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Original Article

Preventive treatments for the invasion of *Leucanthemum vulgare* Lam.: exploring effects in rangeland ecosystems of Iran

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Abstract: Invasive species are increasingly spreading, particularly in rangeland ecosystems. It is essential to evaluate the effectiveness of different methods for controlling invasive plants in these ecosystems. This study aimed to investigate the effects of three strategies- 21-year grazing exclusion (21-YES), mowing-grazing in rotation in alternate years (MGRS), and moderate grazing (MGS)- on the change in cover, density, and biomass of *Leucanthemum vulgare* Lam. (Ox-eye Daisy=OED) and the plant community. To accomplish this, three sites selected for each treatment. In 2021, 270 vegetation plots were sampled using a random systematic method. Subsequently, we recorded the density and canopy cover of all growth forms (forbs, grasses, and ferns), the OED biomass, and the ground cover. The results indicated that MGS reduced OED density, OED canopy, and OED biomass. Furthermore, this strategy demonstrated the highest density and canopy cover of the plant community (including total, forbs, grasses, and ferns). Additionally, the strongest correlation was observed between the total canopy and the OED density (R^2=-0.91, -0.95, -0.94 in 21-YES, MGRS, and MGS, respectively), as well as between the total canopy and the OED canopy (R^2=-0.51, -0.98, -0.97 in 21-YES, MGRS, and MGS, respectively). The MGS led to an increase in diversity indices. In general, the grazing strategy has proven to be effective in controlling the spread of invasive OED and has also resulted in an increase in canopy cover, density, and diversity indices of the plant community. The study highlights the importance of ongoing management efforts to control invasive species, with moderate grazing potentially serving as a more practical, culturally accepted, and cost-effective short-term control strategy for widespread rangeland weed infestations.

Keywords: Grazing; *Leucanthemum vulgare*; *Leucanthemum vulgare*; Canopy cover; Growth forms; Biomass

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1 Introduction

Increasing human activities in natural ecosystems have disrupted ecosystems functioning and ability to provide essential services, resulting in a significant global decline in biodiversity (Foxcroft et al. 2017; Khan et al. 2021). Around one-sixth of the Earth's land area is at risk of invasive species, with substantial areas in developing countries and global biodiversity hotspots being particularly vulnerable (Early et al. 2016; Khan et al. 2021). The structure and function of the ecosystem may be altered by the type of invasive plants, depending on their morphology, ecology, and physiology. This disruption can lead to a change of ecological processes (Le Maitre et al. 2011; Holmes et al. 2020), including biodiversity loss (Vila and Ibáñez 2011), disturbance of nutrient and carbon regulation (Liao et al. 2008), and reduction of primary productivity (McLeod et al. 2016). Additionally, some of the invasive plants can also reduce the availability of palatable forage and alter fire regimes (Holmes et al. 2020). Moreover, shrub encroachment can introduce invasive plant species into ecosystems, resulting in lower community density, reduced herbaceous root presence, and loosened topsoil. While shrub encroachment may enhance soil infiltrability, it simultaneously inhibits the growth of herbaceous species (Liu et al. 2022; Liu et al. 2023).

The main objective of managing biological invasions is to halt or reduce the spread of invaders. This involves intercepting invasion pathways and coordinating efforts to manage invaded landscapes (Holmes et al. 2020). In terms of rangeland condition, the ultimate goal of ecological restoration is to enhance ecosystem recovery. This includes optimizing the structure and functioning of the ecosystem through either natural regeneration or intentional interventions (Holmes et al. 2020; Aronson et al. 2017). There are several ways to control invasive plants at invaded habitats (Weidlich et al. 2020). Which strategy is most effective relies on a number of variables that have a significant environmental impact (Morais et al. 2021), including the species being controlled, available funding, legal framework, and even individual opinions regarding chemical management (Wagner et al. 2017; Dechoum et al. 2018; Weidlich et al. 2020). On the other hand, actively working to re-establish native plant communities in areas where invasive plants have been controlled can help reduce the likelihood of invasive plants recolonizing (Schuster et al. 2018).

The Ox-eye Daisy (OED), *Leucanthemum vulgare* Lam. (Asteraceae), is a perennial forb native to Europe and western Asia. It has become naturalized or invasive in all continents except Antarctica (Holm et al. 1979). In Iran, OED has spread from the northeast of Namin regions to its southeast (Samadi et al. 2022). It affects disturbed habitats such as grazing rangelands, open meadows, roadside areas in newly introduced places, and forest openings (Olson and Wallander 1999; Clements et al. 2004). Its prolific seed production, high germination rates, and long seed viability make this weed highly competitive (Stephens 2017). Its aggressive nature allows it to outcompete plants with deeper roots, making it a formidable competitor in rangeland ecosystems. As a result, it can crowd out preferred forage species (Krueger and Sheley 2003; Stutz et al. 2018), reducing the carrying capacity for grazing and forage value. Additionally, its spread onto rangeland can lead to a decline in plant community diversity and degradation of wildlife habitat (Stephens 2017; Samadi et al. 2020).

Various studies have been performed on the management and control of OED, which can be referred to the studies of Jacobs (2015), Mangold et al. (2021a), McConnachie et al. (2021b), Stephens (2018) and Khan et al. (2021). OED can be controlled through various methods depending on the specific conditions. According to Stephens (2021) and Clements et al. (2003), various methods such as hand pulling, cultivation, mowing, prescribed fire, grazing/herbivory by mammals and insects, herbicides, control through disease (e.g., fungi, bacteria, viruses), higher plant parasites, and cultural approaches are employed to control and manage OED. While there are different strategies for managing this weed, none of them are universally recognized as the most effective. Mowing before the first flowers bloom in rangelands can prevent seed formation. However, in regions with suitable growth seasons (in terms of rainfall, temperature etc.), mowing may actually increase shoot production and subsequent flowering (Olson and Wallander 1999; Jacobs 2008; Mangold et al. 2009; Stephens 2017). Moreover, grazing can either increase or reduce OED invasions. Horses, sheep, and goats are known to readily graze on OED, while cattle and pigs tend to avoid it (Jacobs 2008). Prescribed grazing management, using a variety of livestock species, can be timed to maintain rangeland plant vigor while reducing OED establishment and spread (Jacobs 2008;

Mangold et al. 2009; Stephens 2017).

