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Enhancing Semi-Arid Ecosystem Resilience in Jordan Using Controlled Grazing – A Short and Long-Term Assessment

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ABSTRACT

Grazing management strategies in arid ecosystems are of critical importance to regulate plant regeneration, improve forage quality, and ensure sustainable utilization of rangelands. This study examined the impacts of controlled grazing management on vegetation dynamics (gain/loss) and land cover changes over a 17-year period (2006–2022) at the Royal Botanic Garden, Jordan. Climatic factors, including precipitation and temperature, were analyzed alongside the Normalized Difference Vegetation Index (NDVI) to assess vegetation health and greenness. Autoregression models were used to investigate annual temporal trends between vegetation biodiversity indices and climatic factors. To assess the impact of controlled grazing on vegetation biodiversity, the study period was divided into four periods: the initial period (period 0: 2006–2007) which represented the pre-dating-controlled grazing period, followed by three subsequent periods: period 1 (2008–2012), period 2 (2013–2017), and period 3 (2018–2022). Land cover analysis using yearly averaged NDVI values was assessed, including five distinct classes: water body, barren soil, herbaceous and shrub, open forest, and closed forest. The study identified short-term changes during period 1 and long-term changes during periods 2 and 3. The results revealed a significant annual temporal trend only in NDVI ($P<0.001$), indicating dynamic changes in vegetation health over the whole study period. A positive influence of controlled grazing on vegetation dynamics and biomass production was observed. During period 3, controlled grazing has led to a significant ($P<0.05$) increase in vegetation biomass compared to earlier periods (214.4 ton in period 3 compared to 97.1 and 106.8 ton in periods 1 and 2, respectively). NDVI also showed significantly higher values during the later periods of controlled grazing, emphasizing its positive impact on long-term vegetation health. Furthermore, the study showed interesting trends in plant groups and species, with short-term controlled grazing leading to increased species richness and significant changes in vegetation indices. Over the study period, controlled grazing influenced land cover dynamics, with significant decreases in barren soil (from 66.7% to 9.8%) and increases in herbaceous and shrubland areas (33.2% to 89.6%). The study concluded that controlled grazing significantly shapes plant communities, fostering dynamic changes in species and groups over time. The study provides valuable insights into the ecological impact of controlled grazing management. The obtained findings revealed vegetation resilience to short-term climate variations, with sustained vegetation health under grazing.

Keywords: plant biodiversity indices, NDVI, vegetation cover, vegetation health.

INTRODUCTION

Drylands encompass approximately 50% of the Earth's surface and are classified into different sub-categories based on the amount of rainfall, including dry sub-humid, semi-arid, arid, and hyper-arid regions (Dregne 2002). These drylands mainly comprise dry rangelands (Davies et al., 2015), which refer to uncultivated areas providing natural fodder essential for grazing and browsing animals. This definition excludes barren deserts, farmland, closed-canopy forests, as well as concrete or glacier-covered land (Herrera et al., 2014; Holechek et al., 2020; Lund 2007). However, managed grazing lands are the most common form of land use globally (Asner et al., 2004) and support approximately 50% of the global livestock (UN 2015).

Grazing management strategies encompass various techniques, such as adjusting stocking rates, grazing methods, and employing other factors to regulate plant defoliation by grazing animals (Derner et al., 2022). The primary factors influencing plant regrowth through defoliation are grazing frequency, intensity, and timing (Sollenberger et al., 2020). The primary objectives of a grazing manager involve maximizing plant growth, improving forage quality, and ensuring efficient utilization of forage by grazers. It is imperative to consider economic goals and employ sustainable management practices (Dubeux and Sollenberger 2020). Nevertheless, optimizing plant or animal productivity may not always be the most advantageous approach in terms of maximizing the economic and environmental benefits. The plant-animal interactions play a significant role in the dynamics of grazing lands across different spatial scales. The presence of controlled animal grazing practices drives higher vegetation heterogeneity in grazed lands due to selective grazing and waste deposition (Sándor et al., 2018; Zilverberg et al., 2018).

Jordanian lands are predominantly characterized by arid to semi-arid conditions, covering an area of around 89,000 km². According to agricultural law No. 20, which was first published in 1973, and agricultural law No. 13, published in 2015, the rangelands in Jordan are defined as "all lands registered as state-owned or designated for public use that receive less than 200 mm of rainfall and are not sustainably irrigated" (MoA 2013). The Jordan highlands encompass approximately 450,000 hectares of rangelands, accounting for 2.5% of Jordan's total rangeland area, and receive an annual rainfall exceeding 250 mm. These highland pastures are typically found in small patches near villages in the Ajloun and Jerash governorates. The most significant grazing plants in these lands include clover, vetch, wild wheat, wild barley, and oak trees. Livestock grazing plays a significant role in the agricultural landscape of Jordan and holds deep cultural importance for the Bedouin people (Al-Tabini and Al-Khalidi 2022). However, the health of rangelands in Jordan is a pressing concern, with forage production estimated to be less than 10% of its potential levels (Al-Tabini et al., 2012). Several factors contribute to the degradation and decline of rangeland conditions (Msadek et al., 2022; Sawalhah et al., 2018), including heavy stocking rates, continuous grazing, dryland cultivation, urbanization, and prolonged drought (Al-Tabini 2001).

