Integrated Socio-Ecological Dynamics, Biodiversity Conservation, and Sustainable Management in Shuklaphanta National Park, Nepal

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Abstract— **Shuklaphanta National Park (SPNP), located in Nepal's western Terai, represents one of South Asia's most ecologically significant protected landscapes, characterized by extensive grasslands, wetlands, and forest mosaics that support globally threatened species. However, accelerating anthropogenic pressures, climate variability, and infrastructure expansion increasingly challenge the park's ecological integrity and social sustainability. This interdisciplinary synthesis integrates multiple student-led empirical and conceptual studies conducted in and around SPNP to examine biodiversity conservation, habitat dynamics, invasive species proliferation, wildlife connectivity, water resource management, tourism development, community forestry, and human–wildlife conflict. Drawing on ecological surveys, socio-economic assessments, governance analyses, and policy reviews, the paper highlights how habitat degradation, invasive alien plant species, linear infrastructure, and climate-induced stressors interact to influence wildlife populations such as Swamp Francolin (Ortygornis gularis) and Swamp Deer (Rucervus duvaucelii). Simultaneously, the effectiveness of buffer zone institutions, compensation mechanisms, and community-based conservation approaches is evaluated in relation to livelihood security and local support for conservation. The findings underscore that conservation outcomes in SPNP are shaped not by isolated drivers but by tightly coupled socio-ecological systems. We argue that integrated, climate-sensitive, and participatory management—grounded in ecological science, community engagement, and adaptive governance—is essential for sustaining biodiversity and human well-being in SPNP. This synthesis provides a holistic evidence base to inform policy, park management, and future research across the Nepal protected area network.**

Keywords— Shuklaphanta National Park; socio-ecological systems; grassland ecology; invasive species; wildlife connectivity; buffer zone governance; human–wildlife conflict; sustainable tourism

I. INTRODUCTION

Protected areas in the Global South increasingly operate at the intersection of biodiversity conservation, livelihood security, and development pressures. In Nepal, lowland Terai protected areas are particularly vulnerable due to high human population density, infrastructure expansion, climate variability, and intensive resource dependence (DNPWC, 2021). Shuklaphanta National Park (SPNP), established to conserve one of the largest remaining grassland ecosystems in South Asia, exemplifies these challenges.

SPNP supports globally significant populations of swamp deer, tigers, elephants, and more than 460 bird species, including the globally vulnerable Swamp Francolin (*Ortygornis gularis*) (BirdLife International, 2024; DNPWC, 2025). Despite its ecological importance, the park faces mounting pressures from invasive alien plant species (IAPS), habitat fragmentation by linear infrastructure, declining water

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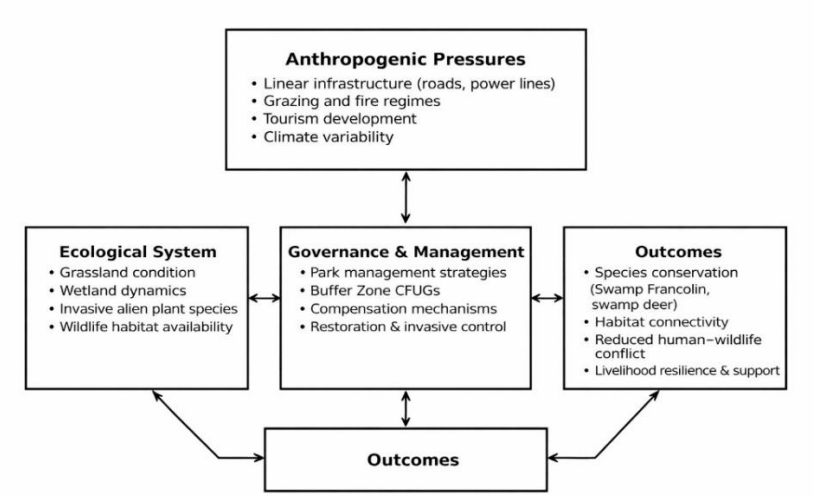
availability during dry seasons, human–wildlife conflict (HWC), and uneven tourism development (Baral & Inskipp, 2023; Magar et al., 2022).

Conventional conservation approaches that prioritize ecological protection without adequate social integration have often led to conflict, inequitable benefit-sharing, and limited long-term effectiveness (Agrawal & Redford, 2009). Nepal's buffer zone policy framework, particularly Buffer Zone Community Forest User Groups (BZCFUGs), represents an effort to reconcile conservation and livelihoods. However, empirical assessments of their effectiveness in SPNP remain limited.

This paper synthesizes multiple student research initiatives to present a holistic understanding of SPNP as a coupled socio-ecological system. By integrating ecological, infrastructural, climatic, and governance dimensions, the study aims to provide actionable insights for adaptive conservation planning.

FIGURE 1. CONCEPTUAL FRAMEWORK DIAGRAM: SOCIO-ECOLOGICAL DYNAMICS IN SHUKLAPHANTA NATIONAL PARK



The diagram illustrates how anthropogenic pressures influence ecological systems, with governance and management acting as the central mediating mechanisms. Effective management responses shape ecological conditions and lead to positive outcomes, including species conservation, improved habitat connectivity, reduced human–wildlife conflict, and enhanced livelihood resilience.

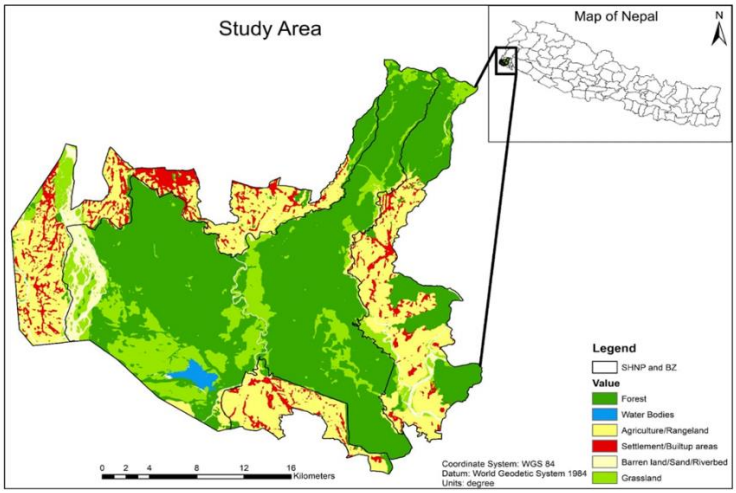
II. STUDY AREA: SHUKLAPHANTA NATIONAL PARK

Shuklaphanta National Park is located in Kanchanpur District of far-western Nepal, bordering India. The park encompasses extensive phantas (grasslands), wetlands, riverine forests, and tropical sal (*Shorea robusta*) forests. Seasonal monsoonal flooding and dry-season water scarcity strongly influence habitat structure and wildlife distribution (Dahal et al., 2009).

