

Comparative Assessment Of Protected Grazing Areas And Reforestation On Pastoral Quality (Pastoral Value Index, IVP) And Carbon Sequestration In The Steppes Of Djelfa, Algeria

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Abstract

Desertification threatens food security in semi-arid regions, particularly in Djelfa (Algeria), exacerbated by climate change and overgrazing. This study aims to comparatively evaluate the long-term effectiveness of two major restoration strategies—Reforestation (R) and Protected Grazing Areas relative to a Control zone (Natural forest). Field measurements were conducted in 2023 on 45 plots (N=15 per treatment), quantifying Overall Coverage (OC), Total Biomass (Phytomass), Annual Forage Production (UF/ha/year), and the Pastoral Value Index (PVI), an indicator of pasture quality. Kruskal-Wallis non-parametric analyses revealed highly significant differences between treatments for all indicators ($p < 0.001$). Notably, *Mise en Défens* recorded a significantly higher IVP than Reforestation ($p < 0.001$), indicating greater resilience and forage quality through natural regeneration. Conversely, Reforestation demonstrated the highest Total Biomass ($p < 0.001$), underscoring its crucial role in carbon sequestration. These results support an integrated approach in which *Mise en Défens* is prioritized for pastoral enhancement, and Reforestation for soil stabilization and woody biomass sequestration.

Keywords: comparative; Reforestation; Pastoral Quality; Carbon Sequestration

INTRODUCTION

Arid and semi-arid regions cover a substantial portion of the Earth's surface and face a high risk of desertification, a process that threatens food security and the livelihoods of millions (P Smith et al., 2020; Pedrinho, A et al., 2024). "Algeria, particularly the Djelfa region, exemplifies these territories confronting ecological degradation intensified by climate change: annual precipitation is declining, and stress on water resources and vegetation is increasing, a phenomenon well documented in the scientific literature on North African arid and semi-arid zones (Lal, 2020; Cherifi et al., 2019). Overgrazing and the conversion of natural forests into pastures constitute major factors, intensifying the loss of vegetative cover and soil erosion (IPCC, 2019; UNCCD, 2024).

In the face of these challenges, various strategies such as reforestation and enclosure are being promoted to restore degraded lands. These approaches aim to increase vegetation cover, improve soil quality, and revive biodiversity (A. Adem et al., 2024; Z. Zhang et al., 2024). Enclosure has proven particularly effective in increasing floristic richness and aboveground biomass in degraded rangelands (A. Adem et al., 2024; J. Liu et al., 2022), whereas reforestation contributes more effectively to erosion control and carbon sequestration (L. E. Nave et al., 2024). However, few quantitative comparative analyses exist that measure the respective effectiveness of these strategies using objective eco-pastoral indicators, particularly in North African steppes subjected to strong human pressure.

Thus, in the Moudjbra area (Djelfa), previous studies (Khaouani et al., 2019, 2022; Senni, 2013) have highlighted the severity of land degradation and the need for effective restoration measures. In this context, the present research aims to quantify, through the calculation of biomass and the Pastoral Value Index (PVI), the long-term comparative impact of reforestation and enclosure. The main objective is therefore to assess the sustained effect of Reforestation and Enclosure (compared to a reference Natural Forest) on four key indicators: Total Vegetation Cover, PVI, Total Biomass, and Annual Forage Production.

We hypothesize that Enclosure, through natural regeneration and the adaptation of local species, will generate greater gains in pastoral vigor and annual productivity, thereby providing better long-term ecological resilience than reforestation.

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2. MATERIALS AND METHODS

2.1. Study Area

The present study was conducted in the Moudjbra region (Figure 1), located in the Wilaya of Djelfa, an emblematic area of the Green Dam project. The ecosystem is of a steppe type (semi-arid bioclimatic zone), characterized by a Mediterranean climate with dry summers and average annual rainfall ranging between 200 and 300 mm (Khaouani et al., 2019). The area is subjected to strong anthropogenic and pastoral pressure, leading to severe degradation of soils and vegetation.

