

Forest Loss, Habitat Fragmentation, and Their Effects on Avian Communities in Balochistan

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DOI: <https://doi.org/10.63163/jpehss.v3i4.921>

Abstract

Balochistan, Pakistan's largest province, hosts globally significant relict high-altitude forests dominated by *Juniperus excelsa* (in Ziarat and Zarghoon) and *Pinus gerardiana* (Chilghoza pine in the Sulaiman Mountains, including Sherani). These semi-arid ecosystems face rapid degradation and habitat fragmentation driven by proximate factors such as fuelwood harvesting, agricultural conversion, urbanization, mining, and uncontrolled grazing, compounded by underlying climatic stresses (drought, reduced snowfall) and institutional weaknesses in governance and enforcement. This review synthesizes drivers of forest loss, quantifies fragmentation mechanisms using landscape ecology principles (edge effects extending >250 m into interiors), and examines impacts on avian communities, including resident passerines and threatened species. Fragmentation reduces core habitat, promotes nested extinctions of specialists, alters microclimates, and diminishes reproductive success, disproportionately affecting forest-dependent guilds. Despite robust legislation, implementation gaps persist. Recommendations emphasize prioritizing large core refugia, climate-resilient sustainable forest management, community engagement, and urgent quantitative remote sensing studies to inform conservation.

Keywords: *Juniperus excelsa*, *Pinus gerardiana*, forest degradation, habitat fragmentation, avian diversity, edge effects, Balochistan, conservation policy, climate stress, sustainable management

Introduction

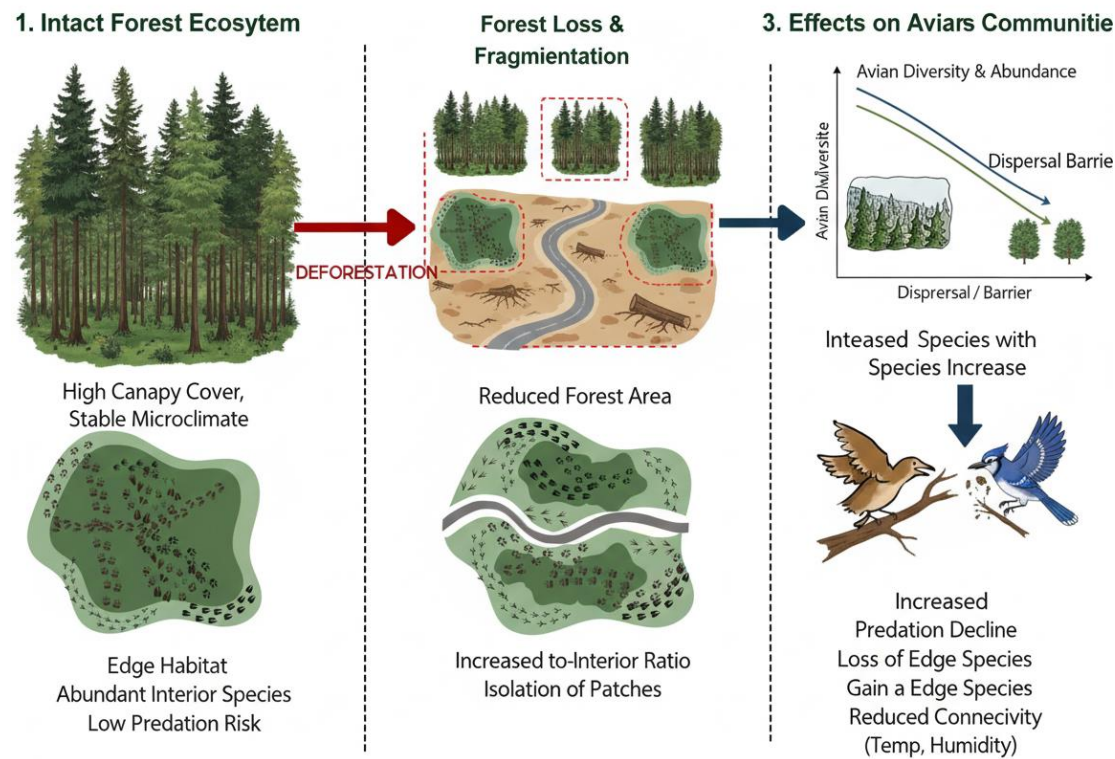
Balochistan, covering approximately 44% of Pakistan's total land area, is the country's largest province. Its vast expanse is defined by highly varied topography and a predominantly semi-arid to arid climate (Ashiq et al., 2020). Ecologically, the province occupies a pivotal position, acting as a transitional zone between the Palaearctic and Oriental zoo-geographical regions. This unique biogeographic location contributes to an impressive variety of ecosystems, habitats, and diverse

