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Land-use change and human-elephant conflict in Sumatran Elephant Conservation

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ABSTRACT
This review aims to explore human-elephant conflict in the context of Sumatran elephant conservation, accounting for the impacts of land-use change and elephants' ability to move freely. The researchers used a method for identifying and selecting information from a large database, Scopus, which they accessed on May 16, 2026. They followed a series of steps to choose the studies, including checking document types and the content of the information, and arrived at 31 studies from different countries. They also used VOSviewer to visualize relationships among various topics. The main finding of this review is that human-elephant conflict is the most significant problem, and the key challenge is achieving peaceful coexistence. They saw that most of the information about this problem comes from India and China. There is not as much information from Indonesia and Sumatra. The review says the problem with Sumatran elephants is not that they raid crops, but how land is used and how the elephants can move. To help save the Sumatran elephants, it suggests people should use computer models to predict where problems will occur, study how the elephants move, and involve the local community in reporting problems and setting up warning systems.
Keywords: Bibliometrics, Co-occurrence Analysis, Scientometrics, VOSviewer, Wildlife conservation

1. Introduction

Human-elephant conflict occurs in areas where elephants live and people farm, settle, or build. It's not about one elephant eating a crop. Often it's because people are changing the land, farming more, and making it hard for elephants to move around and find food and water [1]-[4]. This is a particular problem for elephants, which require a lot of space in which to exist, forage for food and water, and travel between their territories. Recently, researchers have begun to view human-wildlife conflict differently, using maps and computers to study it. Some studies, such as Njomi's, have shown that the loss of elephants' habitat can lead to conflicts with humans [5]-[7].

Research from Indonesia has also shown links between land use and conservation issues, but adds nothing to what is known about elephants [8]. They help us understand the larger picture of human-elephant interactions and how land-use practices and community governance can influence the risk of conflict with elephants.

Human-elephant conflict is a challenge that necessitates more explicit information on the dynamics of land-use change and the nature of local governance that influences conflict risk. Elephants require home ranges, and their movement is related to survival [9]-[12]. Human land-use activities, such as habitat conversion and

agricultural expansion, can result in conflicts with elephants. Understanding such dynamics is therefore essential for mitigating human-elephant conflict.

The Sumatran elephant (*Elephas maximus* sumatranus) is a good example of this. Its remaining habitat occurs within a matrix of forest remnants, plantations, smallholder agriculture, settlements, road networks, and conservation areas. Evidence from Sumatra and Indonesia links conflict with habitat conversion, forest fragments, protected-area edges, and continuing negative interactions despite mitigation efforts [13]-[16]. The wider Asian elephant literature remains dominated by studies from India, China, Nepal, Sri Lanka, Thailand, Vietnam, and Malaysia [2,5,17,18].

Although several reviews discuss human-elephant conflict mitigation, fewer studies have systematically connected land-use change, habitat connectivity, thematic evolution, geospatial methods, and Sumatran elephant evidence gaps within a reproducible Scopus-based review. This article, therefore, addresses four questions: how the literature on land-use change and human-elephant conflict has developed; how the geographic and taxonomic evidence is distributed; which themes dominate the relationship among land-use change, habitat connectivity, and conflict risk; and which research and policy gaps are most relevant to Sumatran elephant conservation. The contribution is not a claim that no previous review exists. Rather, the article narrows the evidence base to land-use and connectivity mechanisms and positions Sumatran elephant conflict as a landscape-connectivity and land-use governance problem, not merely as local crop raiding or a technical mitigation issue.

2. Methods

2.1. Research design and search strategy

This review combined PRISMA 2020-based screening with VOSviewer-assisted thematic co-occurrence mapping. The systematic component identified and synthesized studies that directly or comparatively addressed human-elephant conflict, land-use change, habitat fragmentation, corridor disruption, and connectivity. The bibliometric mapping component was used to summarize thematic structure, not to rank authors or institutions. It relied on a controlled, thematic vocabulary recorded in the screening workbook to compare recurring themes across the metadata corpus. This mixed review design is appropriate for environmental and conservation research because transparent screening can be combined with network visualization to clarify the structure of a developing evidence base [19,20,8].

The literature search was conducted on May 16, 2026. For screening purposes, consistent bibliographic fields were exported from Scopus using Publish or Perish. These fields include the title, availability of the abstract, keywords provided by authors, source title, publication year, document type, DOI, citation information, and, when available, metadata regarding the affiliation. I used Scopus as my source of information to see where all the information is coming from and to ensure all details are consistent. The specific part of Scopus I looked at was the title, abstract, and keywords, which Scopus refers to as TITLE-ABS-KEY and which I pulled from the exported details.

