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Impacts of Camel Grazing on *Avicennia marina* and Strategies for Mangrove Restoration in Saudi Arabia

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Abstract

Mangroves along the Saudi Arabian coastlines of the Red Sea and Arabian Gulf provide essential services, including shoreline protection, nutrient cycling, fisheries support, and carbon sequestration. These ecosystems face natural stressors such as hypersalinity, limited freshwater inflow, and extreme temperatures, which are exacerbated by camel grazing. Browsing reduces canopy biomass, damages seedlings, and limits natural regeneration, while trampling alters soil structure, impairs gas exchange, and suppresses microbial processes. This review synthesizes regional and global evidence on camel impacts on *Avicennia marina* and identifies effective management strategies. Measures such as spatial exclusion, seasonal grazing regulation, and community-based stewardship significantly enhance vegetation recovery, soil integrity, and ecosystem function. When combined with restoration interventions including hydrological enhancement, sediment stabilization, and strategic planning, these practices support long-term resilience and sustainability. The findings provide an evidence-based framework for integrating grazing control into mangrove conservation programs in arid coastal environments.

Keywords

A. marina, Camel Grazing, Soil Compaction, Restoration Strategies, Arid Coastal Ecosystems

1. Introduction

Mangrove ecosystems along the coast of Saudi Arabia provide vital ecological services that support shoreline protection, nutrient exchange, fisheries productivity, and carbon sequestration (Blanco-Sacristán et al., 2022; Bajahmoum & Almaghamsi, 2025). These ecosystems are already constrained by natural stressors such as hyper salinity, limited freshwater inflow, and extreme temperatures (Eid et al., 2019). Under these conditions, camel grazing has emerged as a major factor that intensifies ecological degradation (Dajam et al., 2024). Camels browse on young leaves and branches, break seedlings, and physically disturb mangrove soils. These actions reduce canopy density and limit natural regeneration, a pattern consistent with global findings that herbivory significantly affects mangrove growth and ecosystem stability (Ferreira et al., 2024). Local assessments confirm that camel grazing in Saudi Arabia contributes to the decline of *A. marina* stands, especially in areas where access is not controlled (Almahasheer, 2018).

The broader scientific literature on grazing ecology provides essential insights into how sustained herbivory affects vegetation structure and soil processes. Studies from terrestrial rangelands demonstrate that repeated grazing reduces plant cover, increases bare soil exposure, and weakens soil structure, which ultimately reduces ecosystem resilience (Bajahmoum & Almaghamsi, 2025). Although mangrove systems differ from inland rangelands, the ecological mechanisms are similar. Camel browsing limits the development of new shoots, reduces photosynthetic capacity, and compacts waterlogged sediments (Alhassan & Aljahdali, 2021). These impacts restrict oxygen infiltration and root development, both of which are essential for mangrove survival. In arid coastal environments, where natural recovery is slow, even moderate camel activity can lead to long lasting vegetation loss and soil degradation (van Klink et al., 2015).

Saudi Arabia has initiated extensive restoration and protection programs through the National Center for Vegetation Cover Development and Combating Desertification (NCVC). These efforts include large scale planting of mangroves and rehabilitation of degraded coastal zones. However, the long-term success of these initiatives requires management practices that specifically address camel grazing, which remains one of the most persistent pressures on coastal vegetation. International research shows that effective management of herbivory, whether in forests, rangelands, or wetlands, depends on regulating access, providing sufficient recovery periods, and maintaining soil conditions that support plant resilience (Bartley et al., 2023). Despite the progress in restoration planning, there is limited guidance on how to integrate grazing control with mangrove conservation under the region unique climatic and hydrological challenges.

This study identifies best practices for managing camel grazing in Saudi Arabian mangrove ecosystems. It reviews the impacts of browsing on vegetation, soil, and regeneration, and evaluates strategies such as exclusion fencing, seasonal access, controlled grazing corridors, and community-based monitoring. By integrating global evidence, the study develops a framework tailored to Red Sea and Arabian Gulf conditions, providing practical guidance for policymakers and conservation practitioners to enhance mangrove resilience and ensure long-term ecosystem sustainability.