Numerous rehabilitation and restoration initiatives have been implemented in the degraded rangelands (Badia) of Jordan, but it remains uncertain whether these efforts successfully contributed to restoring the ecosystems to their original conditions (Strohmeier et al., 2017). Conversely, the highland rangelands have received less attention in terms of restoration and management efforts, raising concerns about their sustainability and transitional state. The lack of knowledge regarding the baseline conditions of rangelands further complicates restoration endeavors (Al-Karadsheh et al., 2012; Juneidi and Abu-Zanat 1993). While historical vegetation types are known, it is crucial to acquire the information on the spatial and temporal distributions of rangeland vegetation for effective management and restoration. Unfortunately, Jordan's first native plant species checklist as well as the Jordan Plant Red List Volumes 1 and 2 were only published in 2015 and 2017, respectively, providing only rough estimates of the flora coverage and threatened status in Jordan (Taifour 2017; Taifour and El-Oqlah 2015; Taifour and El-Oqlah 2017). Therefore, the objective of this study was to assess the effectiveness of long-term controlled grazing as a viable rangeland management approach for enhancing semi-arid ecosystem resilience through vegetation dynamics (gain/loss) and land cover changes over a 17-year period.

MATERIALS AND METHODS

Study area

The study was conducted at the Tall Al-Rumman site in Jordan. The site is located in the northwestern part of Jordan at latitude (32.183616°) and longitude (35.825542°) (Figure 1). The site is a remnant of a previously widespread pine-oak forest habitat. The site was managed as a Botanic Garden by the Royal Botanic Garden (RBG), Jordan, since its establishment in 2008. The study

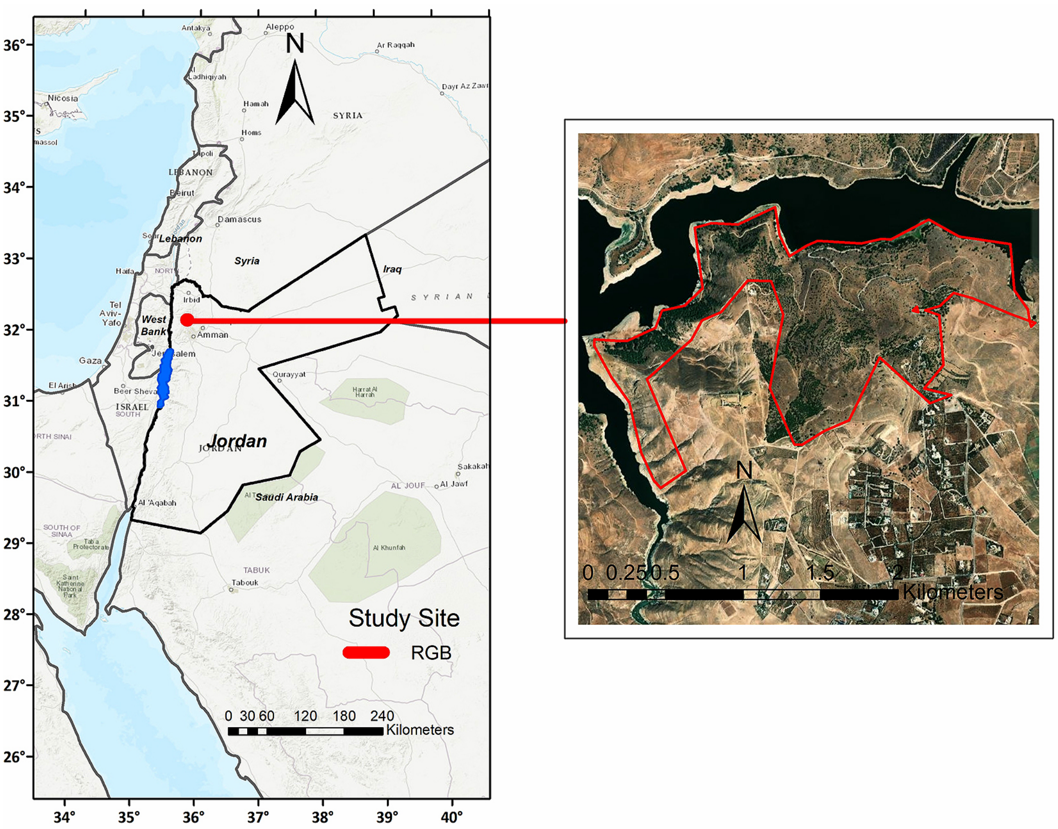

Figure 1. The Tall Al-Rumman Royal Botanic Garden (RBG) study site in Jordan

site area covers 1907 dunam, and its elevation ranges from 150 to 450 m above sea level. Since establishment, managed sheep grazing has been applied during the summer and autumn seasons based on biomass estimation. The climate is semi-arid, with warm summers and cold winters, and it receives a mean annual precipitation of 360 mm, with almost all of it occurring during the winter season (November to March). The temperature varies by season, reaching 4 °C or less in winter and rising up to 40 °C or more in summer.

Vegetation data analysis

The vegetation data was assessed to discover the effectiveness of rehabilitation processes on the study site. Under managed conditions without disturbances, vegetation-dynamic changes typically occur gradually. To gauge the impact of controlled grazing on vegetation biodiversity, the study period from 2006 to 2022 was divided into four distinct periods. The first period (2006–2007, denoted as period 0) represented the time before the implementation of controlled grazing. Subsequently, the remaining study period was divided into five-year intervals to include period 1 (2008–2012), period 2 (2013–2017), and period 3 (2018–2022). In addition to that, the study suggested a short-term response that has occurred within period 1 (2008–2012) and a long-term response that has occurred within periods 2 (2013–2017) and 3 (2018–2022).