Location: Kanchanpur, Nepal (part of Terai Arc Landscape - TAL). Coordinates: 28°50′24.72″N, 80°13′44.40″E. Status History: Royal Hunting Reserve —-Wildlife Reserve (1976) — National Park (2017). Size & Habitat: 305 km2 core area; includes 54km2 grassland, Sal forests, and oxbow wetlands. Key Wildlife: Home to Swamp Deer (Known for one of the world's largest herds), Bengal Tiger, Asian Elephant, and Bengal Florican.

The park is embedded within a densely populated buffer zone where local communities depend on forest resources, agriculture, and emerging tourism for livelihoods. This spatial interdependence makes SPNP an ideal case for examining integrated conservation and development dynamics.

FIGURE 2: LOCATION OF SUKLAPHANTA NATIONAL PARK IN WESTERN NEPAL (MAP SOURCE: SHUKLAPHANTA NATIONAL PARK OFFICE 2025)



III. METHODS: AN INTEGRATIVE SYNTHESIS APPROACH

This paper adopts a qualitative–quantitative synthesis approach, integrating findings from multiple student-led studies conducted between 2024 and 2025. A summary of the methods used across studies and data sources is presented in Table 1.

TABLE 1. SUMMARY OF RESEARCH COMPONENTS, METHODS, AND OBJECTIVES

Research component	Data sources	Methods used	Primary objective
Grassland ecology	Field plots	Vegetation surveys	Assess habitat condition
Invasive species	Field plots,	Cover estimation through analysis of satellite images and GIS	Identify degradation drivers
Wildlife ecology	Transects	Direct observations	Identify habitat preferences
Socio-economic	Households	Surveys, FGDs	Assess livelihoods & perceptions
Governance	Documents	Policy review	Evaluate management effectiveness

Quickly communicates interdisciplinary scope

1) Grassland vegetation surveys and invasive species assessments

Grassland vegetation surveys were conducted to assess habitat composition, structure, and the extent of invasive alien plant species (IAPS) within Shuklaphanta National Park. Stratified sampling was applied across major grassland types, including tall alluvial grasslands, short grasslands, and wetland-associated grasslands. Within each stratum, sample plots were systematically established to record species composition, vegetation height, ground cover, and dominance patterns. Quadrat-based methods were used to quantify relative abundance, frequency, and cover of both native and invasive plant species.

Particular attention was given to identifying and mapping the presence of invasive alien species, including *Mikania micrantha*, *Lantana camara*, and woody encroachers, which are known to alter grassland structure and suppress native flora. Invasive species abundance was estimated using percentage cover and density measures, allowing comparison across habitat types and disturbance gradients. Observations of disturbance indicators, including grazing pressure, fire occurrence, and proximity to infrastructure or settlements, were also recorded to contextualize vegetation patterns.

Data from vegetation surveys were analyzed to examine relationships between grassland condition and invasive species prevalence. This approach enabled the identification of high-risk areas requiring targeted management interventions. The assessment provided a baseline for understanding how invasive species contribute to habitat degradation and how grassland structure influences the availability of suitable habitat for grassland-dependent wildlife species.

2) Wildlife habitat preference and population observations

Wildlife habitat preference and population observations were conducted to examine species distribution in relation to habitat characteristics within Shuklaphanta National Park. Field surveys focused on key indicator species, including grassland-dependent birds and large herbivores, whose presence reflects habitat quality and ecosystem health. Direct observation methods, including line transect surveys and point counts, were used across representative habitat types, including grasslands, wetlands, forest edges, and riverine areas.

Observations were conducted during the early morning and late afternoon, when wildlife activity is highest. For each sighting, species identity, group size, behavior, habitat type, and proximity to water sources were recorded. Habitat attributes, including vegetation height, canopy cover, and evidence of disturbance, were noted to assess habitat selection patterns. Opportunistic signs such as tracks, pellets, and vocalizations were also recorded to supplement direct sightings, particularly for elusive species.

Population trends were inferred through repeated observations and comparisons with existing park records. However, the study did not aim to generate precise population estimates; relative abundance indices were used to assess spatial patterns and habitat associations. This approach allowed identification of critical habitats and seasonal refugia, particularly during dry periods when water availability influences wildlife movement.

The integration of habitat variables with wildlife observations provided insights into how habitat condition, invasive species, and water availability influence species distribution. These findings support adaptive habitat management to sustain viable wildlife populations.

3) Household surveys, key informant interviews (KIIs), and focus group discussions (FGDs)

Socio-economic data were collected through household surveys, key informant interviews (KIIs), and focus group discussions (FGDs) in buffer zone communities surrounding Shuklaphanta National Park. Household surveys were administered using semi-structured questionnaires to capture information on livelihood strategies, resource dependence, experiences of human–wildlife conflict, perceptions of conservation interventions, and awareness of compensation mechanisms. Households were selected using purposive and stratified sampling to ensure representation across socio-economic groups and geographic locations.

Key informant interviews were conducted with park officials, buffer zone committee members, community leaders, tourism operators, and representatives of non-governmental organizations. KIIs provided in-depth insights into governance structures, policy implementation challenges, conflict resolution mechanisms, and institutional perspectives on conservation outcomes.

Focus group discussions were organized separately for men, women, and youth to facilitate inclusive participation and capture diverse viewpoints. FGDs explored community perceptions of park management, benefits and costs of conservation, and locally proposed solutions to conflict and resource constraints. Discussions were facilitated using guiding questions and participatory tools to encourage open dialogue.

