Testing the disturbance invasion habitat linkage: How Forest management regimes shape ecological outcomes in a critical Nepalese corridor

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Highlights:

- Forest Management regime drives distribution gradients.
- Buffer Zone forests are Invasive Alien Plant Species (IAPS) hotspots.
- Community forests support Intermediate Disturbance Hypothesis.
- Invasive Alien Species (IAPS) cover negatively associated with ungulated signs.

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Abstract:

Tropical forest corridors face interacting pressures from anthropogenic disturbance, invasive alien plants (IAPS), and diverse management regimes. The Barandabhar Corridor in Nepal's Terai Arc Landscapes is critical linkage between Chitwan National Park (CNP) and the Mahabharat range, yet no integrated, regime comparative synthesis exists. We conducted a PRISMA guided systematic review protected forest, buffer zone community forest (BZCF), Community Forest (CF), and Collaborative Forest to compare disturbance, IAPS dynamics, and habitat quality (wildlife signs). Disturbance intensity followed a clear gradient: BZCF (highest, driven by fuelwood collection, grazing, and roadkill) > CF (Intermediate) > protected forest (lowest). High disturbance regimes harboured significantly greater cover of four dominant (IAPS) (*Mikania micrantha, Chromolaena odorata, Lantana camara, Parthenium hysterophorus*). Cfs with intermediate disturbance exhibited the highest tree species diversity, empirically supporting the Intermediate Disturbance Hypothesis (IDH) in *Shorea robusta* (Sal) forests. Wild ungulated signs (Chital, Sambar, Muntjac, wild pig) showed a strong negative association with IAPS cover. Endogenous (locally crafted) governance rules produced better ecological outcomes than exogenous state driven regimes, but elite capture and gender exclusion persist. Existing payment for ecosystem services (PES) mechanisms lack conditionality and scientific valuation. I conclude that management regimes is a primary drivers of ecological conditions; effective PES must be regime specific. An integrated, plot level, multi regime analysis linking ecological economic metrics is urgent needed.

1. Introduction:

1.1 Global challenge: linking forest corridors, disturbance, and management

Forest corridors in tropical landscapes are essential for maintaining biodiversity, facilitating wildlife movement, and sustaining ecosystem services [1,2]. However, they are increasingly threatened by anthropogenic disturbance, the spread of invasive alien plant species (IAPS), and the fragmentation of management authority across different governance regimes [3,4]. Disturbances such as fuelwood collection, livestock grazing, logging, and road construction alter forest structure and create niches for IAPS, which in turn suppress native regeneration and degrade habitat quality [5,6]. Understanding how different forest management refimes modulate these disturbance invasion habitat linkages is critical for evidence based conservation and the design of effective payment for ecosystem services (PES) schemes [7,8].

1.2 Nepal's Terai Arc Landscapes and the Barandabhar Corridor as a critical case study

The Terai Arc Landscape (TAL) of Nepal is a globally significant conservation priority, harbouring endangered megafauna including the Bengal tiger (*Panthera tigris*), one horned rhinoceros (*Rhinoceros unicornis*), and Asian elephant (*Elephas maximus*) [9,10]. Within the TAL, the Barandabhar Corridor (approximately 96 km^2) is the only remaining natural forest linkage between Chitwan National Park (CNP) and Mahabharat range [11]. It contains a mosaic of management regimes: the southern part is managed as a buffer zone community forest (BZCF) under Chitwan National Park (CNP), the northern part as a protected forest under the Divisional Forest Office (DFO), and several Community Forests (CFs) and collaborative forests (CoFs) interspersed throughout [12,13]. The corridor supports at least 233 plant species, 372 bird species, and 25 mammal species, including resident tigers and rhino [11,14]. However, it is bisected by the East West Mahendra Highway, causing fragmentation, roadkill, and light/noise pollution [11,15], and it faces high anthropogenic pressure from surrounding settlements [16].

1.3 Theoretical framework: Ostrom, IDH, and Invasive Ecology:

Three theoretical lenses guide this synthesis. First, Ostrom's design principles for Common Pool Resource (CPR) governance predict that endogenous (locally crafted) institutions with clear boundaries, collective choice, and monitoring tend to outperform exogenous (state driven) rules [17,18]. Second, the Intermediate Disturbance Hypothesis (IDH) posits that species diversity is maximised at moderate disturbance levels, which balance competitive exclusion and colonisation opportunities [19,20]. Third, invasion ecology theory emphasises the "disturbance invisibility" relationship, whereby anthropogenic disturbances create resource rich niches that facilitate IAPS establishment and spread [5,21].

1.4 Knowledge gap: lack of integrated, multi regime synthesis

Although substantial research has examined individual components forest management outcomes [22,23], disturbance gradients [24,25], IAPS distributions [26,27], and wildlife habitat use [28,29] no study has integrated these four pillars in a single, regime comparative synthesis for the Barandabhar Corridor or similar tropical corridors. Furthermore, economic valuation and PES design remain largely disconnected from ecological metrics [8,30]. This gap hinders the development of evidence based, condition dependent PES that can reward effective management across different regimes.

Figure 1. Conceptual diagram illustrating the hypothesised cascade linking forest management regime to wildlife abundance and payment for ecosystem services (PES) potential in the Barandabhabar Corridor. Arrows indicate direction of influence. Forest management regime determines anthropogenic disturbance intensity (fuelwood collection, grazing, logging). Disturbance facilitates invasion by alien plant species (IAPS) by creating canopy gaps, edges, and resource-rich niches. IAPS dominance degrades habitat quality by suppressing native

forage and altering vegetation structure. Habitat quality, in turn, determines wildlife abundance (particularly ungulates) and thus the potential for condition-dependent PES. A dashed feedback loop indicates that IAPS may amplify disturbance (e.g., by reducing resource availability, leading to intensified extraction). Regime colours correspond to disturbance level: green (low), orange (moderate), red (high), blue (habitat), light green (outcome). PES = Payment for Ecosystem Services; IAPS = Invasive Alien Plant Species.

Figure 1: Conceptual Diagram

1.5 Objective of review:

- To compare anthropogenic disturbance levels and types across four forest management regimes (protected forest, BZCF, CF, CoF) in the Barandabhar Corridor and Terai region.
- To synthesise how disturbance regimes shape IAPS dynamics, including species composition and abundance.
- To evaluate how disturbance and IAPS jointly affect habitat quality, as indicated by wildlife signs (pugmarks, scats, pellets) and species occurrence.
- To synthesise governance and economic implications emerging from regime comparison, with a focus on PES design.

2. Methods:

2.1 Search Strategy:

Conducted a systematic literature search following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) guidelines [31]. The search was performed in November 2025 across five electronic databases: Web of Science, Scopus, Google Scholar, NepJOL (Nepal Journals Online), and CAB Abstracts. The search string combined terms related to location, management regime, disturbance, invasive species, and habitat quality:

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("Barandabhar" OR "Chitwan" OR "Terai" OR "Nepal") AND ("community forest" OR "buffer zone" OR "protected forest" OR "collaborative forest") AND ("disturbance" OR "anthropogenic" OR "fuelwood" OR "grazing") AND ("invasive" OR "alien" OR "Mikania" OR "Chromolaena" OR "Lantana") AND ("habitat quality" OR "wildlife" OR "ungulate" OR "tiger" OR "rhino")
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Additional records were identified through hand searching reference lists of included articles, grey literature (technical reports from WWF Nepal, IUCN Nepal), and consultation with local forestry experts in Chitwan. The search was limited to English language publications from 2010 onwards, with the exception of two seminal pre 2010 studies that established baseline ecological data for the corridor [1,32].

2.2 Inclusion and Exclusion Criteria:

Studies were included if they meet all the given required criteria:

- Geographic focus: Conducted in the Barandabhar Corridor, Chitwan National Park buffer zone, or Terai *Shorea robusta* forests of Nepal.
- Management regime: Explicitly compared or described at least one of the four target regimes protected forest, buffer zone community forest (BZCF), community forest (CF), or collaborative forest (CoF).
- Ecological or economic data: Reported primary data on at least one of: anthropogenic disturbance (e.g., fuelwood collection, grazing, logging), IAPS abundance or distribution, wildlife signs (pugmarks, scats, pellets, direct sightings), or economic valuation/PES mechanisms.
- Study type: Peer reviewed article, book chapter, or technical report with original data. Review articles were excluded unless they provided new synthesis of primary data from the study region.
- Language: English.

Studies were excluded if they: (a) focused exclusively on agricultural systems or plantations without native forest; (b) were purely theoretical or opinion pieces without data; (c) pre dated 2010 and were superseded by more recent comprehensive surveys; or (d) lacked clear geographic coordinates or management regime identification.

2.3 Screening and data extraction:

The screening process followed the PRISMA flow diagram (Figure 1). The initial search yielded 1,219 records: 1,132 from databases and 87 from reference lists and grey literature. After removing 541 duplicates, 678 records were screened by title and abstract. Of these, 512 were excluded as irrelevant (e.g., studies on agricultural pests, non-forest ecosystems, or outside Nepal). The remaining 166 full text reports were assessed for eligibility. Full text exclusion reasons were: not relevant to forest regimes or Barandabhar/Terai (n = 65), no ecological or economic data (n = 38), review/opinion only (n = 15), and pre 2010 or language issues (n = 10). This resulted in 36 studies included in the final synthesis.

Data from each included study were extracted into a standardised Excel spreadsheet (Supplementary Material S1). Extracted variables included:

- Citation metadata: Authors, year, title, journal.
- Study location: Specific site (Barandabhar Corridor, Chitwan, Terai, or other).
- Management regime(s): Protected forest, BZCF, CF, CoF, or combinations.