landscapes, supporting significant biodiversity, including an estimated 1,750 known plant species and a rich variety of animal life this geographical context determines the distribution of plants and animals, making Balochistan a critical, yet fragile, region for conservation (Shah et al., 2022).

The forest ecosystems of Balochistan are of immense ecological and global significance. This review focuses specifically on the high-altitude forests, dominated by the ancient Juniper (*Juniperus excelsa*) and Chilgoza pine (*Pinus gerardiana*). Juniper forests thrive in areas like Ziarat and Zarghoon hills, typically ranging from 1,980 to 3,350 meters in elevation. (Islam et al., 2013). The Ziarat Juniper forest, in particular, is dominant in Balochistan and is internationally recognized as one of the world's oldest forests, covering an area estimated at 141,000 hectares, establishing it as Asia's largest such woodland (Jallat et al., 2021). Chilgoza forests are found prominently in the Sulaiman Mountains within the Sherani tribal area, at elevations between 2,700 and 3,400 meters. The status of these forests as relict temperate ecosystems elevates their conservation challenge from a regional concern to an international obligation concerning the preservation of global heritage. (Ahmad et al., 2023).

To analyze landscape change effectively, it is essential to distinguish between forest loss and habitat fragmentation, as they represent distinct processes with synergistic ecological outcomes. Forest loss, or deforestation, is defined as the absolute reduction in total forest cover, often resulting from Land Use/Land Cover (LULC) conversion, such as clearing forest land for agriculture or infrastructure (Khan & Akbar, 2023; Balochistan Forest and Wildlife Department, 2015). Habitat fragmentation, conversely, describes the spatial change in the remaining habitat structure. This process leads to the remnant forest becoming smaller, more isolated patches, concurrently increasing the ratio of edge habitat relative to core habitat area (Simonetti et al., 2006).

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This review systematically examines the complex relationship between declining forest health and the structure of avian communities in Balochistan. The primary objectives are threefold: first, to synthesize the prevailing academic literature regarding the proximate and underlying drivers of forest degradation and loss, integrating principles of Forestry science. Second, to analyze the quantifiable spatial mechanisms and metrics of habitat fragmentation within the semi-arid ecological context (Ali et al., 2024). Third, to critically synthesize the documented and predicted ecological responses of the resident and migratory avian communities to these landscape modifications, drawing upon principles of Zoology and Conservation Ecology. This interdisciplinary focus aims to establish robust, evidence-based recommendations for conservation policy and research. (Taj et al., 2023).

Figure 1.1 Forest Loss, Habitat Fragmentation, and Their Effects on Avian Communities

2. Status and Drivers of Forest Loss and Degradation in Balochistan

2.1. Historical and Current Trends in Forest Cover Change

The analysis of remote sensing data, such as NDVI-based assessments, confirms discernible trends of land degradation across Balochistan. While province-wide fragmentation analyses specific to Juniper and Chilghoza forests are rare in published literature (Sherani et al., 2021), comparable LULC studies in other ecologically sensitive regions of Pakistan provide a clear methodological precedent and expectation for the severity of the crisis. For example, recent analyses have documented a substantial reduction in forested areas, including both coniferous and evergreen forests, coupled with increases in barren land and urbanized areas. This spatial transition signifies not just tree removal, but fundamental landscape restructuring that leads to forest fragmentation. (Gao et al., 2014).

