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Cover: Indian Grey Wolf *Canis lupus pallipes* and Smooth-coated Otter *Lutrogale perspicillata* sharing the territory in Chambal basin. Digital art on Procreate by Aakanksha Komanduri.

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COMMUNICATION

Geo-ecological dynamics of Bhairabkunda Grasslands: flood origins, florican dependence, and conservation need

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Abstract: This study investigated the dynamics of land cover change in the Bhairabkunda region of Assam, with a focus on the emergence of grasslands resulting from flood-driven river course changes. The objective was to assess how flooding events and subsequent ecological succession influenced grassland formation and their role in supporting the 'Critically Endangered' Bengal Florican *Houbaropsis bengalensis*. Multi-temporal satellite imagery from Landsat 5, 7, 8, and 9 (1987–2024) with 30 m spatial resolution was analyzed using supervised classification in QGIS to quantify land cover transitions. Ground surveys were conducted in 2024 to validate florican presence and vegetation composition. The results revealed that significant grassland patches emerged after the 1988–1989 floods, which altered the river's course and deposited sandbars, leading to 9.64 km² of grassland by 1991. However, between 2015 and 2024, rapid woodland expansion reduced grassland to 6.29 km², threatening grassland-dependent species. Bengal Florican sightings during field surveys confirmed the ecological significance of these newly formed habitats. Future projections for 2034, based on the MOLUSCE artificial neural network model, indicated further grassland decline to 4.72 km² and woodland expansion to 9.87 km². These findings demonstrated the dynamic nature of floodplain ecosystems, the influence of hydrological changes on vegetation succession, and the vulnerability of specialized species to habitat contraction. The study concluded that continued monitoring and targeted habitat management are urgently required to conserve grassland ecosystems and ensure the survival of the Bengal Florican in the sub-Himalayan landscape.

Keywords: Bengal Florican, emerging grassland, flood dynamics, habitat management, hydrological changes, land cover change, long-term monitoring, sub-Himalayan grassland, vegetation succession.

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Author contribution: Jonmani Kalita contributed to scientific analysis and manuscript writing. Karishma Sharma Chamlagain and Koushik Rajbongshi contributed to data collection. Dhritiman Das critically analyzed all findings.