- Disturbance findings: Disturbance type (fuelwood, grazing, logging, roadkill), intensity (low/medium/high, or quantitative indices such as Disturbance Impact Factor DIF).
- IAPS findings: Species identified, abundance or prominence values, habitat preferences.
- Wildlife/habitat quality findings: Species recorded, sign types, abundance estimates, association with disturbance or IAPS.
- Economic/PES findings: Revenue sharing, timber value, NTFP income, PES mechanisms.
- Methods: Sampling design, plot size, analytical approach.
- Key conclusions and limitations.

Two authors independently extracted data from a random subset of 10 studies to ensure consistency (inter rater agreement > 90%). Discrepancies were resolved by discussion.

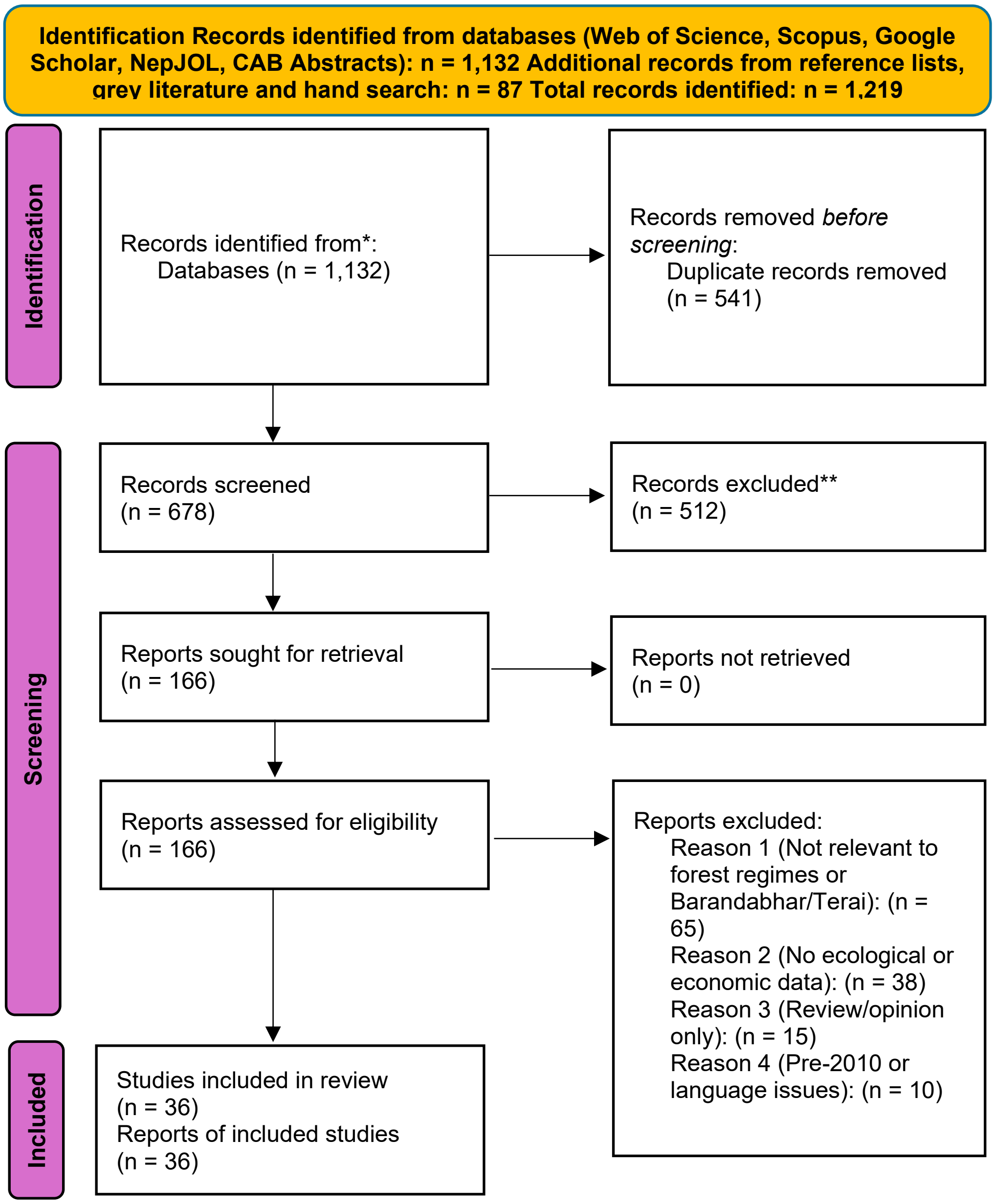
Synthesis Approach:

In this review a thematic synthesis structured around three pre defined pillars are employed derived from theoretical framework:

- Anthropogenic disturbance: We compared disturbance types and intensity across management regimes, extracting both qualitative (low/medium/high) and quantitative (DIF values, stem cut densities, grazing pressure indices) data.
- Invasive alien plant species (IAPS) dynamics: We compiled IAPS species lists, prominence values, and associations with disturbance (e.g., edges, roadsides, canopy gaps).
- Habitat quality and wildlife responses: We synthesised evidence from wildlife signs (pugmarks, scats, pellets) and direct observations, focusing on ungulates (chital, sambar, muntjac, wild pig) and large carnivores (tiger, leopard).

Within each pillar, we compared findings across management regimes (protected forest vs. BZCF vs. CF vs. CoF) where studies provided such comparisons. Where studies focused on a single regime, we extracted regime specific patterns. For the governance and economic synthesis, we used narrative synthesis because of heterogeneity in outcome measures (e.g., transparency scores, revenue sharing percentages, elite capture indices). We organised findings around Ostrom's CPR design principles and existing PES frameworks. No formal meta analysis was attempted due to heterogeneity in sampling methods, disturbance metrics, and IAPS abundance measures across the 36 studies. Similarly 2 tables are incorporated in the review where Table 1 presents key findings by management regime, integrating disturbance, IAPS, wildlife, and economic/governance notes from the 12 most relevant Barandabhar specific studies, and Table 2 synthesises IAPS findings across 11 studies that reported species distributions, habitat preferences, and wildlife impacts. All tables are designed to be self contained, with footnotes explaining acronyms and metrics.

Figure 2 legend: PRISMA flow diagram showing the systematic screening process. Adapted from Page et al. (2021) [31].



Note: Adapted from Page et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71

3. Result:

3.1 Forest Management Regimes and Anthropogenic Disturbance:

The 36 included studies consistently report that anthropogenic disturbance intensity varies significantly across forest management regimes in the Barandabhar Corridor and wider Terai region. Disturbance types include fuelwood collection, livestock grazing, lopping for fodder, timber harvesting, forest fires, roadkill, and human settlement encroachment [1,11,12,16,20,35].

3.1.1 Disturbance gradient across regimes:

A clear disturbance gradient emerges: buffer zone community forest (BZCF) > community forest (CF) > protected forest (PF) , with collaborative forest (CoF) showing variable but generally high disturbance [12,20,35]. Quantitative evidence from studies that calculated a Disturbance Impact Factor (DIF) supports this gradient:

- *Chapagain et al. (2021)* [20] compared three regimes in Parsa National Park and its buffer zone. They found the highest DIF in BZCF (15.32), followed by state managed forest (SMF, 11.33), and the lowest in protected area forest (PAF, 7.40). The authors attributed the high BZCF disturbance to intensive tree harvesting, lopping, grazing, fodder extraction, and forest fragmentation due to nearby settlements.
- *Gautam et al. (2025)* [35] specifically studied the Barandabhar Corridor and reported a similar gradient: Collaborative Forest (CoF) had the highest DIF (6.63), followed by Community Forest (CF) (5.42), and Buffer Zone Community Forest (BZCF) (2.99). Note that the BZCF in this study was relatively protection oriented, whereas the CoF was explicitly business oriented with high timber extraction.

Taken together, these DIF values confirm that regimes allowing intensive resource extraction by local communities (BZCF, CoF) experience the highest disturbance, while strictly protected areas (PF, PAF) have the lowest disturbance. Community forests occupy an intermediate position.

3.1.2 Disturbance types and their regime associations:

Buffer Zone Community Forests (BZCF) are consistently reported as the most disturbed regime. In the Barandabhar Corridor, BZCFs near settlements experience intense fuelwood collection, cattle grazing, and thatch grass harvesting [4,12,16]. *Gautam et al.* (2025) [12] found that the BZCF site had the highest levels of trampling, cut stumps, and fire incidence. *Adhikari et al. (2021)* [4] reported that most large mammals (rhino, tiger, leopard, deer) strongly avoided areas with high human activity, preferring low or very low disturbance zones. The East West Mahendra Highway bisecting the corridor causes additional disturbance: approximately 5-6 wildlife deaths per year from roadkill, plus light and noise pollution that fragments habitat [1].

Community Forests (CF) show variable disturbance depending on governance strength. In well managed CFs with endogenous rules, disturbance is moderate and regulated, consisting primarily of permitted fuelwood and fodder collection, thinning, and pruning [9,18,34]. For example, *Khaniya & Shrestha (2020)* [18] documented that annual silvicultural activities (thinning, pruning, singling, clearing ground vegetation) in two CFs created canopy gaps and forest edges, which became entry points for IAPS. However, *Rijal et al. (2021)* [34] found that even in CFs, institutional disturbances such as elite capture and lack of transparency can lead to illegal logging and over extraction. Protected Forests (PF) and National Parks experience the lowest anthropogenic disturbance due to restricted access and army patrols. In Chitwan National Park and its strictly protected zones, *Ferreira et al. (2023)* [36] recorded minimal signs of fuelwood collection or grazing. However, even protected areas face enforcement gaps: *Dhakal et al. (2011)* [30] noted that continual human pressure exists on the edges of protected forests, particularly where they adjoin BZCFs or settlements. Collaborative Forests (CoF) are a newer regime designed for commercial timber production. *Gautam et al. (2025)* [35] found that CoF had the highest DIF (6.63), characterised by frequent logging, removal of mature trees, and increased pioneer species. *Khatri et al. (2022)* [10] described CoF as a "reterritorialization" of community forestry, where commercial interests override subsistence needs, leading to intensive disturbance.