2.2. Proximate and Underlying Drivers of Deforestation and Fragmentation

Forest degradation in Balochistan is driven by a complex interplay of socioeconomic, infrastructural, and climatic pressures. These drivers can be categorized as either direct (proximate) actions or underlying systemic factors. (Makki et al., 2025).

Socio-economic and Direct Proximate Drivers: The most significant direct cause is the excessive human pressure on forest resources. High population density, poverty, and a lack of alternative livelihood opportunities (off-farm employment) compel communities to rely heavily on the forests (Ashiq et al., 2020). This dependence translates into critical direct drivers, including over-harvesting of forest products and a high demand for fuelwood, which accelerates ecosystem degradation. Furthermore, uncontrolled camping and recreation activities have been documented as contributing factors that actively destroy vegetation cover, reduce regeneration capacity, and increase the soil material's susceptibility to erosion (Sarangzai et al., 2014). Expansion of human settlements and economic activity is a major driver of fragmentation. Direct drivers include the conversion of forest land to agriculture, the expansion of rural infrastructure, and large-scale construction/developmental activities, such as the establishment of industrialization zones. In the North-Eastern regions of Quetta, specific activities like mining, urbanization, and migration to areas surrounding wildlife habitats are identified as potential threats that contribute to widespread habitat degradation and subsequent fragmentation (Ahmad et al., 2023). Table 2.1 summarizes the primary drivers and their manifestations, highlighting the multidimensional nature of the threat:

Table 2.1: Interacting Drivers and Manifestations of Forest Degradation in Balochistan

Driver Category	Specific Manifestations/Mechanism	Ecological Impact/Evidence	Source Example
Socio-economic Pressure	Fuelwood demand, Over-harvesting, Poverty, Population Pressure	Destruction of regeneration capacity; widespread vegetation cover loss	(Balochistan Forest and Wildlife Department, 2015; Ashiq et al., 2020; Sarangzai et al., 2014)
Land Use Change	Conversion to agriculture, Infrastructure, Urbanization, Mining	Deforestation hotspots; habitat fragmentation and pollution	(Taj et al., 2023; Balochistan Forest and Wildlife Department, 2015)
Climatic Stress	Drought, Decreased Snowfall, Changing Precipitation Patterns	Degraded stage of forests; poor soil/regeneration capacity, vulnerability to fungal infections	(Sarangzai et al., 2014; Sarangzai et al., 2014; Umrani & Sangi, 2024)
Institutional Failure	Low specialist count, Lack of enforcement, Research gap	Limited inventory, evaluation, monitoring, and lack of sustainable management practices	(Balochistan Forest and Wildlife Department, 2015; Sarangzai et al., 2014; IUCN Pakistan, 2007)

2.3. The Compounding Role of Climatic Stress and Institutional Weakness

The forest crisis is exacerbated by chronic climatic stress and systemic institutional deficiencies, which act as crucial underlying drivers of vulnerability. Balochistan's climate has experienced severe recent changes, including higher temperatures, decreased snowfall, and changing precipitation cycles (Umrani & Sangi, 2024). These changes lead to drought, which, combined with groundwater depletion, critically impacts the province's water availability. The slow-growing Juniper forests are particularly susceptible to these pressures, exhibiting a degraded state due to drought, poor soil conditions, and resulting vulnerability to infections. (Tamudo et al., 2021). This condition establishes a dangerous positive feedback loop: the natural resilience and regeneration capacity of the forest are reduced by climate stress, rendering the ecosystem highly susceptible to fragmentation caused by otherwise chronic anthropogenic disturbances. For instance, a demand for fuelwood, that might be ecologically sustainable in a climate-resilient forest becomes a non-reversible factor of structural simplification and forest collapse in a drought-stressed semi-arid environment. (Yungstein et al., 2025).