Qualitative data from KIIs and FGDs were thematically analyzed to identify recurring patterns, areas of agreement, and sources of tension between conservation objectives and livelihood needs. Triangulation across data sources enhanced the reliability of findings and provided a nuanced understanding of socio-ecological interactions at the community level.

4) Review of compensation records and park management documents

A systematic review of compensation records and park

management documents was undertaken to assess the effectiveness of institutional mechanisms addressing human–wildlife conflict in Shuklaphanta National Park. Compensation records were obtained from park offices and buffer zone management committees, covering reported cases of crop damage, livestock depredation, human injury, and property loss over recent years. Data extracted included the type of incident, the species involved, the amount claimed, the compensation awarded, and the time required for claim processing.

In addition, park management plans, annual reports, monitoring documents, and policy guidelines were reviewed to understand formal procedures, decision-making frameworks, and conservation priorities. Particular attention was given to the alignment between policy objectives and on-the-ground implementation, including the roles and responsibilities of park authorities and buffer zone institutions.

Quantitative analysis of compensation records focused on identifying trends in conflict frequency, spatial distribution of incidents, and discrepancies between claims and payouts. Qualitative document analysis examined procedural clarity, transparency, and consistency in the delivery of compensation. These findings were cross-referenced with community perceptions obtained through household surveys and interviews.

This combined analysis provided insight into the strengths and limitations of existing compensation mechanisms and highlighted institutional bottlenecks that affect community trust and compliance. The review provided recommendations to improve the timeliness, equity, and effectiveness of conflict mitigation policies.

5) Infrastructure mapping and wildlife connectivity assessments

Infrastructure mapping and wildlife connectivity assessments were conducted to evaluate the influence of linear infrastructure on habitat fragmentation and wildlife movement in and around Shuklaphanta National Park. Spatial data on roads, transmission lines, settlements, and other infrastructure were compiled from park records, satellite imagery, and field verification. These data were mapped using geographic information system (GIS) tools to visualize infrastructure distribution relative to key habitats and wildlife corridors.

Field surveys were conducted along selected infrastructure segments to record evidence of wildlife movement, including tracks, scats, and crossing points, as well as signs of disturbance and mortality. Roadkill observations and reports from park staff and local communities were documented to identify high-risk locations.

Connectivity assessments focused on identifying potential barriers to movement between grasslands, wetlands, and forest patches, particularly for wide-ranging species. Landscape features such as rivers, vegetation cover, and human activity intensity were considered in evaluating permeability. Where available, findings were compared with existing corridor maps and regional connectivity studies.

The integration of spatial analysis and field observations enabled the identification of critical connectivity zones and infrastructure-related threats. These results informed recommendations for mitigation measures, including wildlife crossings, speed control, and strategic infrastructure planning, to reduce fragmentation and enhance ecological connectivity within the broader landscape.

6) Data synthesis and thematic analysis

Data from ecological surveys, socio-economic assessments, interviews, and document reviews were synthesized using a thematic analysis approach to identify convergent patterns, trade-offs, and policy-relevant implications across the study components. Quantitative data from vegetation surveys, wildlife observations, household questionnaires, and compensation records were first summarized using descriptive statistics to identify spatial and temporal trends. These summaries provided an empirical foundation for cross-comparison among ecological and social variables.

Qualitative data from key informant interviews, focus group discussions, and document reviews were transcribed and coded using an inductive–deductive framework. Initial codes were derived from the study objectives, including habitat condition, invasive species, human–wildlife conflict, governance effectiveness, and infrastructure impacts. Additional codes emerged during iterative review of the data, allowing unanticipated themes to be captured. Coded data were then grouped into higher-order thematic categories to examine interactions among ecological processes, institutional mechanisms, and community responses.

Triangulation across data sources enhanced analytical robustness by enabling verification of findings and reducing bias associated with single-method approaches. Thematic synthesis focused on identifying consistent patterns across datasets, key trade-offs between conservation and livelihoods, and contextual factors shaping management outcomes. This integrative approach facilitated the translation of empirical findings into policy-relevant insights, informing recommendations for adaptive management, participatory governance, and climate-resilient conservation planning in Shuklaphanta National Park.

TABLE 2. KEY CONSERVATION CHALLENGES AND MANAGEMENT IMPLICATIONS

Conservation issue	Observed impacts	Management implications
Invasive species	Habitat degradation	Targeted removal & restoration
Infrastructure	Fragmentation	Wildlife-friendly design
Water scarcity	Altered movement	Strategic water provisioning
Human–wildlife conflict	Livelihood losses	Improved compensation systems
Limited tourism	Lost revenue	Community-based ecotourism

Directly supports the Discussion and Recommendations.

TABLE 3. LINKAGES BETWEEN THREATS, GOVERNANCE RESPONSES, AND OUTCOMES

Threat	Governance response	Observed outcome
Crop damage	Compensation schemes	Partial conflict mitigation
Habitat loss	Grassland management	Variable success
Infrastructure	Limited mitigation	Continued fragmentation

Highlights policy gaps and opportunities

IV. Results

1) Habitat Preference and Species Conservation

Swamp Francolin populations in SPNP were closely associated with tall alluvial grasslands dominated by *Saccharum* and *Phragmites* species, particularly near wetland–grassland ecotones. Habitat degradation due to invasive species, uncontrolled fire, and grazing has reduced suitable nesting and foraging areas (Inskipp & Inskipp, 1991; Baral & Inskipp, 2023).

Observations of Swamp Francolin (*Ortygornis gularis*) in Shuklaphanta National Park revealed a strong association with tall alluvial grasslands dominated by *Saccharum* and *Phragmites* species, particularly in areas adjacent to wetlands and seasonally inundated grassland–wetland ecotones. These habitats provide dense vegetation cover essential for nesting, predator avoidance, and foraging, as well as access to moisture-rich substrates that support invertebrate prey. Francolin sightings and vocalizations were consistently recorded in grasslands with minimal woody encroachment and relatively intact hydrological regimes.

