RESEARCH ARTICLE

# Tropical Riverine Grasslands of the Brahmaputra Basin: A Critical Assessment of Biodiversity Threats, Conservation Challenges, and Management Imperatives

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## Abstract

The Brahmaputra grasslands, stretching across the floodplains of Assam and adjoining regions of Bhutan, represent one of South Asia's most ecologically vital and biodiverse tropical riverine ecosystems. This review presents a comprehensive synthesis of existing literature alongside insights from our recent field investigations, which corroborate many of the findings reported in earlier studies. By analysing peer-reviewed publications, government reports, and field data, we outline the distinctive ecological features of these grasslands, their exceptional biodiversity, including critically endangered bird species such as the Yellow-breasted Bunting (Emberiza aureola), White-bellied Heron (*Ardea insignis*), and Manipur Bush-Quail (*Perdicula manipurensis*). Flagship species such as the Bengal tiger (*Panthera tigris*) and the greater one-horned rhinoceros *(Rhinoceros unicornis)* are facing numerous pressing conservation threats. These threats include altered fire regimes, biological invasions, overgrazing, encroachment by woody vegetation, and changes in soil conditions. Although conservation efforts in protected areas like Kaziranga and Manas have shown encouraging results, large portions of the grasslands remain vulnerable due to habitat fragmentation, climate change, ongoing human-wildlife conflict, and anthropogenic activities. Our fieldwork confirms these patterns and has been compiled in alignment with existing scientific evidence.

Furthermore, this synthesis highlights several critical gaps, including the lack of long-term ecological monitoring, an inadequate understanding of grassland-specific management needs, and limited incorporation of community-based conservation approaches. The review offers a foundational framework for developing evidence-based strategies aimed at conserving tropical riverine grasslands. It underscores the pressing need for targeted management protocols tailored to the unique ecological dynamics of the Brahmaputra grasslands. To effectively address these challenges, we advocate for enhanced transboundary cooperation, the adoption of participatory, community-led management models, and the integration of advanced tools such as environmental DNA (eDNA) analysis and remote sensing technologies within adaptive conservation frameworks. These measures are essential to promoting the long-term resilience and ecological sustainability of these critical habitats.

**Keywords**: Brahmaputra grasslands, Biodiversity conservation, Tropical riverine ecosystems, Endangered species, Habitat management

**Highlights**

- Riverine Grasslands' major threats include habitat fragmentation, overgrazing, altered fire regimes, invasive species, and climate change.
- While protected zones like Kaziranga and Manas show positive trends, large unprotected grassland areas remain highly at risk.
- There is a lack of long-term monitoring, a poor understanding of grassland-specific needs, and limited community involvement in conservation.
- Urgent, grassland-specific conservation with community involvement, cross-border collaboration, and landscape-scale planning is essential to avert collapse.

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## Introduction

Grasslands are one of the Earth's dominant biomes, covering up to 40% of the planet's terrestrial surface (DiPaolo, 2020; Gibson, 2009; White *et al.,* 2000), yet their conservation value remains significantly underappreciated compared to forests (Bardgett *et al.,* 2021). The Brahmaputra grasslands of northeastern India and southern Bhutan represent a unique tropical riverine grassland ecosystem of global conservation importance (Sharma *et al.,* 2023a). These grasslands, characterized by their location in the floodplains of the mighty Brahmaputra River, support exceptional biodiversity and provide critical ecosystem services to millions of people (Sharma *et al.,* 2023a)

The Brahmaputra River system creates unique alluvial grasslands across its 2,900 km journey from the Tibetan Plateau to the Bay of Bengal (Kumar and Ambastha, 2016). The Brahmaputra grasslands extend across multiple protected areas in Assam, India, including Kaziranga National Park (UNESCO, 2023), Manas National Park (UNESCO, 2025), Orang National Park, Dibru-Saikhowa National Park, and D'Ering Wildlife Sanctuary in Arunachal Pradesh (Chakdar *et al.,* 2002; Choudhury, 2020). These grasslands continue across the international border into Bhutan's Royal Manas National Park, forming a transboundary ecosystem of immense ecological significance (Thapa and Kelly, 2017). Grasslands globally hold around 12–15% of terrestrial carbon stocks, most of which is stored in deep soil and root biomass, rather than aboveground vegetation (Padbhushan *et al.,* 2020). The Brahmaputra grassland ecosystems support many endangered species, including the golden langur, Indian rhinoceros, and the South Ganges River dolphin, highlighting

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its role as a critical habitat for wildlife (Biswas and Boruah, 2000; Horwich *et al.,* 2013).

The ecological significance of these grasslands transcends their biodiversity value, as they deliver vital ecosystem services such as flood regulation, carbon sequestration, forage provision for livestock, and support for traditional agro-pastoral livelihoods (Adams *et al.,* 2018; Gogoi *et al.,* 2021). However, despite their ecological importance, tropical grasslands remain underappreciated in conservation frameworks, resulting in widespread degradation driven by a combination of anthropogenic pressures and natural disturbances (Bond and Parr, 2010; Ratnam *et al.,* 2011).