Institutional Impediments and Governance Failure: A profound systemic issue is the institutional failure to manage and protect these resources effectively. There is a documented lack of capacity and human resources within agencies like the Environmental Protection Agency (EPA) Balochistan, which is responsible for regulatory enforcement (IUCN Pakistan, 2007). Furthermore, the forestry sector suffers from a critical shortage of technical specialists, limited support for research, and a communication gap between research organizations and forest managers (Balochistan Forest and Wildlife Department, 2015; Sarangzai et al., 2014). This lack of effective governance is not merely a tertiary issue; it transforms socio-economic pressures into

acute crises. The absence of regulatory mechanisms allows localized activities such as mining and uncontrolled urbanization to proceed as immediate, direct drivers of fragmentation and biodiversity loss (Raju et al., 2018). Therefore, the environmental degradation observed is enabled by institutional weakness, making the detailed legal framework such as the Balochistan Forest Regulations 1890 and the Pakistan Forest Act 1927 (Pakistan Forest Institute, 2015).

3. The Landscape Ecology of Fragmentation in Semi-Arid Forests

3.1. Analytical Frameworks: Remote Sensing and GIS Techniques

Understanding the ecological implications of forest loss requires quantifying the resultant fragmentation using landscape ecology metrics. Remote Sensing (RS) and Geographic Information Systems (GIS) are indispensable tools for this purpose, providing methodologies to assess Land Use/Land Cover (LULC) dynamics and spatial changes in forest structure (Dangayach et al., 2025). Specific spatial methodologies, such as the Landscape Fragmentation Tool (LFTv2.0), are used globally to classify forest cover into ecologically meaningful categories patch, edge, perforated, small core, medium core, and large core forest (Hussain et al., 2024). These classification systems are crucial because they directly link landscape geometry to habitat quality. Quantitative studies using these methods have demonstrated that fragmentation significantly reduces large core forest areas while increasing 'patch' forest areas (Ali et al., 2024).

3.2. Quantification of Habitat Fragmentation in Key Balochistan Forest Areas

Although fragmentation is acknowledged as a critical threat to avian fauna in regions like Quetta, driven by mining and construction activities a profound knowledge gap exists concerning the specific, quantitative spatial analysis of this process in Balochistan's defining Juniper and Chilghoza forests. Only one study focusing on spatial forest assessment using remote sensing was identified for Balochistan in a 28-year review period, highlighting a significant research deficiency (ul Haq et al., 2024). Without specific, published quantitative fragmentation maps for these unique high-altitude ecosystems, conservation managers cannot accurately assess the current extent of habitat degradation, nor can they prioritize critical protection zones. (Dhyani et al., 2022). The experience from other parts of Pakistan, which saw a dramatic increase in fragmentation (e.g., a reduction in large core forests from 20.3% to 7.2% over three decades in the Rawalpindi region) strongly suggests that the core forest area in Ziarat and Sherani is likely diminishing rapidly, necessitating urgent, localized modeling efforts (Rafiq et al., 2024).

3.3. Mechanisms of Fragmentation: From Deforestation to Edge Creation

Habitat fragmentation operates primarily by creating sharp, often hostile, boundaries known as habitat edges between forest patches and the surrounding open areas or disturbed matrices. The anthropogenic activities driving this including linear infrastructure expansion (roads) and diffuse resource extraction (fuelwood paths and grazing) introduce destructive edges into what was previously contiguous habitat. (Fletcher et al., 2007).

The creation of these edges fundamentally alters the spatial distribution of ecological factors, leading to detrimental microclimatic edge effects. Fragmentation not only changes the physical structure of the habitat but also disrupts the vertical stratification of the microclimate within the remaining patches (Dovčiak & Brown, 2014). Changes in light, temperature, humidity, and wind penetration at the forest boundary can extend hundreds of meters into the forest interior. In Balochistan's semi-arid environment, characterized by high temperature variability and water scarcity (Umrani & Sangi, 2024), this microclimatic disruption is expected to be substantially more severe than in mesic temperate systems. Increased exposure and reduced humidity near the edges can critically impact food resource availability (e.g., insect biomass) and nesting microhabitats,

thereby amplifying the effects of chronic drought stress on forest-dependent fauna (Bernaschini et al., 2020).