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INTRODUCTION

Grassland and savanna biomes cover 40% of the Earth's land surface (Dixon et al. 2014; Wilsey 2018) and approximately 20% of the area in tropical latitudes (Parr et al. 2014; Bond 2016). The sub-Himalayan grasslands are among the most threatened ecosystems on the Indian subcontinent; they comprise a unique mix of alluvial grassland, savanna, and forest ecosystems, extending in a narrow belt from east to west at the base of the Himalaya (Semwal 2005; Banerjee et al. 2023; Douglas et al. 2023; Rahmani et al. 2016). A tropical to subtropical climate, with over 1,200 mm of annual rainfall, supports high productivity resulting in dense woodlands, extensive grasslands and savannas with varying tree cover (Banerjee et al. 2023). Although famously important for high-profile, 'flagship' species, this grassland also supports a range of lesser-known threatened and endemic species, including the Pygmy Hog *Porcula salvinia*, Bengal Florican *Houbaropsis bengalensis*, Hispid Hare *Caprolagus hispidus*, Hog Deer *Axis porcinus*, and Swamp Francolin *Ortygornis gularis* (Bell & Oliver 1992; Narayan & Deka 2008; Rahamani et al. 2016; Thakur et al. 2024). Their ecological importance makes them a key focus of conservation efforts in this region, particularly as they support these species, which are highly sensitive to habitat changes and serve as an indicator of grassland ecosystem health. This ecosystem experiences seasonal monsoonal flooding due to its geographic position, and the frequency and intensity of floods varies substantially, often changing the course of rivers in the region (Magilligan 1992; Bayley 1995; Lehmkuhl et al. 2006). Studies have also noted that shifts in river course affect the extent and duration of flooding at specific sites. For example, Miller et al. (1995) demonstrated that alterations in river channel patterns led to increased flood frequency and changes in sediment deposition in floodplain ecosystems. Similarly, Biswas (2010) linked changes in river course within the eastern Terai to the loss of grasslands and forests due to altered hydrological regimes and land use patterns. These changes play a role in shaping the distribution, persistence, and succession of forests and grasslands (Walsh & Townsend 1995; Michener & Houhoulis 1997). In addition to flooding, sub-Himalayan grassland habitats experience woody encroachment and anthropogenic disturbance, which impact the structure and function of these ecosystems (Kumar 2000; Bijlmakers 2020). Much of the sub-Himalayan grassland has been converted to agriculture and settlements over the past three decades (Douglas et al. 2023). For instance, the total extent of grasslands declined by 34.4% from 1,417 km² (28% of the total area) in 1988–1989 to 923 km² in 2018–2019, while woodland area increased by 8.7%, expanding from 3,235 km² to 3,516 km² (Johnsingh 2006; Banerjee et al. 2023). Multiple factors drive grassland loss globally, including conversion to croplands (Bullock et al. 2021; Douglas et al. 2023), spread of invasive species (Gornish & Santos 2016), climate change (Sankaran 2019), livestock grazing (Kariuki et al. 2021; Douglas et al. 2023), altered fire regimes (Simpson et al. 2022), bio-resource exploitation (Ryan et al. 2016), tree planting in grassland (Douglas et al. 2023), and woody encroachment (Devine et al. 2017; Buisson et al. 2019; Bardgett et al. 2021). At the same time, grassland formation has also been documented, particularly in riverine systems, where flooding and channel shifts have led to the development of new grass-dominated areas (Biswas 2010).

This study aims to examine the formation of new grasslands in the Bhairabkunda area, a dynamic sub-Himalayan landscape located along the Assam–Bhutan foothills, where recent hydrological disturbances and land-use changes have led to rapid vegetation turnover. The area represents a transitional zone between grassland and woodland ecosystems, making it a suitable model system for understanding the environmental drivers and ecological processes governing grassland emergence and grassland–woodland shifts in the eastern Himalayan foothills. During field visits, the grasslands in this region appeared relatively young and recently formed—a pattern not commonly observed in other sub-Himalayan sites. Indeed, a 1989 extensive survey by Narayan (1992) did not document this grassland, and no Bengal Florican sightings were recorded at that time. This prompted a focused investigation using land-use and land-cover analysis to better understand the drivers and implications of these emerging grassland habitats as well as for the florican. By linking florican occurrence with multi-temporal satellite imagery, the study offers insights into habitat suitability and grassland conservation potential in riverine landscapes of the eastern sub-Himalaya.

METHODS

Study site

The study area, Bhairabkunda (26.89°–26.85° N, 92.11°–92.17° E), is located in the Udalguri District of Assam near the borders of Assam, Arunachal Pradesh, and Bhutan (Image 1). The landscape is dominated by seasonally inundated alluvial grasslands composed

mainly of tall grasses such as *Saccharum spontaneum*, and *Imperata cylindrica*, with grass heights ranging ~1.5–2 m, which experience extensive flooding during the monsoon and remain relatively dry in winter, while being subject to periodic human use including seasonal grazing, and uncontrolled burning. However, invasive species like *Chromolaena odorata* and *Mikania micrantha*, as well as common riverine tree like *Bombax ceiba*, were also present. Additionally, prominent woody species such as Sisoo *Dalbergia sissoo* and Khair *Senegalia catechu* were observed, likely due to plantation efforts. The area features several water channels that deposit sandy sediments, with soil primarily of sandy and loamy texture. Positioned approximately 22 km north of the district headquarters of Udalguri and adjacent to the Bhutanese town of Daifam, Bhairabkunda serves as a transit point for the eastern province of Bhutan, the area is characterized by the confluence of the Jampani and Bhairabi rivers, forming the Jia Dhansiri River, a significant tributary of the Brahmaputra. The study area covers 15.08 km² at an average elevation of 703 m. Bhairabkunda (Reserve Forest) RF also features a man-made forest managed by the Joint Forest Management Committee (JFMC) established through collaboration between local villagers and the forest department.