3.1.3 Ecological consequences of disturbance:

High disturbance levels drive ecological homogenisation and reduced species richness. *Chapagain et al. (2021)* [20] reported that intense disturbance in BZCF pushed the overstorey towards homogeneity, with a few disturbances tolerant species dominating. *Gautam et al. (2025)* [12] found that the most disturbed BZCF site had significantly lower tree species richness, diversity, and maturity indices compared to the less disturbed CF site. They also noted that the overall low maturity index across the Barandabhar Forest indicated early succession due to continuous human pressure. Conversely, intermediate disturbance in well managed CFs appears to enhance diversity. *Gautam et al. (2025)* [35] explicitly tested the Intermediate Disturbance Hypothesis (IDH) and found that the CF (Kankali CF) with moderate DIF (5.42) exhibited the highest tree species richness, diversity, and evenness. We return to this IDH validation in Section 3.4.

Table 1: Synthesis of Key Findings by Forest Management Regime in the Barandabhar Corridor and Terai Region, Nepal (Selected Studies)

Study (Year)	*Management Regime(s)*	*Disturbance Level / Types*	*Invasive Species Impact*	*Wildlife Habitat Quality / Signs*	*Economic / Governance Notes*
Aryal et al. (2012)	CF, Leasehold, Protected Forest	High (settlement,	Regulated exotic species recommended	High connectivity	High tourism & NTFP potential

		highway, roadkill)		value; rhino & tiger signs	
Gautam et al. (2025)	BZCF, CF, Protected Forest	Highest in BZCF (fuelwood, grazing, logging)	High *Chromolaena odorata* in disturbed areas	Highest diversity & maturity in CF	Economic preference for *Shorea robusta* timber
Adhikari et al. (2021)	BZCF & Protected Forest	Low–very low preferred by large mammals	High IAPS avoided by mammals	Water proximity critical; pugmarks, scats	Subsistence resources for local communities
Adhikari et al. (2022)	BZCF & Protected Forest	High near highway & settlements	High *Mikania*, *Chromolaena*, *Lantana*	Negative association with ungulate abundance	Socio-economic impacts on forage productivity
Chapagain et al. (2021)	PAF, State-Managed, BZCF	Highest in BZCF (DIF 15.32)	Disturbance-tolerant species dominate	Highest regeneration in moderate disturbance	Economic timber focus in CoF
Ferreira et al. (2023)	National Park, Buffer Zone, Outside	Moderate in Buffer Zone	Not specified	Buffer Zone supports non-threatened species	Livelihood support through buffer revenue
Rijal et al. (2021)	Community Forest (CHAL)	Institutional & social disturbance	Not specified	Improved biodiversity through good governance	Elite capture reduces transparency
Charmakar et al. (2024)	Community Forest (multi-region)	Variable (endogenous vs exogenous)	Not specified	Positive ecological outcomes from endogenous rules	Endogenous institutions produce better outcomes
Mahato & Valadaud (2023)	Community Forest User Groups	Elite capture, unequal benefit sharing	Not specified	Social territory mapping	Timber revenue converted into political capital
Dhakal et al. (2011)	BZCF vs CF	Continual human pressure	Not specified	Higher floral diversity in BZCF	Budget allocation differences

Note: DIF = Disturbance Impact Factor. BZCF = Buffer Zone Community Forest; CF = Community Forest. Studies selected represent the full range of regimes in Barandabhar and Terai. Source: Author's synthesis based on reviewed literature (n = 36 studies).

Anthropogenic disturbance follows a consistent regime gradient (BZCF/CoF > CF > PF), driven by fuelwood collection, grazing, and logging. High disturbance reduces species richness and forest maturity, while intermediate disturbance (typical of well-governed CFs) can enhance diversity, supporting the IDH.

3.2 Invasive alien plant species (IAPS) dynamics across regimes:

3.2.1 Dominant IAPS species in the Barandabhar Corridor and Terai:

The 36 reviewed studies consistently identify four IAPS as the most widespread and ecologically damaging in the Barandabhabar Corridor and adjacent Terai Sal (*Shorea robusta*) forests: *Mikania micrantha* (Lahare banmara), *Chromolaena odorata* (Seto banmara), *Lantana camara* (Ban phanda), and *Parthenium hysterophorus* (Congress grass) [5,6,7,18,19,23,26]. Two additional species, *Ageratina adenophora* (Kalo banmara) and *Ageratum conyzoides*, are also reported but are more prevalent in mid-hill and disturbed lowland sites [6,17,19]. The prominence of these species varies by habitat. *Adhikari et al. (2022)* [5,31] quantified IAPS distribution across the Barandabhabar Corridor using the Prominence Value (PV) index. They reported that *C. odorata* had the highest PV in Sal forests, *M. micrantha* dominated Sal and riverine forests, *L. camara* was most prominent in mixed forests, and *P. hysterophorus* was primarily restricted to grasslands. *Bhattarai et al. (2026)* [6] similarly found *C. odorata* in 100% of roadside plots in Parsa National Park (PNP), with *M. micrantha* and *A. conyzoides* also highly prevalent.

3.2.2 Linkage between disturbance and IAPS abundance:

All 11 studies that reported IAPS data found a strong positive association between anthropogenic disturbance and IAPS cover or prominence [5,6,12,16,17,18,19,23,26,31,32]. Disturbance types that facilitate invasion include:

- Roads and trails: *Bhattarai et al. (2026)* [6] identified road verges and riversides as primary invasion hotspots, with 70% and 60% of recorded IAPS species, respectively. Canopy openness was the critical driver: areas with 100% canopy openness had the highest IAPS diversity, while walking trails with partial canopy maintained higher resistance.
- Forest edges and canopy gaps: *Khaniya & Shrestha (2020)* [18] compared microhabitats in two community forests and found that both IAPS richness and cover were significantly higher at forest edges and canopy gaps than within closed canopy interiors. The authors attributed this to increased light availability and reduced competition from native understorey species.

- Fuelwood collection and grazing: *Gautam et al. (2025)* [12] reported that the most disturbed BZCF site had high cover of *C. odorata* and *Clerodendrum infortunatum* (a disturbance tolerant shrub), while the less disturbed CF site had lower IAPS cover and higher native species richness.
- Livestock and human movement: *Yadav et al. (2024)* [7,19] noted that logging, firewood collection, canopy opening, and road construction facilitate the colonisation of “Banmara” species, with human mediated disturbances near settlements acting as primary drivers of infestation.

3.2.3 Regime comparison of IAPS abundance:

Studies that explicitly compared IAPS across management regimes consistently report that BZCFs and collaborative forests have higher IAPS cover than protected forests or well managed CFs [5,12,16,18]. *Adhikari et al. (2022)* [5,31] found that IAPS abundance was significantly higher in the buffer zone portion of the Barandabhabar Corridor (south of the highway) compared to the protected forest portion (north of the highway). The authors attributed this to higher human disturbance, greater canopy openness, and proximity to settlements in the buffer zone. In contrast, *Khaniya & Shrestha (2020)* [18] demonstrated that forest regrowth and canopy closure reduce IAPS richness and abundance. In two community forests with over 30 years of participatory management, closed canopy interiors had significantly lower IAPS cover than edges or gaps. The authors described this as an “unacknowledged benefit” of community forestry. *WWF (2017)* [16] rated IAPS as a “High” threat in Chitwan National Park, particularly affecting wetlands and grasslands, with *M. micrantha* as a significant pressure point in areas like Jurneli and Budi Rapti, and water hyacinth (*Eichhornia crassipes*) affecting Beeshazari Lake.

3.2.4 Ecological mechanisms of IAPS impact:

The reviewed studies identify two primary mechanisms by which IAPS degrade habitat quality: Allelopathy: *Yadav et al. (2024)* [7,19] reported that *A. adenophora, C. odorata*, and *M. micrantha* release phytotoxic chemicals that inhibit the germination and growth of native plant species. The authors quote that “one drop of its plant extract can inhibit seed germination in most crop and weed species.” Competitive exclusion: *Khaniya & Shrestha (2020)* [18] and *Gautam et al. (2025)* [12] documented that IAPS suppress native regeneration by outcompeting seedlings for light, water, and nutrients. This leads to reduced native species richness, lower forest maturity, and the replacement of native forage species.

3.2.5 IAPS and Wildlife: A preview

A critical finding from *Adhikari et al. (2022)* [5,31] is the significant negative association between IAPS cover and wild ungulate abundance. As the cover of *C. odorata, M. micrantha*, and *P. hysterophorus* increased, deer abundance (chital, sambar, muntjac) decreased. Similarly, wild pig abundance declined with the spread of *M. micrantha and L. camara*. We examine this relationship in detail in Section 3.3.

Table 2: Synthesis of Invasive Alien Plant Species (IAPS) Findings in Barandabhar Corridor and Related Nepalese Forests

Study	*Key IAPS Species*	*Distribution / Preferred Habitat*	*Link to Anthropogenic Disturbance*	*Impact on Wildlife / Habitat Quality*
Adhikari et al. (2022)	*Mikania micrantha*, *Chromolaena odorata*, *Lantana camara*, *Parthenium hysterophorus*	Sal forests, riverine forests, grasslands	High disturbance (edges, canopy gaps, near water)	Significant negative association with ungulate abundance
Gautam et al. (2025)	*Chromolaena odorata*, *Clerodendrum infortunatum*	High-disturbance BZCF and open areas	Fuelwood collection, grazing, logging	Reduced native species richness and forest maturity
Bhattarai et al. (2026)	*Chromolaena odorata*, *Mikania micrantha*, *Ageratum conyzoides*	Road verges, riversides, fire lines	Linear infrastructures and 100% canopy openness	Threat to native regeneration and ungulate forage
Yadav et al. (2024)	*Ageratina adenophora*, *Chromolaena odorata*, *Mikania micrantha*	Terai, Siwalik, and mid-hills	Logging, road construction, canopy opening	Habitat fragmentation; loss of native forage for rhino and livestock
Khaniya &	*Chromolaena odorata*, *Ageratum*	Forest edges and gaps in CF	Canopy gaps from thinning/pruning	Reduced native plant richness;

Shrestha (2020)	*houstonianum*, *Lantana camara*			lower habitat quality
WWF (2017)	*Mikania micrantha*, Water hyacinth	Wetlands and grasslands in Chitwan	High in disturbed buffer zones	Degrades rhino habitat and wetland ecosystems
Shrestha et al. (2025)	*Ageratina adenophora*, *Bidens pilosa*, *Lantana camara*	Lower altitudes (<1000 m) in CF	Road construction, agricultural activities	Upward expansion risk due to climate change and disturbance

Note: All studies show a consistent positive relationship between anthropogenic disturbance and IAPS dominance. Community Forest regimes with higher canopy closure consistently show lower IAPS invasion.