2. Methodology

2.1. Spatial Grazing Analysis

Data on camel distribution along the Saudi Arabian coastlines of the Red Sea and Arabian Gulf were compiled from official records and relevant literature (General Authority for Statistics, 2024) to provide a contextual framework for the review. The dataset included the number of camels in each coastal province, allowing characterization of spatial variability in grazing pressure across the regions. These data were collected, organized, and analyzed to support subsequent synthesis of literature on mangrove grazing impacts and management strategies.

2.2. Literature Search

A structured search was conducted in Web of Science, Scopus, ScienceDirect, SpringerLink, and Google Scholar for studies published between 1980 and 2025. Keywords included camel grazing, camel browsing, mangrove herbivory, *A. marina*, Arabian Gulf mangroves, and grazing management in arid coasts.

2.3. Comparative Evidence Analysis

A comparative framework was employed to evaluate the ecological impacts of camel grazing by contrasting non-grazed reference sites, such as Abu Ali Island, with heavily grazed mangrove systems in regions including Jazan. The assessment incorporated species-specific zonation patterns, with particular emphasis on how substrate firmness and physical constraints, such as the stilt root architecture of *Rhizophora mucronata*, regulate camel access and grazing preferences relative to *A. marina*. Evidence from traditional Saudi Arabian stewardship practices, including the hima system, was integrated with contemporary regulatory and conservation frameworks to support the development of an effective, context-specific grazing management strategy for mangrove ecosystems under arid coastal conditions.

3. Results and Discussion

3.1. Spatial Grazing Variability

The coastal zones of Saudi Arabia along the Red Sea and the Arabian Gulf span a broad ecological gradient that supports extensive stands of *A. marina*. However, these regions experience markedly different grazing pressures due to substantial variation in camel distribution. As illustrated in **Figure 1**, data from the accompanying table indicate that the Red Sea coast collectively supports approximately 680 thousand camels (680×10^3) across the provinces of Tabuk, Al Madinah Al Munawwarah, Makkah Al Mukarramah, Asir, and Jazan, creating a pronounced west-coast gradient of potential browsing intensity. In contrast, the Arabian Gulf coast is dominated by the Eastern Province, which hosts an additional 361 thousand camels (361×10^3), representing one of the highest regional densities and suggesting considerable grazing pressure on adjacent mangrove habitats. Taken together, the Red Sea coastal regions account for 65% of the camel population, whereas the Eastern Province (Arabian Gulf) accounts for the remaining 35%. This clear spatial variability in camel abundance provides an essential basis for evaluating the ecological impacts of grazing on *A. marina* and for developing targeted restoration and management strategies tailored to the grazing regimes of each coastal region.