While previous studies have examined individual aspects of Brahmaputra grassland ecology, no comprehensive synthesis has integrated biodiversity patterns, threat assessments, and conservation strategies across the entire Brahmaputra basin ecosystem. Existing research remains fragmented, focusing on specific protected areas (e.g., Kaziranga or Manas), single taxonomic groups (primarily megafauna), or isolated conservation challenges. This fragmented approach has created critical knowledge gaps that hinder landscape-scale conservation planning.

The urgency of such a synthesis is underscored by the rapid pace of environmental change in the region, where grassland habitats face unprecedented pressures from infrastructure development, agricultural expansion, and climate variability. By presenting the first comprehensive, evidence-based assessment of the Brahmaputra grassland ecosystem, this study establishes a crucial foundation for informing policy interventions and guiding future research priorities in one of Asia's most biodiverse yet threatened landscapes.

This comprehensive literature review aims to consolidate and critically evaluate the current scientific understanding of Brahmaputra grassland ecosystems. Specifically, it synthesizes biodiversity patterns documented in studies conducted between 2018 and 2020, with particular attention to species richness, endemism, and ecological significance. The review further analyses the primary threats undermining ecosystem integrity and species persistence, including habitat loss, invasive species, and anthropogenic pressures. By identifying key research gaps and unaddressed conservation needs, this study highlights priorities for future ecological research and policy action. Ultimately, it provides evidence-based recommendations to support effective grassland conservation and sustainable management strategies.

## Materials and Methods

This review employed a systematic approach to synthesize existing knowledge on the Brahmaputra grassland ecosystems, integrating both peer-reviewed literature and verified field-based observations. A comprehensive search strategy was employed to identify relevant studies from databases, including Web of Science and Google Scholar. The search utilized key terms such as "Brahmaputra," "Brahmaputra grasslands," "tropical riverine grasslands," "Northeast India biodiversity," "grassland", "biodiversity", "conservation" "Kaziranga," "Manas," "grassland conservation," "invasive species grasslands," and "climate change grasslands." To ensure academic rigor and rigor, only peer-reviewed articles that focused on biodiversity, conservation, or management of Brahmaputra basin grasslands were selected. The comprehensive database search covered peer-reviewed publications from 1990 to 2024, with no initial temporal restrictions applied to ensure complete coverage of available literature. However, our analysis prioritized studies published between 2018 and 2024 to emphasize current threats and recent conservation developments. Both field-based empirical studies and review articles were considered, while research unrelated to grassland ecosystems or published in non-peer-reviewed sources was excluded. In total, 74 peer-reviewed articles were analysed, supplemented by field reports from protected area management authorities, conservation organization assessments, and government wildlife surveys. Additionally, opportunistic field observations gathered during recent fieldwork were integrated following standard ecological documentation protocols. These real-time observations enriched the review with insights into emerging threats and informed context-specific conservation strategies.

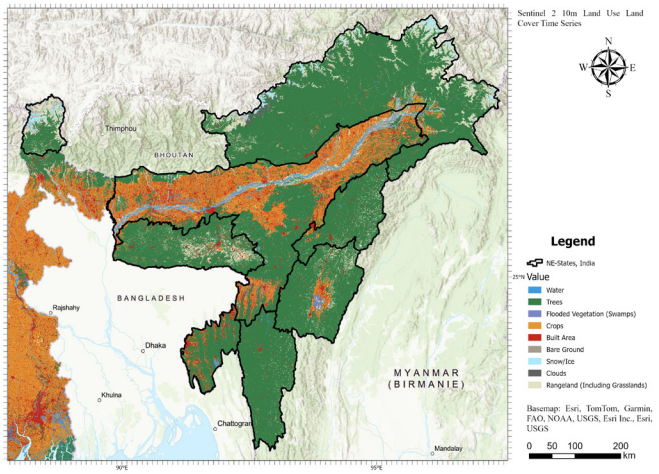


**Fig. 1:** Spatial Distribution of Land Use and Land Cover Patterns in Northeastern India Derived from Sentinel-2 (10 m) LULC Data Series

**Table 1:** Primary Study Areas in Brahmaputra Basin

| *Protected Area* | *State* | *Central Coordinates* | *Area (km²)* | *Key Species* | *Establishment* | *References* |
|---|---|---|---|---|---|---|
| Kaziranga National Park | Assam | 26.663473° 93.433301° | 430 | Asian elephant, Bengal tiger, Greater one-horned rhinoceros | 1905 | Mathur *et al*., 2011; Jhala *et al*., 2018; UNESCO, 2023 |
| Manas National Park | Assam | 26.750462° 91.079529° | 500 | Bengal florican, pygmy hog, golden langur, tiger | 1928 | Ahmed *et al*., 2015; Goswami & Ganesh, 2014; UNESCO, 2025 |
| Orang National Park | Assam | 26.567172° 92.322639° | 78.8 | Greater one-horned rhinoceros, Bengal florican, tiger | 1985 | Borthakur *et al*., 2016; Rahmani *et al*., 1991 |
| Dibru-Saikhowa National Park | Assam | 27.676375° 95.407331° | 340 | Bengal florican, feral horses, white-winged wood duck | 1999 | Kotoky *et al*., 2012; Hazarika *et al*., 2015 |
| D'Ering Wildlife Sanctuary | Arunachal Pradesh | 28.002943° 95.433326° | 190 | hog deer, and Bengal florican | 1978 | Hussain *et al*., 2019; Choudhury, 2020 |
| Pobitora Wildlife Sanctuary | Assam | 26.234831° 92.050690° | 38.8 | Greater One Horned Rhinoceros, Wild Water Buffalo | 1987 | Sarkar *et al*., 2024 |