The annual vegetation data was retrieved from the RBG database. Additionally, the biomass production data were estimated according to the number of sheep allowed to graze and the number of grazing days per year. This allowed the calculation of the carrying capacity, which indicates the number of sheep that can be supported by the available forage. Carrying capacity was calculated based on the estimated sheep feed intake in terms of dry matter per sheep per day. The sheep's intake was determined to be 2.5% of its body weight (Holechek et al., 2011). The final carrying capacity, expressed in Animal Unit Months (AUMs), was calculated based on the assumption of an average Awassi ewe weighing 60 kilograms. This translates to an estimated daily dry matter feed intake of 1.5 kg, resulting in a monthly requirement of 45 kg. Furthermore, to assess and compare the changes among different plant life groups, the vegetation life forms were classified into four groups: perennial (including Chamaephyte, Climber, Geophyte, Halophyte, Hemicryptophyte, and Parasitic plant), annuals, shrubs, and trees.

Vegetation biodiversity indices are numerical measures used to quantify and assess the diversity of living organisms in a specific area or ecosystem. These indices provide valuable insights for ecologists, conservationists, and researchers to understand the composition and distributions of plant species within a given habitat. During the study period, four different indices were utilized to assess and quantify changes in vegetation. These indices included the percentage of change, the number of plant species gained, the number of plant species disappeared, and the Jaccard similarity index (Kaarlejärvi et al., 2021). The percentage of change serves as a measure of relative variation in the number of plant species between two specific time periods (Eq. 1). To track the appearance of new plant species, the gain index was employed, representing the total count of plant species that emerged in the current time frame but were not present in the previous time (Eq. 2). Conversely, the loss index quantifies the number of plant species that were present in the previous time but are absent in the current time (Eq. 3). To assess the similarity between the current and previous time periods, the Jaccard similarity index was used. This index assesses the extent of shared and distinct plant species between the two studied periods. A Jaccard similarity index ranges from 0% to 100%, with 0% indicating no shared species and 100% representing complete similarity or an identical set of species composition between the two communities or sites being compared (Eq. 4).

$$PC = \frac{\#PSCP - \#PSPP}{\#PSPP} \times 100\% \quad (1)$$

where: PC – percentage change, $\#PSCP$ – of plant species in the current period, $\#PSPP$ – of plant species in the previous period

Gain = # of plant species found in current period but not existing in the previous period (2)

Loss= # of plant species found in previous period but not existing in the current period (3)

$$JI = \frac{NP}{TNP} \quad (4)$$

where: JI – Jaccard Index, NP – number of shared plant species between current and previous period, TNP – total number of plant species in both period.

In this study, the annual temporal trend analysis was conducted using the normalized difference vegetation index (NDVI) data to investigate changes in different vegetation classes at the study site. The yearly average NDVI values were retrieved from the Earth Map website (https://earthmap.org/), while the NDVI values used to develop land cover change maps and calculate land cover change areas were acquired from Landsat 5–8 satellite images (30 m). The satellite data was obtained from the Earth Explorer portal (http://earthexplorer.usgs.gov).

The NDVI values were calculated according to the formula shown in Eq. 5, where "NIR" represents the reflectance in the near-infrared band, and "Red" represents the reflectance in the red band. To conduct the classification and calculate the area of each vegetation class for each study period, the study utilized the cell statistics and reclassify tools within the spatial analysis toolbox in ESRI's ArcMap 10.6 software.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (5)$$

The NDVI analysis was performed for each year around the end of the growing season, which facilitated tracking changes in vegetation cover over time effectively. This approach helped gain valuable insights about the dynamics of vegetation classes at the study site. The NDVI values for distinguished classes range from -1 to 1 and serve as a quantitative measure of plant greenness. These values were then used to classify the images into distinct vegetation classes, as detailed in Table 1. The area of each class and the percentage of the areas of these classes relative to the total study area for each period were calculated.

Statistical analysis

The annual temporal trends in vegetation biodiversity indices over the whole study period (2006–2022) were analyzed using PROC AUTOREG procedure in SAS 9.4 (SAS Institute, 2013). Generalized Durbin Watson (DW) statistic was used to diagnose 1st to 10th order autocorrelation and the Portmanteau Test statistic to diagnose heteroscedasticity. When autocorrelation and heteroscedasticity were detected, generalized autoregressive conditional heteroscedasticity (GARCH) or exponential GARCH models were used (Bollerslev 1986). The impact of controlled grazing on NDVI was investigated by subjecting vegetation biomass production, vegetation

Table 1. Normalized difference vegetation index (NDVI) values ranges for each distinguished class as applied in this study (adapted from Anim, et al., 2013)

NDVI Value	Class
< -0.1	Water body: areas covered with water, such as river, stream, dams, lakes, and waterlogged areas
-0.1–0.15	Barren soil: areas with no vegetation cover, degraded land, settlement areas
> 0.15–0.25	Herbaceous and shrub: areas covered mainly with grassland, herbaceous vegetation, and shrub
> 0.25–0.32	Open forest: areas covered with trees growing sparsely
> 0.32	Closed forest: areas with dense deciduous plants

biodiversity indices (during and among periods), and comprehensive data sets to rigorous analysis. First, to assess normal distribution, the Shapiro-Wilk test was employed through the JMP® 11 statistical analysis program. Notably, all variables yielded small p-values ($P<0.05$); consequently, it was determined that no variable followed a normal distribution. Considering these data distributions, non-parametric analysis (Wilcoxon/Kruskal-Wallis tests with Chi-Square Approximation) was utilized for period-to-period comparisons. Whenever the non-parametric analysis model revealed statistically significant differences ($P<0.05$), the non-parametric Dunn Method comparison test was executed to identify which variable exhibited significant variations from others.