Research Design, Materials and Data Sources

The study followed a landscape-scale ecological design integrating remote sensing, GIS-based land cover classification, predictive modeling, and field validation. Multi-decadal satellite imagery was analyzed to detect historical and current land cover changes, followed by projection modeling for future scenarios (Rawat & Kumar 2015). Field surveys were incorporated to validate remote sensing outputs and assess species-habitat associations.

Open-source Landsat satellite images were obtained from the United States Geological Survey (USGS) Earth Explorer. Landsat 5 (1987, 1988, 1989, 1990, 1991), Landsat 7 (1999, 2007), Landsat 8 (2015), and Landsat 9 (2024) datasets were used, each with a spatial resolution of 30 × 30 m, for regional-scale land cover change analysis.

The imagery was processed in QGIS v3.34.13 using a supervised maximum likelihood classification (MLC) approach (Foody 2002; Lu & Weng 2007). Four land

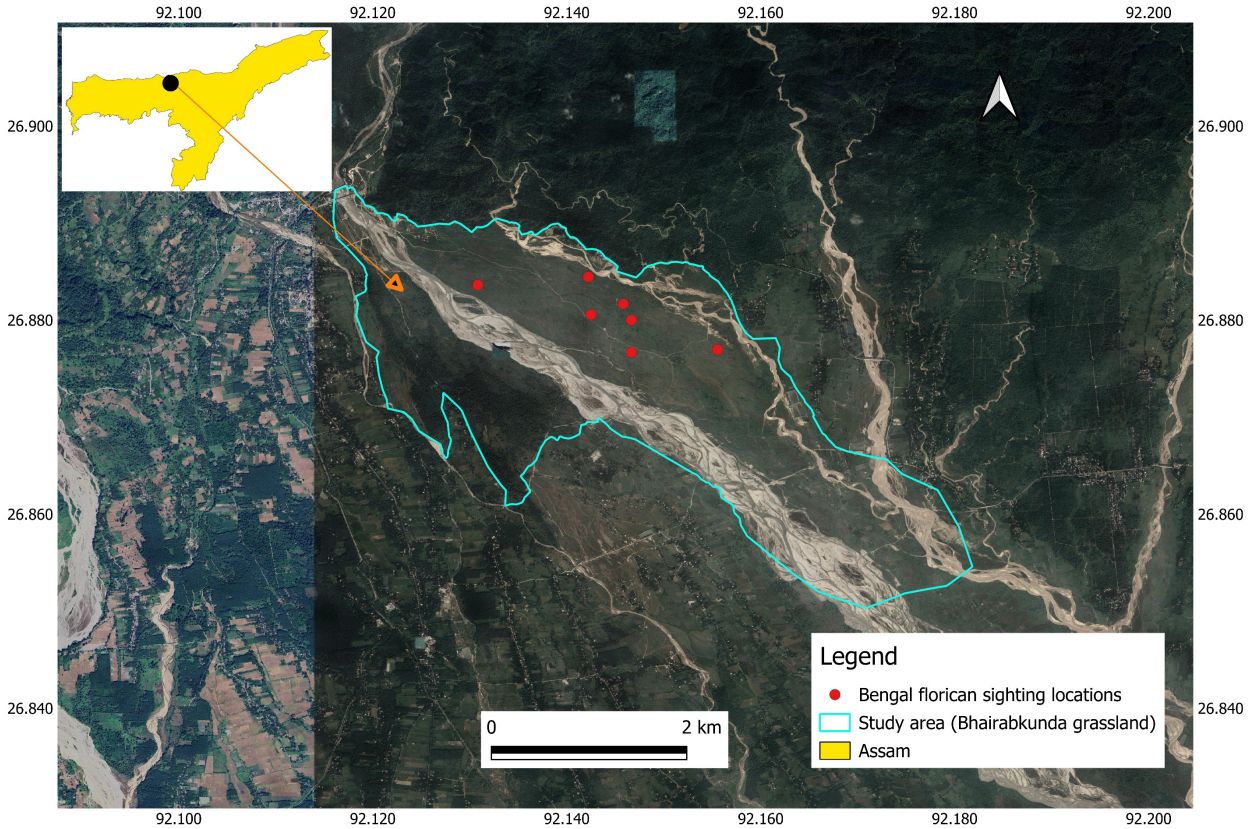

Image 1. Map of the Bhairabkunda grassland study area in Udalguri District, Assam, near the Assam–Bhutan border. The base image is from Google Earth satellite view (Google 2024).

cover classes were delineated: woodland, grassland, waterbody, and sandbar. Post-classification change detection was applied to assess transitions between classes across the study period.

Land cover predictions for 2034 were generated using the MOLUSCE plugin in QGIS, employing an artificial neural network (ANN) model trained on observed land-cover transitions and change trajectories derived from multi-temporal classified maps from 1987–2024 (Bugday & Bugday 2019; El-Tantawi et al. 2019; QGIS 2024). Transition probabilities between land-cover classes were estimated from historical change patterns, while digital elevation and road network data were used as explanatory variables.

From March to June 2024, systematic field surveys were conducted to document Bengal Florican sightings and associated vegetation characteristics within the study area. Surveys were carried out on 32 survey days (n = 32), at bi-weekly intervals, depending on field accessibility, during the early morning (0600–0930 h) and late evening (1500–1800 h) when florican activity is highest. Observations were made on foot along pre-defined transects, following established grassland survey routes. Each survey involved three trained observers, and all detections were recorded as visual sightings. Locations of birds were geo-referenced using handheld GPS units.