The field surveys were conducted in parallel with a systematic assessment of the distribution status of threatened grassland birds across the Brahmaputra floodplain. Sampling was carried out throughout the grassland regions surrounding the Brahmaputra River (Fig.1), including its islands and tributaries. Additionally, the entire areas of Manas National Park, Pobitora Wildlife Sanctuary, and Kaziranga National Park were included (Table 1), as they lie in close proximity to the Brahmaputra and encompass significant expanses of grassland habitats.

## Historical and Biogeographical Background

The Brahmaputra grasslands have evolved over millennia through complex interactions between geological processes, climate, and the dynamic river system (Sarma *et al.,* 2008). This region encompasses a unique ecological continuum, combining the Sub-Himalayan Bhabar-Terai formation with riverine successional gradients that extend into the Sub-Himalayan montane forests, rendering it one of the most biodiversity-rich areas globally (Goswami and Ganesh, 2014; Janardhan *et al*., 2024).

Historically, the structure and composition of these grasslands have been shaped by the annual flooding dynamics of the Brahmaputra River and its tributaries (Goswami and Das, 2002; Hazarika *et al.,* 2015a). The region's position at the intersection of the Indo-Gangetic and Indo-Malayan biogeographical realms has played a pivotal role in fostering its exceptional biodiversity (Myers *et al.,* 2000; Rodgers and Panwar, 1988). Human interactions with these grasslands date back centuries, with indigenous communities developing sophisticated agro-pastoral systems adapted to the seasonal flooding patterns (Mishra *et al.,* 2017). The initiation of protected area networks in the region dates back to the early 20th century, marked by the designation of Kaziranga as a reserve forest in 1905 in response to growing concerns over the declining population of the one-horned rhinoceros (Mathur *et al.,* 2011).

## Vegetation Types and Ecological Processes

The vegetation of the Brahmaputra grasslands is highly diverse and supports a mosaic of habitat types shaped by complex hydrological and geomorphological dynamics (Joshi *et al.,* 2020). Sharma *et al.* (2023a) observed that areas subjected to prolonged inundation were dominated by short grasslands, which exhibited higher plant species diversity. In contrast, regions with shorter flood durations supported tall grasslands characterized by lower species diversity. The dominant vegetation types within these ecosystems comprise alluvial grasslands, characterized by species such as *Erianthus naranga*, *Saccharum spontaneum*, *Phragmites karka*, *Imperata cylindrica*, and *Arundo donax* (Pande, 2015); semi-evergreen forests, found in less flood-prone zones (Champion and Seth, 1968); wetland vegetation, associated with numerous beels (oxbow lakes) and marshes (Dutta and Konwar, 2013); and riverine forests, which occur along riverbanks and on relatively stable river islands (Nandi *et al.,* 2023). Fire is a critical ecological process in these grasslands. Sharma *et al.* (2023a) showed that controlled burning and removal of invasive species effectively reduced woody plant encroachment, improved soil nutrient conditions, and supported native grass regeneration. However, alterations in traditional fire regimes due to changing management practices have resulted in complex ecological outcomes, sometimes undermining long-term habitat stability (Raman, 2001)

## Biodiversity Overview

### *Flora*

The Brahmaputra grasslands support exceptional plant diversity, with numerous endemics and threatened species (Hajra and Verma, 1996). The dominant grass species include various *Saccharum* species, *Imperata cylindrica*, and *Phragmites karka*, which form the characteristic tall grasslands (Pande, 2015). According to Roy (2021), the flora of Manas NP comprises 543

species, including 374 dicotyledons (of which 89 are tree species), 139 monocotyledons, and 30 species of pteridophytes and gymnosperms.

*Fauna*

The Brahmaputra grasslands are internationally recognized for their rich assemblage of megafauna, most notably exemplified by the conservation success of the greater one-horned rhinoceros (Jhala *et al.,* 2021). As per the March 2018 census conducted jointly by the Forest Department of the Government of Assam and accredited wildlife NGOs, the population of the greater one-horned rhinoceros in Kaziranga National Park was recorded at 2,613 individuals (Assam Forest Department, 2018). This represents approximately 70% of the global population (Borthakur *et al.,* 2016).