RESULTS

Annual climatic factors and NDVI index

During the study period (2006–2022), the annual cumulative precipitation exhibited fluctuations, with nine years (2009, 2010, 2012, 2013, 2015, 2016, 2018, 2019, and 2020) recorded higher precipitation levels compared to the long-term average (2006–2022) of 357.61 mm. Conversely, the year 2011 experienced drought conditions, defined as annual precipitation ≤ 75% of the average long-term annual precipitation (Society for Range Management 1989) (Figure 2).

The average air temperature throughout the study period was 19.59 °C, with 2010 being the warmest year (20.93 °C) and 2006 being the coldest year (18.6 °C) (Figure 2). The annual average of NDVI exhibited a general increasing trend over the study period. There was a positive trend observed between NDVI and average annual precipitation. The lowest average NDVI value of 0.19 was observed in 2011 and accompanied by the lowest average precipitation of 261 mm during the same year. On the other hand, the highest average NDVI value of 0.31 was recorded in 2020, coinciding with the highest average precipitation of 484 mm in 2019. Notably, despite the fluctuations in annual precipitation, the average NDVI values continued to increase in general (Figure 2). This trend was particularly evident in 2014 and 2017, where the annual precipitation decreased to the minimum average amount, but the average NDVI did not decrease at the same level, possibly indicating the positive impact of controlled grazing management practices on vegetation dynamics.

Annual temporal trends

The findings from utilizing GARCH-EGARCH autoregression models on the data spanning from 2006 to 2022 (Table 2), surprisingly revealed that there was no significant annual temporal trend observed in the vegetation biodiversity indices and the climatic factors, biomass, and grazing carrying capacity over the study period. However, it is notable to mention that the average NDVI index emerged as the only variable showing a significant temporal trend ($P<0.001$).

Periodic temporal effects of controlled grazing

During the last five-year period (period 3), there was a significant increase ($P<0.05$) in vegetation biomass production (214.4±13.29 ton) compared to the first (97.08±11.17 ton; period 1) and second (106.8±1.2 ton; period 2) five-year intervals after the implementation of controlled grazing. In addition, the annual average NDVI, which serves as an indicator of vegetation health and greenness, exhibited significantly ($P<0.05$) increasing values during the last two periods (0.28±0.01 and 0.29±0.01, periods 2 and 3, respectively) compared to the first two periods. However, no significant difference was observed

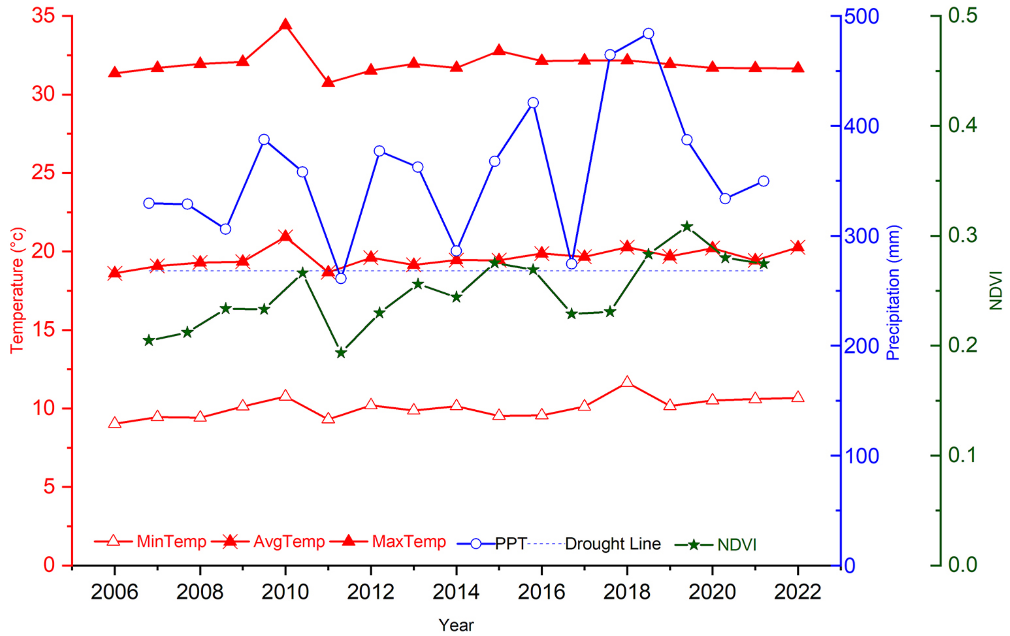

Figure 2. Annual average climatic factors and normalized difference vegetation index (NDVI) for the period 2006–2022 at Royal Botanic Garden, Jordan

between the NDVI values of the first two periods (0.21±0.02 and 0.24±0.01, periods 0 and 1, respectively) (Table 3).

The percentage of change for different plant groups and species also showed interesting periodic trends. During the short-term period (period 1), after the implementation of controlled grazing, there was a significant increase in the total count of plant species and perennial plant species ($P<0.05$). However, in the long-term period (periods 2 and 3), the perennial plant species showed a slight, yet significant, decrease, while the total plant species count remained unchanged. Particularly, the percentage of change for annuals, shrubs, and trees remained relatively stable at short- and long-term control grazing implementation throughout the study periods.

Additionally, the gain and loss indices, which signify the changes in the number of plant species gained or lost during the respective periods, these indices demonstrated fluctuations in total plant numbers but showed no significant differences across the periods. However, during the short-term period (period 1), there was a slight increase in the total number of plant species gained, followed by a sharp decrease during the long-term period (period 3). Also, a smaller number of plant species were lost as the study progressed.