However, habitat quality in several surveyed areas showed signs of degradation. The spread of invasive alien plant species, notably *Mikania micrantha* and *Lantana camara*, has altered vegetation structure by suppressing native grasses and reducing habitat heterogeneity. In invaded sites, grassland patches were characterized by reduced vertical complexity and limited ground cover suitable for nesting. These changes are likely to constrain breeding success and reduce Swamp Francolin habitat occupancy.

Uncontrolled fire regimes further exacerbated habitat degradation. While fire plays a natural role in maintaining grassland systems, poorly timed or frequent burning was observed to reduce grass height and cover during critical breeding periods. Similarly, intensive livestock grazing in buffer-zone-adjacent grasslands resulted in nest trampling, reduced biomass, and increased disturbance. These pressures were most pronounced near park boundaries and areas with higher human activity.

The combined effects of invasive species proliferation, inappropriate fire management, and grazing pressure have contributed to the fragmentation and decline of suitable habitat for Swamp Francolin within SPNP. These findings are consistent with earlier studies highlighting the species' sensitivity to habitat alteration and disturbance (Inskipp & Inskipp, 1991; Baral & Inskipp, 2023). Effective conservation of Swamp Francolin in SPNP will therefore require targeted grassland management, invasive species control, and regulation of fire and grazing practices to maintain structurally complex and seasonally stable grassland habitats.

2) Invasive Alien Plant Species and Grassland Degradation

Invasive alien plant species (IAPS) were found to be a major driver of grassland degradation in Shuklaphanta National Park, with significant implications for habitat quality and biodiversity conservation. Species such as *Mikania micrantha* and woody encroachers were widely distributed across grassland patches, particularly in areas experiencing frequent disturbance. These invasive species altered grassland composition by outcompeting native grasses and herbs, reducing species richness and modifying vegetation structure.

Field observations indicated that invaded grasslands had lower native plant cover and reduced vertical heterogeneity than relatively intact sites. Dense mats of *Mikania micrantha* suppressed the regeneration of native grasses such as *Saccharum* spp., while woody encroachers increased canopy cover in areas traditionally characterized by open grassland. Such structural changes diminished the suitability of these habitats for grassland-dependent fauna, including ground-nesting birds and large herbivores that rely on open habitats for foraging and movement.

Disturbed grasslands located near settlements, roads, and other infrastructure corridors were particularly susceptible to invasion. These areas experienced higher levels of grazing pressure, soil disturbance, and edge effects, creating favorable conditions for the establishment and spread of invasive species. Linear infrastructure also facilitated the dispersal of invasive propagules, further accelerating grassland degradation.

The proliferation of IAPS has cascading ecological effects, including reduced forage availability, altered fire regimes, and increased management complexity. Invasive-dominated grasslands were observed to respond differently to fire, often exhibiting rapid post-burn regrowth of invasive species rather than native grasses. These dynamics reinforce invasive dominance and hinder grassland recovery.

The findings align with broader regional and global evidence highlighting invasive species as a leading threat to grassland ecosystems (Pyšek et al., 2020; Dhakal et al., 2024). Effective conservation in Shuklaphanta National Park will therefore require integrated invasive species management strategies, including early detection, targeted removal, restoration of native vegetation, and reduction of anthropogenic disturbances that facilitate invasion.

3) Linear Infrastructure and Wildlife Connectivity

Linear infrastructure, including roads, highways, and transmission lines, poses significant challenges to wildlife connectivity by fragmenting habitats and disrupting the natural movement of species. In landscapes such as the Shuklaphanta National Park (SPNP), which is part of a broader ecological network, these infrastructures intersect critical wildlife corridors, increasing the risk of mortality and population isolation. Roads and highways not only create physical barriers but also alter animal behavior, leading to avoidance of key habitats, disruption of seasonal migrations, and reduced access to food, water, and breeding sites. Transmission lines further exacerbate these impacts by creating additional linear barriers and increasing the risk of electrocution for birds and climbing mammals (Laurance et al., 2014; DNPWC, 2022).

Evidence from SPNP and the surrounding areas highlights the direct consequences of such fragmentation. Roadkill incidents involving large mammals, including snow leopards, red pandas, and Himalayan tahr, have been reported, indicating that infrastructure development directly contributes to mortality and poses a threat to population viability. Fragmentation also reduces genetic exchange between subpopulations, thereby

increasing vulnerability to disease and environmental change, ultimately threatening long-term ecosystem resilience.

Despite recognition of these impacts, mitigation measures in SPNP remain limited. Wildlife crossings, underpasses, and overpasses, which have been effective in maintaining connectivity in other mountainous landscapes, are scarce. Vegetation buffers and fencing designed to guide animals toward safe crossing points are rarely implemented, reducing the effectiveness of existing conservation measures. Strategic planning of new infrastructure, combined with retrofitting existing roads with wildlife-friendly designs, is essential to maintain functional connectivity. Collaborative efforts among government agencies, local communities, and conservation organizations can ensure that development is balanced with ecological integrity, thereby safeguarding biodiversity while meeting human infrastructure needs.

Addressing the challenges of linear infrastructure is therefore critical not only for reducing wildlife mortality but also for preserving the ecological coherence of SPNP within its larger landscape context, ensuring that species can thrive despite increasing anthropogenic pressures.

4) Wetlands, Waterholes, and Wildlife Distribution

Wetlands and waterholes are fundamental determinants of wildlife distribution, especially in landscapes subject to seasonal water scarcity. In ecosystems such as Shuklaphanta National Park and its surrounding regions, natural wetlands serve as key resources for hydration, foraging, and shelter, supporting both resident and migratory species. However, during dry seasons, water availability becomes a limiting factor, influencing patterns of habitat use and species interactions. In this context, artificial or managed waterholes have emerged as critical tools for sustaining wildlife populations.