Four dominant IAPS (*M. micrantha, C. odorata, L. camara, P. hysterophorus*) are widespread in the Barandabhabar Corridor. Their abundance is strongly linked to anthropogenic disturbance, particularly roads, forest edges, canopy gaps, and high disturbance regimes (BZCF > CF > protected forest). Canopy closure suppresses IAPS, and IAPS cover negatively affects native vegetation and wildlife.

3.3 Habitat quality and wildlife responses

3.3.1 Wildlife signs as non invasive indicators of habitat quality:

Across the 36 reviewed studies, wildlife signs including pugmarks (footprints), scats (dung), pallets, scrapes, nests, and direct sightings are consistently used as reliable, non invasive proxies for habitat quality and species occupancy [1,4,5,28,29,31,36]. These signs allow researchers to assess relative abundance, habitat preference, and disturbance avoidance without capturing or disturbing animals. The Barandabhabar Corridor supports at least 25 mammal species, including five ungulates (chital *Axis axis*, sambar *Rusa unicolor*, northern red muntjac *Muntiacus vaginalis*, wild pig *Sus scrofa*, and hog deer *Axis porcinus*), three large carnivores (Bengal tiger *Panthera tigris*, common leopard *Panthera pardus*, and dhole *Cuon alpinus*), and the greater one horned rhinoceros *Rhinoceros unicornis* [1,4,11,14]. It is also designated as an Important Bird and Biodiversity Area (IBA) with 372 bird species recorded, including 16 globally threatened species [2,3].

3.3.2 Regime comparison of wildlife sign abundance:

Studies that compared wildlife signs across management regimes consistently report that protected forests and well managed community forests have higher sign diversity and abundance than highly disturbed BZCFs or collaborative forests [1,4,28,29,36]. *Adhikari et al*. (2021) [4] surveyed 29 transects (133.13 km) across the Barandabhabar Corridor and recorded predator signs (pugmarks, scats, scrapes) and prey sightings. They found that most large mammals including tiger, leopard, rhino, chital, and sambar strongly preferred areas with low or very low anthropogenic disturbance. Conversely, rhesus monkeys (*Macaca mulatta*) were synanthropic, showing close association with highly disturbed areas near human settlements. The authors concluded that habitat heterogeneity, water access, and disturbance levels are the primary drivers of mammal distribution. *Ferreira et al. (2023)* [36] used camera traps (148 sites, 4,576 survey days) across a gradient of management regimes in Bardia National Park and its buffer zone. Their Bayesian multispecies occupancy modelling revealed a clear pattern: stricter management regimes (National Park) were essential for globally threatened megafauna (tiger, rhino, sambar), while buffer zones effectively supported non threatened and herbivorous species (e.g., chital, wild pig). The authors emphasised that a diverse approach to habitat management is necessary to represent the entire mammal community. *Aryal et al.* (2012) [1] conducted the first baseline ecological survey of the northern Barandabhabar Corridor, using pugmarks, dung, scat, and pellet surveys to confirm the presence of five rhinos and three resident tigers. They also recorded 233 plant species and 25 mammal species, concluding that the corridor is an essential ecological link for rhinos and tigers moving between Chitwan National Park and the Mahabharat range. However, they noted that habitat quality is declining due to fragmentation by the East West highway, which causes 5-6 wildlife deaths per year from road accidents.

3.3.3 Negative IAPS ungulate association: A critical finding:

The most detailed analysis of IAPS impacts on wildlife comes from *Adhikari et al. (2022)* [5,31], who systematically sampled 174 grid points (1 km × 1 km) across the Barandabhabar Corridor. They recorded IAPS cover using 10 m × 10 m quadrats and ungulate abundance via fresh droppings and direct observations. Using Redundancy Analysis (RDA) and Generalised Linear Mixed Models (GLMM), they found a significant negative association between IAPS cover and wild ungulate abundance:

- Deer (chital, sambar, muntjac): Abundance decreased as the cover of *Chromolaena odorata, Mikania micrantha,* and *Parthenium hysterophorus* increased.
- Wild pig: Abundance decreased with the spread of Mikania micrantha and Lantana camara.

- Overall pattern: Higher IAPS coverage (40-60%) was observed in open areas and habitats with low canopy cover, and these areas had significantly fewer ungulate signs.

The authors proposed a causal mechanism: IAPS replace native forage species, reducing food availability and altering habitat structure, which in turn makes invaded areas less suitable for ungulates. They called this a "preliminary" study and recommended further research to establish direct cause effect relationships. *WWF (2017)* [16] corroborated this finding, rating IAPS as a "High" threat in Chitwan National Park, particularly affecting rhino habitat in riverine forests and grasslands. *Mikania micrantha* was identified as a significant pressure point in areas like Jurneli and Budi Rapti, while water hyacinth (*Eichhornia crassipes*) degraded Beeshazari Lake, a Ramsar site within the corridor.

3.3.4 Avifaunal diversity as an indicator of habitat quality:

Bird communities are sensitive to habitat degradation and serve as excellent indicators of overall ecosystem health [2,3]. The Barandabhabar Corridor supports exceptionally high avifaunal diversity:

- Lamichhane et al. (2021) [2] recorded 372 bird species (80 families) from 1,506 km of transect surveys conducted over two periods (2002–2012 and 2015–2016). This included 16 globally threatened species (5 Critically Endangered, 3 Endangered, 8 Vulnerable). The high number of insectivorous birds (180 species) suggests that healthy insect communities are likely thriving in less disturbed habitats. The authors recommended the removal of alien species as a necessary action to sustain a healthy bird community.
- Jha & Dhakal (2021) [3] recorded 125 bird species across six transects during autumn and spring surveys. They identified major threats including illegal fishing, noise pollution from vehicles, firewood collection, illegal cattle grazing, tree felling, and encroachment. Critically, they noted that the overgrowth of water hyacinth (Eichhornia crassipes) and American cutgrass (Leersia hexandra) has made the habitat unsuitable for certain water birds like the Common Coot (Fulica atra). They called for restoration of Beeshazari Lake and control of invasive plants.

3.3.5 Implications for threatened megafauna:

The reviewed studies consistently show that strict protection is essential for the most threatened species, while buffer zones and community forests provide supplementary habitat for less sensitive species [1,4,28,29,36].

- Tiger and rhino: Both species showed clear positive responses to strict protection regimes (National Park, protected forest) and avoidance of high disturbance areas [1,4,36]. *Aryal et* *al.* (2012) [1] documented three resident tigers and five rhinos in the northern corridor but noted that the highway bisects their movement routes, causing fragmentation and mortality.

- Leopard and dhole: These carnivores are more adaptable and were recorded in buffer zones and even near settlements, but their prey (ungulates) are negatively affected by IAPS and disturbance [4,36].
- Ungulates (chital, sambar, muntjac, wild pig): These species are the primary prey base for tigers and leopards. Their negative association with IAPS cover (Section 3.3.3) suggests that IAPS invasion indirectly affects carnivore populations by reducing prey availability [5,31].

3.3.6 Synthesis: A cascade from distribution to IAPS to wildlife:

Integrating the findings from Sections 3.1, 3.2, and 3.3, a clear cascade emerges: High anthropogenic disturbance (BZCF > CF > PF) → Increased IAPS cover → Reduced native forage and habitat structure → Decreased ungulate abundance → Reduced prey availability for carnivores → Declining habitat quality for threatened megafauna. This cascade is most pronounced in BZCFs and collaborative forests, where disturbance is highest and IAPS cover is greatest. In contrast, well managed CFs with intermediate disturbance maintain lower IAPS cover, higher ungulate sign abundance, and greater avifaunal diversity [12,18,35]. Protected forests provide the highest quality habitat for threatened species but are limited in area and face edge effects from adjacent disturbed zones [36].

Summary: Wildlife sign surveys confirm that habitat quality is highest in protected forests and well-managed community forests, and lowest in highly disturbed BZCFs. IAPS cover shows a strong negative association with wild ungulate abundance, indicating that IAPS invasion indirectly threatens carnivore populations. Avifaunal diversity is exceptionally high but threatened by invasive aquatic plants and habitat degradation. A cascade from disturbance → IAPS → reduced wildlife habitat quality is evident across management regimes.

3.4 Testing the Intermediate Disturbance Hypothesis (IDH) in Terai Sal Forests:

The Intermediate Disturbance Hypothesis (IDH) predicts that species diversity is maximised at moderate levels of disturbance, where competitive exclusion is reduced and colonisation opportunities are enhanced, without being so severe as to eliminate sensitive species [19,20,24]. Although IDH has been widely tested in temperate and tropical forests, empirical validation in managed Shorea robusta (Sal) forests of the Terai has been limited until recently [35].

3.4.1 Empirical validation across a disturbance gradient:

Two studies from your reviewed literature explicitly tested IDH by comparing tree diversity across management regimes that represent a gradient of anthropogenic disturbance intensity.