During the short-term period (period 1), there was a significant gain in the perennial and tree plant species ($P<0.05$). However, in the long-term period (periods 2 and 3), the perennial and tree plant species showed a slight, significant decrease in gain, while the total plant species, annuals, and shrubs remained unchanged. Also, in the short term (period 1), there was a significant loss in the annuals, perennials, and tree plant species ($P<0.05$). However, in a long-term period (periods 2 and 3), the annuals, perennials, and tree plant species showed a slight, significant decrease in loss, while the total plant species and shrubs remained relatively stable.

The similarity index values provided an indicator of similarity between the different periods regarding the composition of plant groups. The similarity index for total plant species and shrubs remained unchanged (Table 3), suggesting that controlled grazing did not lead to significant alterations in the overall plant species and shrubs at both short- and long-term periods. On the other hand, annual, perennial plants, and trees showed a significant difference in similarity index between the short-term (period 1) and the long-term (period 3) periods of controlled grazing implementation, where the plant composition showed more similarities at the long-term periods after implementing controlled grazing (Table 3).

Overall, the results suggest that the implementation of controlled grazing had a positive impact on biomass production and vegetation health in the

Table 2. Annual temporal trend significance of vegetation biodiversity indices, biomass production, carrying capacity, average NDVI and climatic factors using a generalized autoregressive conditional heteroscedasticity (GARCH) or an exponential GARCH (EGARCH) model for the 2006–2022 period at Royal Botanic Garden, Jordan

Variables	Model*	Estimate	P-Value	R^2
Percent of change (%)				
Total plants census	EGARCH	-0.0161	0.4947	
Annual	EGARCH	-0.0212	0.6846	
Perennial	EGARCH	-0.0109	0.9056	
Shrub	GARCH	-0.0137	0.0718	
Tree	EGARCH	-0.00473	0.6461	
Gain (plant)				
Total plants census	GARCH	-16.1527	0.4133	
Annual	GARCH	-9.5661	0.5883	
Perennial	EGARCH	-5.8202	0.4349	
Shrub	EGARCH	-0.3549	0.3924	
Tree	GARCH	-0.4672	0.4567	
Loss (plant)				
Total plants census	GARCH	-0.0504	0.7836	
Annual	EGARCH	-4.7438	0.3387	
Perennial	EGARCH	-4.2981	0.3682	
Shrub	GARCH	-0.3497	0.7092	
Tree	GARCH	-0.224	0.1363	
Similarity index				
Total plants census	EGARCH	0.0231	0.6502	
Annual	GARCH	0.0273	0.1988	
Perennial	GARCH	0.0287	0.2147	
Shrub	EGARCH	0.057	0.4385	
Tree	EGARCH	0.0613	0.4335	
Estimated biomass (Ton)	EGARCH	11.3086	0.5042	
Average NDVI Index	EGARCH	-0.001454	<0.001	0.4913
Carrying capacity (AUM**)	EGARCH	143.1649	0.3241	
Average temperature (℃)	EGARCH	0.0389	0.2916	
Maximum temperature (℃)	GARCH	-0.0995	0.6794	
Minimum temperature (℃)	EGARCH	0.0639	0.506	
Precipitation (mm)	GARCH	4.4378	0.6351	

Note: Model were select based on lowest Akaike information criterion (AIC),**AUM: animal unit month.

study area. The controlled grazing practice seemed to play a significant role in shaping the plant community composition and species availability, leading to dynamic changes in certain plant groups and species over time. These findings provide valuable insights for understanding the ecological effects of managed grazing and its potential benefits for vegetation management and conservation.

Periodic land cover changes

Five distinct land cover classes were identified based on the yearly average NDVI values, including water body, barren soil, herbaceous and shrub, open forest, and closed forest (Figure 3). During the no-control grazing period (period 0), the water body covered 0.9 dunam, while barren soil occupied the largest area, amounting to 1271.7 dunam (66.7%). The herbaceous and shrubland area was 633.6 dunam (33.2%), and both open and closed forests covered 0.9 dunam and 0 dunam, respectively. In the short-term period of control grazing (period 1), the water body area remained unchanged at 0.9 dunam, while barren soil decreased to 1080 dunam (56.6%). The herbaceous and shrubland area increased to

Table 3. Comparison of the yearly NDVI, vegetation biomass production, and vegetation biodiversity indices among different periods since control grazing was applied in 2008 at the Royal Botanic Garden, Jordan. The data in the table shows the median (mean)