4. Avian Diversity and Vulnerability in Balochistan's Forests

4.1. Overview of Avian Biogeography and Species Richness

Balochistan is recognized as a major wildlife hotspot in Pakistan, supporting an impressive vertebrate fauna. Field surveys conducted between 2015 and 2019 documented 373 species of birds across the province's major ecological zones (Aslam et al., 2022). This richness reflects the province's location in a transitional zone, supporting a mixture of ecological guilds. Recorded avifauna includes a substantial number of resident species (44 species in some analyses), winter visitors (57 species), and passage migrants (Derebe et al., 2023). The scattered wetland habitats, though small, are ecologically vital, attracting thousands of waterfowls, including herons, geese, and swans, serving as crucial migratory stops, such as Spin Karez and Hanna Lake near Quetta (Mandokhail et al., 2025).

4.2. Identification of Avian Guilds Dependent on Forest Habitats

Avian community studies in the mountain ranges associated with Quetta (Takatu, Murdar, Zarghoon) have documented 30 resident avian species, including 18 passerines, utilizing the wild forest habitats (Komel Ahmed et al., 2024). These forests serve as critical habitats for numerous species, ranging from large raptors, such as the Golden Eagle, to game birds like the Chukar Partridge and See-see Partridge, as well as various finches and magpies. The health of these communities is fundamentally tied to the structural integrity and resource availability provided by the Juniper and Chilghoza woodlands (Redmond et al., 2023).

4.3. Status of Threatened and Endemic Avian Species

The vulnerability of Balochistan's avifauna is reflected in the official conservation status assessments. Among the birds recorded in recent surveys, threat levels are concerning two species are listed as Critically Endangered (CR), four as Endangered (EN), three as Vulnerable (VU), and 15 as Near-threatened (NT). Species like the Houbara Bustard, though often associated with arid steppe and rangeland, represent the broader conservation crisis in the transitional forest-rangeland habitats (Ghalib et al., 2019).

Anthropogenic threats—encompassing deforestation, habitat degradation, disturbance, fragmentation, and direct over-exploitation (hunting and trapping) are severely impacting these populations (Pereira et al., 2013). Resident, forest-dependent passerines, which constitute a large fraction of the recorded diversity are acutely vulnerable to fragmentation. Unlike migratory species that can seasonally exploit different habitats, residents must cope with continuous resource stress and habitat disturbance year-round. If the forest structure degrades significantly due to fragmentation and chronic physiological stress from drought (Saranzai et al., 2014), resident species face chronic resource limitation, leading to reduced reproductive success and high mortality, potentially causing localized extinctions in isolated patches (Taj et al., 2023),

Furthermore, ecological modeling suggests that avian richness in Pakistan is highly sensitive to projected changes in precipitation, with central and southern regions (including Balochistan) projected to face the strongest changes (Biedermann et al., 2023). This vulnerability indicates that forest fragmentation, when combined with drought, disproportionately isolates populations during critical periods (breeding and wintering seasons), amplifying resource depletion and limiting dispersal capacity, thereby intensifying the negative climate impact on avian community viability. (Ehlers Smith et al., 2018). Table 4.1 provides a brief overview of selected avian conservation concerns:

Table 4.1 Conservation Status and Ecological Guild Vulnerability of Selected Avian Species in Balochistan