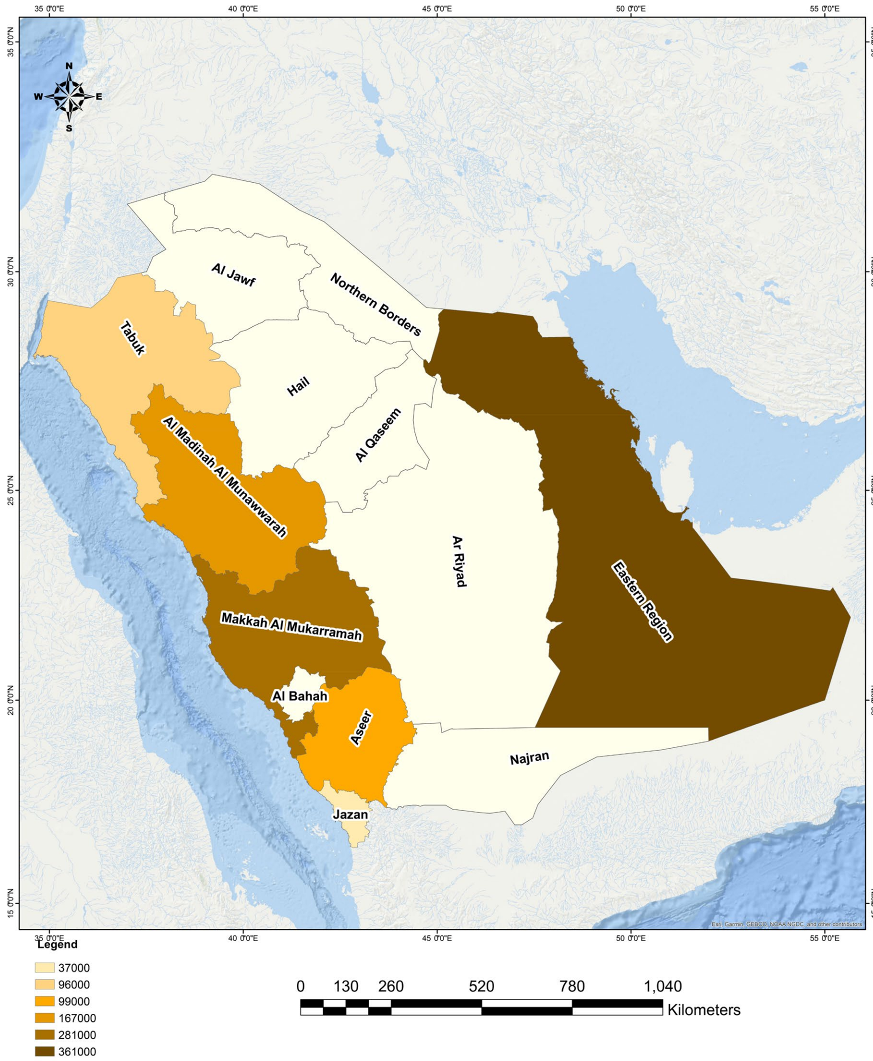

Figure 1. Distribution and population of coastal camels in Saudi Arabian regions.

Figure 1 illustrates the coastal regional distribution of camels across Saudi Arabia, showing a pronounced concentration in coastal provinces, particularly the Eastern Province and Makkah Al Mukarramah, which host the largest populations ranging from 281,000 to 361,000 animals. Despite similar population densities, the environmental exposure and coastal accessibility of camel herds differ markedly between regions. Along the Arabian Gulf, camels in the Eastern Province often have limited access to mangrove ecosystems (*Avicennia marina*) due to industrial development, road networks, and urban expansion that physically separate grazing areas from the shoreline. In contrast, western and southwestern coastal regions such as Jazan retain more traditional pastoral systems and relatively unobstructed coastlines, allowing camels to graze extensively on mangroves. Sustained grazing pressure in these regions leads to repeated leaf browsing and trampling of pneumatophores, resulting in stunted mangrove growth and broader degradation of mangrove ecosystem structure and function.

3.2. Grazing Preference

The diagram clearly illustrates why camels primarily graze on *A. marina* and avoid *R. mucronata*, reflecting a major ecological challenge to mangrove conservation (**Figure 2**). *R. mucronata* grows in limited, scattered areas along the southern and southwestern Red Sea coast of Saudi Arabia, including the Farasan Islands and Jazan coast, in intertidal zones. It is less common and more fragmented than *A. marina*. Camels can access and graze the *A. marina* fringe because this species typically occupies the higher, landward edge of the tidal mudflat, where the substrate is firmer and less frequently flooded, allowing the camel to walk without sinking. Furthermore, *A. marina* often has a lower content of defensive compounds like tannins, making it more palatable to the camels, which rely on the foliage for high-quality nutrition, especially during winter (Nawata, 2013). In stark contrast, *R. mucronata* is found deeper in the intertidal zone, where the mud is soft and waterlogged (flooded for longer periods), causing the camel to sink. Crucially, the Rhizophora species is characterized by a dense network of tall, elaborate stilt/prop roots which create a physical barrier that prevents the camel from moving further into the forest and accessing the canopy for grazing (Zhang et al., 2015; Mori et al., 2022). This selective pressure from camel grazing, which is a known significant contributor to mangrove degradation along the Saudi Red Sea coast, leads to the heavy pruning and reduced reproductive capacity specifically of the *A. marina* stands, making its restoration a primary focus (Dajam et al., 2024).