Variables	Period 0 (2006–2007)	Period 1 (2008–2012)	Period 2 (2013–2017)	Period 3 (2018–2022)
Biomass (Ton)	-	92 (97.1) ^{b}	108 (106.8) ^{b}	214 (214.4) ^{a}
NDVI index	0.19 (0.21) ^{b}	0.20 (0.24) ^{b}	0.23 (0.28) ^{a}	0.25 (0.29) ^{a}
Percent of change (%)				
Total plants species	-0.25 (-0.25) ^{b}	0 (0.17) ^{a}	0 (0) ^{a}	0 (0) ^{a}
Annual	-0.35 (-0.35) ^{a}	0 (0.22) ^{a}	0 (0) ^{a}	0 (0) ^{a}
Perennial	-0.11 (-0.11) ^{b}	0 (0.11) ^{a}	0 (0) ^{ab}	0 (0) ^{ab}
Shrub	-0.45 (-0.45) ^{a}	0 (0.21) ^{a}	0 (0.02) ^{a}	0 (0) ^{a}
Tree	0.4 (0.4) ^{a}	0 (0.07) ^{a}	0 (0.08) ^{a}	0 (0) ^{a}
Gain (plant)				
Total plants species	268 (268) ^{ab}	253 (223.6) ^{a}	253 (181.8) ^{ab}	75 (60.2) ^{b}
Annual	144.5 (144.5) ^{a}	160 (131.8) ^{a}	160 (112.4) ^{a}	41 (33) ^{a}
Perennial	111 (111) ^{ab}	78 (78.6) ^{a}	78 (57.6) ^{ab}	27 (21.6) ^{b}
Shrub	7 (7) ^{a}	8 (6.8) ^{a}	8 (6.4) ^{a}	4 (3.2) ^{a}
Tree	5.5 (5.5) ^{ab}	7 (6.4) ^{a}	7 (5.4) ^{ab}	3 (2.4) ^{b}
Loss (plant)				
Total plants species	245 (245) ^{a}	76 (96.6) ^{a}	76 (61.4) ^{a}	3 (3) ^{a}
Annual	144 (144) ^{ab}	41 (48.8) ^{a}	41 (33.4) ^{ab}	3 (3) ^{b}
Perennial	89 (89) ^{ab}	28 (41) ^{a}	28 (22.4) ^{ab}	0 (0) ^{b}
Shrub	8 (8) ^{a}	3 (3.4) ^{a}	5 (4) ^{a}	0 (0) ^{a}
Tree	4(4) ^{ab}	2 (3.4) ^{a}	2 (1.6) ^{ab}	0 (0) ^{b}
Similarity index				
Total plants species	0.26 (0.26) ^{a}	0.54 (0.53) ^{a}	0.77 (0.77) ^{a}	0.77 (0.77) ^{a}
Annual	0.27 (0.27) ^{ab}	0.5 (0.52) ^{b}	0.78 (0.82) ^{ab}	0.98 (0.98) ^{a}
Perennial	0.27 (0.27) ^{ab}	0.61 (0.55) ^{b}	0.77 (0.81) ^{ab}	1 (1) ^{a}
Shrub	0.21 (0.21) ^{a}	0.47 (0.42) ^{a}	0.47 (0.56) ^{a}	1 (1) ^{a}
Tree	0.09 (0.09) ^{ab}	0.5 (0.38) ^{b}	0.64 (0.67) ^{ab}	1 (1) ^{a}

Note: $^{a, b}$ Values within the same row that have different superscripts differ (P≤0.05).

826.2 dunam (43.3%). No open forests were observed during this period, and closed forests remained at 0 dunam. In the long-term period (period 2), the water body area remained constant at 0.9 dunam. The barren soil area decreased significantly to 186.3 dunam (9.8%), while the herbaceous and shrubland areas increased remarkably to 1709.1 dunam (89.6%). A small open forest area of 10.8 dunam was detected, and closed forests remained unchanged (0 dunam). Finally, during the second long-term period (period 3), the water body area continued to occupy 0.9 dunam. The barren soil area slightly increased to 225.9 dunam (11.9%), while the herbaceous and shrubland areas decreased to 1679.4 dunam (88.1%). The open forest area decreased to 0.9 dunam, and closed forests remained at 0 dunam (Figure 4). In summary, the land cover changes over the study periods showed fluctuations in different classes. Particularly, there was a significant decrease in barren soil (from 66.7% to 9.8%) and an increase in herbaceous and shrubland areas (33.2% to 89.6%) from the no-control grazing period to the long-term period (Figure 4). However, in the long-term period (period 3), the barren soil increased slightly to 11.9%, while the herbaceous and shrubland areas decreased slightly to 88.1%. In addition, open forests appeared in the long-term periods of control grazing (periods 2 and 3) as well as showed a reduction in size in periods 2 and 3 to represent 10.8% and 0.1% of the total study area, respectively. However, this reduction could be due to floods, fires, and the dieback effect (Figure 4).