Strategically placed artificial water sources attract large herbivores such as Himalayan tahr, musk deer, and blue sheep, which in turn influence predator distribution, including snow leopards and red foxes. Observations indicate that herbivores preferentially congregate around these waterholes, thereby enhancing their visibility and accessibility to predators and maintaining natural trophic dynamics (Poudel, 2007; Shrivas et al., 2024). By mitigating seasonal water scarcity, artificial water provisioning not only sustains population health but also reduces the likelihood of wildlife encroaching on human settlements in search of water, thereby lowering the potential for human-wildlife conflict.

The placement and design of waterholes are crucial. Those situated along traditional migration routes or within critical foraging zones maximize ecological benefits, promoting habitat connectivity and supporting diverse species assemblages. Conversely, poorly located waterholes may create ecological traps or exacerbate predation pressures in confined areas. Long-term monitoring of wildlife visitation patterns to these water sources can guide adaptive management, ensuring that water provision aligns with natural behavioral rhythms and ecosystem requirements.

Managed waterholes, therefore, serve as a climate-adaptive conservation strategy. They buffer the effects of seasonal droughts and climate change-induced hydrological variability, sustaining both herbivore and predator populations. Integrating artificial waterholes with broader habitat management and conservation planning can enhance the resilience of wildlife communities, ensuring the maintenance of functional ecosystems even under increasingly unpredictable environmental conditions.

5) Buffer Zone Governance and Livelihoods

Buffer zone governance plays a pivotal role in reconciling conservation objectives with local communities' socioeconomic needs. In Shuklaphanta National Park (SPNP), Buffer Zone Community Forest User Groups (BZCFUGs) have been instrumental in promoting sustainable forest management while providing avenues for income generation through timber, non-timber forest products, and eco-tourism initiatives. By engaging local communities directly in decision-making and resource management, BZCFUGs help foster a sense of ownership and stewardship over forested landscapes, enhancing compliance with conservation regulations and reducing illegal extraction.

However, challenges remain in ensuring equitable benefit distribution. Disparities in access to resources, limited participation by marginalized groups, and a lack of transparency in financial management can erode community trust and undermine the effectiveness of conservation efforts. Coordination among multiple stakeholders—including park authorities, local governments, and community groups—often faces bureaucratic hurdles, leading to fragmented management and inefficiencies in implementing joint initiatives. Additionally, limited awareness and capacity-building programs constrain some communities' ability to participate in governance fully or to derive optimal livelihood benefits.

Evidence suggests that governance structures characterized by inclusivity, transparency, and active participation consistently correlate with stronger community support for conservation. When women, indigenous populations, and other marginalized groups are involved in decision-making, communities are more likely to adopt sustainable practices and to monitor and protect forest resources. Conversely, top-down approaches or exclusionary governance tend to generate local resentment, undermining both ecological and social outcomes.

Integrating livelihood considerations with conservation planning is therefore essential. Strengthening institutional frameworks, enhancing capacity-building, and establishing equitable benefit-sharing mechanisms can improve both the ecological integrity of buffer zones and the socioeconomic well-being of local populations. Inclusive governance not only reinforces the long-term sustainability of buffer zone forests but also creates resilient communities capable of supporting broader conservation goals, bridging the gap between environmental stewardship and human development.

6) Human–Wildlife Conflict and Compensation

Human–wildlife conflict (HWC) in Shuklaphanta National Park (SPNP) is influenced by multiple interacting factors, including climate variability, altered wildlife movement, and resource scarcity. Seasonal and climate-induced changes in water and forage availability force wildlife to move into human-dominated landscapes, increasing encounters with crops, livestock, and property. Large herbivores and predators alike

may enter agricultural lands or settlements, causing direct economic losses and heightening risks for local communities. Climate variability—such as prolonged dry periods or irregular rainfall—intensifies these dynamics by concentrating wildlife around limited resources, thereby amplifying the frequency and severity of conflicts.

Compensation schemes are a primary mitigation tool, designed to reimburse communities for crop damage, livestock depredation, or other wildlife-induced losses. These programs are crucial for maintaining tolerance toward wildlife and supporting coexistence. However, in SPNP, the effectiveness of compensation mechanisms has been limited. Delays in disbursement, complex bureaucratic procedures, and inadequate coverage relative to actual losses undermine trust in the system and reduce community participation in conservation initiatives. In some cases, repeated conflicts without timely or fair compensation can foster resentment and retaliatory behavior toward wildlife.

To address these challenges, a combination of adaptive strategies is necessary. Strengthening the efficiency and transparency of compensation schemes ensures timely support for affected households. Proactive measures, such as predator-proof livestock enclosures, crop-protection fencing, early-warning systems, and community-based monitoring, can reduce direct losses and prevent conflicts before they escalate. Integrating local knowledge with formal governance structures fosters equitable solutions and builds resilience to climate-induced pressures.

Ultimately, effective HWC management in SPNP requires balancing ecological integrity with human well-being. By improving compensation frameworks and implementing preventive interventions, conservation authorities can reduce negative encounters, promote coexistence, and sustain both biodiversity and livelihoods in climate-sensitive landscapes (Bhandari, 2024; Poudel, 2007; Shrivas et al., 2024).

7) Tourism Potential and Constraints

Shuklaphanta National Park (SPNP) possesses significant tourism potential due to its high biodiversity, unique ecosystems, and scenic landscapes. The park hosts diverse flora and fauna, including several endangered and charismatic species, which could attract ecotourists, wildlife enthusiasts, and researchers alike. Nature-based tourism, if strategically developed, can generate substantial revenue for conservation, strengthen local livelihoods, and foster awareness of environmental protection. Well-managed ecotourism can create employment opportunities, stimulate local economies, and incentivize communities to participate in forest and wildlife conservation initiatives.

Despite these advantages, tourism in SPNP remains underdeveloped. Weak infrastructure, including limited accessibility, inadequate accommodation facilities, and insufficient visitor amenities, constrains the park's ability to attract and retain tourists. Additionally, low levels of promotion and marketing have led to limited visibility at the national and international levels, thereby reducing potential visitor numbers. Local community participation is also minimal, partly due to insufficient capacity-building, lack of awareness of tourism opportunities, and limited mechanisms to ensure equitable benefit-sharing. Consequently, the park's rich biodiversity remains underutilized as a sustainable development and conservation tool.