The Namin rangelands in northwestern Iran play a significant role in the economy, society, and ecology of the region (Samadi et al. 2021a, b). Based on a literature review and the indigenous knowledge of local residents, it has been determined that the major invasive plant in this region is OED. This plant has been spreading throughout various parts of the rangelands for approximately 40 years (Samadi et al. 2019) by humans, vehicles, and animals (Clements et al. 2004; Stephens 2017). Due to the beautiful blooming landscape (Khan et al. 2021), this weed has created a remarkable attraction for recreation and tourism, and this may be one of the factors that caused the seed of OED to spread in the Namin rangelands. The presence of this weed at the rangelands of the Namin region, which are home to many palatable species, calls for additional attention (Khan et al. 2021). Despite OED's invasion of every continent, its scientific management has received less focus in Iran. So, two fundamental questions have been raised: 1) did OED experience changes in cover, density, or biomass due to the treatments of 21-year grazing exclusion, mowing-grazing in rotation in alternate years, and moderate grazing? 2) did canopy (density, canopy cover of total species and growth forms), ground cover (litter cover and bare ground) and diversity indices (richness, diversity, and evenness) change by the treatments at the study habitats?

2 Materials and Methods

2.1 Study area

The Namin region is situated in the northwest of Iran, with geographical coordinates ranging from 38°6'30" to 38°39'07" N and 48°15'35" to 48°42'33" E (Fig. 1). Its minimum elevation reaches 1300 meters above sea level (masl), while the maximum elevation is 2500 masl. The area experiences an average precipitation of 271.80 mm and an average temperature of 10.20°C, based on data from the nearby Namin synoptic station, which has been operational since its establishment until 2020 (Statistics Yearbooks of Ardabil Province 2020). The climate in this region is influenced by the Caspian Sea and the Sabalan Mountain, which enhance relative humidity, limit evapotranspiration due to fog formation, and create optimal conditions for vegetation growth (Samadi et al. 2021).

The primary land uses in the Namin region consist of rangelands and dry farming lands. Additionally, there are scattered forests with dense canopy in certain areas, as well as open forests in others. The region also includes gardens and irrigated farms (Teimoorzadeh et al. 2015; Samadi et al. 2021). Some of the rangelands, particularly those near the Gilan province border, Shoghaldare, Fandoghlou, Nanekaran, KalehSar, and Aladizgeh, are affected by invasive plant of the OED (Teimoorzadeh et al. 2015; Samadi et al. 2020). These areas were previously forests that have been converted into rangelands. From mid-May to mid-November, these rangelands serve as grazing areas for livestock, including sheep, goats, cattle, and horses, for approximately seven months. During the spring, some of these rangelands are harvested (that is, fodder mowing is done by rural ranchers using harvesters or scythes) to provide winter hay for livestock (Fig. 2A). So, these rangelands are vital for rural ranchers as they provide valuable resources for livestock production. In addition, certain parts of the study area serve as the primary recreational area from early spring to early autumn (Ghorbani et al. 2020; Samadi et al. 2021c).

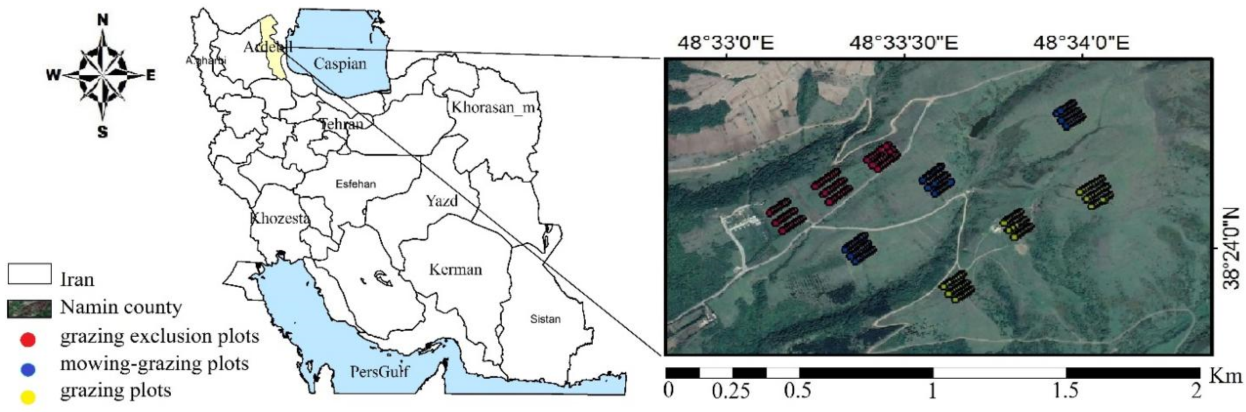

Fig. 1 Location of the study area and the sampling points in Ardabil province of Iran.