The Brahmaputra grasslands also serve as critical habitat for several flagship species (Table 2), reflecting their high conservation value (Borah *et al*., 2010). Among them, the Bengal tiger (*Panthera tigris*) holds particular prominence; Kaziranga was declared a Tiger Reserve in 2006 and currently supports the highest recorded tiger density in the world, with approximately one individual per five square kilometers, an estimated population of 135 tigers (Jhala *et al*., 2018). The Asian Elephant (*Elephas maximus*) is another key species, with substantial populations utilizing these grasslands on a seasonal basis, highlighting the area's importance as part of their migratory corridor (Thapa *et al.,* 2019). Asiatic Wild Water Buffalo (*Bubalus arnee*), an endangered species, finds its largest extant population in Kaziranga National Park, making this landscape vital for its survival (Sarkar *et al.,* 2024). Additionally, the Eastern Swamp Deer, a rare subspecies endemic to these grasslands, is now restricted to Kaziranga and Manas National Parks, making these habitats vital for its continued existence (Islam *et al.,* 2022; Paul *et al.,* 2018).

The Brahmaputra grasslands are a vital refuge for exceptional avian diversity, including numerous globally threatened and endemic bird species (Table 3). Narasimmarajan *et al.* (2013) emphasized the region's significance for bird conservation. Among the most critically important species is the Bengal Florican (*Houbaropsis bengalensis*), a globally threatened bird, along with other notable species such as the Ferruginous Pochard (*Aythya nyroca*), Lesser White-fronted Goose (*Anser erythropus*), and Swamp Francolin (*Ortygornis gularis*), all of which were documented in Kaziranga by Rahmani *et al.* (1991). The Greater Adjutant Stork (*Leptoptilos dubius*), another endangered species, is frequently observed in wetland patches within the grasslands (Singha *et al.,* 2003). Notably, the Swamp Prinia (*Laticillacinerascens*), an endangered species, has been reported from the floodplain grasslands of Assam and Arunachal Pradesh (Hussain *et al.,* 2019). Furthermore, these habitats support several critically endangered species, including the Yellow-breasted Bunting (*Emberiza aureola*), White-bellied Heron (*Ardea insignis*), and Manipur Bush-Quail (*Perdicula manipurensis*), underscoring the grasslands' irreplaceable role in avian conservation. The grasslands support diverse reptilian and amphibian communities (Sengupta *et al.,* 2019). Basumatary and Sharma (2013) documented that Kaziranga Tiger Reserve hosts a remarkable diversity of reptiles, including the endangered

**Table 2:** Major flagship megafauna of the Brahmaputra Basin grasslands

| *Scientific Name* | *Common Name* | *IUCN Status* | *Population (Latest)* | *Key Locations* |
|---|---|---|---|---|
| *Rhinoceros unicornis* | Greater One-horned Rhinoceros | Vulnerable | 2,613 (Kaziranga, 2018) | Kaziranga, Orang, Pobitora |
| *Panthera tigris* | Bengal Tiger | Endangered | 135 (Kaziranga) | Kaziranga, Manas |
| *Elephas maximus* | Asian Elephant | Endangered | Seasonal populations | Corridor areas |
| *Bubalus arnee* | Asiatic Wild Water Buffalo | Endangered | Largest population in Kaziranga | Kaziranga NP |
| *Rucervus duvaucelii ranjitsinhi* | Eastern Swamp Deer | Vulnerable | Restricted populations | Kaziranga, Manas |

**Table 3:** Occurrence of major threatened avifaunal species in the grasslands of the Brahmaputra Basin

| *Scientific Name* | *Common Name* | *IUCN Status* | *Habitat Preference* | *Conservation Priority* |
|---|---|---|---|---|
| *Houbaropsis bengalensis* | Bengal Florican | Critically Endangered | Tall grasslands | Extremely High |
| *Emberiza aureola* | Yellow-breasted Bunting | Critically Endangered | Grassland edges | Extremely High |
| *Ardea insignis* | White-bellied Heron | Critically Endangered | Wetland-grassland interface | Extremely High |
| *Perdicula manipurensis* | Manipur Bush-Quail | Critically Endangered | Short grasslands | Extremely High |
| *Leptoptilos dubius* | Greater Adjutant Stork | Endangered | Wetland patches | High |
| *Aythya nyroca* | Ferruginous Pochard | Near Threatened | Aquatic areas | Moderate |
| *Anser erythropus* | Lesser White-fronted Goose | Vulnerable | Seasonal wetlands | High |
| *Ortygornis gularis* | Swamp Francolin | Vulnerable | Dense grasslands | High |
| *Laticilla cinerascens* | Swamp Prinia | Endangered | Floodplain grasslands | High |

Assam Roofed Turtle and many other endemic herpetofauna. However, research on invertebrate diversity remains limited, representing a significant knowledge gap.