Vegetation characteristics were recorded at florican sighting locations and at representative points along transects using 5 × 5 m quadrat sampling (Narayan 1992; Thakur et al. 2024). Measurements of dominant grass species, grass height, vegetation structure, and the presence of woody or invasive elements were recorded, and these field data were subsequently compared with classified satellite imagery to validate grassland emergence and habitat suitability inferred from remote sensing analyses.

RESULTS

Land use land cover change

Land use and land cover analysis indicated temporal changes in landscape composition between 1987 and 2024 (Table 1; Images 2&3). In the late 1980s, frequent transitions among woodland, waterbody, and sandbar classes were observed, reflecting active fluvial processes. During this period, woodland cover declined, while waterbody and sandbar areas increased, followed by the appearance of grassland. Grassland expansion was evident in the early 1990s, with grassland becoming the dominant land-cover class by 1991. This phase was accompanied by a reduction in woodland and waterbody cover, indicating a shift from sandbar and woody habitats to grassland. By the late 1990s and mid-2000s, land-cover classes were more evenly distributed, suggesting relative stability. By 2015, woodland cover increased, consistent with successional processes and grassland extent decreased. By 2024, grassland again became the dominant land-cover class, followed by woodland, while waterbody and sandbar occupied smaller areas. Overall, the observed patterns indicate recurrent cycles of grassland formation and succession associated with fluvial processes and vegetation change in the Bhairabkunda landscape.

Table 1. Temporal changes in land-cover area (km²) in Bhairabkunda (L5: 1987, 1988, 1989, 1990, 1991; L7: 1999, 2007; L8: 2015; L9: 2024 and predicted LULC map of 2034).

