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Habitat Transformation of Urial Sheep (Ovis vignei) in Golestan National Park: A Landscape-Ecology Approach

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ABSTRACT

Aims: This study assessed six-year changes (2018–2023) in the vegetation cover of Golestan National Park, a critical habitat for the vulnerable urial sheep (*Ovis vignei*). The research specifically sought to quantify transformations in forest, woodland, and grassland classes and evaluate the implications of these changes for urial sheep habitat quality using a landscape-ecology approach.

Materials & Methods: Landsat 8 satellite imagery from 2018 and 2023 was analyzed using supervised classification in ENVI 5.6 and ArcGIS to produce vegetation maps categorized into forest, woodland, and grassland. Changes in habitat structure were quantified using six landscape metrics: class area (CA), percentage of landscape (PLAND), number of patches (NP), mean patch size (MPS), total edge (TE), and edge density (ED).

Findings: The analysis revealed a marked transformation in the park's vegetation structure. Forest cover declined by 373 ha and woodland by 2,784 ha, while grassland, the urial sheep's preferred habitat, expanded by 3,152 ha. Landscape metrics indicated a consolidation of grassland habitats, as evidenced by increases in CA and PLAND, decreases in NP, and increases in MPS. In contrast, forests and woodlands exhibited signs of fragmentation, with increasing NP and decreasing MPS.

Conclusion: The findings highlight a significant shift in the landscape of Golestan National Park, characterized by the fragmentation of forest and woodland and the consolidation and expansion of grasslands. This transformation is likely to enhance habitat suitability for the urial sheep. The study provides a scientific basis for developing targeted management and conservation strategies to maintain habitat quality and ensure the long-term sustainability of the urial sheep population.

Keywords: Golestan National Park; Habitat Fragmentation; Landscape Metrics; Remote Sensing; Vegetation Dynamics.

CITATION LINKS

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Introduction

Protected areas are globally recognized as the cornerstone of strategies to conserve biodiversity and sustain human well-being by providing essential ecosystem services [1]. However, their effectiveness is increasingly undermined by anthropogenic pressures, particularly land-use change occurring within and around their boundaries [2]. This leads to habitat loss and fragmentation, which can isolate populations, disrupt ecological processes, and compromise the long-term viability of the very ecosystems these areas were established to protect [3,4]. Despite a global expansion of protected area networks, evidence shows their performance in halting habitat loss is highly variable [5], underscoring the urgent need for quantitative monitoring and assessment to inform effective management.

Protected areas in Iran are classified into four categories, each serving specific conservation mandates. First, National Parks refer to areas of the country's natural resources, including forests, pastures, natural groves, woodlands, plains, water, and mountains, that represent outstanding examples of the country's nature. These areas are strictly managed to preserve their pristine state and ensure the natural breeding of flora and fauna. Second, National Natural Monuments are designated to protect rare plant or animal phenomena, unique landscapes, or historic ancient trees within specific boundaries. The third category, Wildlife Refuges, comprises natural habitats with unique climatic conditions that are essential for the protection and restoration of wildlife populations. Finally, Protected Areas refer to specific ecosystem segments where all biotic and abiotic elements are comprehensively managed under internal zoning plans to achieve targeted conservation goals. Today, a total of 309 protected areas, including 32 national parks, cover over 10% of the country's total area and inland lakes [6].

Among these, Golestan National Park (GNP) stands out as the country's first and most ecologically significant protected area, established in 1957 [7]. Situated at a critical biogeographical ecotone between the humid Hyrcanian forests and the arid Iran-Turanian steppes, the park harbors exceptional biodiversity, including over 50% of Iran's mammalian species [8, 9]. It serves as a crucial refuge for the urial sheep (*Ovis vignei*), a flagship herbivore classified as Vulnerable (VU) on the IUCN Red List due to significant population declines across its range. Regarding the species' distribution, the urial sheep is not limited to Iran; its range extends across Pakistan, Afghanistan, Tajikistan, Kazakhstan, Uzbekistan, Turkmenistan, and India. Currently, the global population of this species is estimated at approximately 30,000 individuals [10] .In Iran, the eastern regions provide the most suitable habitats, with Golestan and Tandooreh National Parks being recognized as the most prominent strongholds for the species [11]. With GNP harboring a substantial portion of the world's remaining urial sheep population, understanding the dynamics of its habitat is paramount for the species' survival [10,12]. Historically, the Urial Sheep population in Iran was estimated to be at least 15,000 individuals in the mid-1970s [13,14]. Focusing on GNP, while historical data indicate fluctuations, the 2023 census recorded 10,252 individuals, highlighting the area's continued significance [15]. The pressing need for conservation action is rooted in a clear understanding of habitat trends.