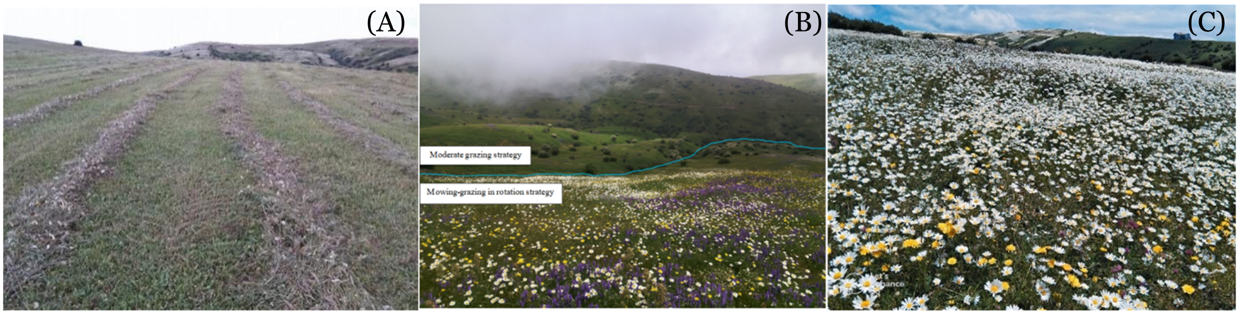

Fig. 2 (A) Fodder mowing by rural ranchers using harvesters; (B) Mowing-grazing in rotation and moderate grazing strategies; and (C) 21-year grazing exclusion strategy.

2.2 Data collection

Samadi et al. (2022) identified the spread of OED in the rangelands of Namin region. In our current study, we selected locations affected by the invasion of this weed to investigate the effect of various management and control strategies. These strategies included a 21-year grazing exclusion (21-YES), mowing-grazing in rotation (in alternate years) (MGRS), and moderate grazing strategies (MGS). The 21-YES, was implemented by the Natural Resources and Watershed Management Organization in Ardabil Province, Iran. The MGRS and MGS were practiced by the local villagers over an extended period of time (Fig. 2A,2B). When evaluating the scope of these treatments, we relied on data from the Natural Resources and Watershed Management Organization in Ardabil Province and conducted interviews with local and knowledgeable people. It is important to mention that local residents believe that the application of these treatments has resulted in alterations to the area's vegetation and the emergence of the OED species.

In the treatment of 21-YES, the Natural Resources and Watershed Management Organization in Ardabil Province has fenced off this area since 2001, effectively excluding livestock from the rangeland (Fig. 2C). As a result, the plant community has developed without the influence of grazing livestock. The treatment of MGRS has been a traditional practice among native people for many years (according to interviews with native people, this treatment has been implemented for over 40 years). In this approach, plant biomass is mowed and harvested by people for one year to be used as winter hay for livestock. It is important to note that this mowing occurs during the flowering stage of OED. After the hay is harvested and removed from the area, livestock may enter at the end of the season to consume any remaining fodder. Then, in other year, this area is grazed by livestock from beginning of the grazing season (mid-May) to the end of the grazing season (mid-November), with sheep, cattle, horses, and goats being the dominant livestock in that order. This cycle is repeated. The intensity of livestock grazing in this treatment (in the year when livestock grazing is done) was moderate, with 4 heads of sheep per hectare (Moghani breed sheep weighing 50.98 kg), resulting in a 50% forage utilization. It is necessary to note that one native cattle, horse, and goat were approximately equivalent to 5, 6, and 0.8 sheep, respectively, based on their feed intake. Moreover, in the MGS treatment, livestock (predominantly sheep, cattle, horses, and goats) are allowed to graze in this area without restrictions from mid-May to mid-November each year. The intensity of livestock grazing in this treatment was also moderate, with 4 heads of sheep per hectare (Moghani breed sheep weighing 50.98 kg), resulting in a 50% forage utilization. It is necessary to note that one native cattle, horse, and goat were approximately equivalent to 5, 6, and 0.8 sheep, respectively, based on their feed intake.

To assess the impact of various management treatments on the canopy cover and biomass of OED, and diversity indicators and plant cover of growth forms (including total species, Forbs, Grasses and Ferns), we selected three sites for each treatment (Fig. 1). The first site for each treatment was chosen randomly, and subsequent sites were selected at varying intervals based on the specific conditions of the area, taking into account factors such as sampling feasibility and coverage of the region in alignment with our research objectives. In order to minimize variations in environmental conditions, there were no significant differences in elevation, slope, aspect, and landscape position among the three groups of selected sites. Then, using a random systematic method, we established three sample transects at each site, each with a length of 100 meters and perpendicular to the main slope direction. The location of the first transect was randomly determined, and subsequent transects were positioned at a distance of 50 meters from the first transect and parallel to it. Along each sampling transect, ten plots measuring 1m² were established at intervals of 10 meters. The size and number of plots were determined according to the vegetation structure and number of samples required as well as previous studies (Arzani 1997; Bonham 2013; Dadjou et al. 2018). It is important to note that the actual replication in this research consists of three sites for each of the management treatments. To ensure an adequate number of plots within each site and to enhance the accuracy of sampling, as well as to facilitate the deployment of 30 plots within each site, three transects were considered within each site (Arzani 1997).

Sampling was carried out from late May to late June 2021. Sampling was carried out during the peak growth stage (blooming) of dominant plants (Rezaei et al. 2006), including OED. Then, density (Number/m²) and canopy cover percentage of all growth forms (including total species, Forbs, Grasses and Ferns), OED biomass, and ground cover percentage (including litter cover, and bare ground) were recorded in 270 plots. Plant density was recorded by counting the plants in each plot (Number/m²). Canopy cover percentage of growth forms (including total species, Forbs, Grasses and Ferns) was calculated in 1m² plots. OED biomass was estimated using clipping and weighing (harvesting) method in sampling plots during the blooming stage of OED (Arzani 1997; Rezaei et al. 2006). Species were identified by considering standard taxonomic literature (Mobayen 1975-1979; Ghahraman 1975-1999; Assadi 1989-2015). Moreover, the canopy cover of the total species was employed to compute the diversity indicators. During the research, 110 species from 86 genera and 25 families were documented (Appendix 1).