Year ↓ / Habitat →	Grassland	Woodland	Waterbody	Sandbar
1987	0.56	10.04	4.3	0.18
1988	1.97	3.85	7.11	2.16
1989	1.93	2.35	5.05	5.76
1990	6.17	1.93	1.93	5.05
1991	9.64	0.83	1.6	3.01
1999	6.7	4.51	1.53	2.35
2007	5.58	3.3	2.22	3.99
2015	4.97	7.42	0.58	2.11
2024	6.49	6.29	0.47	1.83
2034	4.72	9.87	0.22	0.28

Based on the MOLUSCE model, land-cover projections for 2034 indicate further changes in Bhairabkunda region (Table 1). Woodland is projected to become the dominant land-cover class, reflecting continued expansion since 2015. Grassland extent is projected to decline relative to 2024, while sandbar and waterbody areas are expected to decrease further. Overall, the projections suggest continued land-cover transitions characterized by woodland expansion, contraction of grassland, and reduced waterbody and sandbar features. These predicted patterns reflect ongoing changes in vegetation distribution and fluvial processes influencing the landscape.

Bengal Florican sightings and vegetation composition

Ground surveys revealed the presence of *Houbaropsis bengalensis* across seven survey sites (Images 1&4), although detections were not made on every visit at each site. A total of five individual floricans were recorded