While habitat change is recognized as a major threat within GNP, a quantitative, spatially explicit understanding of recent habitat transformation in this critical park is lacking [16]. Such an analysis is essential for moving beyond anecdotal observations to evidence-based conservation planning. Landscape ecology provides a robust framework for this task, utilizing landscape metrics to quantify changes in both the composition (the amount of each habitat type) and configuration (the spatial arrangement of habitats) of a landscape [17,18]. Recent studies in Iran have successfully employed these metrics to quantify landscape degradation caused by infrastructure development [19] and land-use changes affecting vulnerable species [20]. By applying these metrics, it is possible to measure complex ecological processes such as habitat fragmentation, the breaking apart of large, contiguous habitats into smaller, more isolated patches, and consolidation, where habitats become larger and more connected. This approach allows for a direct link to be drawn between observable landscape patterns and their potential ecological consequences, providing a robust tool for assessing habitat quality and integrity over time.

This study, therefore, aims to quantify the spatiotemporal changes in the forest, woodland, and grassland habitats of Golestan National Park between 2018 and 2023 using a suite of landscape metrics and to evaluate the implications of these changes for the conservation of the vulnerable urial sheep. Specifically, this research addresses the following questions: (1) How have the composition and configuration of critical habitats (forest, woodland, and grassland) changed over the studied six-year period? (2) Does the landscape exhibit trends of fragmentation or consolidation? and (3) What are the potential implications of these landscape transformations for the urial sheep population? Based on these questions, we hypothesized that: (1) Anthropogenic pressures and climatic factors have led to a reduction in the area of woody habitats (forests and woodlands) and increased their fragmentation; and (2) Conversely, grassland habitats have undergone structural changes that may temporarily favor grazing species, despite the broader context of landscape degradation.

Materials & Methods

Study Site

Golestan National Park is located in northeastern Iran, on the border of Golestan, Khorasan, and Semnan provinces, between 37°16′43″ and 37°31′35″ N latitude and 55°43′25″ and 56°17′48″ E longitude [21]. Covering approximately 92,000 ha, it is Iran’s oldest protected area and was designated a UNESCO Biosphere Reserve in 1977 [7-9]. The park is characterized by a steep elevation gradient, ranging from 450 m to 2,411 m above sea level, which drives a sharp climatic gradient; mean annual precipitation varies from 700 mm in the west to just 142 mm in the east. This unique geography places GNP at the junction of two major biogeographical zones: the temperate Hyrcanian forests to the west and the semi-arid Iran-Turanian steppes to the east [8]. This ecotone supports exceptional biodiversity, including approximately one-eighth of Iran's vascular plant species and over half of its mammalian species [9]. The park is also influenced by significant anthropogenic pressure from surrounding settlements. According to recent census data, there are roughly 40 villages within the park's interaction zone with a combined population exceeding

35,000 inhabitants, whose agricultural and pastoral activities often encroach upon park boundaries [22]. The spatial context of the study area is provided in Figure 1.