2.3 Data analysis

The normality of parameters was tested using the Kolmogorov-Smirnov test, and the homogeneity of variances was evaluated using Levene's test. One-way analysis of variance (ANOVA) and Duncan test were employed to investigate the effect of management treatments on density, canopy cover, and biomass OED. The first site for each treatment was randomly selected, and subsequent sites were chosen at varying intervals. Additionally, the location of the first transect was randomly determined for each site, and subsequent transects were positioned 50 meters away from the first transect. Therefore, the principle of random sampling was adhered to in order to utilize the ANOVA method. The findings from this analysis were utilized to categorize OED-infested habitats as highly invaded, moderately invaded, or low invaded, and to identify the most effective strategy for OED control.

Moreover, to assess the effect of management treatments on plant cover (including total species, Forbs, Grasses and Ferns) and ground cover (Litter cover and Bare ground) ANOVA and Duncan test were used in IBM $SPSS_{ver.22}$ (IBM Corp. Released 2013). We removed OED from this analysis, because we wanted to examine how plant communities change as a result of OED invasion.

We also estimated the plant species richness, diversity, and evenness. The diversity indices such as Simpson’s (1-D) index of diversity, species richness (total species count), and Simpson’s ($E_{1/D}$) index of evenness were calculated using ecological $methodology_{ver.6.0.3}$ (Krebs 1999). To assess the effect of management treatments on diversity indicators ANOVA and Duncan test were used in IBM $SPSS_{ver.22}$.

To assess the difference in species composition and to identify indicator species for each management strategies, the indicator species analyses (ISA) were implemented by PC-ORD $_{ver.\ 5.10}$ (McCune and Mefford 2006).

The correlation and regression between the canopy cover and OED canopy factors was calculated using IBM $SPSS_{ver.22}$. The indices of high correlation and significance for canopy cover and OED canopy factors were selected as the best canopy cover factors predictors. Canopy cover factors prediction was established using a linear regression equation with the help of Eq. (1).

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 \quad (1)$$

where, Y was the response variable (canopy factors), a was a constant, b were the regression coefficients, and x was the value of the independent variable (OED canopy factors).

3 Results

3.1 Effects of management strategies on OED

The density, canopy cover, and biomass of OED were compared to evaluate the effectiveness of different management strategies. The analysis revealed significant differences in these characteristics across all strategies ($p<0.05$). Results indicated that MGS reduced the OED density, OED canopy, and OED biomass, while 21-YES increased these factors. This reveals that 21-YES led to a high invasion of OED, indicating its inefficacy in controlling this weed. MGRS resulted in a moderate invasion of OED, whereas MGS led to a low invasion of OED (Table 1). On the other hand, in terms of the intensity of OED infestation, the sites 21-YES (highly invaded), MGRS (moderately invaded), and MGS (low invaded) were ranked first to third.

3.2 Effects of management strategies on plant community

The findings indicated significant differences in density (total, forbs, grasses, and ferns) and canopy cover (total, forbs, grasses, and ferns) among the OED management strategies ($p<0.05$). The mean comparison using Duncan's test revealed that the MGS exhibited the highest density (total, forbs, grasses, and ferns) and canopy cover (total, forbs, grasses, and ferns), while the 21-YES resulted in the lowest values. Furthermore, ground cover factors showed significant differences across the various management strategies, with the 21-YES demonstrating much higher percentages of litter cover (Table 2).

Table 3 presents the correlation coefficients and regression equations for canopy cover and OED canopy factors in different treatments. The table shows that the strongest correlation coefficient was observed between the total canopy of the plant community and the OED Density (R^2=-0.91, R^2=-0.95, R^2=-0.94 in 21-YES, MGRS, and MGS, respectively), as well as between the total canopy of the plant community and the OED canopy (R^2=-0.51, R^2=-0.98, R^2=-0.97 in 21-YES, MGRS, and MGS, respectively). Furthermore, other factors of the plant community exhibited correlations with OED canopy factors in subsequent priorities. Predictive equations were then developed using a linear regression model based on indices with the highest correlation with OED canopy factors (Table 3). The regression equations reveal that in the majority of cases, there was a negative correlation between plant community canopy factors and OED canopy factors. As OED increased, the amount of canopy factors of community decreased.

In the 21-YES, the Forb density and Grass density showed a correlation with OED density, OED biomass, and OED canopy. Forb canopy and Grass canopy had also a correlation with OED density and OED canopy. In the MGRS, the Forb density, Grass density, Forb canopy and Grass canopy showed a correlation with OED density, and OED canopy. Forb canopy had also a correlation with OED biomass. In the MGS, only the Forb density, showed a correlation with OED biomass, and OED canopy. After examining the correlation between the indicators, certain ones were included in

Table 1 Comparison of the effect of management strategies on OED

Characteristics (Mean)	Applied strategies			df	*F* statistics
	21-YES	MGRS	MGS		
OED density (number/m²)	129.2[a]	65.7[b]	3.5[c]	2	102.9*
OED canopy cover (%)	26.7[a]	14.4[b]	0.8[c]	2	92.8*
OED biomass (Kg/ha)	664.5[a]	276.4[b]	37.3[c]	2	38.5*

Note: *: Significant difference at the level of 5%. 21-YES: 21-year grazing exclusion strategy; MGRS: mowing-grazing in rotation strategy; MGS: moderate grazing strategy. Letters on the numbers in each row, show the significant differences between the strategies at 5% level according to Duncan's test.