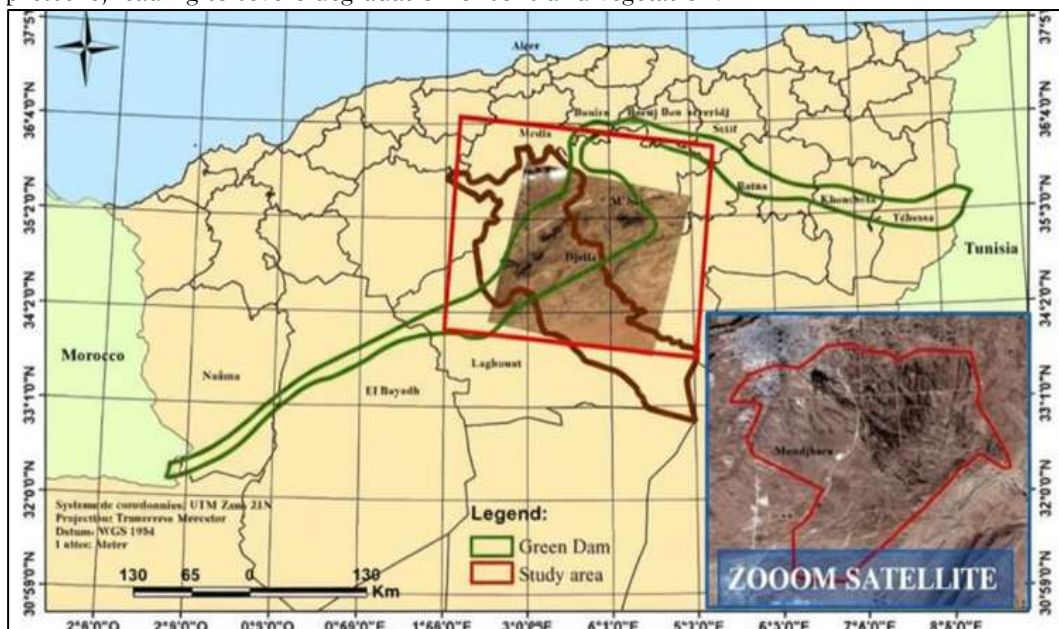


Figure 1. Location of the Moudjbra study area within the steppe context of the Green Dam project (Djelfa, Algeria). Map produced/modified based on WGS 1984 data and Khaouani et al. (2019).

2.2. Experimental Design and Treatment Duration

The experiment was conducted in spring 2023 on three types of plots:

Reforestation (R): Plots planted with Aleppo pine (**Pinus halepensis**) in 1984 (39 years old at the time of sampling).

Enclosure (EX): Fenced plots excluded from all pastoral activities and wood cutting, representing assisted natural regeneration.

Control (REF): Natural forest subjected to local pastoral pressure, used as a reference for the degraded state.

For each treatment, 15 plots were sampled, resulting in a total of 45 surveys.

2.3. Measurement of Ecological Indicators

Data collection was carried out in spring 2023.

2.3.1. Total Vegetation Cover (TVC) and Species Frequency (SFi)

Total vegetation cover (TVC) and species frequency (SFi) were determined using the line-intercept method or transect method (Daget & Poissonet, 1971), along a 10 m linear transect per plot with 100 reading points. TVC corresponds to the percentage of points intercepted by vegetation, while SFi represents the presence ratio of a given species out of 100 points.

2.3.2. Pastoral Value Index (PVI)

The Pastoral Value Index (PVI) was calculated following the methodology developed by Aidoud (1989). The PVI calculation is based on the sum of species-specific contributions, integrating the species frequency (FS_{ii}), weighted by the quality coefficient (Q_{ali}) and the production coefficient (Pro_{di}), according to the following formula:

$$IVP = \sum_{i=1}^n (FS_{ii} \times Q_{ali} \times Pro_{di}) / 100$$

2.3.3. Total Biomass (Phytomass) and Annual Forage Production

Total biomass and annual forage production (kg/ha) were estimated using species frequencies (S_{Fi}) through non-destructive regression models (Aidoud, 1989), adjusted according to species and presence conditions.

2.4. Statistical Analysis

All statistical analyses were performed using R software (version 4.3.1; R Core Team, 2024).