As shown in Figure 1, the environs of Golestan National Park include four protected zones, Qorkhod, Zav A, Zav B, and Loveh, that serve as vital buffer areas maintaining the park's ecological integrity [23]. Qorkhod Protected Area, situated to the east, is characterized by mountainous and steppe habitats. Zav A and Zav B lie to the west and northwest, encompassing predominantly forested terrain with montane summer pastures at higher elevations. Loveh Protected Area, in the southwest, completes this protective mosaic. The park's heterogeneous environment supports three principal habitat types: Hyrcanian forests dominate the western sector, Iran-Turanian elements prevail in the east, and the intervening ecotone supports a mixed assemblage of arboreal species and rangeland flora [23,9], which was the focus of this study's classification:

- **Forest:** This habitat consists of dense, contiguous stands of deciduous trees with a developed understory, characteristic of the humid Hyrcanian zone in the park's western sector. Dominant species include oak (*Quercus* spp.), European hornbeam (*Carpinus betulus*), and Persian ironwood (*Parrotia persica*) [11, 24].
- **Woodland:** This transitional habitat consists of open stands of trees and shrubs, such as Grecian juniper (*Juniperus excelsa*), with sufficient spacing to allow for a well-developed understory of shrub and herbaceous vegetation. It forms an ecotone between the dense forests and the open steppes [11, 24].
- **Grassland and Steppe:** These habitats, dominated by shrubs and grasses, represent the Iran-Turanian vegetation communities in the park's drier eastern sector. They

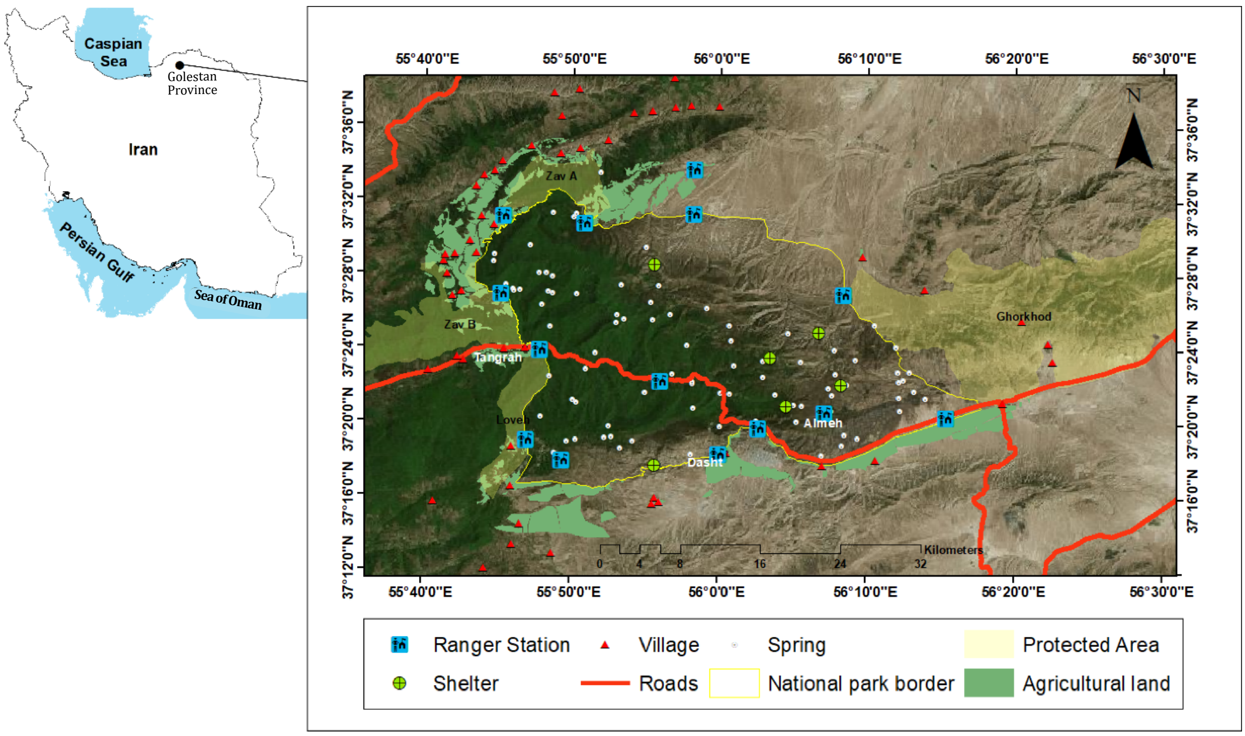

Figure 1) Location and key features of Golestan National Park, Iran. The map displays the park boundary, adjacent protected areas, major infrastructure, and surrounding land-use.

constitute the primary foraging grounds for ungulates like the urial sheep, which are predominantly grazers that depend on grass availability [24, 25].