Species/Guild Example	Conservation Status (IUCN/Local)	Primary Habitat Association	Vulnerability to Fragmentation
Houbara Bustard	Critically Endangered/Endangered (Khan & Ghalib, 2020)	Transitional Rangeland/Scrub adjacent to forest	Habitat loss; hunting pressure (Khan & Ghalib, 2020; Pereira et al., 2013)
Golden Eagle	Threatened (General) (Khan & Ghalib, 2020)	High-elevation forest/rocky niches	Nesting site disturbance and resource base reduction
Resident Passerines	Varies; typically high forest dependence (Taj et al., 2023)	Core forest and wild habitats (Takatu, Zarghoon)	Edge effects, local extinction due to fragment isolation (Simonetti et al., 2006; Taj et al., 2023)
Forest Insectivores (Guild)	Highly sensitive to microclimate (Ferreira & Luther, 2022)	Forest understory/canopy strata	Loss of foraging success due to edge microclimate disruption (Dovčiak & Brown, 2014)

5. Ecological Effects of Fragmentation on Avian Communities

5.1. Impacts on Species Diversity and Distribution

The most immediate consequence of habitat fragmentation is the loss of contiguous area, which is necessary to maintain minimum viable populations (MVPs) and shield species from local extinction pressures (Yuan et al., 2024). Fragmentation leads to a non-random distribution of species across the remaining forest fragments, a pattern observed in relict temperate forests elsewhere. This "nested subset pattern" means that generalist species may persist across all fragments regardless of size, while specialist, vulnerable species require significantly larger patches to remain viable against local extirpation (Dondina et al., 2022). The cumulative effect of fragmentation in Balochistan, where species like resident passerines utilize specific wild habitats is an accelerated decline in forest specialists and a compositional shift toward species that tolerate human disturbance (e.g., House Crow, House Sparrow) (Ghalib et al., 2019).

5.2. The Dynamics of Edge Effects

The creation of habitat edges constitutes a primary demographic threat to forest-dwelling birds. Edges expose nests to higher rates of predation and brood parasitism, driven by increased access for generalist predators and human disturbance. Academic meta-analyses focused on forest birds establish a clear demographic threshold core areas located greater than 250 meters from the habitat edge consistently exhibit significantly higher nest success rates for mature forest species (Tarwater et al., 2020). This critical 250-meter metric provides an essential, quantifiable target for spatial conservation planning. Given the steep environmental gradients, heightened temperature fluctuations, and lower ambient humidity characteristic of Balochistan's semi-arid high-altitude forests the functional distance of ecological disruption imposed by edges may be even wider or more intense than the threshold established in mesic temperate systems (Umrani & Sangi, 2024).

5.3. Demographic and Physiological Effects

Fragmentation imposes severe demographic and physiological stress. The combined effects of reduced core area and high edge exposure significantly reduce the effective reproductive output of the forest. This leads to reduced recruitment rates, making isolated populations highly susceptible to demographic and genetic stochasticity, increasing the overall risk of local extirpation (Simonetti et al., 2006).

Beyond demographics, fragment isolation affects the body condition and fitness of resident birds. Studies in fragmented systems reveal that the physiological response (e.g., changes in body mass) is highly variable and depends on the bird's feeding guild. For instance, some insectivorous species might exhibit stable or increased weight after isolation, potentially due to reduced inter-specific competition or complex resource shifts, while the response in other guilds, such as frugivores, may be stable or negative (Ferreira & Luther, 2022). In the context of Juniper and Chilgoza degradation, which involves the loss of understory vegetation (impacting insect populations) and direct damage to mature canopy trees (impacting mast crops), the differential resource availability will determine which guilds suffer the steepest population declines. Specialized monitoring of body condition and stress physiology is necessary to identify populations that are stressed before widespread demographic collapse occurs. (Dhyani et al., 2022). Table 5.1 summarizes the key ecological consequences of fragmentation:

Table 5.1 Ecological Consequences of Forest Fragmentation on Avifauna

Fragmentation Mechanism	Ecological Parameter Affected	Observed Effect (General Ecological Precedent)	Specific Relevance to Balochistan's Semi-Arid Forests
Area Loss & Isolation	Species Distribution and Extinction Risk	Nested subset patterns; large fragments afford better protection against local extinction (Simonetti et al., 2006)	Crucial for resident and endemic forest specialists in relict Juniper habitat.
Edge Creation (Increased Perimeter)	Nest Survival/Success Rate	Significant decline in success closer than 250m from edges for mature forest birds (Tarwater et al., 2020)	Provides a quantitative threshold for managing forest boundaries and prioritizing large, interior patches.
Edge Creation	Microclimate/Foraging Resources	Disruption of vertical microclimate stratification (temperature/humidity) (Dovčiak & Brown, 2014)	Likely amplified stress on birds and insect prey due to extreme semi-arid climate variability.
Fragment Isolation	Physiological Condition/Fitness	Variable changes in body mass based on feeding guild and resource availability (Ferreira & Luther, 2022)	Required focus for long-term health monitoring to identify stressed populations before demographic collapse.

6. Policy Frameworks, Management Gaps, and Conservation Recommendations

6.1. Review of Existing Conservation Legislation and Strategy

Balochistan possesses a foundation of strategic planning and legal instruments designed to protect its natural heritage. The Balochistan Conservation Strategy (BCS) outlines crucial programs, including institutionalizing environmental education, promoting sustainable agriculture, managing rangelands, and using forests sustainably, alongside general efforts to conserve biodiversity and wetlands. Furthermore, the province established the comprehensive Balochistan Wildlife Protection, Preservation, Conservation, and Management Act of 2014 (Khan & Ghalib, 2020; Umrani et al., 2023). This detailed legislation, comprising 96 articles, mandates the protection of wild animals, regulates hunting and trade, defines protected areas, and addresses adherence to Multinational Environmental Agreements (MEAs) (Islam et al., 2013).

6.2. Institutional Limitations and Implementation Failure

Despite the presence of robust, detailed legislation, particularly the 2014 Wildlife Act the practical effectiveness of conservation efforts is severely compromised by a substantial enforcement gap. The central challenge is not the absence of policy, but the institutional failure to execute it. Agencies mandated for enforcement, such as the EPA, lack necessary capacity, human resources, and standardized regulatory mechanisms, often relying on outdated techniques (IUCN Pakistan, 2007). This deficiency creates a governance vacuum where chronic socio-economic drivers (Balochistan Forest and Wildlife Department, 2015) operate effectively outside the intended regulatory structure.

For avian conservation, an unenforced or poorly monitored protected area boundary offers little buffering capacity. Fragmentation drivers such as mining, development, and fuelwood extraction continue at the site level because the Balochistan Forest and Wildlife Department lacks the capacity for effective inventory, evaluation, and long-term monitoring of its resources (Sarangzai et al., 2014). While initial pioneering attempts, such as the Integrated Natural Resource Development Programmed (IRLDP), introduced community-based natural resource management, long-term sustainability was hampered by the lack of support for research and the chronic communication gap between researchers and managers (Milupi et al., 2017).

6.3. Strategies for Mitigating Fragmentation Impacts and Enhancing Resilience

Effective conservation requires shifting focus from simply having a policy to ensuring its rigorous implementation, coupled with climate adaptation planning. Prioritizing Core Area Protection Based on established ecological thresholds, conservation efforts must prioritize the identification and formal protection of remaining core forest areas that exceed the crucial 250-meter buffer distance from edges (Tarwater et al., 2020). Spatial planning must leverage existing RS/GIS methodologies (LFT metrics) to map these core refugia within the Juniper and Chilghoza forests. This quantitative approach allows managers to prioritize the creation of forest blocks large enough (e.g., minimum 50 hectares) to sustain these crucial, fragmentation-resistant refugia (Simonetti et al., 2006).

Climate-Resilient Management (SFM): Given the projected impacts of climate change, including changing precipitation patterns (Biedermann et al., 2023) and existing drought stress (Umrani & Sangi, 2024), simple protection is insufficient. Management must integrate proactive adaptation strategies. Pakistan's participation in the UN-REDD Program provides a framework for Sustainable Forest Management (SFM), focusing on carbon stock conservation and enhancement (Pakistan Forest Institute, 2015; Aleem, 2024). Mitigation efforts should improve governance of SFM practices and enhance ecological resilience through researching and promoting afforestation

and reforestation techniques that are robust against anticipated climate impacts (Ahmad et al., 2023).