Data for each ecological indicator (TVC, PVI, phytomass, FU/ha/year) were tested for normality within each habitat using the Shapiro–Wilk test. Homogeneity of variances was assessed using Levene’s test.

When parametric assumptions (normality and/or homogeneity of variances) were not met, a non-parametric Kruskal–Wallis test was applied to compare indicators among the three habitats (exclosure, reforestation, and natural forest).

When the Kruskal–Wallis test indicated significant differences, post hoc Mann–Whitney (Wilcoxon) tests were conducted for all pairwise habitat comparisons, with Bonferroni correction applied to control the risk of Type I error.

The level of statistical significance was set at $p < 0.05$.

Comparative results (means \pm standard deviation, p-values, and significance levels) were presented in summary tables.

Value distributions were visualized using grouped boxplots, highlighting differences among habitats.

3. Results

Statistical analyses focused on comparing four key ecological indicators—Total Vegetation Cover, Pastoral Value Index (PVI), Total Biomass, and Annual Forage Production—across the three treatments studied: Reforestation (R), Exclosure (EX), and Control (REF).

3.1. Descriptive Statistics of Ecological Indicators

Table 1 presents the descriptive statistics (mean \pm standard deviation, N = 15) for the four indicators measured across the three plot types.

Indicator	Reboisement (R)	Put on Defense (MD)	Witness (REF)
Global Recovery (%)	54.80 \pm 8.28	62.07 \pm 8.79	35.40 \pm 10.38
Pastoral Value Index (PVI)	16.99 \pm 2.68	25.79 \pm 4.35	13.94 \pm 3.73
Total Biomass (kg/ha)	3025.13 \pm 566.69	2753.11 \pm 769.11	1713.82 \pm 799.40
Annual Forage Production	167.04 \pm 23.95	193.38 \pm 31.86	112.95 \pm 30.63

Tableau 1 : Statistiques descriptives (moyenne \pm écart-type) des indicateurs pour les trois traitements de restauration écologique à Moudjbra (Djelfa, N=15).

Table 1. Descriptive statistics (mean \pm standard deviation) of the indicators for the three ecological restoration treatments at Moudjbra (Djelfa, N = 15).

The results indicate that:

Exclosure (EX) exhibits the highest mean values for Total Vegetation Cover, Pastoral Value Index (PVI), and Annual Forage Production.

Reforestation (R) records the highest Total Biomass.

Natural Forest (REF) consistently shows the lowest values, with the greatest variability observed for Total Vegetation Cover.

3.2. Graphical Representation of Results (Individual Boxplots of TVC, PVI, Phytomass, and FU/ha/year)

Each indicator was represented using a boxplot to visualize its distribution across treatments.

Figure 2 illustrates the distributions of annual forage production values (FU/ha/year) for the three treatments. The boxplots confirm that **Exclosure** shows the highest mean value (193.38 FU/ha/year) as well as the greatest variability. Conversely, the **Reforestation** area displays the lowest mean value (112.95 FU/ha/year) with reduced variability. The **Natural Forest** occupies an intermediate position, with a mean value of 167.04 FU/ha/year, exhibiting a data distribution similar to that of the Exclosure treatment.