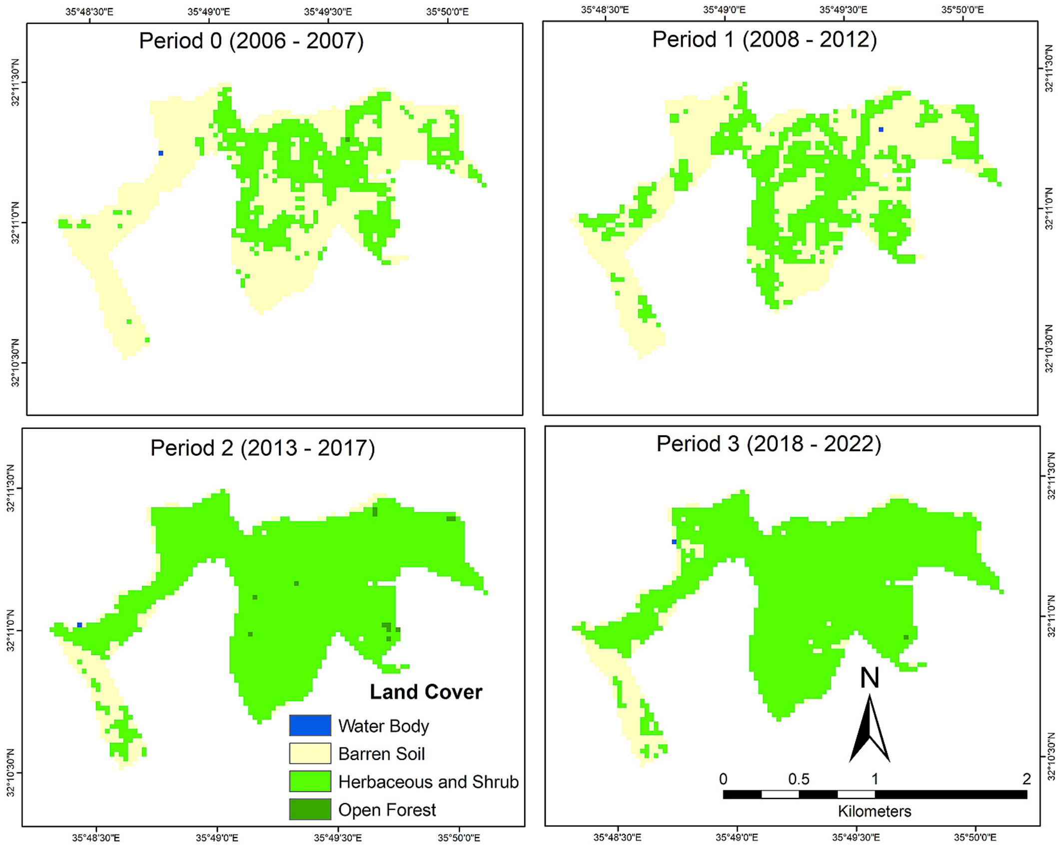

Figure 3. Land cover maps based on the NDVI values over the periods since control grazing was applied in 2008 at the Royal Botanic Garden, Jordan.

Overall, the controlled grazing practice applied in the study area appears to have influenced the land cover dynamics, particularly in terms of barren soil, herbaceous, and shrubland areas.

DISCUSSION

The observed increase in the NDVI over time in this study indicates positive changes in vegetation dynamics and the potential benefits of controlled grazing management practices in the study area (Figure 2). The positive effects of precipitation on NDVI were found to be the dominant climatic factor contributing to vegetation greening in the study area (Wang et al., 2003). It is noteworthy that the increase in NDVI persisted even during years with below-average precipitation. This suggests the resilience of vegetation health to suboptimal climatic conditions, which is likely attributed to the positive impact of controlled grazing on vegetation dynamics (Giralt-Rueda and Santamaria 2021; Zhao et al., 2022). Surprisingly, controlled grazing was also observed to have a positive effect on grassland greenness, as confirmed through grazing experiments on the Inner Mongolian steppe (Miao et al., 2021; Yan et al., 2013). Miao et al. (2021) conducted research on the Mongolian Plateau and found that animal density, precipitation, temperature, as well as radiation were the main determinants of grassland NDVI changes. They explained that the annual variation in precipitation and grazing intensity has a complex and nonlinear relationship with aboveground net primary production changes. These findings highlight the intricate interplay of environmental factors and human activities shaping vegetation greenness in the study area. The research provides quantitative evidence that the changes in precipitation and to a lesser extent, temperature play a dominant role in influencing vegetation greenness, while controlled grazing also contributes to vegetation greening, particularly during short-term drought periods. In other words, controlled grazing enhances biomass productivity resilience to short-term climatic variability, which agrees with the previously mentioned

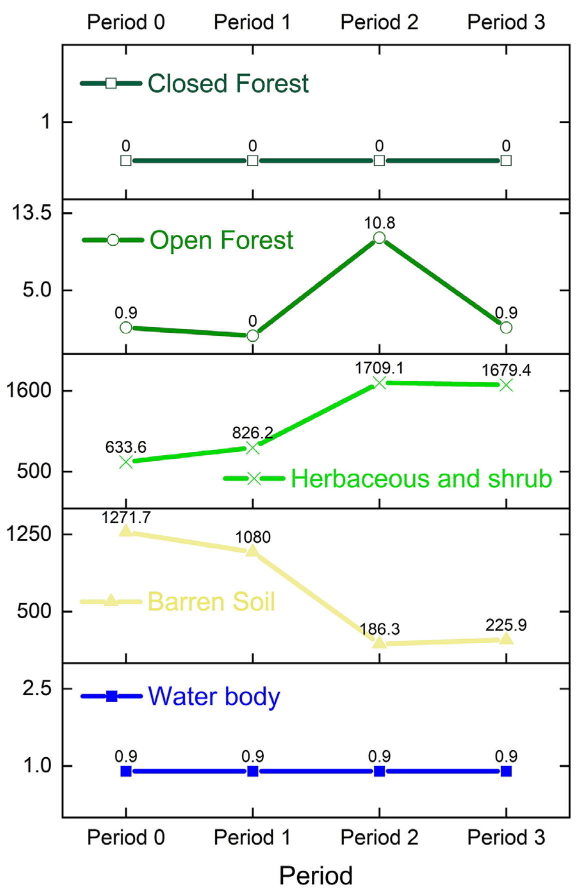

Figure 4. Land cover area (in Dunam) and percentage change (%) based on the NDVI values over periods since control grazing was applied in 2008 at the Royal Botanic Garden, Jordan

literature. The stable trends in vegetation biodiversity indices and most climatic factors indicate a relatively limited interplay between these factors over the years. However, the significant temporal trend in NDVI suggests dynamic changes and fluctuations in vegetation health and greenness over time (Table 2), hence emphasizing the importance of monitoring NDVI as a critical indicator of vegetation dynamics and as a measure of ecosystem health. The notion that NDVI serves as an indicator of vegetation health was well supported by Meneses-Tovar's (2011) research. According to Meneses-Tovar. (2011) NDVI serves as an indicator of degradation in ecosystem vegetation, with a decline in the NDVI value signaling a decrease in vegetation greenness. Consequently, the relationship between the indicator estimates (i.e., aerial biomass in various ecosystems) and NDVI can be used to observe processes of vegetation dynamics and health. Similarly, the findings of Wang et al. (2022) aligned with the outcomes of this research to emphasize the assertion that NDVI is widely recognized as the most popular indicator for monitoring vegetation dynamics and health.