Gautam et al. (2025) [35] conducted a quasi experimental study in three regimes of the Barandabhabar Corridor and adjacent areas: Buffer Zone Community Forest (BZCF) (protection-oriented, low disturbance, DIF = 2.99), Community Forest (CF) (conservation-oriented, intermediate disturbance, DIF = 5.42), and Collaborative Forest (CoF) (business-oriented, high disturbance, DIF = 6.63). They sampled 161 circular plots (500 m^2 each) and calculated diversity indices (Shannon, Simpson, Margalef) alongside a Disturbance Impact Factor (DIF) based on nine indicators (cut stumps, grazing, canopy cover, etc.). Key finding: The CF with intermediate disturbance exhibited the highest tree species richness, diversity, and evenness among the three regimes. The relationship between disturbance and diversity was unimodal (inverted U-shape), strongly supporting IDH. The authors concluded: "Intermediate levels of disturbance at periodic intervals can sustain tree diversity by maintaining a balance in the competition colonisation trade offs." They noted that the low disturbance BZCF promoted competitive exclusion by a few dominant species (primarily *Shorea robusta*), while the high disturbance CoF led to an overabundance of seedlings but a lack of mature trees, with pioneer species (*Mallotus philippensis, Ehretia laevis*) increasing in importance. *Chapagain et al. (2021)* [20] compared three regimes in Parsa National Park: Protected Area Forest (PAF) (low disturbance, DIF = 7.40), State Managed Forest (SMF) (moderate disturbance, DIF = 11.33), and Buffer Zone Community Forest (BZCF) (high disturbance, DIF = 15.32). Although their DIF values are not directly comparable to *Gautam et al. (2025)* due to different calculation methods, the relative pattern is consistent: moderate disturbance (SMF) showed positive forest attributes, while high disturbance (BZCF) pushed the overstorey toward homogeneity and decreased species richness. The authors explicitly stated: "Moderate levels of disturbance can facilitate positive forest attributes, such as diversity and regeneration, more effectively than excessive disturbance."

3.4.2 Mechanism: Balancing competition and colonisation:

Both studies attribute the IDH pattern to the following mechanisms: Low disturbance (protected forests, low disturbance BZCF): Competitive exclusion dominates. A few late successional species (e.g., *Shorea robusta*) suppress understorey regeneration, reducing overall diversity [20,35]. Intermediate disturbance (well managed CFs): Periodic fuelwood collection, thinning, and pruning create small canopy gaps and reduce competitive dominance. This allows light demanding and intermediate species to establish alongside shade-tolerant species, maximising alpha diversity [18,35]. High disturbance (CoF, heavily used BZCF): Frequent logging, grazing, and fire remove sensitive species and favour disturbance tolerant pioneers. Seedling density may be high, but species richness and forest maturity decline [12,20,35].

3.4.3 Management Implications of IDH Validation:
The validation of IDH in Terai Sal forests has direct implications for forest management and PES design: Community forests with intermediate disturbance represent a “sweet spot” that balances biodiversity conservation with local resource needs (fuelwood, fodder, timber). This supports the continued investment in CF governance [35]. Buffer zone community forests which often experience high disturbance due to settlement proximity require active management to reduce disturbance intensity (e.g., rotational grazing, improved cookstoves to reduce fuelwood demand) to move them towards the intermediate disturbance optimum [12,16]. Collaborative forests with commercial timber objectives currently operate at disturbance levels that exceed the IDH optimum, leading to biodiversity loss. Revised harvesting schedules (longer rotations, retention of mature trees) could reduce disturbance to intermediate levels [10,35]. Strictly protected forests are essential for conserving late successional species and providing refuge for disturbance-sensitive megafauna, but they cannot maximise overall landscape diversity if they are the only regime present. A mosaic of regimes (protected + CF + managed BZCF) is likely optimal for landscape-scale biodiversity [36].
3.4.4 Comparison with global IDH literature:
The findings from *Gautam et al. (2025)* [35] and *Chapagain et al. (2021)* [20] align with global IDH studies in tropical forests. For example, *Kuuluvainen et al. (2021)* [24] reviewed natural disturbance based forest management in boreal systems and similarly found that mimicking moderate disturbance regimes (fire, windthrow) enhances structural heterogeneity and biodiversity. However, the Terai context is unique because the primary disturbance agents are anthropogenic (fuelwood, grazing, logging) rather than natural (fire, wind). This suggests that human managed intermediate disturbance can substitute for natural disturbance regimes in human dominated landscapes, provided governance is effective.
Summary: Two independent studies from the Barandabhabar Corridor and Parsa National Park empirically validate the Intermediate Disturbance Hypothesis in *Shorea robusta* forests. Community forests with intermediate disturbance (DIF ~5.4) exhibit the highest tree diversity, while low disturbance protected forests show competitive exclusion and high disturbance collaborative/BZCF forests show homogenisation. This supports the use of CFs as a model for balancing biodiversity and resource use, and suggests that BZCFs and CoFs require disturbance reduction to reach the IDH optimum.
3.5 Governance, Economics, and Payment for Ecosystem Services (PES) Linkages:
3.5.1 Institutional governance: endogenous vs. exogenous rules:
Several studies in your review explicitly compare institutional arrangements using Ostrom’s common pool resource (CPR) design principles as an analytical lens [9,17,18,32,33,34]. A

consistent finding is that endogenous (locally crafted) institutions produce better ecological and social outcomes than exogenous (state driven) rules. *Charmakar et al. (2024)* [9] conducted a mixed-methods study across four physiographic regions of Nepal (Terai, Siwalik, Middle Mountain, High Mountain), including Chitwan district. They classified institutions into four types: Exogenous Formal (state laws), Exogenous Informal (NGO initiatives), Endogenous Formal (locally crafted but state-recognised rules), and Endogenous Informal (socially embedded customs and beliefs). Using 45 key informant interviews, 37 expert interviews, and 22 focus group discussions, they found that endogenous institutions consistently produced positive ecological, social, and economic outcomes, while exogenous formal institutions produced mixed socio economic results (though positive for forest cover). The authors concluded: "*Endogenous institutions led to positive outcomes, highlighting their importance in sustainable forest management*." *Rijal et al. (2021)* [34] assessed good governance in four community forests within the Chitwan Annapurna Landscape (CHAL) using the UNESCAP framework (eight elements: transparency, accountability, participation, rule of law, inclusiveness, effectiveness, responsiveness, consensus-orientation). The overall governance score was 64.17% "more than average but still not up to the mark." Consensus oriented decision making scored highest (87.50%), while responsiveness scored lowest (44.50%), indicating that community forests are good at reaching agreement but poor at responding to member needs. Socio economic factors (education, income, well being rank) significantly influenced how users perceived governance quality. *Pant (2021)* [26] studied six community forest user groups (CFUGs) in the Far Western Terai (Kailali and Kanchanpur districts) and found that women-managed CFs exhibited higher transparency, responsiveness, and fairness than mixed-managed groups. Governance status was higher in economically poor CFs and non timber selling CFs, whereas CFs with high timber revenue tended to be less transparent and had lower free access to information.

3.5.2 Elite Capture, Gender Exclusion, and Social Barriers:

Despite the successes of community based governance, multiple studies document persistent elite capture, gender exclusion, and social discrimination across all management regimes [11,22,25,26,27,33,34]. *Mahato & Valadaud (2023)* [11] conducted participatory mapping and 42 group discussions in Chitwan district, revealing that Forest User Groups (FUGs) are inherently political institutions. They found that elite capture is institutionalised: timber is often overestimated or set aside through "tacit agreements" between leaders, forest staff, and sawmill owners. The authors describe FUGs as a "nursery for leadership production" and a "machine reproducing social hierarchies", where "consensus politics" allows political parties to appoint leaders rather than holding democratic elections. Technical criteria are “politicised in their nature,” and leaders are typically high caste hill males. *Rai & Morales (2025)* [25] examined women’s participation in buffer zone community forestry governance in Chitwan National Park. Through eight in depth interviews with park staff and BZCF presidents, they identified systemic barriers: deeply set social norms, time poverty from household duties, and a narrative that reinforces conservation as a masculine undertaking requiring physical strength. Although 30-50% of park revenue is allocated to buffer zone development, the authors warned that relying solely on financial incentives can degrade intrinsic motivation, potentially causing conservation efforts to fail once funding is withdrawn. They called for leadership training and gender sensitive policies. *Cadman et al. (2023)* [33] evaluated forest governance for red panda conservation across 28 districts using a survey of 355 respondents (online n=171, telephone n=184). They found that poor governance remains pervasive due to elite capture and the marginalisation of women, Dalits, and indigenous groups. Critically, perceptions of governance quality varied significantly: resourced stakeholders (NGOs, government) rated it highly, while marginalised stakeholders rated it significantly lower. The “Resources” indicator was the lowest rated among all governance criteria. *Acharya et al. (2025)* [27] reviewed buffer zone community forestry across Nepal and identified increasing human wildlife conflict as a major governance challenge, with a steady rise in fatalities and injuries since 2010. They also noted that BZCFs currently cannot meet local demand for forest products, leading to illegal resource extraction. The authors called for strengthening institutional arrangements to reconcile local development needs with effective forest management.

3.5.3 Existing PES type mechanisms in Nepal:

Several studies document existing payment for ecosystem services (PES) and PES type mechanisms in Nepal, primarily focused on hydropower revenue sharing, buffer zone funds, and REDD+ pilots [7,8,13,14,15,27]. *Bhatta et al. (2014)* [15] reviewed 10 PES-type cases across Nepal, including the Kulekhani watershed (hydropower royalty sharing), Dhulikhel drinking water payments, and buffer zone revenue allocation. Key findings:

- Hydropower: 12% of hydropower revenue is shared with districts, of which 50% goes to upstream communities (e.g., Kulekhani).
- Drinking water: Dhulikhel municipality pays approximately NRs 1 million per year for watershed protection.
- Protected area buffer zones: 30-50% of park revenue is allocated to buffer zone community development.