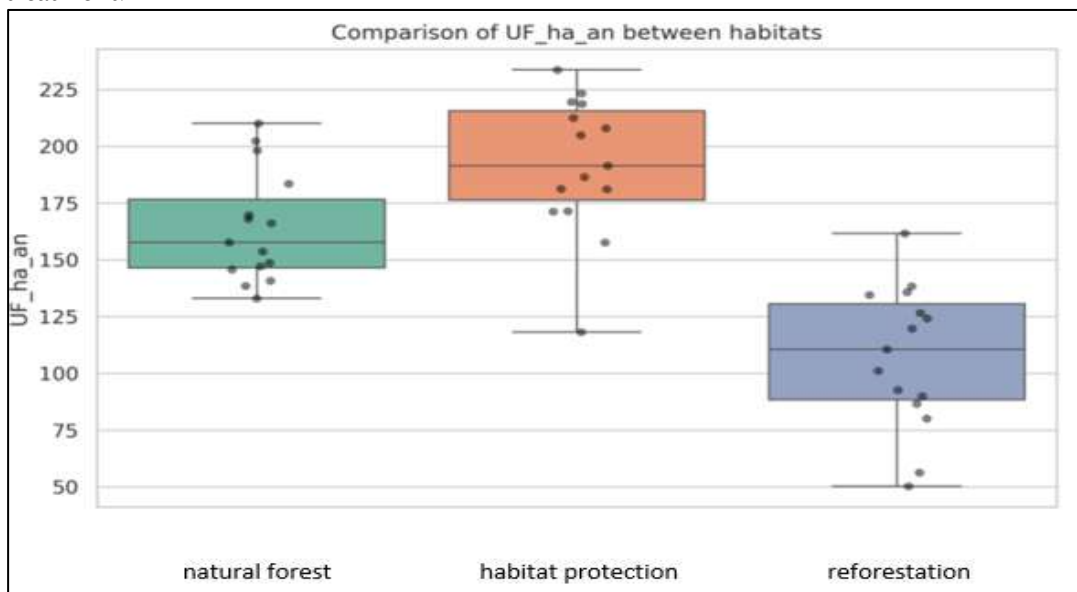


Figure 2: Comparative boxplots of Annual Forage Production (FU/ha/year) among Natural Forest, Exclosure, and Reforestation habitats in the Moudjbra study area (Djelfa, Algeria).

Figure 3 shows the distributions of Total Biomass values (kg/ha) for the three treatments. The boxplots clearly indicate that the **Natural Forest** and **Exclosure** areas exhibit high and similar median values (approximately 2800 kg/ha and 2900 kg/ha, respectively), with notable variability. In contrast, **Reforestation** displays a significantly lower median (around 1700 kg/ha) and a more compact data distribution.

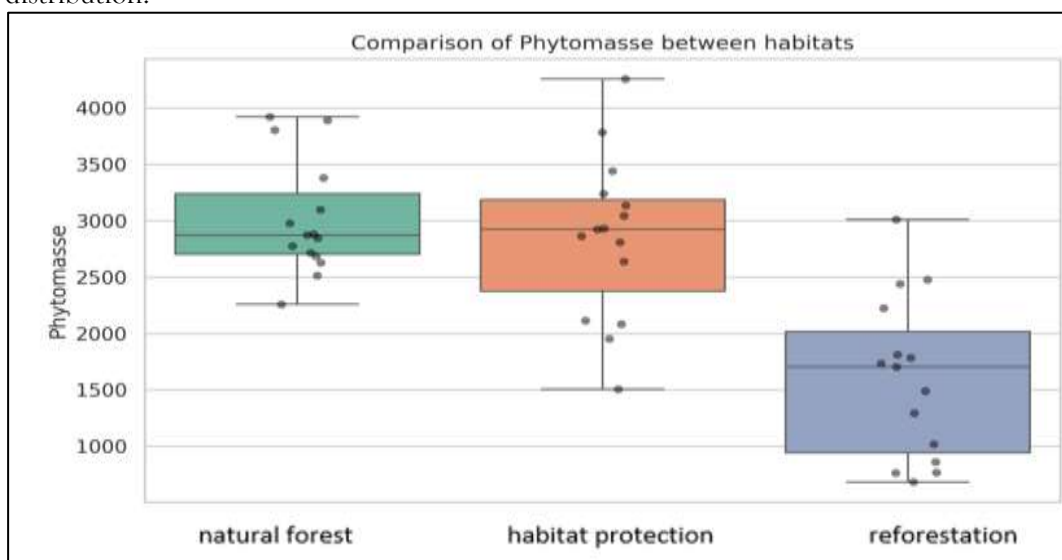


Figure 3: Comparative boxplot of Total Biomass (Phytomass, kg/ha) between Natural Forest, Protected Area, and Reforestation habitats in the Moudjbra study area (Djelfa, Algeria).