## Human Interactions and Land Use

### *Traditional Agro-pastoral Systems*

The Brahmaputra grasslands have long supported traditional agro-pastoral communities who developed sustainable land use practices adapted to the seasonal flooding regime (Saha *et al.,* 2021). Felding (2013) and Saharia *et al.* (2017) documented how indigenous communities have historically adapted to local geo-climatic conditions by developing and sustaining livestock production systems. These traditional systems involve seasonal grazing patterns, with communities moving their livestock to higher ground during floods (Begum *et al.,* 2025).

### *Contemporary Land Use Pressures*

Modern land use changes present significant and escalating threats to the ecological integrity of the Brahmaputra grasslands. Agricultural expansion continues to be a major driver of habitat loss, particularly in unprotected areas where natural grasslands are increasingly being converted into croplands (Saikia *et al.,* 2019). Infrastructure development further exacerbates fragmentation and disturbance; for instance, National Highway 715, which connects Tezpur and Jorhat, passes through ecologically sensitive zones such as Kaziranga and Karbi Anglong, leading to frequent wildlife-vehicle collisions and habitat disruption (Menon, 2017). Additionally, human settlements and encroachment pose critical challenges. Bhagabati and Deka (2022) reported that increasing human population pressure along the riverine plains and chars of the Brahmaputra significantly threatens the habitats of rare and migratory bird species. Collectively, these land use pressures undermine the long-term sustainability of the region's grassland ecosystems and call for urgent landscape-level planning and conservation interventions (Morrison, 2006).

### *Human-Wildlife Conflict*

The interface between human settlements and wildlife habitats creates ongoing conflicts (Vasudev *et al.,* 2023). Crop raiding by elephants and rhinoceros, livestock predation by tigers, and retaliatory killing of wildlife remain persistent challenges (Naha *et al.,* 2020). Das *et al.* (2025) and Roy *et al.* (2025) documented that increasing anthropogenic pressure like cattle grazing, timber felling and expansion of human settlement, has resulted in the fragmentation and degradation of habitat.

## Conservation Challenges

### *Habitat Fragmentation and Degradation*

Habitat fragmentation represents one of the most severe threats to the Brahmaputra grasslands (Kushwaha, 2005). Kotoky *et al.* (2012) reported that Dibru-Saikhowa experienced the highest decline in land area, approximately 37.6%primarily as a result of riverine dynamics and anthropogenic pressures. The fragmentation disrupts wildlife movement corridors and isolates populations, potentially leading to genetic bottlenecking (Sharma *et al.,* 2009). Habitat fragmentation is widespread throughout the grassland ecosystem, with particularly severe effects observed in unprotected areas, where natural grassland habitats have been almost destroyed. Remnant patches of grassland persist primarily on inhabited or inaccessible riverine islands. However, these remaining patches are highly isolated, supporting only limited populations of birds and other wildlife. The geographic isolation has also led to restricted gene flow between populations in these islands and those in protected areas, which may impact long-term species viability.

The expansion of human settlements and agricultural activities has been a major driver of grassland reduction and fragmentation, leading to substantial alterations in habitat structure and connectivity (Lahiri *et al.,* 2022). Many species that are specialized to grassland habitats are now confined to these fragmented patches. In some cases, species have become locally extinct due to their strict habitat requirements. As a result, populations of birds, mammals, and endemic species have declined substantially in these regions, raising concerns about their long-term conservation.

### *Fire Regime Changes*

Traditional fire management practices are being disrupted, with consequences for grassland ecology (Sharma *et al.,* 2023b). The study further documented that habitat degradation, driven by encroachments, expanding settlements, intensive grazing, grass cutting, the proliferation of invasive species, and uncontrolled savanna fires, contributes to the alteration of natural fire regimes essential for the maintenance of grassland ecosystems (Sharma *et al.,* 2023b). Our field observations confirm that grassland fires are a recurring phenomenon in the Brahmaputra grassland (Fig.2), with peak fire activity occurring between February and May. Alarmingly, a significant number of these fire incidents were recorded within the unprotected zones, though large-scale fires within protected areas are also not uncommon, highlighting management challenges even in supposedly regulated areas. Fires in unprotected regions, however, were found to be more extensive and frequent, with evidence of regular and widespread burning.

Interviews with local hunters revealed that in some areas, particularly within the riverine islands, fires are sometimes deliberately set to facilitate hunting by flushing out wildlife. In protected areas, what is intended as controlled burning often escalates into uncontrolled wildfires. This is primarily due to inadequate monitoring and the influence of strong winds, which frequently render fire containment efforts ineffective. As a result, entire islands within protected zones have experienced complete burns during peak fire months. These findings emphasize the urgent need for the implementation of stringent fire management and monitoring protocols, including early warning systems, community engagement, capacity building for park staff, and systematic monitoring frameworks applicable across both protected and non-protected grassland landscapes.