Table 2 Comparison of effect of management strategies on canopy cover factors of plant community

Characteristics (Mean)			Applied strategies			df	*F* statistics
			21-YES	MGRS	MGS		
Plant cover	Density (number/m²)	Total species	403.2[c]	457.7[b]	516.7[a]	2	9.1*
		Forbs	229.6[b]	274.3[a]	276.5[a]	2	4.3*
		Grasses	173.6[b]	183.3[b]	239.1[a]	2	4.1*
		Ferns	0.0[b]	0.02[b]	1.01[a]	2	11.7*
	Canopy cover (%)	Total species	71.1[c]	84.58[b]	98.98[a]	2	102.0*
		Forbs	56.3[c]	65.0[b]	71.6[a]	2	18.3*
		Grasses	14.8[c]	19.53[b]	25.0[a]	2	9.2*
		Ferns	0.00[b]	0.03[b]	2.3[a]	2	11.5*
Ground cover (%)		Litter cover	1.6[a]	0.5[b]	0.4[b]	2	4.1*
		Bare ground	0.3[a]	0.4[a]	0.06[b]	2	7.0*

Table 3 Correlation and regression between canopy cover and OED canopy factors

Treatments	Canopy cover/OED canopy	Correlation			Regression	
		OED density	OED biomass	OED canopy	Equation	R^2
21-YES	Total canopy	-0.918**	-0.412*	-0.510**	(1) Total canopy= 98.25 -0.007 OED density-0.01 OED biomass-0.98 OED canopy	0.97
	Total density	-0.457**	-0.198ns	-0.987**	(2) Total density= 583.49 +0.42OED density -0.36 OED canopy	0.37
	Forb density	-0.263**	-0.307**	-0.298**	(3) Forb density = 293.86 -0.2OED density-0.9 OED biomass-2.7 OED canopy	0.16
	Grass density	-0.345**	-0.263**	-0.382**	(4) Grass density= 289.6 + 0.22OED density -4.64 OED canopy	0.18
	Forb canopy	-0.542**	-0.063ns	-0.581**	(5) Forb canopy=72.26-0.01OED density - 0.56 OED canopy	0.34
	Grass canopy	-0.419**	-0.150ns	-0.453**	(6) Grass canopy= 26.26+0.004OED density -0.42 OED canopy	0.38
MGRS	Total canopy	-0.952**	-0.270*	-0.985**	(1) Total canopy= 98.86 -0.03OED density-0.01 OED biomass-1.1 OED canopy	0.97
	Total density	-0.499**	-0.053ns	-0.526**	(2) Total density= 542.79 +0.87OED density -10.48 OED canopy	0.29
	Forb density	-0.210**	-0.161ns	-0.239**	ns	0.07
	Grass density	-0.368**	-0.065ns	-0.374**	(3) Grass density= 240.66 + 0.07OED density -5.26 OED canopy	0.17
	Forb canopy	-0.378**	-0.219**	-0.396**	(4) Forb canopy=72.25+0.02OED density-0.1 OED biomass-0.54 OED canopy	0.16
	Grass canopy	-0.413**	-0.003ns	-0.422**	(5) Grass canopy= 26.6+0.009OED density - 0.6 OED canopy	0.19
MGS	Total canopy	-0.941**	0.145ns	-0.977**	(1) Total canopy= 99.89 +0.06OED density - 1.2 OED canopy	0.95
	Total density	0.043ns	0.273**	-0.002ns	(2) Total density= 506.52 +11.11 OED biomass	0.11
	Forb density	-0.189ns	0.303**	-0.208**	(3) Forb density=277.53+3.55 OED biomass - 27.05 OED canopy	0.12
	Grass density	0.187ns	0.038ns	-0.158ns	ns	0.04
	Forb canopy	-0.192ns	-0.021ns	-0.168ns	ns	0.03
	Grass canopy	0.139ns	0.055ns	0.113ns	ns	0.19

Notes: ** p<0.01, * p<0.05. ns, no significant.

regression equations (Table 3).

The indicator species analysis (ISA) based on 1000 permutations revealed that the species *L. vulgare*, *Ranunculus millefolius*, *Trifolium micranthum*, and *Geranium molle* were indicators in a 21-YES. *Trifolium pratense*, *Plantago lanceolata*, *Vulpia myuros*, *Trifolium compestre*, *Carex divulsa*, *Capsella bursa-pastoris*, *Convolvulus arvensis*, *Papaver rhoeas*, and *Asperula setosa* were indicators in MGRS. While, *Cynosurus echinatus*, *Stachys byzantina*, *Trifolium repense*, *Hypericum tetrapterum*, *Leontodon hispida*, *Origanum vulgare*, *Chaerophyllum aureum*, *Lolium rigidum*, *Potentilla reptans*, *Dryopteris borreri*, *Trifolium arvense*, and *Cirsium echinus* were indicators in MGS. In all of these cases, the order of the species was determined by the observed indicator value (IV), which was statistically significant (p <0.01) (Table 4).

Furthermore, the results revealed significant differences in diversity, richness, and evenness indices among the different management strategies (p<0.05). In particular, there was a decreasing trend in species diversity, richness, and evenness in the MGS, MGRS, and 21-YES strategies, respectively. Consequently, the MGS strategy increased the values of Simpson's (1-D) diversity index, richness index, and Simpson's (E1/D) evenness index, while 21-YES decreased these values (Table 5). Table 6 shows the correlation coefficients and regression equations for diversity indices and OED canopy factors in different treatments. Based on the results, there was a significant correlation between the Evenness and Richness indices and OED biomass in the 21-YES. Additionally, a significant correlation was observed between Richness and OED biomass in the MGS. However, other indicators across different treatments did not exhibit a significant correlation with OED canopy factors.