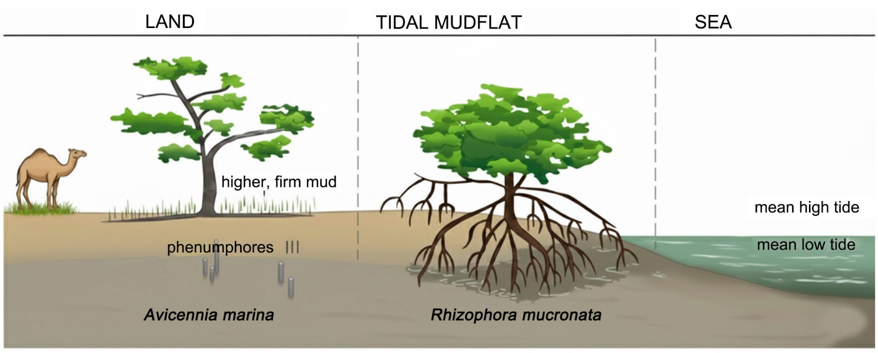

Figure 2. Cross-sectional diagram illustrating zonation of dominant mangrove species (*A. marina* and *R. mucronata*) and constraints on camel grazing within a typical Saudi Arabian tidal mudflat.

3.3. Grazing Impacts

Camel grazing exerts profound impacts on *A. marina* stands across Saudi Arabia and other arid coastlines, altering both forest structure and ecosystem functioning. Repeated browsing reduces leaf area, apical meristems, and branch density, which constrains vertical and lateral canopy growth and diminishes photosynthetic capacity and nutrient assimilation. Studies such as Almahasheer (2018) report significant declines in canopy height, crown cover, and overall stand vigor in Red Sea mangroves subjected to chronic grazing, while similar research in arid and semi-arid regions demonstrates that persistent herbivory suppresses regeneration, delays recruitment, and reduces sapling survival by removing essential photosynthetic tissues (Geisler et al., 2022; Zhang et al., 2019). Moreover, grazed mangroves are more vulnerable to heat stress, hypersalinity, and hydrological variability, compounding long-term losses in productivity and resilience (Teshome et al., 2020; Ma et al., 2020). Beyond these immediate effects, camel grazing simultaneously limits canopy expansion and reduces reproductive output, seedling establishment, and stand turnover, thereby reinforcing degradation through a self-perpetuating cycle (Gallacher & Hill, 2006; Tulloch et al., 2023). Comparative observations between non-grazed forests on Abu Ali Island and grazed mangroves in the Jazan region illustrate these structural and functional consequences (**Figure 3**), while international studies further highlight declines in carbon sequestration, habitat complexity, and coastal protection. Together, these findings indicate that persistent camel grazing is a primary driver of mangrove decline in arid coastal systems, emphasizing the urgent need for management strategies to mitigate herbivory, preserve forest structure, and maintain ecosystem resilience.

Figure 3. *A. marina* forest on Abu Ali Island, showing non-grazed conditions due to no camel access, compared with grazed forest in the Jazan region.