Satellite Imagery and Classification

To analyze spatiotemporal habitat changes, cloud-free Level-2 Surface Reflectance products from the Landsat 8 Operational Land Imager (OLI) were acquired from the United States Geological Survey (USGS) Earth Explorer platform. The images were selected for the peak vegetation growth season (June-July) of 2018 and 2023 to maximize spectral distinguishability between vegetation classes. As Level-2 products, these images had already been processed using the USGS Land Surface Reflectance Code (LaSRC) algorithm, ensuring geometric and atmospheric corrections; therefore, no further radiometric rectification was required. However, the images were subset to the boundaries of Golestan National Park to facilitate processing.

Image processing and classification were conducted using ENVI 5.6 software. A supervised classification approach employing the Maximum Likelihood Classifier algorithm was applied. This parametric algorithm assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class [26].

The classification process involved three main steps:

1. Training Sample Collection: For the three target classes (Forest, Woodland, and Grassland), training polygons were selected based on field knowledge and high-resolution Google Earth imagery. Special care was taken to ensure that training samples were uniformly distributed and spectrally pure.
2. Spectral Band Selection: To optimize classification accuracy, spectral bands sensitive to vegetation health and structure, specifically Band 3 (Green), Band 4 (Red), and Band 6 (SWIR 1), were utilized.
3. Accuracy Assessment: Post-classification, the accuracy of the generated maps was evaluated using a confusion matrix. Ground-truth points, independent of the training samples, were used to calculate the Overall Accuracy and Kappa Coefficient, thereby ensuring the reliability of the derived land-cover maps. Finally, the Majority Filter and Boundary Clean tools were applied in ArcGIS to eliminate isolated pixels and smooth the class boundaries, respectively.

To explicitly link the landscape changes to the ecology of the urial sheep, the vegetation classification was based on the species' specific habitat requirements. Urial sheep are specialized grazers that predominantly inhabit open, rolling terrain and grasslands, which provide essential forage and visibility for predator detection. Conversely, dense forests and woodlands often act as barriers to their movement or are less preferred due to higher predation risk and lower forage availability [10, 16, 27]. Therefore, in this landscape-ecology approach, the "Grassland" class is considered a proxy for the primary suitable habitat, while "Forest" and "Woodland" are treated as matrix or less-suitable habitats. Consequently, structural changes in these vegetation classes, specifically the consolidation of grasslands or fragmentation of woodlands, are interpreted as direct indicators of habitat transformation for the urial sheep.

Landscape Metrics

In this study, landscape metrics were calculated for three main vegetation classes (forest, woodland, and grassland) to assess habitat transformation. Following the methodology suggested by [27], six class-level metrics were selected to quantify both habitat composition and configuration. These metrics were chosen based on their ability to capture distinct landscape patterns and their proven efficacy in monitoring structural habitat changes. The detailed descriptions, ecological significance, and units of the selected metrics are presented in Table 1.

Accuracy Assessment

The accuracy of the 2018 and 2023 classification maps was validated to ensure the reliability of the landscape metric analysis. An error matrix was generated in ENVI by comparing the classified pixels against a set of ground-truth reference pixels. From this matrix, the overall accuracy

Table 1) Description and ecological significance of landscape metrics used in this study [28].

Metric	Abbreviation	Description and Ecological Significance	Unit	Range
Class Area	CA	Sum of the areas of all patches of the corresponding patch type. It serves as a primary measure of habitat loss or gain over time (e.g., expansion of foraging grounds for urial sheep).	ha	> 0
Percentage of Landscape	PLAND	Percentage of the total landscape area comprised of the corresponding patch type. It quantifies the dominance of each habitat type within the study area.	%	0 < P ≤ 100
Number of Patches	NP	Total number of patches of the corresponding patch type. An increase in NP over time typically indicates habitat fragmentation.	None	≥ 1
Mean Patch Size	MPS	Average area of patches of the corresponding patch type. A decrease in MPS coupled with an increase in NP confirms the fragmentation process.	ha	> 0
Total Edge	TE	Sum of the lengths of all edge segments involving the corresponding patch type. It reflects the total amount of edge created by habitat alteration.	m	≥ 0
Edge Density	ED	The sum of the lengths of all edge segments divided by the total landscape area. Higher values indicate greater edge effects, which can impact species interactions and microclimates.	$m.ha^{-1}$	≥ 0

Table 2) Changes in landscape metrics for forest, woodland, and grassland habitats in Golestan National Park between 2018 and 2023.

