity than those with chickens (Figure 8c). Percent grass cover was significantly lower when grazed by cattle than by chicken (diff = 15.0303, p = 0.0011) or sheep (diff = 13.1406, p = 0.0467) (Figure 8d).

Chicken-grazed sites exhibited a 3.6% increase in manure cover compared to cattle-grazed sites (p = 0.0461). However, in contrast to the pronounced species effects on vegetation parameters, no significant effects of grazer species on arthropod community measures were detected for pitfall trap counts, pitfall trap diversity, or sweep net diversity.

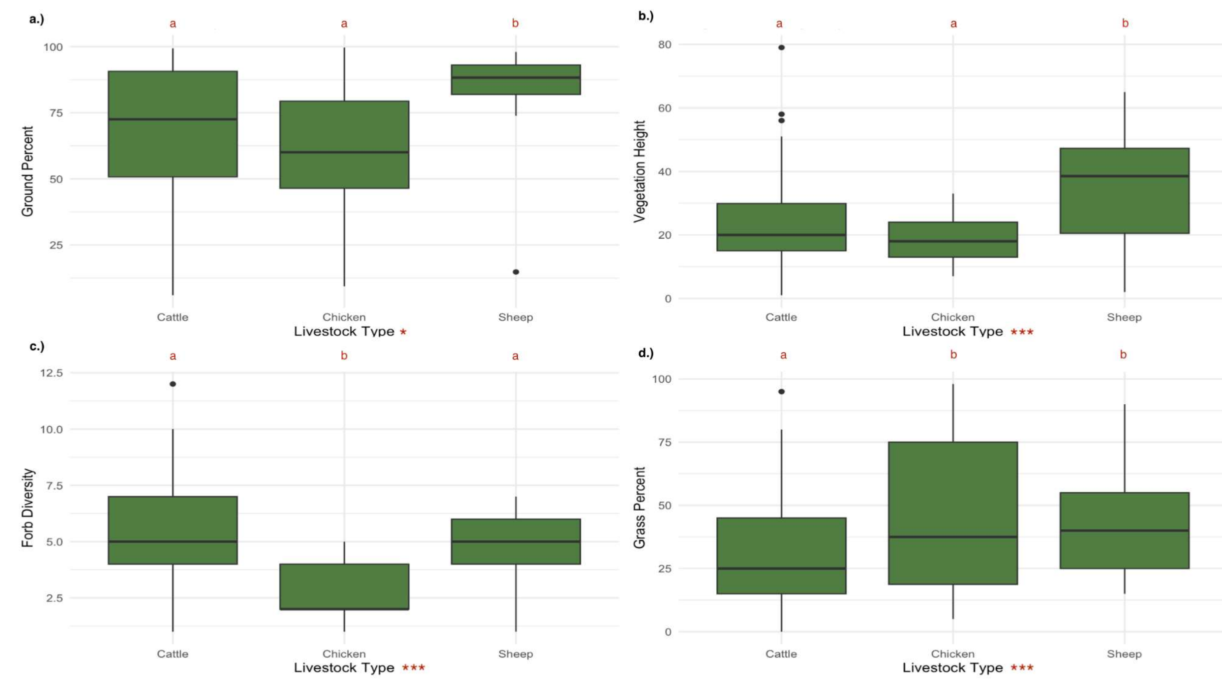

Figure 8. Effect of livestock type on : a) percent groundcover, b) vegetation height, c) forb diversity, d) grass percent. Different letters denote significant differences within each graph.

Frequency of return to paddock

The number of times a particular paddock was grazed over a single season was associated with a decrease in vegetation height, explaining 20.8% of the variance ($p = 9.6e-12$) (Figure 9). Ground cover percentage ($p = 0.0052$), forb diversity ($p = 0.0022$), and grass cover percentage ($p = 0.0338$) also decreased with increased grazing frequency, although they explained much less variance, with no values exceeding 5% (Figure 9). In contrast, the amount of dead vegetation present increased with more frequent grazing ($p = 2.14e-05$; $R^2 = 0.0853$) (Figure 9). There was no significant association found between any of the arthropod variables collected and grazing frequency.