Sustainable ecotourism presents a viable pathway to address these constraints while supporting both ecological and socioeconomic goals. By implementing carefully planned tourism strategies that prioritize low-impact activities, community engagement, and environmental education, SPNP can enhance conservation financing without compromising ecological integrity. Capacity-building programs for local communities, inclusive governance of tourism enterprises, and strategic promotion at national and international levels can further strengthen participation and benefits. Moreover, monitoring and adaptive management can ensure that tourism growth remains compatible with biodiversity conservation and the preservation of cultural values.

While SPNP faces infrastructural and institutional challenges that limit its tourism potential, adopting a sustainable ecotourism framework can simultaneously enhance conservation outcomes, generate community income, and raise awareness about the park's ecological importance (WWF Nepal, 2017; Bhandari, 2024). Such approaches can transform the park into a model of conservation-compatible economic development.

V. Discussion

The synthesis reveals that conservation outcomes in Shuklaphanta National Park (ShNP), Nepal, are profoundly shaped by interacting ecological and social drivers rather than isolated threats. This understanding is critical for developing effective and sustainable conservation strategies within the park. The research indicates that several key interactions are at play, necessitating an integrated socio-ecological systems perspective.

Firstly, habitat loss, a pervasive ecological challenge in many protected areas, is not merely a standalone issue in ShNP. Instead, it is significantly exacerbated by the proliferation of invasive species. These non-native plants, such as Mikania micrantha, can rapidly colonize open areas, outcompeting native grasses and other vegetation crucial for herbivores like deer and swamp deer, which are vital prey for apex predators like tigers. Invasive species alter natural habitat structure, reduce forage availability, and can even affect water flow, thereby intensifying the negative consequences of habitat degradation and complicating restoration efforts. This interaction highlights that addressing habitat loss effectively requires concurrent and aggressive management of invasive species.

Secondly, infrastructure development, while often necessary for regional development and park management, frequently exacerbates habitat fragmentation within ShNP. Roads, canals, and other constructions can act as barriers, dissecting critical wildlife corridors and isolating populations of species such as tigers, elephants, and rhinos. This fragmentation can lead to

reduced gene flow, increased inbreeding, and heightened vulnerability to local extinctions. Furthermore, infrastructure development can increase human encroachment into sensitive areas, further degrading and disturbing habitats. The research suggests that simply building infrastructure is not the problem; rather, the lack of wildlife-friendly design and strategic placement exacerbates fragmentation, underscoring the need for careful planning and mitigation measures.

Thirdly, climate change emerges as a significant overarching driver, intensifying existing pressures, particularly water scarcity and subsequent human-wildlife conflict. ShNP, located in the Terai lowlands, is susceptible to altered precipitation patterns, including more extreme droughts and floods. Reduced water availability during dry seasons can force wildlife, especially large mammals like elephants and rhinos, to venture outside park boundaries in search of water and forage, leading to increased encounters with human settlements. This can result in crop damage, livestock depredation, and even loss of human life, fueling retaliatory actions against wildlife. The research indicates that climate change does not just impact ecological processes; it directly translates into social tensions and challenges for local communities, making climate-sensitive water management a critical component of conflict mitigation.

Finally, the quality and effectiveness of governance are identified as paramount in determining whether conservation gains in ShNP are socially sustainable. Even well-intentioned conservation initiatives can falter if they lack transparent decision-making, equitable benefit-sharing, and meaningful community participation. Poor governance can lead to local resentment, illicit activities such as poaching and illegal logging, and a general lack of support for park regulations. Conversely, robust and inclusive governance, which empowers local communities, recognizes their traditional knowledge, and ensures that they benefit from conservation, is essential for fostering a sense of ownership and long-term commitment to conservation goals. This socio-political dimension is crucial for ensuring that conservation efforts are not only ecologically sound but also socially just and enduring.

In light of these interconnected challenges, the research strongly advocates an integrated socio-ecological systems perspective as essential for conservation in ShNP. This approach demands that conservation interventions be pursued not in isolation but simultaneously and adaptively. Specifically, the findings call for adaptive grassland management to maintain optimal habitat for key species, recognizing the dynamic nature of ecosystems. Invasive species control is highlighted as a continuous, vital effort to prevent further habitat degradation. Wildlife-friendly infrastructure design is crucial to minimizing fragmentation and maintaining connectivity. Climate-sensitive water management strategies are necessary to mitigate the impacts of water scarcity and reduce human-wildlife conflict. Most importantly, inclusive governance is underscored as the foundational element that can bind these diverse efforts together, ensuring that conservation in ShNP is not only ecologically effective but also socially equitable and sustainable in the long term.

VI. Policy and Management Implications

1) Integrated Grassland and Invasive Species Management Plans

Grasslands in Suklaphanta National Park (ShNP) are critical habitats that support diverse species, including swamp deer, Blue Bull, and numerous avian species. Effective management requires a dual focus: promoting native grassland health and controlling invasive species. Invasive plant species, such as *Chromolaena odorata* and *Eichhornia crassipes*, in wetland zones can outcompete native flora, reducing forage availability and altering ecological dynamics. Integrated management plans should involve detailed habitat mapping, regular monitoring of invasive species spread, and the adoption of both mechanical and ecological control methods. Prescribed burning, rotational grazing, and selective removal of invasive species are proven strategies that maintain grassland productivity while minimizing ecological disruption. Collaboration with local communities, particularly Buffer Zone Community Forest User Groups (BZCFUGs), is vital to implement rotational grazing schedules and community-led monitoring programs. Adaptive management frameworks that integrate scientific research with traditional ecological knowledge can enhance resilience against climate variability and anthropogenic pressures. Policy frameworks must also encourage long-term funding for restoration projects and establish clear legal mandates for invasive species control, ensuring that interventions are systematic rather than ad hoc. Additionally, capacity-building initiatives should train park staff and local stakeholders in species identification, habitat restoration techniques, and data collection, which enhances the sustainability of management efforts. By aligning invasive species management with grassland restoration, ShNP can preserve habitat heterogeneity, support species diversity, and strengthen ecological connectivity across the Terai grasslands, thereby sustaining biodiversity and the livelihoods of communities that depend on these natural resources.