Metric Type	2018	2023	2018	2023	2018	2023
Habitat class	Forest	Forest	Woodland	Woodland	Grassland	Grassland
Class Area (ha)	29,195	28,822	33,093	30,309	26,745	29,897
Percentage of Landscape	32.79	32.37	37.16	34.04	30.03	33.58
Number of Patches	161	162	581	585	366	319
Mean Patch Size (ha)	181.33	177.91	56.95	51.81	73.07	93.72
Total Edge (m)	658,700	613,014	1,558,555	1,476,541	954,457	922,737
Edge Density (m^{-1})	7.39	6.88	17.50	16.58	10.72	10.36

and the Kappa coefficient were calculated. The Kappa coefficient measures the degree of agreement between the classification and the reference data, accounting for agreement that could occur by chance alone [29].

Findings

The analysis of satellite imagery revealed a significant transformation in the landscape structure of Golestan National Park between 2018 and 2023. The spatial distribution of these changes is visualized in the habitat classification maps for 2018 and 2023 (Figure 2). A detailed quantitative assessment using landscape metrics highlights two contrasting trends: the consolidation of grasslands and the fragmentation of forests and woodlands. The most significant change was the consolidation of grassland habitats, the primary forage for urial sheep. Grasslands increased in total area (CA) by 3,152 ha, from 26,745 ha in 2018 to 29,897 ha in 2023. A structural consolidation accompanied this expansion, as the number of grassland patches (NP) decreased from 366 to 319. Consequently, this led to a substantial 28% increase in mean patch size (MPS), which grew from 73.07 ha to 93.72 ha (Table 2). In contrast, both forest and woodland habitats showed clear signs of fragmentation. The woodland area experienced the largest decline, shrinking by 2,784 ha, while forest cover decreased by 373 ha. This loss in area was accompanied by increases in the number of patches (NP) for both classes (from 161 to 162 for forest and from 581 to 585 for woodland). This subdivision of habitat resulted in smaller, potentially more isolated patches, as reflected by declines in mean patch size (MPS) for both forest (from 181.33 ha to 177.91 ha) and woodland (from 56.95 ha to 51.81 ha) (Table 2).