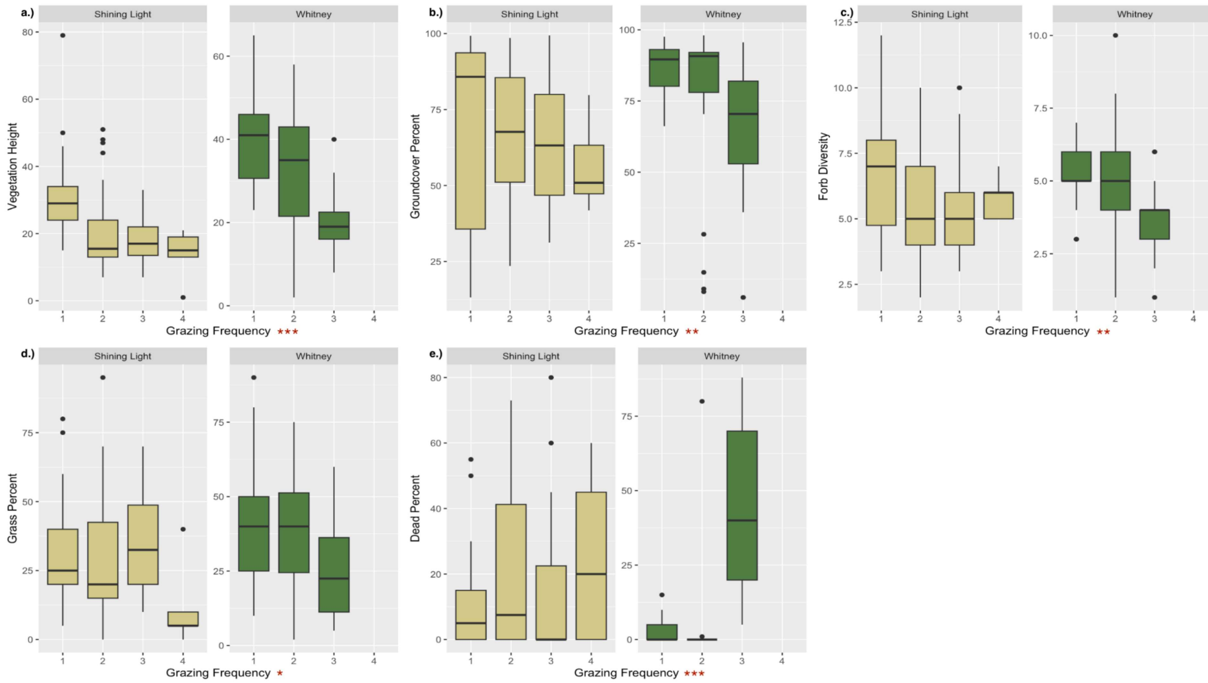

Figure 9. Relationship between the management decision of grazing frequency and vegetative community responses: a) vegetation height, b) percent groundcover, c) forb diversity, d) grass percent cover, and e) dead vegetation percent cover.

Precipitation & Soil compaction

Unlike the management decision variables, the environmental variables–specifically weekly average precipitation and soil compaction–did not explain a large amount of variance in the vegetation responses, with none above a 10% variance explained. Nonetheless, a significant positive association was found between the previous week's average precipitation and grass cover percentage ($p = 3.27e-06$) as well as dead plant material percentage ($p = 0.0013$). Forb diversity showed a significant negative relationship with the previous week's average precipitation ($p = 0.0357$). An increase in soil compaction was associated with an increase in total percent ground cover ($p = 0.0278$) and forb diversity ($p = 0.0006$), but a decrease in dead vegetation cover percentage ($p = 0.0024$).

Discussion

In this study, we investigated the ecological consequences of specific intensive rotational grazing management practices, allowing for a more farm-specific analysis. By examining two farms with similar stocking rates and grazing durations—Whitney Farm and Shining Light Farm—we aim to delineate the effects of other specific grazing management decisions on ecological outcomes, such as arthropod and vegetation diversity. With some portions of rotational grazing management controlled in this study, we were able to explore our research questions of ecological variation that may occur due to intervals of days between grazes, grazing frequency, livestock type, and even outside environmental factors. While farmers within this category of rotational grazing can adopt a wide variety of practices, our study provides a glimpse of the significant differences that may exist between farms categorized the same in larger studies.