2) Wildlife-Sensitive Infrastructure Planning and Monitoring

Infrastructure development, including roads, visitor facilities, and park boundaries, can significantly disrupt wildlife behavior and ecosystem integrity. In Shuklaphanta National Park, poorly planned infrastructure may fragment habitats, increase human-wildlife conflicts, and facilitate the spread of invasive species. Wildlife-sensitive planning emphasizes minimizing ecological footprints while maintaining functional accessibility. Strategic measures include conducting Environmental Impact Assessments (EIAs) before construction, siting roads and pathways away from high-density wildlife corridors, and using wildlife underpasses or overpasses at road intersections where animal movement routes cross roadways. Continuous monitoring through camera traps, GPS telemetry, and community reporting ensures that infrastructure impacts are detected early, enabling adaptive management. Traffic regulation, seasonal road closures, and zoning for low-disturbance areas further reduce anthropogenic pressures. Integrating local communities into monitoring efforts strengthens awareness and accountability while fostering a

sense of ownership over conservation outcomes. Policy guidelines should mandate wildlife-friendly construction materials and designs, emphasizing low-noise and low-light alternatives to minimize disturbance. Coordination with tourism planning is essential to balance visitor access with species protection, particularly during sensitive periods such as breeding or migration. Capacity-building programs for park officials and contractors are necessary to ensure adherence to wildlife-sensitive practices. By systematically embedding ecological considerations into infrastructure planning, Shuklaphanta can maintain habitat connectivity, reduce mortality risks for key species, and harmonize human development with long-term conservation goals (Bhandari, 2022, 2023, 2024, 2025).

3) Expansion and Strategic Management of Artificial Waterholes

Water availability is a critical limiting factor in the Terai grasslands of Shuklaphanta, particularly during the dry season when natural wetlands shrink. Artificial waterholes provide essential sources of water for wildlife, especially ungulates such as swamp deer, hog deer, and nilgai, and indirectly benefit predators such as tigers and leopards. However, the design and placement of these waterholes must be strategically planned to avoid ecological imbalance, overgrazing, and potential human-wildlife conflicts. Expansion of waterholes should be informed by habitat use studies, seasonal migration patterns, and vegetation monitoring to prevent local degradation. Management includes maintaining water quality, regulating access to prevent excessive congregation, and monitoring the influence on predator-prey dynamics. Community involvement in waterhole management can increase protection and maintenance efficiency while fostering local stewardship. From a policy perspective, guidelines should prioritize ecological sustainability over short-term wildlife attraction, ensuring that waterholes do not disrupt natural wetland hydrology or encourage poaching. Additionally, adaptive management is essential: regular assessment of ecological impacts allows modifications to placement, size, and accessibility, aligning artificial water sources with conservation objectives. Incorporating climate-resilient water retention techniques, such as rainwater harvesting or small-scale check dams, can further enhance year-round availability. Overall, strategically managed waterholes contribute to population stability of key species, support grassland regeneration, and enhance the overall ecological integrity of ShNP.

4) Strengthening Transparency and Efficiency of Compensation Schemes

Human-wildlife conflict remains a significant challenge in Shuklaphanta National Park, particularly due to crop and livestock depredation. Effective compensation schemes mitigate negative perceptions of conservation, promote coexistence, and strengthen local participation in biodiversity protection. Current challenges include delays in claim processing, inadequate compensation amounts, and a lack of transparency in decision-making, which may erode community trust. Strengthening these schemes requires digitized reporting, clear eligibility criteria, and timely disbursement of compensation. Policies should integrate participatory monitoring, allowing communities to report incidents with real-time verification by park officials. Engaging BZCFUGs in oversight ensures accountability, reduces bureaucratic inefficiencies, and promotes equitable benefit distribution. Additionally, schemes should incentivize proactive measures, such as predator-proof corrals, crop protection strategies, and early-warning systems, thereby linking compensation to preventive practices. Legal and institutional frameworks must guarantee sustainable funding sources, possibly through park revenue allocation, conservation trust funds, or insurance mechanisms. Public awareness campaigns and capacity-building workshops can educate communities on claim procedures, dispute resolution, and coexistence strategies. Transparent and efficient compensation mechanisms not only reduce antagonism toward wildlife but also enhance collaborative conservation governance, ensuring that both ecological and socio-economic objectives are met in Shuklaphanta National Park.

5) Community-Centered Ecotourism Development

Ecotourism in Shuklaphanta National Park offers opportunities to generate local livelihoods, enhance conservation awareness, and fund park management. Community-centered ecotourism emphasizes inclusive participation, equitable benefit-sharing, and capacity building, ensuring that tourism development aligns with ecological sustainability. Local communities can operate homestays, guide services, handicraft sales, and cultural experiences, directly linking economic incentives to wildlife protection. Planning should prioritize low-impact infrastructure, seasonal visitor management, and educational components that highlight conservation values. Policies must define clear benefit-sharing mechanisms, transparent governance, and roles for BZCFUGs and other stakeholders in decision-making. Training programs for community members enhance hospitality skills, wildlife interpretation, and language proficiency, improving visitor experiences while fostering local empowerment. Environmental monitoring ensures that tourism does not disturb sensitive habitats or key species. Strategic marketing can attract responsible tourists who respect conservation ethics, thereby increasing revenue without increasing ecological pressure. By embedding conservation education into tourism experiences, ShNP can promote behavioral change among visitors and residents, reinforcing the intrinsic value of biodiversity. Moreover, community-centered ecotourism strengthens social cohesion, reduces pressure on natural resources, and creates sustainable economic alternatives that align local interests with park objectives (Bhandari, 2024).