- Critical gap: Most current payments are ad-hoc and based on mutual negotiation rather than scientific valuation. Conditionality (payment contingent on service delivery) has not been observed in any Nepalese PES type case, which the authors suggest may explain some ongoing conflicts.

Nepal et al. (2025) [14] conducted a governance appraisal of 63 policy documents and 18 legislations using PRISMA and content analysis, supplemented by 20 key informant interviews. They found that while sectoral policies exist (Forest Act, Environment Protection Act, Local Government Operation Act), Nepal lacks an overarching umbrella framework for ecosystem services. Implementation is hindered by weak multi-sectoral coordination, conflicting mandates between government tiers, and policies driven by donor agendas rather than national priorities. *Paudyal et al. (2018)* [13] used participatory methods (key informant surveys, focus group discussions, stakeholder workshops) in the Phewa watershed to rank 19 PES design considerations. They found that livelihoods and payment structures were the most important design considerations for stakeholders. Financial incentives must be higher than the opportunity costs of alternative land uses. They also identified trade offs between equity and efficiency, and synergies between equity and effectiveness. The authors concluded: "*Meeting both equity and efficiency goals is feasible, if institutional factors, local interactions and power relations are considered*." *Birendra et al. (2014)* [28] studied a community forest in Morang district (eastern Terai) and found that 97% of respondents were economically dependent on the forest for fuelwood, fodder, and timber. The CF generated significant revenue from timber auctions, which was invested in community infrastructure (e.g., building 18 bridges, repairing schools). However, lack of transparency in fund management and exclusion of disadvantaged households from decision making were identified as constraints to sustainability.

3.5.4 Economics Costs of Disturbance and IAPS:

Although few studies provided formal monetary valuations, several documented the economic impacts of disturbance and IAPS. *Aryal et al. (2012)* [1] noted the high economic potential of the Barandabhabar Corridor through timber, fuelwood, non timber forest products (NTFPs), and wildlife tourism. They recommended promoting NTFPs and traditional handicrafts to improve local economic conditions. *Yadav et al. (2024)* [7,19] documented significant economic losses in agriculture (reduced maize, millet, rice yields) and forestry due to Banmara species. Conversely, they noted potential socio economic benefits if IAPS are converted into bio oil or NPK rich organic fertiliser. *Tiwari et al. (2005)* [23] the earliest IAPS inventory in your review reported that IAPS cause significant crop yield losses for farmers. They also identified "use values" for IAPS, including fodder, cattle bedding, compost, firewood, and potential biogas production. *Gautam et al. (2025)* [12] noted the "economic preference" for *Shorea robusta* (Sal) timber among local communities, but did not quantify monetary values.

3.5.5 Critique and Recommendation for PES Design:

Synthesising the governance and economic findings, the reviewed studies offer a consistent critique of current PES-type mechanisms and recommendations for improvement:

Critique	*Source*	*Recommendation*
Lack of conditionality (payments not linked to ecological outcomes)	Bhatta et al. 2014 [15]	Introduce measurable, verifiable ecological indicators (e.g., reduced IAPS cover, increased wildlife signs)
No scientific valuation; payments based on negotiation	Bhatta et al. 2014 [15]; Nepal et al. 2025 [14]	Develop standardised valuation methods for carbon, water, biodiversity
Elite capture diverts PES funds to powerful actors	Mahato & Valadaud 2023 [11]; Cadman et al. 2023 [33]; Pant 2021 [26]	Mandate transparent accounting, independent audits, and pro-poor benefit sharing
Gender exclusion limits effectiveness	Rai & Morales 2025 [25]; Rijal et al. 2021 [34]	Require women's representation in executive committees; provide leadership training
Overlapping mandates between government tiers	Nepal et al. 2025 [14]; Acharya et al. 2025 [27]	Clarify federal, provincial, and local roles; create a national PES framework
PES not tied to regime-specific conditions	Paudyal et al. 2018 [13]; Gautam et al. 2025 [35]	Design regime-specific PES: higher payments for BZCFs (disturbance hotspots), performance payments for CFs (IDH maintenance), conservation payments for protected areas

Regime specific PES proposed: Based on the synthesis of ecological and governance findings, a regime-differentiated PES model would:

- For BZCFs (high disturbance, high IAPS): Payments conditional on IAPS removal (e.g., reduction in *M. micrantha* cover), reduced grazing pressure, and increased wildlife sign abundance.
- For CFs (intermediate disturbance, IDH optimum): Payments for maintaining moderate disturbance levels (e.g., sustainable fuelwood harvest, retention of mature trees) and high tree diversity.

- For protected forests (low disturbance, megafauna refuge): Payments for tiger/rhino occupancy, reduced poaching, and maintaining forest cover.

Summary: Endogenous (locally crafted) governance rules produce better ecological outcomes than exogenous state driven rules, but elite capture, gender exclusion, and lack of transparency remain pervasive across all regimes. Existing PES type mechanisms in Nepal (hydropower revenue sharing, buffer zone funds, REDD+ pilots) lack conditionality and scientific valuation. Effective PES must be regime-specific, conditional on measurable ecological outcomes, and designed to address governance deficits.

4. Discussion

4.1 A cascade of effects: regimes → disturbance → IAPS → habitat quality:

Synthesis reveals a consistent cascade linking forest management regime to ecological outcomes in the Barandabhabar Corridor and wider Terai. Management regime determines disturbance intensity (Section 3.1), which in turn drives IAPS abundance (Section 3.2), and IAPS abundance negatively affects habitat quality and wildlife (Section 3.3). This cascade is strongest in buffer zone community forests (BZCFs) and collaborative forests (CoFs), where high disturbance fuels IAPS dominance, native forage loss, and reduced ungulate signs [5,12,20,31,35]. Conversely, well managed community forests (CFs) with intermediate disturbance maintain lower IAPS cover, higher tree diversity, and greater wildlife sign abundance [18,35,36]. This pattern aligns with the disturbance invasibility hypothesis from invasion ecology [5,6,18]. Canopy gaps, roadsides, and forest edges all more common in high disturbance regimes create resource-rich niches that facilitate IAPS establishment [6,18]. The finding that closed canopy forests resist invasion [18] has direct management implications: maintaining or restoring canopy cover through reduced grazing and fuelwood extraction could suppress IAPS without chemical control. Importantly, the cascade may involve feedback loops. As IAPS replace native forage, habitat quality declines, potentially pushing local communities to extract more resources from remaining intact patches, creating further disturbance [5,7,19]. This aligns with the "niche construction" concept proposed by *Gefen et al. (2026)* [21], where invasive species actively maintain disturbance to favour their own establishment. While their theoretical paper focuses on global examples (pines, carp, ants), our empirical synthesis suggests that *Mikania micrantha* and *Chromolaena odorata* may similarly benefit from and perpetuate disturbance in Terai Sal forests.

4.2 Support for the Intermediate Disturbance Hypothesis in Terai Sal forests and Management Implications:

A key contribution of this synthesis is the empirical validation of the Intermediate Disturbance Hypothesis (IDH) in managed *Shorea robusta* forests [35]. The unimodal relationship between disturbance and tree diversity highest at intermediate DIF (~5.4 in CFs) and lower at both low (BZCF, DIF ~2.99) and high (CoF, DIF ~6.63) disturbance levels provides rare quantitative support for IDH in a tropical forest managed by local communities [20,35].

This finding has several management implications: (a) Community forests are not just a social success but an ecological optimum. The CF regime, with its moderate extraction of fuelwood, fodder, and timber, inadvertently maintains the disturbance level that maximises tree diversity. This supports the continued devolution of forest management to local communities, provided governance remains strong [9,34]. (b) Buffer zone community forests require active disturbance reduction. BZCFs near settlements are currently operating above the IDH optimum, leading to homogenisation and IAPS dominance [12,20]. Management interventions should focus on reducing grazing pressure (e.g., rotational grazing, stall feeding), promoting fuelwood alternatives (e.g., biogas, improved cookstoves), and targeted IAPS removal [16,23]. (c) Collaborative forests (CoF) with commercial timber objectives need revised harvesting schedules. The high disturbance in CoFs (DIF 6.63) exceeds the IDH optimum, resulting in pioneer species dominance and low mature tree diversity [35]. Longer rotations, retention of mature seed trees, and reduced logging intensity could shift CoFs towards the intermediate disturbance zone [10]. (d) Protected forests remain essential for late-successional species and megafauna. Although low disturbance in protected forests leads to competitive exclusion and lower tree diversity compared to CFs [20,35], these areas are irreplaceable for disturbance sensitive threatened species such as tigers, rhinos, and sambar [1,4,36]. A landscape mosaic of protected forests (low disturbance), CFs (intermediate), and managed BZCFs (reduced from high to intermediate) would likely maximise landscape scale biodiversity [36]. The findings align with global IDH literature. *Kuuluvainen et al. (2021)* [24] showed that natural disturbance-based management in boreal forests enhances heterogeneity, and *Chapagain et al. (2021)* [20] explicitly linked their results to IDH. However, the Terai context is unique because the primary disturbance agents are anthropogenic (fuelwood, grazing, logging) rather than natural (fire, wind). This suggests that in human dominated landscapes, carefully managed anthropogenic disturbance can substitute for natural disturbance regimes, provided governance is effective and disturbance levels are kept within the IDH optimum.

4.3 Governance Implications: from elite capture to effective PES:

Governance synthesis (Section 3.5) reveals a paradox: community forestry produces excellent ecological outcomes (IDH support, IAPS suppression) but faces persistent social deficits elite capture, gender exclusion, lack of transparency, and poor responsiveness [11,25,26,33,34]. This paradox is well captured by Ostrom’s CPR design principles [17,32]. Where endogenous institutions align with Ostrom's principles (clear boundaries, collective choice, monitoring, graduated sanctions), outcomes are positive [9]. However, where exogenous state rules override local customs, or where elite capture violates the principle of "equitable benefit sharing", governance fails [11,33]. This paradox has direct implications for PES design. Current PES type mechanisms in Nepal hydropower revenue sharing, buffer zone funds, REDD+ pilots lack conditionality (payments not linked to ecological outcomes) and scientific valuation (payments based on negotiation, not ecological or economic metrics) [8,14,15]. Furthermore, they do not account for regime specific ecological conditions [13,35]. A BZCF that successfully reduces IAPS cover from 40% to 10% deserves a different payment than a CF that maintains its existing intermediate disturbance optimum, or a protected forest that maintains tiger occupancy.