Figure 4 shows the distributions of Global Cover (GC) values among the different treatments. The boxplots clearly show that the Protected Area has the highest median (about 64%) and the greatest

variability. The Natural Forest is in an intermediate position, with a median around 52%. Reforestation displays the lowest median (about 33%) and a relatively compact data distribution, indicating significantly lower vegetation cover.

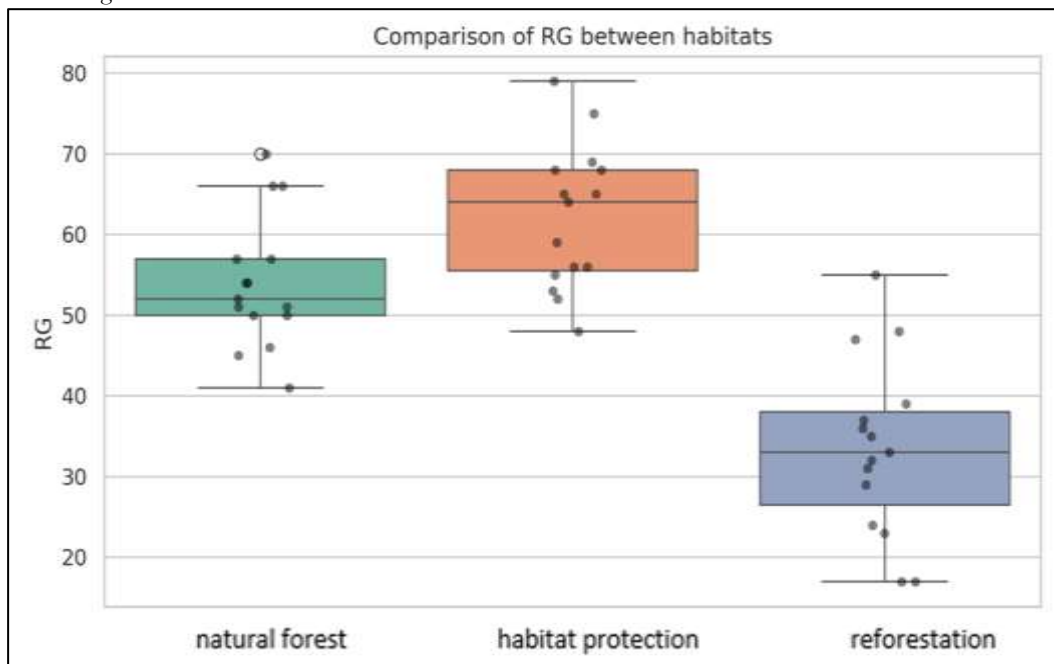


Figure 4: Comparative boxplot of Overall Cover (RG, %) between Natural Forest, Protected Area, and Reforestation habitats in the Moudjbra study area (Djelfa, Algeria).

Figure 5 shows the distributions of IVP values between the different treatments. The boxplots confirm that the Protected Area has the highest median (around 26), indicating the best pastoral quality. The Natural Forest and Reforestation show similar and significantly lower medians (around 17 and 15 respectively), with reduced variability for both.