A salient finding from our analysis illuminates a portion of the mechanisms behind our research question of the ecological effect of variation in days since grazed on vegetative and arthropod communities. Our linear models indicated a clear positive relationship between the days since grazed and the health of vegetative communities. Specifically, extended intervals between grazing periods were associated with notable improvements in vegetative regrowth, as evidenced by increased ground cover and vegetation height. This aligns with findings from Pereira et al. (2020), where rest periods of varying lengths—24, 35, and 46 days—were evaluated for their impact on pasture; a rest period of 24 days was found to result in the highest biomass production and nutritional value. Similarly, this positive correlation with vegetative growth supports observations by Billman et al. (2020), who noted that rotational grazing led to greater pregrazing biomass and favored grass compositions, indicating its suitability for producing consistent, high-value forage in temperate grass-legume pastures.

Furthermore, when assessing the days since grazing as a categorical variable, our study observed differing recovery trends across the defined intervals—1-15, 16-40, 41-60, and 365+ days. For instance, Whitney Farm displayed swift restoration of ground cover within the 16-40 day interval, while Shining Light Farm required a longer rest period of 41-60 days to achieve similar ground cover levels. These differing recovery rates across the farms suggest the presence of unaccounted management factors that may be at play.

However, Lagendijk et al. (2017) highlight that in rotational grazing systems managed over a six-year period, changes in vegetation biodiversity were minimal, pointing to the potential benefits of fallow periods, especially in marshlands with cattle grazing. This contrasts with our study's findings regarding biomass and suggests that biodiversity responses might be context-dependent, possibly varying with ecosystem type and management history. Overall, the collective evidence underscores the complexity of gauging ecological responses to grazing practices and the necessity for more nuanced management strategies that consider both recovery intervals and ecosystem conservation goals.

Our study suggests that under similar rotational grazing parameters, ecological responses such as ground cover regeneration can differ significantly between farms. Although arthropod and vegetation diversity remained relatively unchanged across both farms, the variations in ground cover recovery rates point towards underlying differences in farm management practices. These could include grazing species, grazing frequency, and soil compaction, among others.

The examination of livestock type as a variable revealed that different species exert distinct effects on vegetation, with sheep grazing leading to greater vegetation height, increased ground cover, and enhanced forb diversity compared to cattle and chickens. Variations in manure and grass cover percentages further exemplify the unique impacts of different grazers on grassland ecosystems. A significant difference was found overall between grazing species; however, analyzing only cattle (the only species present on both farms) showed the relationship between ground cover percentage and days since last grazed to be similar to the linear regression that included all grazing species. This indicates that the difference in ground cover response is not solely attributable to the species grazing or pasture variation. However, it could also be attributed to the higher representation of cattle in the dataset.

For the question of how grazing frequency, or the amount of times grazing returned to a paddock, the results suggest that higher grazing frequency detrimentally impacts some measures of pasture health, potentially due to repeated disturbances impeding vegetation regrowth. However, the observed trend might not fully capture the actual patterns due to potential sampling bias or uncontrolled variables, as reflected by the low explanatory power of most models analyzing grazing frequency. The results of the relationship between grazing frequency and vegetation height, the only model with high R^2 value, may be impacted by variation due to the change in season rather than repeated disturbance. That is, more frequent returns coincided with later in the season, during which vegetative growth tends to slow. To more accurately assess this variable, a more comprehensive dataset may be required.

The analysis identified two primary variables—soil compaction and grazing history—as possible influences on the relationship between days since grazed and ground cover percent. Soil compaction was found to be significantly related to ground cover percent and forb diversity. Despite conventional wisdom suggesting that increased compaction typically reduces plant productivity, our data associated higher compaction with enhanced ground cover. This unexpected result raises the question of whether soil characteristics associated with type, rather than compaction itself, might be more crucial to pasture recovery. Whitney Farm, with its silty clay soil, consistently demonstrated higher levels of soil compaction yet also exhibited better vegetative recovery post-grazing compared to Shining Light Farm, which has sandy loam soil with less compaction but also less favorable recovery conditions.