3.4. Sediment Alteration and Regeneration Constraints

Camel grazing exerts sustained pressure on Saudi Arabian mangroves and adjacent drylands. Browsing removes leaves and apical meristems, reducing photosynthetic area and disrupting apical dominance, which limits shoot extension and canopy growth (Aljahdali et al., 2021). Trampling compacts surface soils and sediments, reducing pore space and slowing oxygen diffusion, which restricts root elongation and impairs pneumatophore gas exchange required for internal aeration (Ola et al., 2024; van Klink et al., 2015). Trampling also lowers sediment redox potential and slows microbial nutrient transformations, reducing nitrogen and phosphorus cycling rates that support seedling development. As compaction intensifies, erosion susceptibility increases due to greater exposure to tidal shear stress and the loss of fine sediments, weakening root anchorage and restricting vertical accretion, processes needed for elevation stability under sea level rise (Li et al., 2024). Structural damage to pneumatophores and surface sediments further undermines root-sediment interactions and gas exchange capacity (**Figure 4**). Recruitment failure is reinforced because A. marina propagules and seedlings are readily buried, dislodged, or uprooted in trampled substrates. Repeated browsing shifts carbon allocation away from root systems, delaying recovery of branching and sediment-stabilizing tissues (Aljahdali et al., 2021; Ola et al., 2024). Similar grazing-driven regeneration limitations have been reported where camels and large herbivores use intertidal forests in arid regions under strong abiotic stress (El-Keblawy et al., 2009; Xu et al., 2023). Along the Saudi Red Sea coast, natural elevation gain and recruitment remain slow, making sustained grazing likely to exceed recovery thresholds and promote persistent sediment instability and regeneration failure if unmanaged. Grazing exclusion combined with active restoration is required to reverse compaction impacts and support recruitment recovery (Ola et al., 2024).

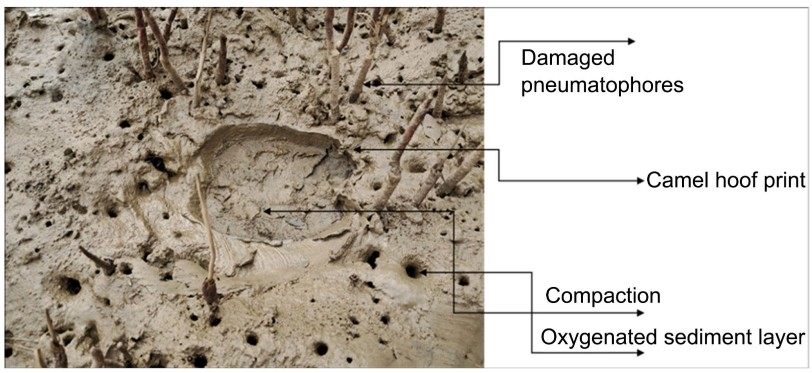

Figure 4. Impact of camel grazing on sediment structure and pneumatophore integrity in *A. marina*.

3.5. Management Strategy

Grazing management measures such as controlled access, exclusion fencing, and spatial zoning emerge as highly effective tools for reducing camel pressure and supporting the recovery of *A. marina* stands. Across reviewed studies, protected areas consistently exhibit higher seedling survival, improved canopy density, and increased aboveground biomass compared with grazed sites, demonstrating that limiting herbivore access rapidly facilitates structural regeneration and physiological recovery. Similar outcomes have been reported in other dryland and coastal ecosystems, where herbivore exclusion promotes soil restoration, enhances vegetation cover, and improves ecosystem function (Zhang et al., 2024; Hoppe-Speer & Adams, 2015).

In Saudi Arabia, the effectiveness of these measures is reinforced by a tradition of community-based stewardship, which combines tribal and herder knowledge with formal governance. Historically, Bedouin and tribal customs employed hima systems to allocate grazing rights and protect lands through collective norms and leadership, preventing overuse and degradation (Japan Wildlife Research Center & Ichikawa, 2018). Today, this approach is integrated into national strategies by the NCVC under the Ministry of Environment, Water and Agriculture, which regulates grazing through designated sites, seasonal permits (e.g., via the digital Nabati platform), and carrying capacity assessments that align herder practices with ecological limits (NCVC, 2025). Local herders and tribal networks collaborate with NCVC staff and community committees to obtain permits, apply sustainable practices, and contribute indigenous knowledge, blending traditional stewardship with scientific planning to enhance compliance and ecological outcomes (NCVC, 2025). The broader legal and policy framework further supports local participation in land management decisions, ensuring pastoral voices influence rules affecting grazing patterns (United Nations in Saudi Arabia, 2024).