Table 4 Indicator species analyses influenced by different management strategies

Species	Groups (applied strategies)	Observed indicator value (IV)	IV from randomized groups (mean)*	*Sig*
Leucanthemum vulgare Lam.	21-YES	63.6	28.2	0.001
Ranunculus millefolius Banks & Soland.	21-YES	20.8	5.0	0.001
Trifolium micranthum Viv.	21-YES	15.4	7.1	0.001
Geranium molle L.	21-YES	10.4	7.7	0.001
Trifolium pratense L.	MGRS	43.8	27.3	0.001
Plantago lanceolata L.	MGRS	42.6	13.9	0.001
Vulpia myuros (L.) J. F. Gmel.	MGRS	29.9	8.4	0.001
Trifolium compestre Schreb.	MGRS	29.7	14.0	0.001
Carex divulsa Gaudin	MGRS	16.4	5.0	0.001
Capsella bursa-pastoris (L.) Medik.	MGRS	10.7	4.3	0.001
Convolvulus arvensis L.	MGRS	10.0	2.6	0.001
Papaver rhoeas L.	MGRS	10.0	2.5	0.001
Asperula setosa Jaub. & spach.	MGRS	7.8	2.3	0.001
Cynosurus echinatus L.	MGS	70.3	13.2	0.001
Stachys byzantina K.Koch.	MGS	51.1	17.7	0.001
Trifolium repense L.	MGS	43.8	27.3	0.001
Hypericum tetrapterum Fries.	MGS	37.3	10.0	0.001
Leontodon hispida L.	MGS	35.2	23.8	0.001
Origanum vulgare L.	MGS	33.3	6.1	0.001
Chaerophyllum aureum L.	MGS	30.0	5.8	0.001
Lolium rigidum Gaudin	MGS	29.6	11.9	0.001
Potentilla reptans L.	MGS	20.4	5.5	0.001
Dryopteris borreri (Newman) Newman ex Oberh. & Tavel	MGS	17.8	3.9	0.001
Trifolium arvense L.	MGS	7.8	2.3	0.001
Cirsium echinus (M. Bieb.) Sch. Bip.	MGS	7.8	2.2	0.001

Notes: 21-YES: 21-year grazing exclusion strategy; MGRS: mowing-grazing in rotation strategy; MGS: moderate grazing strategy.
*: proportion of randomized trials with indicator value equal to or exceeding the observed indicator value.
Sig= (1 + number of runs ≥ observed)/(1 + number of randomized runs).

Table 5 Comparison of effect of OED management strategies on species diversity indicators

Indices (Mean)	Applied strategies			df	*F* statistics
	21-YES	MGRS	MGS		
Simpson's (1-D) index of diversity	0.8^b	0.9^a	0.9^a	2	4.1^*
Species richness (total species count)	70.0^c	84.0^b	90.0^a	2	5.8^*
Simpson's ($E_{1/D}$) index of evenness	0.2^b	0.3^a	0.3^a	2	1.3^*

Notes: *: Significant difference at the level of 5%. 21-YES: 21-year grazing exclusion strategy; MGRS: mowing-grazing in rotation strategy; MGS: moderate grazing strategy. Letters on the numbers in each row, show the significant differences between the strategies at 5% level according to Duncan's test.

Table 6 Correlation and regression between diversity indices and OED canopy

Treatments	Canopy cover/ OED canopy	OED density	OED biomass	OED canopy	Equation	R^2
21-YES	Diversity	-0.082^{ns}	-0.051^{ns}	-0.079^{ns}	ns	0.01
	Evenness	-0.021^{ns}	-0.220^{**}	-0.00^{ns}	ns	0.05
	Richness	-0.074^{ns}	-0.379^{**}	-0.166^{ns}	(1) Richness= 583.49 -1.9 OED biomass	0.21
MGRS	Diversity	-0.167^{ns}	-0.000^{ns}	-0.186^{ns}	ns	0.04
	Evenness	-0.148^{ns}	-0.004^{ns}	-0.123^{ns}	ns	0.03
	Richness	-0.064^{ns}	-0.160^{ns}	-0.043^{ns}	ns	0.08
MGS	Diversity	-0.095^{ns}	0.008^{ns}	-0.055^{ns}	ns	0.03
	Evenness	-0.046^{ns}	-0.069^{ns}	-0.034^{ns}	ns	0.01
	Richness	0.095^{ns}	-0.263^{*}	0.049^{ns}	(2) Richness= 506.38+ 11.12 OED biomass	0.11

Notes: $^{**}p<0.01$, $^{*}p<0.05$, ns is no significant.

4 Discussion

4.1 Effects of management strategies on OED

The findings revealed that the 21-YES cannot be regarded as an effective method for controlling the OED species. This treatment resulted in significantly higher OED coverage, with density of 49.1% and 97.26%, canopy cover of 46.1% and 96.79%, and biomass of 58.41% and 94.39%, respectively, compared to the MGRS and MGS. As grazing is removed for an extended period, the seed production of OED increases, leading to a larger seed bank compared to other species (Stephens 2017) and increases the presence of this species in the plant community. Additionally, the rise in biomass of invasive plants is generally attributed to high nitrification capacity of soil microbial communities and their efficient utilization of nutrients (Khan et al. 2021). Some other studies have also pointed to the increase of invasive plants following long-term grazing exclusion of rangelands (Porensky et al. 2017; Vermeire et al. 2018), particularly if the native plants that compete most effectively with invaders are lost (Milchunas et al. 1992).

The results showed that the OED density, OED canopy, and OED biomass in the MGRS were moderate compared to the other two strategies (21-YES and MGS). This suggests that this strategy has led to fewer OED attacks than the 21-YES but more attacks than the MGS. Mowing can reduce OED seed production, stress its carbohydrate root reserves, and decrease its capacity to compete with desirable grasses and forbs. It is recommended to begin mowing as soon as the flowers appear in order to minimize seed production. However, it is important to note that mowing can also lead to increased shoot production and flowering, so mowing treatments should be repeated throughout long growing seasons (Stephens 2017). According to Georgia (1942), mowing OED-infested meadows as the first blooms appear is an efficient method for controlling seed production and distribution. Similarly, MacDougall and Turkington (2004) found that mowing for 5-years during the blossoming of invasive grasses transformed the plant community into desirable forbs and grasses. On the other hand, Simmons et al. (2007) stated that mowing had little or no effect on an invasive perennial grass and native species, while Brandon et al. (1997) observed that mowing increased the abundance of invasive forbs. As a result, repeated mowing should be considered as a suppression technique, with no expectation of plant death. Annual mowing of OED -infested European pastures (to remove hay), led to an increase in OED abundance. However, if timed correctly, it was successful in reducing seed distribution (Jacobs 2008). On the other hands, the impact of grazing on OED invasions can vary depending on how it is implemented, as it may either increase or decrease OED populations (Mangold et al. 2009). Prescribed grazing (sheep, goats, horses) at the beginning of OED flowering should be part of a sustainable management approach of this weed (Krueger and Sheley 2003; Jacobs 2008). In general, according to the results, MGRS has a little detectible effect on OED invasion. While this approach holds promise for managing the invasive species, it is crucial to execute it effectively, involving frequent mowing and grazing at the onset of OED flowering. Ceasing mowing allows OED roots to regenerate, leading to the emergence of new seedlings from the soil seed bank. Similarly, discontinuing grazing results in the rapid reversion of invaded communities to their pre-grazing weedy condition.