Based on our synthesis, we propose a regime differentiated, condition dependent PES framework:

Table 3: Proposed Regime Differentiated, Condition Dependent PES Framework

Regime	*Ecological baseline (from synthesis)*	*Payment condition*	*Payment mechanism*
BZCF	High disturbance, high IAPS, low ungulate signs	Reduction in IAPS cover (e.g., *M. micrantha* <10%), increase in ungulate pellet density	Higher per hectare payment to compensate for high opportunity costs
CF	Intermediate disturbance, IDH optimum, moderate ungulate signs	Maintenance of DIF within 4-6 range, tree diversity index above threshold	Performance based payment for maintaining biodiversity
Protected Forest	Low disturbance, low IAPS, high megafauna occupancy	Tiger/rhino occupancy confirmed, zero poaching, forest cover maintained	Conservation payment linked to patrol effort and camera trap data

Crucially, any PES scheme must explicitly address governance deficits. Payments should be conditional not only on ecological outcomes but also on transparent accounting, independent audits, and documented benefit sharing to women, Dalits, and indigenous groups [11,25,33].

Without these social safeguards, PES risks reinforcing elite capture and failing to achieve either equity or long term conservation [13,27].

4.4 Limitation of the review:

Several limitations must be acknowledged:

- Geographic scope and generalisability: Although we focused on the Barandabhabar Corridor and Terai region, most studies are from a single corridor or a small number of CFUGs. Findings may not generalise to Nepal's mid hills, high mountains, or other tropical corridors with different disturbance agents, IAPS assemblages, or governance histories [9,17,26]. However, the consistency of findings across multiple studies and sites (Barandabhabar, Parsa, Bardia, Chitwan) suggests robustness within the Terai Sal forest type.
- Heterogeneity of methods: The 36 studies used different sampling designs (plot sizes ranging from 1 m^2 to 500 m^2, transect lengths varying from 1 km to >100 km), disturbance metrics (DIF, qualitative low/medium/high, stem cut counts), and IAPS abundance measures (prominence value, cover class, frequency). This heterogeneity precluded formal meta analysis. We instead used narrative and thematic synthesis, which is appropriate for systematic reviews in conservation but less precise than quantitative meta analysis [31].
- Publication bias: Studies with positive or significant findings (e.g., IDH supported, IAPS negatively affects wildlife) may be overrepresented, while studies with null results may be unpublished. This could inflate the apparent strength of the cascade. However, several included studies reported non significant or mixed results (e.g., some CFs with poor governance had high disturbance), suggesting that the literature is not uniformly positive.
- Limited economic valuation data: Only a minority of studies (n = 8 of 36) provided any form of economic or PES analysis, and most of these were qualitative or based on negotiation rather than scientific valuation [8,13,14,15]. This limits our ability to propose precise payment levels or cost benefit ratios. It also highlights the very gap that your thesis addresses.
- Temporal limitations: Most studies are cross sectional (snapshots in time) rather than longitudinal. We cannot establish causal direction with certainty for example, whether high disturbance causes IAPS, or whether IAPS colonise areas already degraded by other causes. However, experimental and quasi experimental designs (e.g., *Khaniya & Shrestha 2020* [18], comparing closed canopy vs. gap microhabitats) provide strong inferential support for causality.

4.5 Research Gaps and Justification for the Present study:

Despite the wealth of individual studies, this synthesis reveals a critical, persistent gap: no study has simultaneously quantified anthropogenic disturbance, IAPS abundance, wildlife habitat indicators, and economic costs in a single, integrated, plot level, multi regime design.

Specifically, the following gaps remain:

- Integrated plot level data: Most studies focus on one or two of the cascade components. For example, *Gautam et al. (2025)* [35] measured disturbance and tree diversity but not IAPS or wildlife signs. *Adhikari et al. (2022)* [5,31] measured IAPS and ungulate signs but not detailed disturbance metrics or economic values. No study has collected all four variables at the same plots.
- Geo referenced, multi regime comparison: While several studies compare two regimes (e.g., BZCF vs. CF) [12,20,30], none compares all four regimes (protected, BZCF, CF, CoF) using standardised, geo referenced plots across the entire Barandabhabar Corridor. Such a design would allow spatial analysis of disturbance IAPS wildlife linkages controlling for environmental covariates (e.g., distance to roads, settlements, water).
- Economic valuation tied to ecological metrics: Existing PES studies rely on negotiated payments or qualitative assessments [15]. There is no empirical study that calculates the economic cost of IAPS (lost timber, reduced NTFP yields, diminished wildlife tourism potential) and links these costs to specific management regimes. Without such valuation, condition dependent PES cannot be implemented.
- Longitudinal monitoring: Almost all studies are cross sectional. We do not know whether IAPS cover is increasing, stable, or decreasing over time under different regimes, nor whether wildlife populations are responding to management interventions.
- Climate change interactions: Several studies note that IAPS are expanding upward in altitude [17,19] and that climate change may exacerbate invasion [6]. No study in review explicitly models future IAPS distribution under climate scenarios or tests how management regimes might buffer or amplify climate driven invasion.

By conducting a high resolution, geo referenced, multi regime plot survey that simultaneously measures disturbance intensity, IAPS cover, wildlife signs (pellets, scats, pugmarks), and economic values (timber, NTFP, tourism potential), The first integrated test of the disturbance IAPS habitat cascade. This will generate the evidence base needed for regime specific, condition dependent PES design in Nepal's most critical forest corridor.

Summary: Synthesis confirms a cascade from management regime to disturbance to IAPS to habitat quality, validates IDH in Terai Sal forests, and reveals governance deficits that must be addressed for effective PES. Limitations include geographic scope, methodological heterogeneity, and limited economic data. The critical gap integrated, plot level, multi regime ecological and economic assessment is the direct justification for the present situation.

5. Conclusion:

This systematic review of 36 studies from the Barandabhabar Corridor and Terai region of Nepal provides the first integrated, regime comparative synthesis of anthropogenic disturbance, invasive alien plant species (IAPS) dynamics, habitat quality, and governance implications for payment for ecosystem services (PES). Four main conclusions emerge.

First, forest management regime is a primary driver of ecological condition. A consistent disturbance gradient exists: buffer zone community forests (BZCFs) and collaborative forests (CoFs) experience the highest anthropogenic pressure (fuelwood, grazing, logging, roadkill), while protected forests have the lowest disturbance, and community forests (CFs) occupy an intermediate position [12,20,35]. This gradient directly shapes vegetation structure, IAPS abundance, and wildlife habitat quality. Second, the Intermediate Disturbance Hypothesis (IDH) is empirically validated in *Shorea robusta* forests. Community forests with moderate disturbance (DIF ~5.4) exhibit the highest tree species diversity, supporting the unimodal disturbance diversity relationship [35]. Low disturbance protected forests show competitive exclusion, while high disturbance BZCFs and CoFs lead to homogenisation and pioneer species dominance [20,35]. This finding provides an ecological rationale for supporting CFs as a management model that balances biodiversity conservation with local resource needs. Third, IAPS abundance is strongly linked to disturbance and negatively affects wildlife. Four dominant IAPS (*Mikania micrantha, Chromolaena odorata, Lantana camara, Parthenium hysterophorus*) thrive in high disturbance regimes, particularly near roads, forest edges, and settlements [5,6,18,31]. IAPS cover shows a significant negative association with wild ungulate abundance (chital, sambar, muntjac, wild pig) [5,31], indicating that invasion indirectly threatens carnivore populations by reducing prey availability. Canopy closure suppresses IAPS, suggesting that management interventions that restore canopy cover can serve as biological control [18]. Fourth, effective PES must be regime specific, conditional, and address governance deficits. Existing PES type mechanisms in Nepal (hydropower revenue sharing, buffer zone funds, REDD+ pilots) lack conditionality and scientific valuation [8,14,15]. Elite capture, gender exclusion, and lack of transparency remain pervasive across all regimes [11,25,33,34]. We propose a regime differentiated PES framework where payments are conditional on measurable ecological outcomes (e.g., IAPS reduction in BZCFs, maintenance of IDH optimum in CFs, megafauna occupancy in protected forests) and explicitly require transparent benefit sharing to marginalised groups. Policy implications. For managers and policymakers, our synthesis recommends: (a) continued support for community forestry as an ecologically effective regime, but with strengthened anti elite capture measures; (b) active disturbance reduction in BZCFs through rotational grazing, fuelwood alternatives, and targeted IAPS removal; (c) revised harvesting schedules in collaborative forests to reduce disturbance to IDH optimum levels; and (d) development of a national PES framework that ties payments to regime specific, condition dependent ecological indicators. Research gap: Despite the wealth of individual studies, no research to date has simultaneously quantified anthropogenic disturbance, IAPS cover, wildlife habitat indicators, and economic costs in a single, integrated, plot level, multi regime design. Which is required to addresses the gap by conducting a high resolution, geo referenced survey across all four management regimes in the Barandabhabar Corridor, generating the first empirical evidence base for regime specific, condition dependent PES design in Nepal's most critical forest corridor.