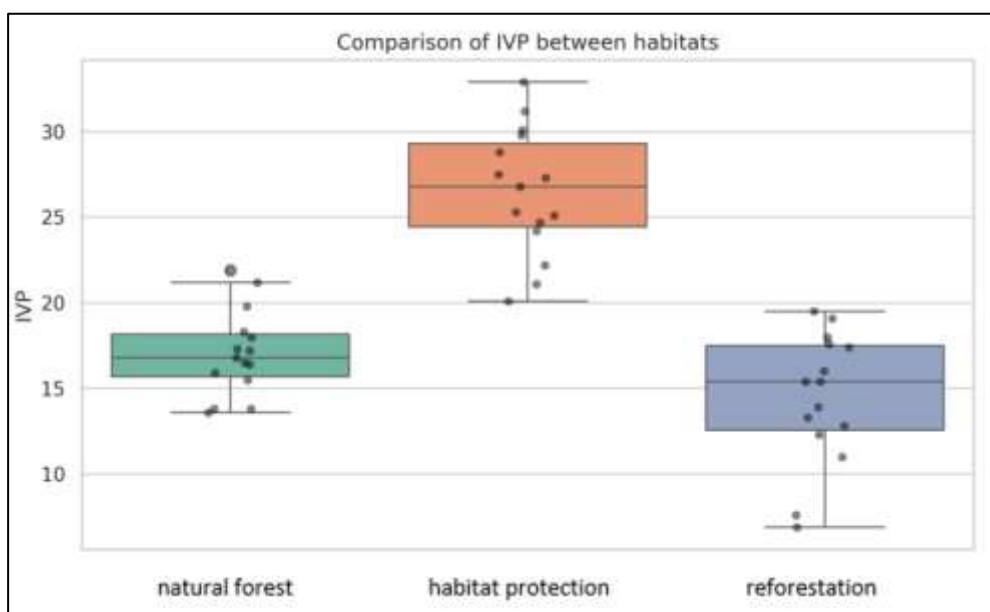


Figure 5: Comparative boxplot of the Pastoral Value Index (PVI) between Natural Forest, Protected Area, and Reforestation habitats in the Moudjbra study area (Djelfa, Algeria).

3.3. Synthetic visualization of indicators by habitat:

The following figure presents an overview of the distribution of all measured ecological indicators (Overall Cover, PVI, Phytomass, Annual Forage Production) according to the applied treatment, facilitating cross-comparison of restoration performances.

Visual examination of this synthetic figure highlights several converging trends:

- **Pastoral Performance:** The Protected Area shows a notable superiority for **PVI** and **Global Recouvrement**.
- **Biomass Sequestration:** **Reforestation** presents the highest total biomass (Phytomass).
- **Control Position:** The Control plot (**Natural Forest**) occupies an intermediate position for most indicators, except Phytomass which is comparable to the protected area.

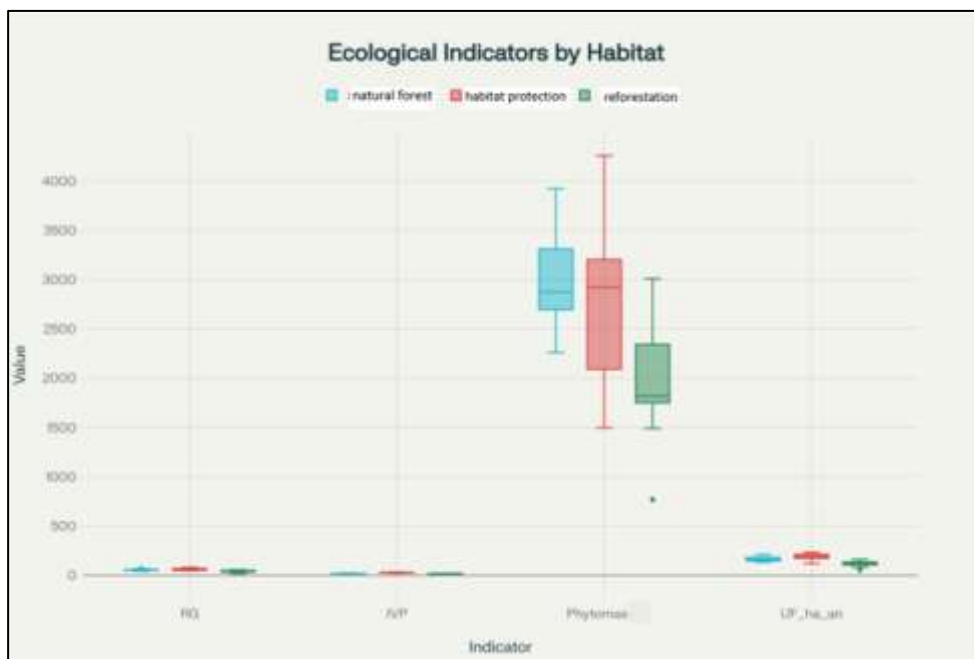


Figure 6: Synthetic boxplots comparing the distribution of the four ecological indicators (RG, IVP, Phytomass, UF/ha/year) between Natural Forest, Protected Area, and Reforestation habitats in Moudjbra (Djelfa, Algeria).