### *Invasive Alien Species*

Invasive species represent a significant and growing threat to native grassland biodiversity (Lahkar *et al.,* 2011). Barua *et al.* (2010) reported that invasive species, including *Mimosa* spp. and wild rose, have posed substantial threats to native plant communities in the region, contributing to shifts in species

**Fig 3:** Extensive grazing and fire-affected grasslands were recorded in Kaziranga National Park and its surrounding areas during the study period

composition and ecosystem structure. Among these, the spread of *Chromolaena odorata* (Siam weed) is particularly concerning. Bhattacharjee *et al.* (2017) in their study titled 'Silent Stranglers: Eradication of *Mimosa* in Kaziranga National Park, Assam', were the first to document the spread of *Mimosa* species along the riverbanks bordering Kaziranga National Park. *Mimosa diplotricha* and *M. invisa* have become particularly problematic, with Pande (2015) reporting that 43 percent of the area of Kaziranga was covered with the species at its peak invasion.

The proliferation of invasive plant species is a growing concern across the Brahmaputra grasslands, particularly within protected areas (Singh, 2017). *Mimosa* species have become widespread and dominant, especially in marshy regions, posing a significant ecological threat by altering native vegetation structure and reducing habitat quality. The spread of *Ipomoea* has also been recorded, although to a lesser extent. In contrast, the presence of Lantana and other commonly problematic invasive species remains negligible in this region.

Water bodies across the landscape, particularly in districts such as Tinsukia, are heavily dominated by *Eichhornia crassipes* (water hyacinth), which has severely impacted aquatic ecosystems by depleting oxygen levels and obstructing water flow (Villamagna and Murphy, 2010). Additionally, *Tamarix dioica,* although native, exhibits invasive behaviour in several areas. It has become particularly dominant in the Assam portion of the Brahmaputra floodplains, often outcompeting native grasses and altering the ecosystem structure.

### *Grassland extraction*

Grasslands in the Brahmaputra basin, particularly within ecologically sensitive floodplain regions like Kaziranga and Manas, are experiencing severe degradation due to unsustainable extraction practices. These include biomass harvesting, overgrazing, topsoil removal, and increasing conversion to agriculture, all of which pose serious threats to the ecological integrity of the region (Dutta and Konwar, 2013; Sharma *et al.,* 2023b). The invasion of exotic species such as *Mikania micrantha* and *M. diplotricha* has further disrupted native grassland ecosystems, leading to a marked decline in habitat quality for key species, including the greater one-horned rhinoceros (Lahkar *et al.,* 2011). Satellite-based land cover analyses reveal a significant reduction in natural grasslands, driven by river migration, erosion, and human encroachment (Debnath *et al*., 2022; Hazarika *et al*., 2015b). Moreover, removal of grasses and bush cover alters fire regimes and nutrient cycling, undermining grassland regeneration and wildlife support systems (Kotoky *et al.,* 2015; Pande, 2015). The compounded effects of invasive species, hydrological alterations, and land-use changes demand urgent, ecologically informed grassland management to prevent biodiversity collapse in the Brahmaputra floodplains (Pradhan *et al.,* 2021).

Grassland extraction for constructing temporary shelters, wooden huts, and tourist resorts is increasingly common across the riverine islands and tourism-focused regions (Fig.3), particularly under the guise of promoting ecotourism. Additionally, local communities frequently harvest grass to build animal shelters for cattle and goats. This practice, while traditional in some areas, has become more prevalent even within protected zonesraising serious concerns about its ecological consequences.

The extraction of native grass species is particularly evident in parts of Arunachal Pradesh and some parts of Assam (Sarania *et al*., 2021). For example, in the Dering region, we observed extensive harvesting of *Vetiveria* and *Saccharum* species from island grasslands by local inhabitants. Although such activities are deeply embedded in the cultural practices and subsistence livelihoods of local communities and may be permissible to a limited extent, unregulated extraction presents a substantial threat to native biodiversity. Uncontrolled grass harvesting can degrade critical habitats, affecting threatened and endemic species that depend on intact grassland ecosystems.

## Sediment Filtration and Siltation in Brahmaputra Grasslands

Sediment filtration has been observed across various parts of the Brahmaputra floodplain, particularly along riverine islands and shoreline grasslands where such landscapes are prevalent. While

**Fig 4:** Harvested grassland was observed being transported for utilization from areas near the Behbari Gaon region

tall grassland regions exhibit comparatively lower sediment accumulation than areas dominated by woodlands or mixed land types, grasslands still demonstrate a moderate capacity to stabilize soil and reduce sediment runoff. However, during peak flood events, significant siltation has been recorded in several regions, notably in Majuli Island and Dibru-Saikhowa National Park. These events suggest that although grasslands contribute to sediment retention under normal conditions, their capacity is often overwhelmed during high-intensity floods.