Moreover, land use history, not accounted for in a single season's management, can have long-term effects. Whitney farm in comparison to Shining Light has had multiple seasons of being under rotational grazing management. Therefore, giving it time to gain the possibly regenerative benefits that are suggested by this study and others (Briske et al., 2011). If differences in post-grazing ground cover regrowth are not fully explained by soil compaction results, then the length of land use for grazing may also be a contributing factor. Whitney Farm's quick ground cover recovery, compared to Shining Light Farm, may stem from their different grazing histories. This points to the necessity for further research into how the duration of rotational grazing practices might alter optimal reintroduction times for grazing based on pasture recovery conditions.

Our study's examination of the immediate effects of rotational grazing on the insect community, particularly arthropod diversity, indicated that the only significant relationship was with the intervals between grazing events. This suggests that the practice of intensive rotational grazing might have limited immediate impact on arthropod populations. Aligning with this, Klink et al. (2014) propose that enhanced arthropod diversity is contingent upon the extent of heterogeneity generated by grazing practices. According to their review, an increase in arthropod diversity from grazing occurs only when the created habitat heterogeneity sufficiently offsets the decrease in total resource abundance and the rise in mortality rates. Thus, our findings may reflect a situation where the altered heterogeneity in pasture due to specific grazing management has not reached the threshold necessary to promote a significant increase in arthropod diversity. However, a long term trend of increased diversity of arthropods, specifically foliar and dung-associated species, has been documented in areas with multipaddock grazing in comparison to continuous grazing (Schmid et al., 2024). This finding prompts exploration into which specific rotational grazing management decisions could promote biodiversity and requires long-term research to better understand the dynamics.

From an agricultural management perspective, a history of rotational grazing can foster faster regrowth and pasture resilience, offering farmers economic benefits like reduced reliance on external feed and land rentals. Early implementation of rotational grazing in a farm's planning could be strategic for long-term ecological and economic health, balancing immediate productivity with the goal of sustaining ecosystem health for agricultural longevity.

While the overall question of how much variation intensive rotational grazing management can affect overall pasture health remains, we call for further research into the complex interplay of soil texture, plant growth, and grazing methods, as well as the long-standing influence of prolonged rotational grazing on soil and insect communities. Insights into the financial ramifications of different grazing techniques and more targeted recommendations for grazing strategies would support farmers in optimizing both ecological and economic outcomes.

In summary, the analysis of within and between farm variation in this study underscores the potential for specific management decisions within intensive rotational grazing systems to differentially affect pasture recovery, arthropod responses, and broader operational and ecological considerations. It is this type of study, along with future questions of the impact of site variation on pasture health and management, that have potential to better inform farmers on the best practices for their fields. Comprehensively exploring these intricate relationships through long-term research that integrates various dimensions of agricultural science and practice remains a crucial next step.

Conclusion

Our study sheds light on just a sample of the complex ecological dynamics of intensive rotational grazing and emphasizes the need for a nuanced understanding of such practices on a granular level. The findings from the comparative analysis of Whitney Farm and Shining Light Farm call attention to the significant variations that can manifest even within seemingly similar grazing systems. These differences possess the potential to exert profound effects on pasture recovery and, by extension, the ecological health and sustainability of the farming practice.

By uncovering the differential effects of grazing intervals, soil compaction, and land use history on vegetation recovery and the minimal impact on arthropod populations, this research demonstrates that intensive rotational grazing cannot be uniformly applied or generalized. Each farm's unique environmental conditions, management practices, and historical land usage necessitate individualized approaches to rotational grazing – approaches that optimize ecological benefits while also considering economic viability.

The insights gleaned from our study serve as a critical resource for advancing the current body of knowledge on rotational grazing practices. However, translating these scientific findings into practical applications for day-to-day farming requires a bidirectional exchange of knowledge. It is imperative that we integrate the empirical data and scientific analyses from studies like ours with the rich, experiential knowledge of farmers. By doing so, we can jointly identify knowledge gaps and refine research designs to address practical challenges faced in the field and more sufficiently assess and support the the future of regenerative ranching.