Community Engagement and Institutional Reform Long-term sustainability requires successfully integrating local communities, whose socio-economic needs drive much of the resource depletion (Ashiq et al., 2020). Promoting community-based natural resource management and raising public awareness is vital. Furthermore, significant investment is needed to reorganize and enhance the technical training and capacity of the Forest and Wildlife Department staff to ensure they can effectively implement detailed conservation inventories, monitoring programs, and enforcement actions required by the existing robust legislation (IUCN Pakistan, 2007; Umrani et al., 2023).

7. Conclusions and Future Research Directions

7.1. Synthesis of Key Findings

The semi-arid Juniper and Chilghoza forests of Balochistan, globally significant relict ecosystems, are currently subject to rapid degradation and intense habitat fragmentation. This crisis is fueled by a destructive synergy between acute climatic stressors (drought, temperature rise), chronic socio-economic pressures (fuelwood demand, grazing), and systemic institutional deficiencies that prevent effective enforcement of existing conservation laws. (Sola et al., 2019). The resulting fragmentation severely compromises the forest structure, particularly by reducing the extent of core habitat area. Avian communities, especially resident forest specialists, are highly vulnerable to the consequences, exhibiting nested patterns of localized extinction and reduced reproductive success due to heightened edge effects, which extend at least 250 meters into the forest interior. (Chen et al., 2024).

7.2. Critical Knowledge Gaps

Quantitative Fragmentation Analysis There is an urgent need for localized, systematic, landscape-level modeling (e.g., using GIS/RS and LFT methodology) to accurately quantify fragmentation metrics, such as patch density and core area decline, specifically across the Juniper and Chilghoza forests of Ziarat and Sherani (Ali et al., 2024). Such spatial data is foundational for effective landscape planning.

Long-Term Demographic Studies The absence of localized, species-specific demographic data (nesting success, survival rates, recruitment) prevents a definitive assessment of the direct causal link between fragmentation and avian population viability in Balochistan (Tarwater et al., 2020). Focused field studies are required to establish baseline ecological parameters.

Avian-Habitat and Climate Modeling: Research must be conducted to model the seasonal exposure and sensitivity of specific forest avian guilds (e.g., insectivores versus granivores) to the combined stresses of fragmentation and projected climate change impacts, including drought and altered precipitation patterns (Biedermann et al., 2023; Ferreira & Luther, 2022). This will allow for proactive identification of the most vulnerable species and habitats.

7.3. Recommendations for Interdisciplinary Research and Policy Action

The evidence requires an urgent, integrated policy response. Management plans should explicitly incorporate the ecological finding that core areas greater than 250 meters from edges are essential for successful mature forest bird demographics. (Arcilla et al., 2023). Policy must therefore prioritize the delineation and strictly monitored protection of forest blocks that maximize these large, contiguous interior refugia. Furthermore, the long-term viability of the ecosystem dictates that conservation must move beyond simple protection to include proactive climate change adaptation, such as implementing SFM practices to enhance forest resilience and connectivity. (Ramola et al., 2024) Crucially, the institutional capacity and scientific research support provided

to the Balochistan Forest and Wildlife Department must be significantly strengthened to bridge the existing gap between robust conservation legislation and practical, effective enforcement at the landscape level (IUCN Pakistan, 2007; Umrani et al., 2023).

Acknowledgment

We would like to express my deepest gratitude to my parents for their unconditional love, constant encouragement, and unwavering support throughout my academic journey. Their guidance and prayers have always been a source of strength and motivation for me. We are also sincerely thankful to my teachers, whose dedication, knowledge, and mentorship have shaped my learning and inspired me to strive for excellence. Their continuous support and valuable guidance played an essential role in the completion of this work.

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