*Climate change impacts*

Climate change is increasingly recognized as a major threat to the ecological stability and long-term resilience of the Brahmaputra grassland ecosystem. Uddin *et al.* (2024) highlighted that global warming has intensified the regional water cycle, thereby increasing the frequency and severity of hydrological disasters through altered precipitation patterns. These changes are reshaping flood dynamics, temperature regimes, and rainfall distribution of which are critical factors governing grassland ecology and species distribution (Tamuly *et al.,* 2019). Key impacts of climate change include altered flooding patterns, which hinder natural grassland regeneration (Brotherton *et al.,* 2019); Shifts in species phenology and migration patterns, driven by climate variability, are disrupting ecological interactions and altering established seasonal cycles within the grassland ecosystems (Dong *et al.,* 2024); and a marked increase in extreme weather events, such as unseasonal floods and droughts (Dodd *et al.,* 2023). Furthermore, vegetation communities are undergoing structural changes, with some native grass species being replaced by more resilient or invasive flora (Roy *et al.,* 2015). Collectively, these climate-induced shifts pose long-term risks to the ecological balance, biodiversity, and resilience of the Brahmaputra grasslands.

Although natural seasonal flooding is an inherent ecological process in Brahmaputra riverine grassland ecosystems (Fig.4), recent patterns of unprecedented flooding, driven by climate change and anthropogenic interventions such as dam construction and unregulated water release, have disrupted the natural hydrological rhythm of the flood plain. These alterations can significantly affect the structure and function of habitats that are highly dependent on seasonal flood dynamics. Although no major threats have been identified in the Brahmaputra flood plain so far for grassland bird species, the intensified and unseasonal flooding poses serious challenges to megafauna such as elephants, rhinoceroses, and other large mammals. These species, which rely on stable habitat conditions and predictable water regimes, are increasingly vulnerable to habitat degradation, displacement, and resource scarcity caused by erratic flood events.

## Future Directions and Management Strategies

Modern technological innovations offer powerful tools for enhancing the conservation and management of grassland ecosystems. Remote sensing and GPS mapping can track habitat changes in real-time, detect fires, map floods, and assess vegetation health (Pettorelli *et al.,* 2014; Roy *et al.,* 2006). Environmental DNA sampling now allows for species detection from minimal environmental samples such as water or soil, offering a non-invasive and efficient method to monitor

**Fig 5:** A local village near Biswanath Ghat was submerged by seasonal flooding during the July 2019 flood

biodiversity from flagship animals to tiny insects and bacteria (Thomsen and Willerslev, 2015). Camera traps, acoustic sensors and sound recording devices facilitate continuous wildlife surveillance without disturbing animals, enabling population counts and behaviour studies (Karanth *et al.,* 2006; O'Connell *et al.,* 2011).

Although many isolated grassland patches remain intact and relatively unaffected by invasive species, the current spread of these invasive species is in an early yet rapidly expanding stage. Immediate intervention through active monitoring, management, and eradication measures is essential to prevent large-scale ecological degradation. Delayed action could lead to irreversible impacts on habitat quality, biodiversity, and ecosystem function. Managing grasslands under climate change requires strategies that reduce current threats while building ecosystem strength. Low-risk approaches include changing grazing patterns to increase biodiversity and reducing existing stressors (Hannah *et al.,* 2020). Conservation planning must move beyond individual protected areas to cover entire landscapes, recognizing that grassland distribution is now highly fragmented, though large populations may still exist in eastern areas, particularly along the Brahmaputra River (Wikramanayake *et al.,* 2004).

International partnerships have proven essential, especially the India-Bhutan Transboundary Manas Conservation Area, which helped preserve wildlife diversity during periods of civil conflict (Ahmed *et al.,* 2015; Chettri *et al.,* 2007). Local communities play a pivotal role in conservation success through their engagement in eco-development committees, alternative livelihood initiatives, conservation education, and community-based ecotourism programs (Badola *et al.,* 2010; Goodwin, 2009). Future success depends on meaningful community engagement through shared decision-making, benefit-sharing from conservation programs, and integrating traditional knowledge with modern management (Armitage *et al.,* 2009; Berkes, 2007).

Despite their ecological importance, most studies on Brahmaputra grasslands remain disproportionately descriptive, lacking information about habitat variety, landscape patterns, natural disturbances, and grazing impacts (Rawat and Adhikari, 2015). Long-term monitoring programs are essential but currently inadequate (Dutta and Jhala, 2014). Comprehensive mapping of grassland extent and changes over time remains limited, and research has focused mainly on large, charismatic animals while neglecting other species. Additionally, the traditional ecological

knowledge of pastoral communities, crucial for understanding local adaptation strategies and ecosystem resilience, remains poorly documented and underutilized in current management strategies (Singh *et al.,* 2017).

Our opportunistic field observations were integrated as supplementary evidence to corroborate patterns documented in peer-reviewed literature rather than as primary quantitative data. These observations possess several inherent limitations that warrant consideration in data interpretation. Species detection probabilities varied substantially based on environmental conditions, observer experience, and habitat characteristics. Cryptic or rare species may have been underrepresented in our observations, while conspicuous species in open habitats likely received disproportionate attention. Despite these limitations, our field observations provide valuable contemporary insights into ecosystem conditions, threat patterns, and species occurrence that complement and validate findings from systematic studies. We emphasize that these observations serve as contextual support for literature-derived conclusions rather than independent evidence for conservation recommendations.