References

Adhikari, S., & Menalled, F. D. (2020). Supporting beneficial insects for agricultural sustainability: The role of livestock-integrated organic and cover cropping to enhance ground beetle (Carabidae) communities. Agronomy, 10(8), 1210.

Armstrong, J., & Heins, B. (2021). Grazing and pasture management for cattle. University of Minnesota.
Ascencio-Álvarez, A., Martín, R., Tucuch-Haas, J., Valdez-Carrasco, J., Huchin, E., Andrade-Canto, S., Gámez-Vázquez, A., & Larqué-Saavedra, A. (2015). Gall (Trioza rusellae Tuthill) insect identification in Brosimum alicastrum Swartz leaves in Yucatán, Mexico. Revista Chapingo Serie Ciencias Forestales y Del Ambiente, XXI, 123–132.

Badgery, W., Millar, G., Broadfoot, K., Martin, J., Pottie, D., Simmons, A., & Cranney, P. (2017). Better management of intensive rotational grazing systems maintains pastures and improves animal performance. Crop and Pasture Science, 68(12), 1131-1140.

Barry, S., & Huntsinger, L. (2021). Rangeland land-sharing, livestock grazing's role in the conservation of imperiled species. Sustainability, 13(8), Article 8.

Batary, P., Orci, K. M., Baldi, A., Kleijn, D., Kisbenedek, T., & Erdos, S. (2007). Effects of local and landscape scale and cattle grazing intensity on Orthoptera assemblages of the Hungarian Great Plain. Basic and Applied Ecology, 8(3), 280–290.

Billman, E. D., Williamson, J. A., Soder, K. J., Andreen, D. M., & Skinner, R. H. (2020). Mob and rotational grazing influence pasture biomass, nutritive value, and species composition. Agronomy Journal, 112(4), 2866-2878.

Briske, D. D., Sayre, N. F., Huntsinger, L., Fernández-Giménez, M., Budd, B., & Derner, J. D. (2011). Origin, persistence, and resolution of the rotational grazing debate: integrating human dimensions into rangeland research. Rangeland Ecology & Management, 64(4), 325-334.

Erb, K.-H., Fetzel, T., Kastner, T., Kroisleitner, C., Lauk, C., Mayer, A., & Niedertscheider, M. (2016). Livestock grazing, the neglected land use. In H. Haberl, M. Fischer-Kowalski, F. Krausmann, & V. Winiwarter (Eds.), Social Ecology: Society-Nature Relations across Time and Space (pp. 295–313). Springer International Publishing.

Farruggia, A., Dumont, B., Scohier, A., Leroy, T., Pradel, P., & Garel, J. P. (2012). An alternative rotational stocking management designed to favour butterflies in permanent grasslands. Grass and Forage Science, 67(1), 136-149.

Ferreira, Pedro M. A., Bianca O. Andrade, Luciana R. Podgaiski, Amanda C. Dias, Valério D. Pillar, Gerhard E. Overbeck, Milton de S. Mendonça Jr, and Ilsi I. Boldrini. "Long-Term Ecological Research in Southern Brazil Grasslands: Effects of Grazing Exclusion and Deferred Grazing on Plant and Arthropod Communities." PLOS ONE15, no. 1 (January 13, 2020): e0227706.

Franke, A. C., & Kotzé, E. (2022). High-density grazing in southern Africa: Inspiration by nature leads to conservation?. Outlook on Agriculture, 51(1), 67-74.

Ganche, E., O'Donovan, M., Delaby, L., Boland, T. M., & Kennedy, E. (2015). Does post-grazing sward height influence sward characteristics, seasonal herbage dry-matter production and herbage quality? Grass & Forage Science, 70(1), 130–143.

Gonzalez-Hernandez, M. P., Mouronte, V., Romero, R., Rigueiro-Rodriguez, A., & Mosquera-Losada, M. R. (2020). Plant diversity and botanical composition in an Atlantic heather-gorse dominated understory after horse grazing suspension: Comparison of a continuous and rotational management. Global Ecology and Conservation, 23, e01134.

Herrero, M., Henderson, B., Havlík, P., Thornton, P. K., Conant, R. T., Smith, P., Wirsenius, S., Hristov, A. N., Gerber, P., Gill, M., Butterbach-Bahl, K., Valin, H., Garnett, T., & Stehfest, E. (2016). Greenhouse gas mitigation potentials in the livestock sector. Nature Climate Change, 6(5), Article 5.