Our research revealed that the MGS has a significantly greater potential for reducing OED compared to the other two strategies. In this approach, the OED density was 97.26% and 94.62%, the OED canopy was 96.79% and 94.04%, and the OED biomass was 94.39% and 86.50%, respectively, lower than those observed in the 21-YES and MGRS. Controlled grazing is most advantageous when it decreases both the standing vegetation and the subsequent biomass of invasive plants. The impact of grazing on the biomass of invasive plants is influenced by the timing, intensity, and frequency of grazing, as well as the type of livestock involved. Some unpalatable species have stages in their life cycle that are palatable and sensitive to grazing, and grazing timing (and intensity) can be adjusted to coincide with periods when the invading species (unpalatable) is most susceptible (Rinella and Hileman 2009). The duration of grazing is also important because many invasive species require repeated defoliations to be effective (e.g., leafy spurge; Kirby et al. 1997). In this study, it was also observed that MGS in invaded rangeland during the flowering stage suppressed the presence of OED. Sheep, goats, cattle, and horses are known to graze OED (Stephens 2017), so introducing them into rangeland (before blooming) can help reduce OED invasion. In general, by limiting grazing to periods when OED is most sensitive to defoliation and palatable plants are mostly dormant, the impact of grazing on favorable vegetation can be minimized while maximizing its advantage for OED management.

4.2 Effects of OED management strategies on plant community

According to the results, a 21-YES reduced total density, total canopy, and bare ground while increased the abundance of litter cover. In this treatment, the plant community's total canopy showed a strong correlation with OED density (R^2=-0.91), OED biomass (R^2=-0.41), and OED canopy (R^2=-0.51), all of which were included in the regression equation. Additionally, total density had a significant correlation with OED density (R^2=-0.45) and OED canopy (R^2=-0.98), both of which were included in the regression equation. This indicates that as OED density, OED biomass, and OED canopy increase, the total canopy and total density of the plant community decrease. Moreover, the Forb density and Grass density showed a correlation with OED density (R^2=-0.26, R^2=-0.34, respectively), OED biomass (R^2=-0.30, R^2=-0.26, respectively), and OED canopy (R^2=-0.29, R^2=-0.38, respectively). Forb canopy and Grass canopy had also a correlation with OED density (R^2=-0.54, R^2=-0.41, respectively) and OED canopy (R^2=-0.58, R^2=-0.45, respectively), both of which were included in the regression equation. The issue arises from the fact that, following the presence of this species in the habitat, each plant produces a significant number of seeds annually and seeds germinates quickly (Coulson et al. 2001). These seeds give rise to numerous seedlings in close proximity to the parent plants, rapidly forming colonies and ultimately leading to its dominance (Clements et al. 2004; Stephens 2017). In this way, by forming dense colonies, it can quickly and in a short time replace 50% of the herbaceous species in a given area (Stephens 2017), and reduces the canopy and density of native plants (Porensky et al. 2020). Consequently, OED canopy, biomass, and density will increase significantly compared to the plant community. The 21-YES increases the OED density, OED biomass and OED canopy, and as a result, it causes an increase in plant litter. Litter can enhance OED by creating safe sites for seedling establishment. In addition to shifts in the competitive biotic environment, the combination of high litter and low bare ground inside of grazing exclusion may promote higher values of non-native plants (Porensky et al. 2020). However, there is evidence that grazing exclusion can reduce bare ground and indicators of erosion (Veblen et al. 2015) while increasing litter cover (Davies et al. 2009) and shifting the abundances of common bunchgrasses (Veblen et al. 2015). These results are consistent with the results of other studies (Veblen et al. 2015; Porensky et al. 2017; Root et al. 2020).

Compared to the other two techniques, the MGRS had moderate plant and ground cover values. In the MGRS, the plant community's total canopy showed a significant correlation with OED density (R^2=-0.95), OED biomass (R^2=-0.27), and OED canopy (R^2=-0.98), all of which were included in the regression equation. Moreover, total density had a significant correlation with OED density (R^2=-0.49) and OED canopy (R^2= -0.52), both of which were included in the regression equation. This indicates that as OED density, OED biomass, and OED canopy increase, the total canopy and total density of the plant community decrease. The findings revealed in this treatment, only the Forb density, showed a significant correlation with OED biomass, and OED canopy. In this treatment, while the harvesting (mowing) of forage occurs during the flowering stage of dominant plants and OED, in certain hard-to-reach areas (such as near waterways, around shrubs or trees, or next to stones), where the harvester cannot easily access the forage, some of the plant individuals remain. Consequently, their seeds are dispersed around the parent plants, leading to the establishment and spread of OED in regions. On the other hands, the remaining rootstock sprout and new seedlings emerge from the soil seed bank (Khan et al. 2021). Thus, follow-up treatments are needed where a persistent seed bank or rhizomes continues to exist. However, Howarth and Williams (2010), stated that the abundance of *L. vulgare* seems to be linked to the intensity of cutting or grazing, and that it shows resistance to cutting. Although timely mowing will prevent or reduce *L. vulgare* seed production, it may also lead to an increase in *L. vulgare* stand density by removing competitive forage growth, particularly after multiple mowings (Clements et al. 2004). So, to optimize this treatment, it appears essential to fully mowing the forage at the appropriate flowering stage and to introduce grazing livestock during the plant's active growth phase. This approach will enhance the effectiveness of the treatment.