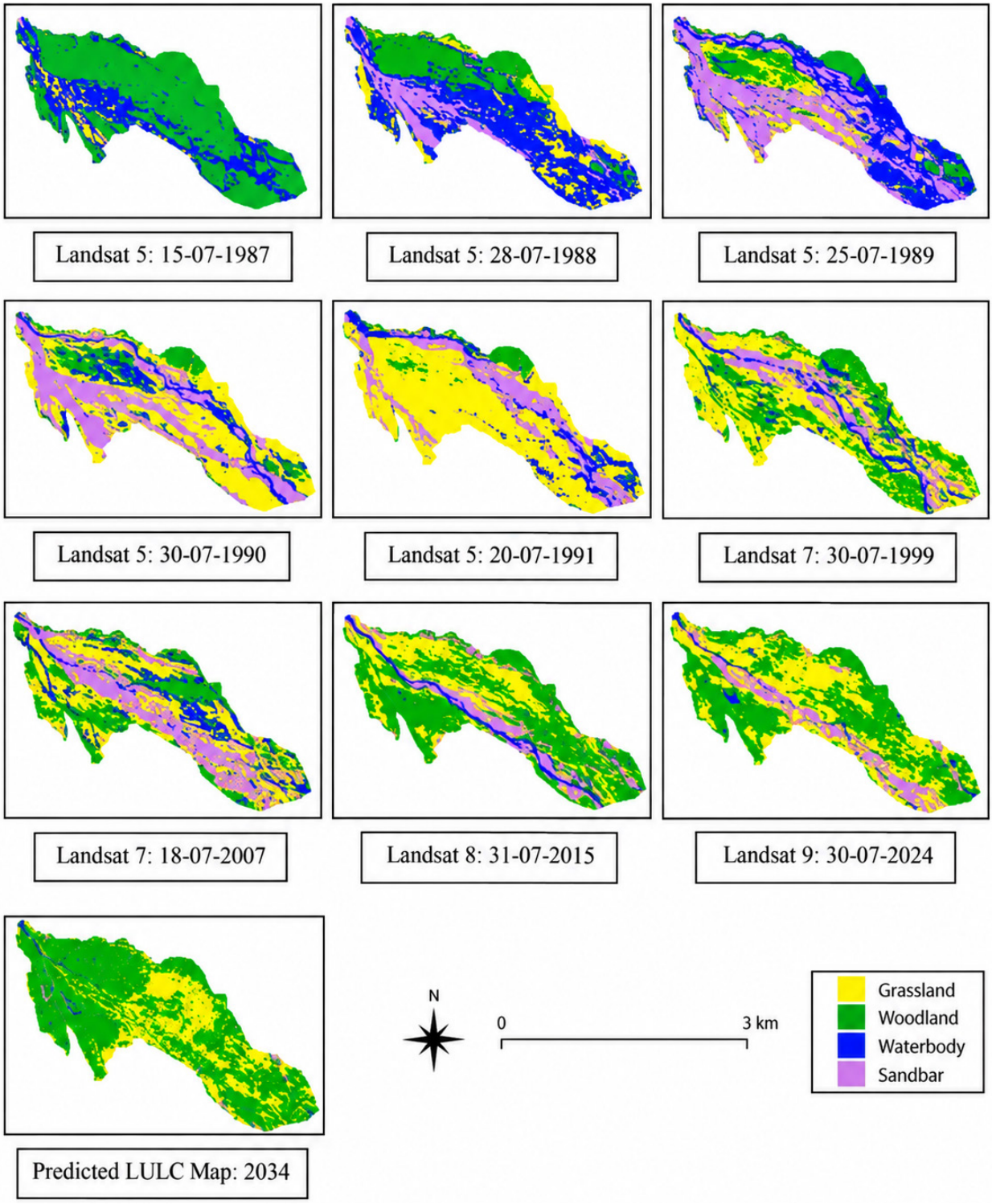

Image 2. Land cover classification map of the study area for nine time points, Landsat 5 (1987, 1988, 1989, 1990, 1991), Landsat 7 (1999, 2007), Landsat 8 (2015), Landsat 9 (2024), and predicted LULC Map (2034).

during the survey period, comprising four males detected in flight display and one female observed on the ground within grassland vegetation. These observations indicate that the newly formed grasslands are being used by floricans, while not implying uniform or continuous occupancy across all surveyed sites.

And most of the Bengal Florican habitats where they are recorded in the grassland have short grass *Imperata*