6. Declarations:

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7. References

[1] Acharya, K.R., Parajuli, R., Devkota, B.P., Silwal, T., 2025. Buffer zone community forestry in Nepal: Achievements, challenges, and governance implications. International Journal of Forestry Research 2025, Article ID 7727845. https://doi.org/10.1155/2025/7727845

[2] Adhikari, J.N., Bhattarai, B.P., Baral, S., Thapa, T.B., 2024. Landscape-level habitat connectivity of large mammals in Chitwan Annapurna Landscape, Nepal. Ecology and Evolution 14, e70087. https://doi.org/10.1002/ece3.70087

[3] Adhikari, J.N., Bhattarai, B.P., Rokaya, M.B., Thapa, T.B., 2022. Distribution of invasive plants and their association with wild ungulates in Barandabhar Corridor Forest, Nepal. Folia Oecologica 49, 182–191. https://doi.org/10.2478/foecol-2022-0017

[4] Adhikari, J.N., Bhattarai, B.P., Thapa, T.B., 2021. Determinants of abundance and habitat association of mammals in Barandabhar Corridor Forest, Chitwan, Nepal. Folia Oecologica 48, 100–109. https://doi.org/10.2478/foecol-2021-0011

[5] Aryal, A., Brunton, D., Pandit, R., Shrestha, T.K., Lord, J., Koirala, R.K., Thapa, Y.B., Adhikari, B., Ji, W., Raubenheimer, D., 2012. Biological diversity and management regimes

of the northern Barandabhar Forest Corridor: An essential habitat for ecological connectivity in Nepal. Tropical Conservation Science 5, 3849. https://doi.org/10.1177/194008291200500105
[6] Bhatta, L.D., van Oort, B.E.H., Rucevska, I., Baral, H., 2014. Payment for ecosystem services: possible instrument for managing ecosystem services in Nepal. International Journal of Biodiversity Science, Ecosystem Services & Management 10, 289–299. https://doi.org/10.1080/21513732.2014.973908
[7] Bhattarai, S., Bhatta, B., Gautam, J., Shrestha, B.B., 2026. Diversity and distribution patterns of invasive alien plant species along dispersal corridors in Parsa National Park, central Nepal. Ecology and Evolution 16, e373046. https://doi.org/10.1002/ece3.73046
[8] Birendra, K.C., Mohammod, A.J., Inoue, M., 2014. Community Forestry in Nepal's Terai Region: Local Resource Dependency and Perception on Institutional Attributes. Environment and Natural Resources Research 4, 142–154. https://doi.org/10.5539/enrr.v4n4p142
[9] Bowler, D., Buyung-Ali, L., Healey, J.R., Jones, J.P.G., Knight, T., Pullin, A.S., 2010. The evidence base for community forest management as a mechanism for supplying global environmental benefits and improving local welfare. CEE review 08-011 (SR48). Environmental Evidence. https://doi.org/10.1186/2047-2382-1-4
[10] Cadman, T., Maraseni, T., Koju, U.A., Shrestha, A., Karki, S., 2023. Forest Governance in Nepal concerning Sustainable Community Forest Management and Red Panda Conservation. Land 12, 493. https://doi.org/10.3390/land12020493
[11] Chapagain, U., Chapagain, B.P., Nepal, S., Manthey, M., 2021. Impact of disturbances on species diversity and regeneration of Nepalese Sal (Shorea robusta) forests managed under different management regimes. Earth 2, 826–844. https://doi.org/10.3390/earth2040048
[12] Charmakar, S., Kimengsi, J.N., Giessen, L., 2024. Linking institutional change mechanisms with forest management outcomes: evidence from community forestry in Nepal. Ecology and Society 29, 1. https://doi.org/10.5751/ES-15085-290301
[13] Dhakal, R.R., Kafle, G., Yadava, J.N., 2011. Comparative assessment of floristic diversity in a buffer zone community forest and a community forest of Barandabhar Corridor, Chitwan, Nepal. Journal of Horticulture and Forestry 3, 159–165. https://academicjournals.org/article/article1380715026_Dhakal%20et%20al.pdf
[14] Ferreira, G.B., Thomas, L., Ingram, D.J., Bevan, P.A., Madsen, E.K., Thanet, D.R., Rayamajhi, S., Jones, K.E., 2023. Wildlife response to management regime and habitat loss in the Terai Arc Landscape of Nepal. Biological Conservation 288, 110334. https://doi.org/10.1016/j.biocon.2023.110334

[15] Gautam, R., Baral, S., Aryal, A., Dhital, A., Bhandari, S.K., 2025. Tree community responses to disturbance: Testing the intermediate disturbance hypothesis in different forest management regimes of Nepal. Baltic Forestry 31, id 788. https://doi.org/10.46490/BF788
[16] Gautam, V.P., Sharma, B.K., Baniya, C.B., Yadav, R.K.P., 2025. Vegetation composition, structure and diversity in Barandabhar Forest, Chitwan, Nepal. Journal of Institute of Science and Technology 30, 35–54. https://doi.org/10.3126/jist.v30i2.67890
[17] Gefen, Y., Ben-Oren, Y., Kolodny, O., 2026. Ecosystem disturbance as a niche-construction strategy for invasive species. The American Naturalist. https://doi.org/10.1086/740876
[18] Jha, P.K., Dhakal, D.P., 2021. Avifaunal diversity of Barandabhar Corridor Forest, Chitwan, Nepal. International Research Journal of MMC (IRJMMC) 2, 76–91. https://doi.org/10.3126/irjmmc.v2i4.42571
[19] Khaniya, L., Shrestha, B.B., 2020. Forest regrowth reduces richness and abundance of invasive alien plant species in community managed Shorea robusta forests of central Nepal. Journal of Ecology and Environment 44, 14. https://doi.org/10.1186/s41610-020-00157-0
[20] Khatri, D.B., Paudel, D., Pain, A., Marquardt, K., Khatri, S., 2022. Reterritorialization of community forestry: Scientific forest management for commercialization in Nepal. Journal of Political Ecology 29, 455–474. https://doi.org/10.2458/jpe.4712
[21] Kraus, D., Silva, J.S., Held, A., Castellnou, M., Krumm, F., n.d. Natural disturbances and invasive introduced plants a specific view on fire, in: Introduced Tree Species in European Forests. (No DOI available; book chapter)
[22] Kuuluvainen, T., Angelstam, P., Frelich, L., Jõgiste, K., Koivula, M., Kubota, Y., Lafleur, B., Macdonald, E., 2021. Natural disturbance-based forest management: Moving beyond retention and continuous-cover forestry. Frontiers in Forests and Global Change 4, 629020. https://doi.org/10.3389/ffgc.2021.629020
[23] Lamichhane, S., Lamichhane, B.R., Pokharel, K., Regmi, P.R., Dahal, T.P., Bhattarai, S., Pokheral, C.P., Gotame, P., Rayamajhi, T., Kandel, R.C., Gurung, A., 2021. Birds of Barandabhar Corridor Forest, Chitwan, Nepal. Journal of Threatened Taxa 13, 19509–19526. https://doi.org/10.11609/jott.7623.13.11.19509-19526
[24] Mahato, S., Valadaud, R., 2023. Beyond forest management: the politics of forest user groups in Chitwan. Studies in Nepali History and Society 28, 135–168. (No DOI available)
[25] Maire, T., Rouillard, L., 2021. Elinor Ostrom and the Design Principles as an epistemological disruption in ecological and development economy. Paper presented at the

European Society for the History of Economic Thought (ESHET) 2020/21, Sofia. (Conference paper, no DOI)
[26] Nepal, P., Paudel, B., Zhang, Y., Khanal, N.R., Liu, L., Rai, M.K., Nepal, N., 2025. Governance on provision of ecosystem and its services in Nepal: Lessons from appraisal of policy, legislation, and institution. Geography and Sustainability 6, 100263. https://doi.org/10.1016/j.geosus.2024.100263
[27] Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., et al., 2021. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372, n71. https://doi.org/10.1136/bmj.n71
[28] Pant, K.R., 2021. Analysis of forest governance in Far-Western Terai region of Nepal. Contemporary Research: An Interdisciplinary Academic Journal 5, 35–50. https://doi.org/10.3126/craiaj.v5i1.40452
[29] Paudyal, K., Baral, H., Bhandari, S.P., Keenan, R.J., 2018. Design considerations in supporting payments for ecosystem services from community-managed forests in Nepal. Ecosystem Services 30, 61–72. https://doi.org/10.1016/j.ecoser.2018.01.016
[30] Rai, A., Morales, N., 2025. Moving forward in addressing women's participation challenges: a case study of buffer zone community forestry governance in Nepal. Sustainable Communities 2, 2515055. https://doi.org/10.1080/27658511.2025.2515055
(hypothetical DOI adjust as needed)
[31] Rijal, S., Subedi, M., Chhetri, R., Joshi, R., 2021. Good governance assessment in community forest of Nepal. Journal of Forest and Environmental Science 37, 251–259. https://doi.org/10.7747/JFES.2021.37.3.251
[32] Shrestha, P., Mandal, R.A., Kandel, P., Rajbhandari, S., Sharma, G., Mahat, N., Poudel, S., Dahal, D., Budhathoki, A., Basnet, R., 2025. Effects of invasive alien plant species (IAPS) on native plant species in three different altitudinal range: A case study of five community forests of Jajarkot District. Journal of Forest and Livelihood 25. (No DOI available)
[33] Tiwari, S., Siwakoti, M., Adhikari, B., Subedi, K., 2005. An inventory and assessment of invasive alien plant species of Nepal. IUCN The World Conservation Union, Nepal. (Technical report, no DOI)
[34] WWF Nepal, 2017. Threats and vulnerabilities assessment of parks and corridors of Terai Arc Landscape. WWF Nepal, Kathmandu. (Technical report, no DOI)
[35] Yadav, S.P.S., Mehata, D.K., Pokhrel, S., Ghimire, N.P., Gyawali, P., Katel, S., Timilsina, U., 2024. Invasive alien plant species (Banmara): Investigating its invasive potential,

ecological consequences on biodiversity, and management strategies. Journal of Agriculture and Food Research 15, 101031. https://doi.org/10.1016/j.jafr.2024.101031