6) Capacity Building for BZCFUGs and Equitable Benefit Sharing

Buffer Zone Community Forest User Groups (BZCFUGs) are central to the success of conservation initiatives in Shuklaphanta National Park. Strengthening their capacity involves enhancing governance, technical skills, and resource management practices, enabling equitable participation in decision-making and in the distribution of benefits. Capacity-building programs should include training on sustainable forest

management, wildlife monitoring, conflict mitigation, and participatory planning. Equitable benefit-sharing ensures that all community members, particularly marginalized groups, gain tangible returns from conservation activities such as ecotourism revenue, carbon credit schemes, and non-timber forest products. Policy frameworks must formalize roles and responsibilities, transparency measures, and conflict resolution mechanisms within BZCFUGs. Facilitating partnerships with NGOs, research institutions, and government agencies can provide technical support and access to innovative management approaches. Monitoring and evaluation systems should track both ecological outcomes and socio-economic impacts, ensuring that benefit-sharing aligns with conservation goals while reducing inequality. By empowering local communities, Shuklaphanta National Park not only fosters stewardship but also creates resilient social-ecological systems that support biodiversity, sustainable livelihoods, and long-term conservation success (Bhandari, 2025).

VII. Conclusion

Shuklaphanta National Park stands at a critical crossroads where ecological resilience and social legitimacy must be secured in tandem. This synthesis demonstrates that sustainable conservation in SPNP depends on integrated, participatory, and adaptive approaches that recognize the park as a living socio-ecological system. By aligning biodiversity protection with livelihood security and climate resilience, SPNP can serve as a model for protected area management across Nepal and the wider Himalayan region.

. The park's ecological complexity—characterized by expansive grasslands, seasonal wetlands, and a diversity of large mammals and birds—cannot be effectively protected solely through traditional, top-down conservation approaches. Instead, sustainable conservation in SPNP depends on integrated, participatory, and adaptive management frameworks that treat the park not as an isolated ecological entity but as a living socio-ecological system where human well-being and biodiversity outcomes are deeply interconnected.

At the heart of this integrated approach is the recognition that biodiversity protection and livelihood security are not antithetical but mutually reinforcing. In many of his works, Bhandari emphasizes that sustainable environmental governance must bridge ecological integrity with social equity and human development goals (Bhandari, 2025). In the context of SPNP, this means that grassland restoration, invasive species management, and wildlife conservation strategies should be co-designed with the people who live around and within the park's buffer zones, particularly the Buffer Zone Community Forest User Groups (BZCFUGs), whose traditional ecological knowledge complements scientific monitoring and adaptive management (Bhandari, 2024). By formalizing these partnerships, conservation actions become more socially legitimate and locally relevant, enhancing both compliance and effectiveness.

Adaptive management, a central concept in SPNP's sustainable future, emphasizes monitoring, learning, and flexibility. It is a dynamic process in which conservation actions are continually evaluated and modified in response to new information and changing conditions (Bhandari, 2025). This is especially important in the face of climate variability—where hydrological extremes and shifts in species distributions challenge static conservation plans—and in landscapes where human-wildlife interactions are a routine aspect of life. In SPNP, adaptive management can facilitate responsive strategies for artificial waterhole placement, grassland fire regimes, and wildlife corridors, ensuring that ecological interventions remain aligned with evolving ecological and social realities (Bhandari, 2025).

Participatory governance further strengthens resilience by embedding local voices in decision-making processes. Rather than positioning communities solely as beneficiaries or stakeholders, meaningful participation treats community members as co-managers and stewards with agency. This shift is well articulated by Bhandari (2024), who argues that equitable benefit-sharing mechanisms and transparent compensation schemes for human-wildlife conflict build trust and reciprocity between park authorities and local people. Such mechanisms reduce resentment and foster shared responsibility for conservation outcomes, thus enhancing the park's social legitimacy.

Moreover, sustainable conservation in SPNP must recognize the multiscale pressures that stem beyond its boundaries—ranging from regional development plans to global climate dynamics. As Bhandari (2025) points out, protected areas nested within broader social and ecological landscapes cannot be effectively managed in isolation; they require coordination across governance levels and sectors, including agriculture, tourism, infrastructure, and disaster risk reduction.

By aligning biodiversity protection with livelihood security and climate resilience, SPNP can serve as a model for protected area management across Nepal and the wider Himalayan region. This model is not only about conserving wildlife and habitats but also about co-creating governance systems that uphold ecological sustainability and human dignity in a reciprocal relationship.

VIII. A Way Forward: Addressing Conservation and Social Challenges in Shuklaphanta National Park

Addressing the complex challenges facing Shuklaphanta National Park (ShNP) requires a forward-looking approach that integrates ecological science, inclusive governance, and long-term socio-economic planning. The way forward lies in transformative, participatory, and adaptive conservation, where ecological resilience and social legitimacy are strengthened simultaneously rather than treated as separate objectives.

First, institutionalizing integrated landscape management is essential. Grassland restoration, invasive species control, water resource management, and wildlife corridor protection should be coordinated under a unified ecological framework that

transcends administrative boundaries. This approach must be supported by long-term monitoring systems that incorporate remote sensing, field-based ecological assessments, and community-led data collection to inform adaptive decision-making. Embedding climate risk assessments into management plans will further ensure that conservation strategies remain responsive to changing hydrological patterns and species dynamics.

Second, strengthening community co-governance is critical for resolving persistent human–wildlife conflicts and building trust. Buffer Zone Community Forest User Groups (BZCFUGs) should be formally empowered as co-managers, with clear roles in habitat management, conflict monitoring, and benefit-sharing mechanisms. Transparent and efficient compensation schemes—supported by digital reporting and timely disbursement—can reduce resentment while incentivizing preventive measures such as predator-proof enclosures and crop protection strategies.

Third, capacity building and knowledge integration must be prioritized. Continuous training for park staff and community members in ecological monitoring, restoration techniques, and governance processes will enhance local stewardship. Integrating scientific research with Indigenous and local knowledge systems can improve ecological outcomes while respecting cultural practices and lived experience.

Finally, sustainable financing and policy coherence are necessary to ensure long-term impact. Dedicated conservation funds, reinvested ecotourism revenue, and partnerships with research institutions and NGOs can provide stable resources. Aligning park-level actions with national biodiversity strategies and global conservation commitments will strengthen accountability and scalability.

By adopting these measures, ShNP can move from reactive management toward a resilient socio-ecological model, demonstrating how protected areas can harmonize biodiversity conservation, climate adaptation, and human well-being in Nepal and beyond.

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