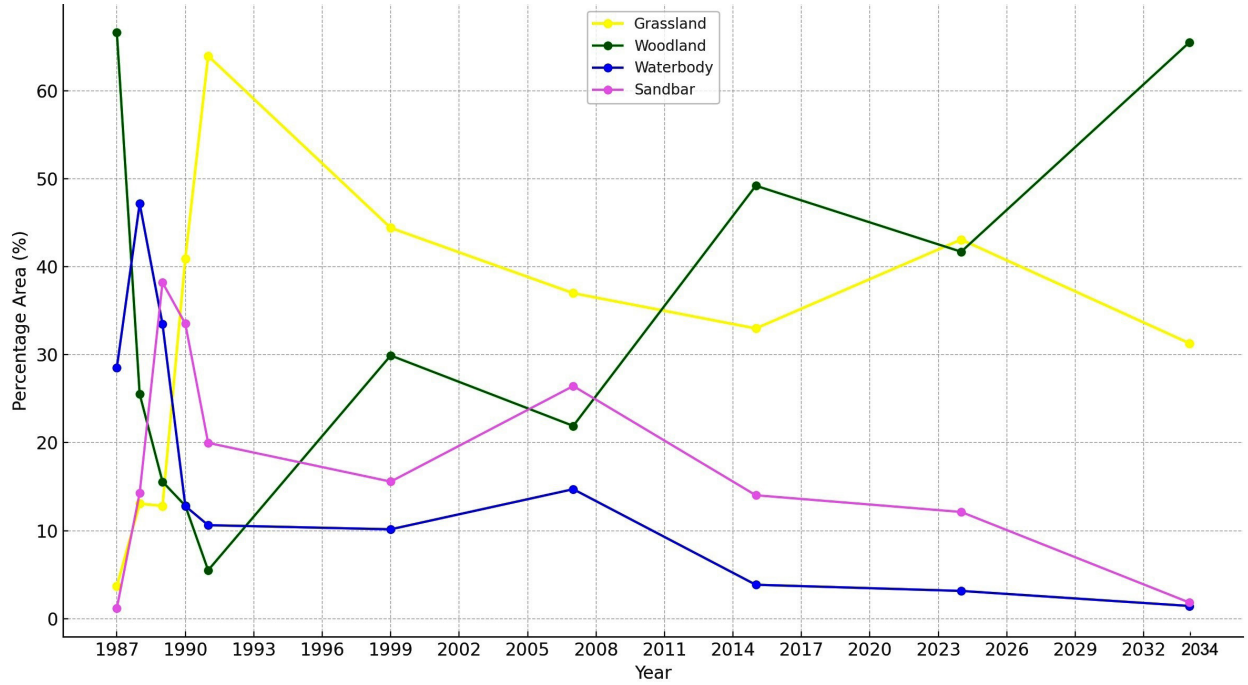

Image 3. Scatter plot showing the habitat transitions of the study area for nine-time points (1987, 1988, 1989, 1990, 1991, 1999, 2007, 2015, 2024).

Image 4. Male Bengal Florican in flight. © Jonmani Kalita.

cylindrica and moderately tall and dense grasses like *Saccharum spontaneum* followed by some other shrub species *Leea* spp. and *Grewia sapida.*

DISCUSSION

The results of our study highlight the dynamic nature of land cover changes in the Bhairabkunda region, emphasizing the emergence of new grassland patches and significant shifts in vegetation distribution over the years. A pronounced phase of grassland formation was observed by 1991, when grassland expanded to 9.64 km². This expansion followed extensive sandbar deposition in 1989 and widespread inundation during the major flood events of 1988–1989, indicating that flooding and subsequent sediment deposition played a key role in facilitating grassland development. These floods altered the course of the river from the north-west to the north-east, leading to significant sand deposition, which contributed to grassland formation. Similar observations were made by Biswas (2010), who reported that flooding and changes in the river course during the 1968 flood in Jaldapara National Park led to considerable alterations in the grassland distribution within the park. In line with this, research suggests that the frequency and duration of floods play critical roles in shaping the spatial distribution

of plant communities within floodplains (Bayley 1995; Miller et al. 1995). Any shift in the flooding regime is likely to modify the vegetation patterns. As flood frequency and duration decrease, moist grasslands may gradually transition to savanna, woodland, or forest (Walsh & Townsend 1995; Michener & Houhoulis 1997), while increased flooding could reverse this process, reinstating grassland areas. Between 2015 and 2024, woodlands expanded to 7.42 km², leading to a reduction in grassland areas to 6.29 km². Projections for 2034 indicate that woodland is expected to dominate, occupying 9.87 km² (65.48%), while grassland is projected to decline to 4.72 km² (31.29%). These trends are extrapolated from observed historical land-cover transitions, suggesting that vegetation succession and reduced flooding influence continue to shape the regional landscape.

The Bengal Florican, listed as 'Critically Endangered' by the IUCN Red List and protected under Schedule I of the Wild Life (Protection) Act, 1972 (as amended by the Wild Life (Protection) Amendment Act, 2022), is a flagship grassland-dependent species (Collar et al. 2017; Baral et al. 2020; BirdLife International 2024). This highlights the ecological importance of grassland habitats, where the emergence of specific conditions allows threatened species like the Bengal Florican to naturally return to their habitat. Narayan's 1989 survey indicated no extensive grassland patches in the study area (Narayan 1992). To investigate this further, land cover classification was performed, confirming the recent formation of suitable grassland habitats. These findings underscore the need for adaptive, site-specific management of floodplain grasslands that explicitly accounts for seasonal hydrological variability and successional change. In dynamic systems such as Bhairabkunda, grassland conservation should prioritize the maintenance of early successional stages through regulated disturbance regimes, including controlled burning, selective removal of woody encroachment, and the prevention of plantation activities within grassland patches. For the Bengal Florican, management should focus on retaining large, contiguous tracts of short and tall grassland dominated by *Imperata* and *Saccharum*, while minimizing habitat fragmentation and human disturbance during the breeding season (Rahmani et al. 2016; Jha et al. 2018). Long-term scientific monitoring and repeat land-cover assessments are essential to understand inter-annual variability, evaluate management effectiveness, and ensure the persistence of suitable florican habitat under changing flood and land-use regimes.

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