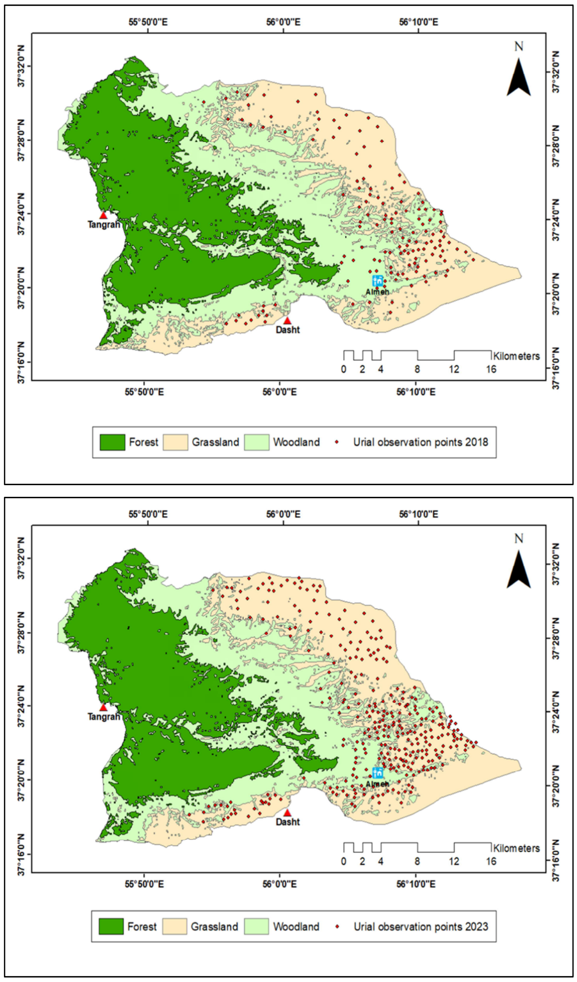

Figure 2) Classified habitat maps of Golestan National Park for 2018 (top) and 2023 (bottom). The maps illustrate the spatial distribution of forest, woodland, and grassland habitats, along with the recorded locations of urial sheep flocks.

Changes in edge metrics reflected the complex nature of the landscape transformation. Total edge (TE) and edge density (ED) decreased for all three habitat classes over the six years. Woodland habitats consistently maintained the highest edge density in both years, though it decreased from 17.50 $m.ha^{-1}$ to 16.58 $m.ha^{-1}$. The classification accuracy for both years was very high, with an overall accuracy of 99.8% and Kappa coefficients of 0.998 (2018) and 0.997 (2023), indicating a reliable basis for the landscape analysis (Table 3).

Table 3) Accuracy assessment results for the 2018 and 2023 land-cover classifications.

Image	Kappa Coefficient	Overall Accuracy (%)
Landsat 2018	0.998	99.8
Landsat 2023	0.997	99.8

Discussion

The transformation of Golestan National Park's landscape over six years reveals a counterintuitive trend in which forest and woodland habitat fragmentation coincides with improved habitat conditions for the vulnerable urial sheep due to grassland consolidation. This dual process highlights the complex ecological shifts occurring within one of Iran's most critical protected areas and provides a vital, evidence-based foundation for future conservation planning.

The observed decline in forest and woodland cover, coupled with an increase in patch numbers and a decrease in mean patch size, aligns with patterns of habitat fragmentation reported in protected areas both regionally and globally. This short-term trend is consistent with a much longer pattern of degradation within the park. A comprehensive 44-year study of Golestan National Park (1973–2017) by Sepahvand et al. (2022) documented a similar, persistent process of fragmentation, finding that forest area decreased by 4,689 ha and woodlands (described as scrublands) shrank by 2,377 ha over that period [27]. This historical context confirms that the habitat loss observed in our study is part of a multi-decadal trend. For instance, a study in Tehran Province, Iran, documented similar metrics of increasing patch numbers and decreasing patch sizes in protected areas, driven by land-use and land-cover changes [28]. Likewise, analysis of Bale Mountains National Park in Ethiopia revealed progressive fragmentation of grasslands and woodlands due to agricultural expansion, showing comparable landscape dynamics of increased patch and edge density alongside reduced mean patch size [30]. These parallels suggest that the fragmentation observed in GNP is part of a broader trend in which anthropogenic pressures compromise the integrity of protected ecosystems, even those with high biodiversity value.

Our analysis identified woodland habitats as the most vulnerable class, having experienced the largest area loss (a decline of 2,784 ha) and the greatest reduction in mean patch size (from 56.95 ha to 51.81 ha). As ecotonal or transitional zones between dense forests and open steppes, these woodlands are disproportionately susceptible to a combination of climatic shifts, such as aridification [20], and direct human activities, including livestock grazing, firewood collection, and forage harvesting by adjacent communities [27]. This vulnerability of transitional ecosystems to fragmentation aligns with findings in other regions, where increased anthropogenic pressure drives significant habitat alteration [19]. The degradation of these ecotones can have cascading effects on biodiversity and ecosystem resilience, warranting specific management attention to prevent irreversible isolation of forest patches.