3.4. Summary of statistical results and main interpretations:

The results of non-parametric statistical analyses and post-hoc comparisons allow the identification of the effects of different treatments on each ecological indicator. The overall **Kruskal-Wallis** test reveals a highly significant difference between treatments for all studied indicators ($p < 0.001$).

Table 2: Results of the Kruskal-Wallis test (indicative values)

Indicator	Sum of Squares	DDL	Mean of Squares	F	p
Global Recovery	3535.40	2	1767.70	20.67	<0.001
Pastoral Value Index	328.61	2	164.30	48.01	<0.001
Total Biomass	12,042,429	2	6,021,214.50	10.04	<0.001
Annual Forage Production	50,580.46	2	25,290.23	33.74	<0.001

To specify which pairs of treatments show significant differences, **Mann-Whitney** post-hoc analyses were performed for each indicator:

Table 3: Pairwise comparisons of the main ecological indicators (Overall Cover, Pastoral Value Index, Phytomass, Annual Forage Production) between treatments (Forest, Protection, Reforestation): p-values and significance of differences (**Mann-Whitney post-hoc test**)

Indicator	Comparison (Pair)	p-value	Significant difference
RG	Forest vs Defenses	0.014	Yes

Indicator	Comparison (Pair)	p-value	Significant difference
	Forest vs. Reforestation	<0.001	Yes
	Défens vs Forest vs. Reforestation	<0.001	Yes
PVI	Forest vs Defenses	<0.001	Yes
	Forest vs. Reforestation	0.055	No (tendance)
	Forest vs. Reforestation	<0.001	Yes
Phytomass	Forest vs Defenses	0.72	No
	Forest vs. Reforestation	<0.001	Yes
	Forest vs. Reforestation	<0.001	Yes
UF/ha/ year	Forest vs. Defenses	0.004	Yes
	Forest vs. Reforestation	<0.001	Yes
	Forest vs. Reforestation	<0.001	Yes

Significant differences favor Protection for pastoral vigor (PVI, OC, UF/ha/year), while total biomass is mostly optimized through Reforestation. Natural Forest shows intermediate or the lowest values, depending on the indicators.

Tables 2 and 3 provide a comprehensive view of the differences between treatments. All indicators show significant differences via a non-parametric Kruskal-Wallis analysis ($p < 0.001$). Post-hoc analyses specify the most marked comparisons. Protection stands out for pastoral quality and forage production, Reforestation for biomass, confirming the differentiated effectiveness of restoration strategies.

DISCUSSION

The objective of this study was to evaluate the effectiveness of the two major pastoral restoration strategies, Reforestation (R) and Fencing (MD), on the ecological vigor and productivity of the degraded steppes of Moudjbra (Djelfa). The significant results obtained validate the need for restorative interventions and highlight the superior performance of Fencing for indicators of pastoral quality and resilience.

The robustness of the conclusions relies on an appropriate non-parametric statistical methodology, which ensures a reliable assessment of differences between treatments. Our results align with those of recent studies in Mediterranean and subarid steppe areas, where pastoral exclusion (fencing) promotes the regeneration of locally adapted species, plant diversity, and annual productivity (Adem et al. 2024; Liu et al. 2022; Salemkour, 2022).

4.1. Degree of Degradation and Urgency of Intervention

The Natural Forest (Control) consistently shows the lowest values for Overall Cover, Total Biomass, and Annual Forage Production: a finding consistent with the deteriorations caused by overgrazing and climate change (Araujo et al., 2024; Smith et al., 2020). This situation of an active desertification state requires rapid intervention to halt the loss of ecosystem services and the threat to food security.

4.2. Exclosure: Proof of Superiority and Ecological Impacts

The Exclosure is distinguished by a significantly higher PVI and annual forage production compared to Reforestation, validating the recommendations advocated in national and international restoration plans (World Bank, 2024; ASJP-CERIST, 2022). The rapid increase in vegetation cover and pastoral capacity is explained by the spontaneous regeneration of indigenous species, adapted to the water constraints of the Algerian semi-arid zone (Adem et al., 2024). This phenomenon has been confirmed in Ethiopian and Moroccan exclosures, where floristic richness and biomass rates notably increase after ecological rest (Liu

et al., 2022). Moreover, the restoration dynamics are economically advantageous: recent studies show that pastoral exclusion generates a rapid increase in forage productivity without heavy investment (Pedrinho, A et al., 2024, Amghar et al., 2012).