## Conclusion and Future Prospects

The Brahmaputra grasslands of northeastern India and southern Bhutan represent one of Earth's most biodiverse yet underappreciated ecosystems, supporting exceptional wildlife populations including the world's highest density of tigers and approximately 70% of the global one-horned rhinoceros population. This comprehensive review reveals that while these tropical riverine grasslands provide critical ecosystem services and harbour numerous endangered species, they face unprecedented threats from habitat fragmentation, invasive species proliferation, altered fire regimes, and climate change impacts that are fundamentally disrupting their ecological integrity. The analysis demonstrates that habitat fragmentation has reached alarming levels, with natural grasslands surviving primarily as isolated patches on riverine islands, while invasive species like *Mimosa* sp. have colonized up to 43% of protected areas at peak invasion periods. Traditional fire management practices are being disrupted, leading to uncontrolled wildfires that compromise grassland regeneration, while climate change is intensifying flood patterns and altering species distribution dynamics.

Despite these challenges, the research identifies significant opportunities for conservation success through integrated landscape-level management approaches that combine modern technology with traditional ecological knowledge and meaningful community engagement. The documented success of transboundary conservation initiatives, particularly the India-Bhutan Transboundary Manas Conservation Area, demonstrates the potential for effective cross-border collaboration in preserving these ecosystems. However, critical research gaps remain, particularly regarding invertebrate diversity, long-term ecological monitoring, and the integration of pastoral communities' traditional knowledge into management strategies. The findings underscore that immediate intervention is essential to prevent irreversible ecological degradation, as many invasive species are still in early stages of colonization and can be effectively managed with prompt action. Moving forward, the conservation of Brahmaputra grasslands requires urgent implementation of landscape-scale planning, grassland-specific policies, strengthened international cooperation, and climate adaptation strategies that recognize both the ecological significance and socio-economic importance of these unique ecosystems for sustainable biodiversity conservation and human livelihoods.

### Future Research Priorities

Several critical research gaps require immediate attention to advance grassland conservation science. Long-term ecological monitoring programs must be established to track ecosystem responses to management interventions and climate variability. Comprehensive invertebrate biodiversity assessments are urgently needed, as these taxa remain severely understudied despite their fundamental ecological roles. Landscape-scale connectivity analyses should quantify habitat fragmentation effects on population genetics and species movement patterns across protected and unprotected areas.

### Technological Integration and Innovation

Future conservation efforts should harness emerging technologies to enhance monitoring and management effectiveness. Environmental DNA (eDNA) sampling protocols should be developed for grassland-specific biodiversity assessment, enabling the detection of cryptic species and ecosystem health indicators. Remote sensing applications require refinement for real-time fire detection, invasive species mapping, and flood impact assessment. Artificial intelligence and machine learning approaches should be integrated into camera trap networks and acoustic monitoring systems for automated species identification and population estimation.

### Management and Policy Directions

Grassland-specific management policies must be developed that recognize the unique ecological requirements of tropical riverine systems. Adaptive fire management protocols should integrate traditional ecological knowledge with contemporary conservation science to restore natural burning regimes. Transboundary conservation frameworks require strengthening, particularly the India-Bhutan collaborative initiatives, with

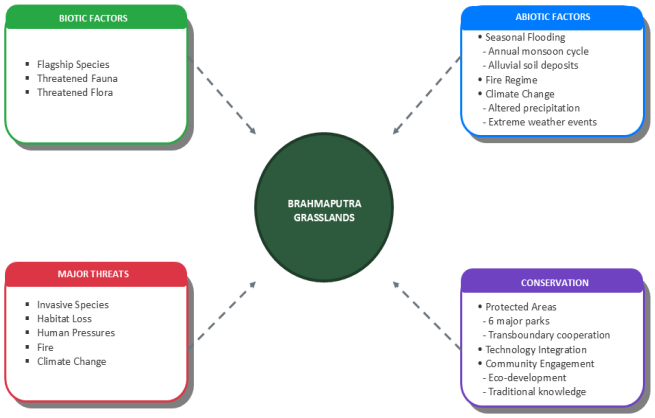


**Fig 6:** Diagrammatic representation of major biotic and abiotic factors influencing the grasslands of the Brahmaputra floodplain

expansion to include Bhutan and China for comprehensive watershed management.

### Community Engagement and Capacity Building

Future conservation success depends on meaningful integration of local communities through participatory management approaches. Community-based monitoring programs should be established to support traditional ecological knowledge while building local capacity for biodiversity assessment. Alternative livelihood programs must be expanded to reduce anthropogenic pressure on grassland resources while providing sustainable economic opportunities for pastoral communities.

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## Author Contributions

Harif Parengal led the conceptualization, methodology, data curation, photographs, writing the original draft, and review and editing of the manuscript. Padijareveedu Ramachandran Aruncontributed through investigation, supervision, writing, review, and editing. Sethu Madhav Reghu was involved in conceptualization and writing, review and editing. Haris Parengal, Bency Gertrude Choyikandi, and Sumayyabi Palliveedu all contributed to the writing, review, and editing of the manuscript.

## Conflict of Interests

The authors declare no competing interests

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