These governance and community engagement mechanisms complement ecological tools such as exclusion fencing, controlled access, and spatial zoning, strengthening restoration efforts. Temporary exclusion periods allow mangrove stands to rebuild biomass and resilience under controlled conditions (**Figure 5**). Integrating grazing regulation with national mangrove rehabilitation programs therefore provides a practical and evidence-based pathway for improving restoration outcomes, reducing long-term degradation, and ensuring the sustainability of mangrove ecosystems along the Red Sea and Arabian Gulf coasts.

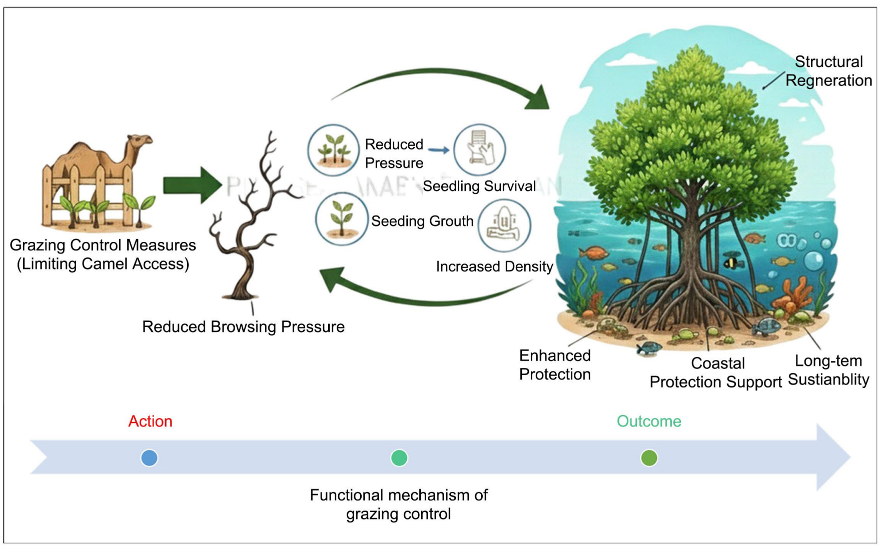

Figure 5. The functional mechanism of grazing control measures, demonstrating how limiting camel access to *A. marina* stands promotes structural regeneration and contributes to broader mangrove ecosystem benefits and long-term sustainability.

3.6. Implications for Restoration

The collective evidence indicates that camel grazing is a major anthropogenic constraint on the persistence, regeneration, and functional stability of *A. marina* along the Saudi Arabian coast. Sustained browsing suppresses natural recruitment, reduces canopy structure, and accelerates soil degradation, while trampling-induced compaction and erosion push ecosystems beyond recovery thresholds (Figure 6). Without targeted management, these pressures limit the effectiveness of restoration efforts and undermine long-term habitat resilience. The findings thus emphasize the urgent need for a national grazing management framework that combines spatial exclusion, regulated seasonal access, and community-based stewardship to mitigate herbivory impacts across priority mangrove zones. When paired with complementary restoration measures such as hydrological enhancement, sediment stabilization, and strategic planning, well-designed grazing control can significantly improve survival, growth, and ecosystem functioning, strengthening the long-term sustainability of mangrove habitats along the Saudi coastlines of the Red Sea and Arabian Gulf.

Figure 6. Highly degraded mangrove forest resulting from climate impacts and camel grazing, alongside ongoing restoration efforts in the Jazan region, South Red Sea.

4. Conclusion

The findings show that camel overgrazing is a major and complex driver of degradation in *A. marina* mangroves along the Saudi Arabian coastlines of the Red Sea and Arabian Gulf. The main impacts include intensive browsing, which reduces canopy biomass and limits growth, and trampling, which damages pneumatophores and disrupts the root zone. These pressures impair gas exchange, lower oxygen availability, and suppress key microbial processes, resulting in disrupted biogeochemical cycling and weakened ecosystem function. By identifying these stress pathways, the study provides a set of evidence-based best practices, including localized exclusion zones, seasonal grazing rotations, and assisted regeneration methods adapted to the environmental conditions of both regions. Timely implementation of these practices is essential to halt degradation, promote natural recovery, and ensure long-term resilience and sustainability of Saudi Arabia mangrove resources.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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