In a significant and positive development for urial sheep conservation, the expansion and consolidation of grasslands represent a marked improvement in the quality of their primary habitat. Urrial sheep are grazing ungulates that primarily inhabit open, hilly terrain, and their foraging strategies are optimized in larger, more contiguous grassland patches. Larger patches reduce the energy expended traveling between forage areas and can lower predation risk by providing greater visibility. The observed increases in grassland area and mean patch size, coupled with a decrease in patch number, create a more favorable landscape configuration for the species. This habitat improvement appears to be directly correlated with the species' population dynamics; recent 2023 census data recorded a population of 10,252 individuals in the park [15], indicating that the species has effectively shifted its distribution to utilize these expanded grassland consolidations. This trend contrasts sharply with findings from other parts of Iran, such as Yazd Province, where rangeland degradation has severely fragmented wildlife habitats.

From a landscape ecology perspective, the expansion and consolidation of grasslands represent a marked improvement in the structural availability of the species' primary habitat. Urial sheep are specialized grazing ungulates that primarily inhabit open, hilly terrain [10,16, 27], and their foraging strategies are optimized in larger, more contiguous grassland patches. Larger patches reduce the energy expended traveling between forage areas and can lower predation risk by providing greater visibility [32]. Therefore, the quantitative outputs of this study, specifically the increase in Grassland Class Area (CA) and Mean Patch Size (MPS) (Table 2), suggest a higher carrying capacity at the landscape scale. The observed habitat improvement appears to be directly correlated with the species' population dynamics; recent 2023 census data recorded a population of 10,252 individuals in the park [22], indicating that the species has effectively shifted its distribution to utilize these expanded grassland consolidations. This trend contrasts sharply with findings from other parts of Iran, such as Yazd Province, where rangeland degradation has severely fragmented wildlife habitats [33]. However, this positive trend in habitat suitability must be interpreted with caution, as it reveals a critical paradox when viewed in a longer historical context. The same 44-year study by Sepahvand et al. (2022) found that, while steppe habitats expanded by 34% (6,821 ha), the urial sheep population declined by more than 60% during that period [27]. This stark contradiction strongly suggests that while habitat structure is improving for grazers, it is not the primary limiting factor for the urial sheep population. Instead, other anthropogenic pressures, such as illegal hunting, road mortality, and reduced habitat security, have likely been the dominant drivers of the species' long-term decline. This highlights that habitat improvement alone is insufficient for population recovery if direct mortality threats are not concurrently and effectively addressed. The positive trajectory in GNP's grasslands may therefore be a key factor supporting the stabilization of the urial sheep population, rather than its full recovery, and underscores the park's immense value for the species' long-term survival [27, 7].

The suite of landscape metrics selected for this study, CA, PLAND, NP, MPS, TE, and ED, proved effective in quantifying both the compositional and configurational dimensions of habitat change. The use of multiple, complementary metrics provides a more holistic and robust understanding of landscape dynamics than any single metric could provide on its own. The strong alignment between the patterns revealed by these metrics and the findings of other fragmentation studies reinforces their utility for monitoring ecological changes across diverse landscapes. It provides a reliable baseline for long-term monitoring in GNP. Despite these strengths, this study has certain limitations. The six-year interval provides a valuable snapshot of recent changes but may not capture longer-term ecological cycles or successional dynamics. Furthermore, while remote sensing offers a powerful tool for landscape-scale analysis, it cannot fully elucidate the specific drivers (e.g., climate change, illegal grazing, fire) of the observed transformations. Future research should integrate extended temporal analyses with field-based ecological data on vegetation dynamics and wildlife responses to provide a more comprehensive understanding of the ecosystem's trajectory and to further strengthen conservation recommendations.

Conclusion

The vegetation transformations observed in Golestan National Park between 2018 and 2023 are consistent with broader patterns of habitat change driven by combined human and environmental pressures. The simultaneous fragmentation of forests and woodlands alongside the expansion and consolidation of grasslands underscores the complex nature of habitat dynamics affecting flagship species such as the urial sheep. This landscape-level shift signals a potential improvement in grazing habitat suitability for the urial sheep while also highlighting the need for targeted management interventions to mitigate habitat degradation in the park's forested and woodland zones. These findings provide a critical evidence base for adaptive management. We therefore recommend that park management prioritize protecting consolidated grassland cores from anthropogenic encroachment and implement measures to reduce the drivers of forest and woodland fragmentation to ensure overall ecosystem resilience.

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