The MGS tends to increase the total density, total canopy, Grass density, Forb canopy, Grass canopy, Forb density, Ferns canopy, Ferns density, while reducing litter cover and bare ground. In the MGS, the total canopy of the plant community was found to have a strong negative correlation with OED density (R^2= -0.94) and OED canopy (R^2=-0.97), both of which were included in the regression equation. This suggests that OED density and OED canopy have an inverse relationship with the total canopy of the plant community. Additionally, total density showed a negative correlation with OED biomass (R^2=-0.27), indicating that grazing significantly affects the OED biomass, leading to a reduction in the OED biomass and an increase in the total density of the plant community. The results showed that the Forb density, Grass density, Forb canopy and Grass canopy showed a significant correlation with OED density, and OED canopy. Forb canopy had also a significant correlation with OED biomass. The effect of grazing on other plants is also dependent on the grazing intensity, with low and medium grazing having a positive effect on vegetation cover, and increases the canopy, biomass and diversity of the plant community (Holechek et al. 2010). In the study area, the moderate intensity of livestock grazing in the grazing treatment has led to an increase in vegetation factors of native plants within the community, as well as effectively controlling the spread of invasive OED species. This treatment causes the increase of native plants (forbs and grasses) in the region, and the OED is defeated in competition with them. When other native plants grows and shades OED, it becomes less dominant in the plant community. Ensuring that the associated plant species maintain a sufficient canopy is important for their competitiveness and for reducing the amount of light that reaches the seedlings, rosettes, and basal leaves of flowering OED in the lower levels of the canopy (Olson and Wallander 1999). In addition, according to the ISA analysis, the impact of 21-YES was found to have a negative effect on floristic composition. Conversely, MGRS had a moderate effect, while MGS had a positive effect. The 21-YES resulted in fewer species compared to the other strategies, with only four species out of 25 ISA allocated to it in the study area. The MGRS showed a moderate species composition and number of ISA compared to the other two strategies. On the other hand, MGS were associated with the most species, with 12 out of 25 ISA allocated to it in the research area. These effects are likely due to the severity of the OED invasion as a result of each strategy.

The invasion of OED under a 21-YES led to a decrease in diversity indicators by displacing native species, resulting in a significant negative impact on native communities. The Evenness and Richness indices showed a significant negative correlation with OED biomass in the 21-YES, with an increase in OED leading to a decrease in Evenness and Richness. This highlights the significant effect of exclusion on the proliferation of this weed and the reduction of the plant community diversity. The rapid and vigorous growth of OED, along with its high reproductive potential, as well as its fast reproductive capability, is likely one of the causes of its significant negative impact on species diversity (Khuroo et al. 2010). These characteristics enable OED to achieve high coverage and form taller stands compared to native species in invaded habitats (McDougall et al. 2018). Other researches on invasive species support the findings of this research (Saatkamp et al. 2017; Vermeire et al. 2018; Demeter et al. 2021). As a result, a disparity arises in the composition, structure, and function of invaded communities, resulting in the formation of apparent wide monocultures, where the predominant plant species in invaded habitats appear as uniform masses. This phenomenon is supported by a recent study on this species (Ahmad et al. 2019; Khan et al. 2021) and is substantiated by another researches (Hejda et al. 2009; Khuroo et al. 2010; Afreen et al. 2018). The MGS led to a relative increase in diversity indicators by reducing the OED density, OED biomass and OED canopy. A significant correlation was found between Richness and OED biomass in the GS, indicating that a decrease in OED biomass resulted in an increase in Richness. This demonstrates the beneficial impact of livestock grazing in reducing the presence and growth of OED, consequently enhancing diversity indicators. While correlation analysis and regression relationships revealed a weaker connection between diversity indices and OED canopy factors, there were observable relative changes in diversity indices across different treatments. Moderate grazing strategy has been found to have a positive effect on diversity indicators, with grazing being well-suited for removing of organs OED. Most studies show that moderate levels of grazing result in the higher species diversity (Holechek et al. 2010; Rosa García et al. 2012; Demeter et al. 2021).

5 Conclusions

This study assessed the effect of three strategies -

21 years of grazing exclusion (21-YES), mowing and grazing in rotation every other year (MGRS), and Moderate grazing (MGS) - on changes in cover, density, and biomass of *Leucanthemum vulgare* Lam. (OED). It also investigated the effects on canopy cover and density factors, as well as diversity indices of the plant community. It is essential to select management strategies carefully considering the invasion severity and potential impact on ecosystem function and diversity. We found that grazing strategies can be employed to manipulate the species composition in favor of desirable components in the rangelands of the Namin region in Iran. The grazing strategy has proven to be effective in controlling the spread of invasive OED species and has also resulted in an increase in canopy cover, density, and diversity indices of native plants within the community. These findings have the potential to be applicable to other regions dealing with invasive species in rangeland ecosystems, offering valuable insights into management and restoration practices. The study highlights the importance of ongoing management efforts to control invasive species, with grazing potentially serving as a more practical, culturally accepted, and cost-effective short-term control strategy for widespread rangeland weed infestations.

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Authors' Contributions

All authors contributed to the study conception and design. M. Moameri, introduction, methodologist, statistical analyst, writing- review and editing (35%); S. Samadi Khanghah, statistical analyst, discussion, writing-review and editing (30%); A. Ghorbani, statistical analyst (15%); R. Mostafazadeh, statistical analyst, writing-review and editing (10%); A. Esmali Ouri, writing-review (5%); A. Biswas, writing- review and editing (5%).

Ethics Declarations

Availability of Data/Materials: All data generated or analysed during this study are included in this published article.

Conflict of Interest: The authors declare no conflict of interest.

Electronic Supplementary Material

Supplementary materials (Appendix 1) are available in the online version of this article at https://doi.org/10.1007/s11629-024-8704-y

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