Hohbein, R. R., & Conway, C. J. (2018). Pitfall traps: A review of methods for estimating arthropod abundance. Wildlife Society Bulletin, 42(4), 597–606.

Jáuregui, J. M., Delbino, F. G., Bonvini, M. I. B., & Berhongaray, G. (2019). Determining yield of forage crops using the Canopeo mobile phone app. Journal of New Zealand Grasslands, 41–46.

Jansen, A., & Healey, M. (2003). Frog communities and wetland condition: relationships with grazing by domestic livestock along an Australian floodplain river. Biological Conservation, 109(2), 207-219.

James, R. E. (2011). Replacement Management in Cattle | Growth Diets. In J. W. Fuquay (Ed.), Encyclopedia of Dairy Sciences (Second Edition) (pp. 403–409). Academic Press.

Lagendijk, D. G., Howison, R. A., Esselink, P., Ubels, R., & Smit, C. (2017). Rotation grazing as a conservation management tool: Vegetation changes after six years of application in a salt marsh ecosystem. Agriculture, Ecosystems & Environment, 246, 361-366.

Pereira, F. C., Machado Filho, L. C., Kazama, D. C., Júnior, R. G., Pereira, L. G., & Enríquez-Hidalgo, D. (2020). Effect of recovery period of mixture pasture on cattle behaviour, pasture biomass production and pasture nutritional value. animal, 14(9), 1961-1968.

Pulsford, S. A., Barton, P. S., Driscoll, D. A., & Lindenmayer, D. B. (2019). Interactive effects of land use, grazing and environment on frogs in an agricultural landscape. Agriculture, ecosystems & environment, 281, 25-34.

Reisinger, A., & Clark, H. (2018). How much do direct livestock emissions actually contribute to global warming?. Global change biology, 24(4), 1749-1761.

Roche, L. M., Cutts, B. B., Derner, J. D., Lubell, M. N., & Tate, K. W. (2015). On-Ranch Grazing Strategies: Context for the Rotational Grazing Dilemma. Rangeland Ecology & Management, 68(3), 248–256.

Sánchez‐Bayo, Francisco, and Kris AG Wyckhuys. "Further evidence for a global decline of the entomofauna." Austral Entomology 60.1 (2021): 9-26.

Schieltz, J. M., & Rubenstein, D. I. (2016). Evidence-based review: Positive versus negative effects of livestock grazing on wildlife. What do we really know? Environmental Research Letters, 11(11), 113003.

Schmid, R. B., Welch, K. D., Teague, R., & Lundgren, J. G. (2024). Adaptive Multipaddock (AMP) Pasture Management Increases Arthropod Community Guild Diversity Without Increasing Pests. Rangeland Ecology & Management, 94, 141-148.

Solascasas, P., Azcárate, F. M., & Hevia, V. (2022). Edaphic arthropods as indicators of the ecological condition of temperate grassland ecosystems: A systematic review. Ecological Indicators, 142, 109277.

Sondakh, D. S. I., Tulungen, F. R., Kampilong, J. K., Rumondor, F. S. J., Kawuwung, Y. S., & Sanggelorang, E. P. (2024). Estimation of livestock greenhouse gas for impact mitigation. Global Journal of Environmental Science and Management, 10(2), 857-872.

Steinfeld, H., Gerber, P., Wassenaar, T. D., Nations, F. and A. O. of the U., Castel, V., Rosales, M., M, M. R., & Haan, C. de. (2006). Livestock's Long Shadow: Environmental Issues and Options. Food & Agriculture Org.

van Klink, R., van der Plas, F., Van Noordwijk, C. G. E., WallisDeVries, M. F., & Olff, H. (2015). Effects of large herbivores on grassland arthropod diversity. Biological reviews, 90(2), 347-366.

Whitt, C., & Wallander, S. (2022). Study Examines How and Where US Cow-Calf Operations Use Rotational Grazing. Amber Waves: The Economics of Food, Farming, Natural Resources, and Rural America, 2022.