4.3. Reforestation: Structuring Assets and Pastoral Limits

Although Reforestation (Aleppo Pine, 39 years) presents the highest total biomass, it remains behind on the criteria of forage quality and pastoral resilience. Its main contribution remains carbon sequestration and soil stabilization, essential processes demonstrated by numerous studies (Lal, 2020; Don et al. 2023; Babalola et al., 2024). However, two major ecological factors limit pastoral improvement in these reforested stations:

On the one hand, the water competition established by the dense tree layer reduces access to water for the herbaceous flora, limiting its growth and diversity; on the other hand, competition for light, aggravated by a high density of pines in some stations, greatly reduces ground-level light. This reduction in available light slows the germination, development, and photosynthesis of pastoral species, which negatively impacts the Pastoral Value Index (PVI) and forage yield. This dual phenomenon – water and light – is frequently observed in Mediterranean and Maghreb silvopastoral systems, where the closure of the forest canopy limits the dynamics of the underlying herbaceous species and the floristic diversity useful for grazing (Campagnaro et al. 2018; Bugalho et al. 2011).

4.4. Towards an Integrated and Sustainable Management of Steppe Lands

The results obtained advocate for an integrative land management in semi-arid contexts, whose strategies benefit from being refined by recent scientific advances:

- **Priority Fencing:** This method must be systematized to quickly restore productivity and pastoral diversity, particularly in ecological emergency plans. The effectiveness of fencing is maximized when dynamically adapted through geoinformatics and remote sensing tools, allowing precise monitoring of biomass evolution and erosion.
- **Targeted Reforestation:** This action should remain reserved for sectors aiming at carbon neutrality and combating severe erosion, or be combined with fencing to enhance overall ecosystem benefits. The focus is now on using native species resilient to climate change to ensure the sustainability of plantations.

Adapted planning, taking into account pedoclimatic conditions and management objectives (pastoral versus forestry), is essential to ensure restoration sustainability (Salemkour, 2022; ASJP-CERIST, 2022).

Improved limits and perspectives:

The initial study was limited by the analysis of four key indicators. For a more comprehensive understanding of restoration success, future research now includes:

- **The addition of crucial parameters:** The integration of precise pedoclimatic data, faunistic indicators (animal biodiversity), and, above all, socio-economic parameters is essential. The participation and acceptance of local pastoral communities are recognized as fundamental for the long-term success of projects.
- **The deepening of mixed systems and pastoral agroforestry:** The possibility of applying and monitoring combined systems (enclosures, native plantations, pastoral rotation) is explored further, investigating innovative techniques such as selecting livestock with high energy efficiency to improve forage production and soil quality without overgrazing.

5. CONCLUSION

This study provides an unprecedented quantitative and comparative assessment of the effectiveness of the two main ecological restoration strategies – enclosure and reforestation – in the semi-arid steppe of Moudjbra (Djelfa). The results confirm that enclosure, through the natural regeneration of adapted indigenous species, significantly improves pastoral vigor (PVI) and annual productivity (+54% PVI and +71% forage production compared to the control), ensuring ecological resilience superior to that of reforestation. Reforestation, for its part, optimizes total biomass (+76% vs. control), making it a key strategy for carbon sequestration and erosion control, although its pastoral performance is limited by water and light competition generated by the tree layer.

Faced with the severe degradation observed, it is urgent to adopt integrated land management: prioritize enclosure to quickly restore production and pastoral diversity, while reserving reforestation for areas targeting soil stability and carbon neutrality, or even combining the two approaches to enhance their complementary benefits.

Research perspectives should broaden the analysis to include soil, water, faunal, and socio-economic parameters in order to optimize the long-term sustainability of restoration actions. This framework can be adapted to all North African or Mediterranean steppes, offering concrete solutions against desertification and contributing to regional food security.

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