The study found interesting trends in terms of the percentage of change for different plant groups and species when comparing short- and long-term periods, particularly after the implementation of controlled grazing. During the short-term period (period 1), there was a significant increase in both total plant species and perennial plant species. However, over subsequent periods, the percentage of change for perennial plant species exhibited a slight decrease. The number of plant species gained, and lost demonstrated fluctuations over time, with significant differences observed across the periods (Table 3). Nonetheless, implementing controlled grazing led to a noticeable rise in the overall species diversity during a short-term period, which agrees with the findings from other studies (Guo et al., 2019; Liu et al., 2020; Tang et al., 2016; Zhang et al., 2022). This increase can be attributed to the reduction of trampling damage caused by herbivores, hoof tillage effects, and the promotion of seedling establishment due to the buried seeds in the soil (Ma et al., 2013). Therefore, lost plant species including annual species or short-lived perennials with higher colonization capacity, rapidly establish themselves during short-term grazing control (Zhang et al., 2022). Furthermore, during the short-term period of controlled grazing, plant interspecific facilitation plays a significant role in the colonization of species (Bonet 2004). However, a shift occurs in the long term, where resource limitation in high-productivity grasslands results in aggravated interspecific competition. Consequently, slow-growing and long-lived species with higher competitive advantages suppress or even exclude less competitive species (Borer et al., 2014; Liu et al., 2019; Van Der Wal et al., 2004). As a result, numerous previous studies have reported significant decreases in vegetation indices during long-term controlled grazing (Kelemen et al., 2013; Oba et al., 2001; Wu et al., 2009).

The controlled grazing approach has emerged as a significant factor in shaping the composition of plant communities and influencing the distribution of different plant groups and species (He et al., 2023; Smith et al., 2017). The findings of this research underscore the potential of controlled grazing to positively impact vegetation management and conservation efforts, leading to favorable changes in vegetation health and composition over long-term periods (Anderson et al., 2022; Gibson et al., 2022). By managing the intensity and timing of grazing, land managers can strategically influence plant growth and diversity, thus enhancing overall ecosystem resilience (Ghahramani et al., 2019; Pent and Fike 2021). On the other hand, the long-term grazing exclusion period has been shown to reduce species richness due to intensified interspecific competition when productivity approaches the environmental carrying capacity (Chesson 2018; Kenkel, 1988). As a result, the efficiency of vegetation restoration declines with increasing grazing exclusion duration (Sacha 2020); these findings indicate that grazing exclusion, if maintained for an extended period of over eight years, may have negative consequences on species diversity and overall ecosystem health.

Considering land cover changes, vegetation dynamics, biomass production, and average NDVI values in tandem is of crucial importance when evaluating the impacts of controlled grazing management (Figure 3; Table 3). Controlled grazing emerges as a powerful factor in shaping the composition and distribution of land cover, thus significantly contributing to the biomass production, overall health, and stability of ecosystems. By avoiding constant and uniform grazing pressure on vegetation, controlled grazing enables certain plant species to recover and flourish, ultimately leading to a substantial increase in herbaceous and shrub land cover (Lawrence et al., 2019).

The results suggest that the implementation of controlled grazing had a positive impact on biomass production and vegetation health in the study area. The controlled grazing approach seems to play a significant role in plant diversity, plant community composition and plant species distribution, leading to dynamic changes in certain plant groups and species over time. These findings hold valuable insights towards understanding the ecological effects of managed grazing as well as its potential benefits for vegetation management and conservation. Furthermore, controlled grazing proves to be an effective strategy for mitigating the adverse effects of overgrazing and soil trampling. Implementation of such grazing practices could potentially mitigate soil erosion and degradation, minimize bare soil cover, as well as offer a more favorable environment for vegetation growth (Apfelbaum et al., 2022).

CONCLUSIONS

The study aimed to investigate the effect of controlled grazing management along with prevailing environmental conditions on vegetation dynamics and land cover changes over a 17-year period (2006–2022). The results revealed a positive trend between NDVI and average annual precipitation, indicating the importance of precipitation for vegetation health. Despite fluctuations in annual precipitation, the NDVI values showed a general increasing trend, possibly influenced by controlled grazing practices. The study also found no significant temporal trends between annual vegetation biodiversity indices and climatic factors, except for NDVI, which exhibited dynamic changes over time. The implementation of controlled grazing positively affected vegetation biomass production and enhanced NDVI in the long-term periods of the study. Short-term controlled grazing resulted in higher species gain, while long-term controlled grazing contributed to changes in plant composition and distribution. The land cover analysis showed fluctuations in different classes, with a significant decrease in barren soil and an increase in herbaceous and shrubland areas, likely influenced by controlled grazing practices. Overall, the findings suggest that controlled grazing management plays a crucial role in shaping vegetation dynamics and land cover changes, contributing to a healthier and more resilient ecosystem. These results provide valuable insights for vegetation management and conservation efforts, emphasizing the importance of considering both land cover changes and vegetation dynamics in conjunction when assessing the impact of grazing practices on ecosystems.

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