The search for information was initially without a lower year limit. However, it was later limited to 2022-2026 to find recent data on land use, connectivity, and the likelihood of conflict, especially with Asian elephants. The search also focused on human-elephant coexistence in the space and the impact on the land. Older sources were only used if they helped with reporting or mapping.

The search used words and symbols to make sure it found the right information. It looked for things like “human-elephant conflict”. Also used other terms to ensure no important studies were missed. These terms included “crop raiding”, “wildlife conflict”, “land use”, “fragmentation”, and “elephant”. The search also looked at topics such as plantations, agriculture, and how elephants affect crops.

The exact search terms used were: TITLE-ABS-KEY ((“elephant conflict” OR “human elephant conflict” OR "elephant-human conflict" OR "elephant conflict" OR "crop raiding" OR "crop damage" OR “elephant depredation” OR “wildlife conflict” OR "human-wildlife conflict") AND ("land use" OR "land-use change" OR "land cover change" OR "land-use/land-cover" OR LULC OR deforestation OR "habitat loss" OR “habitat fragmentation” OR “landscape fragmentation” OR “forest fragmentation” OR “habitat connectivity” OR corridor* OR plantation* OR agriculture OR “oil palm”) AND (elephant* OR “Asian elephant” OR “Elephas maximus” OR “Sumatran elephant” OR “*Elephas maximus* sumatranus”)).

Table 1. Search protocol and database criteria.

Component	Description
Database	Scopus
Access tool	Publish or Perish
Search date	May 16 2026
Search fields	Title, abstract, and keywords as far as available in Scopus metadata exported through Publish or Perish. Screening used title, DOI, source title, document type, abstract availability, and full-text validation recorded in the workbook.
Publication-year range	No lower year limit was imposed at the search stage. The focused synthesis included studies published between 2022 and 2026 to represent the most recent land-use, connectivity, and conflict-risk literature.
Language criteria	No separate language filter was documented in the workbook. The focused synthesis required sufficient English bibliographic metadata and codable full text.
Document types retained	Journal articles and review articles.
Duplicate checking	Duplicate records removed = 0. DOI, title, and author information were used as duplicate-checking fields in the screening workbook.
Automation tools	No record was excluded by automation. Records marked ineligible by automation = 0.
Coder documentation	The workbook recorded one final coding decision for each record. Formal inter-coder reliability was not calculated. Final coding was documented through structured fields and validation notes.
Review framework	PRISMA 2020.
Thematic mapping tool	VOSviewer Online for thematic co-occurrence mapping, overlay visualization, density visualization, and cluster summary from the refined thematic co-occurrence network.
Exact Scopus field	TITLE-ABS-KEY, exported through Publish or Perish metadata fields.
Boolean and wildcard logic	OR combined synonyms within each concept block; AND combined conflict, land-use/connectivity, and elephant blocks; corridor*, plantation*, and elephant* captured plural and derivative forms.
Search string	TITLE-ABS-KEY (("human-elephant conflict" OR "human elephant conflict" OR "elephant-human conflict" OR "elephant conflict" OR "crop raiding" OR "crop damage" OR "elephant depredation" OR "wildlife conflict" OR "human-wildlife conflict") AND ("land use" OR "land-use change" OR "land cover change" OR "land-use/land-cover" OR LULC OR deforestation OR "habitat loss" OR "habitat fragmentation" OR "landscape fragmentation" OR "forest fragmentation" OR "habitat connectivity" OR corridor* OR plantation* OR agriculture OR "oil palm") AND (elephant* OR "Asian elephant" OR "Elephas maximus" OR "Sumatran elephant" OR "*Elephas maximus* sumatranus"))
Manual verification	Title, abstract, keywords, DOI, source title, document type, retrieval status, and full text (where available) were manually checked. Coding differences were resolved through author consensus.

Table 2. Inclusion and exclusion criteria.

Type	Operational criterion
Inclusion	Scopus-indexed journal articles or reviews addressing human-elephant conflict, crop raiding, coexistence, movement, mitigation, or elephant conservation with a land-use, habitat, fragmentation, corridor, agriculture, plantation, protected-area, or spatial-planning component.
Inclusion	Studies directly relevant to Indonesia, Sumatra, or Sumatran elephants, or comparatively relevant to Asian elephant landscapes through land-use change, habitat connectivity, or corridor governance.
Exclusion	Non-article and non-review documents, records without a clear elephant or HEC focus, captive or welfare-only studies, studies without a land-use, habitat, or connectivity component, and reports not retrieved for full-text coding.

Focused exclusion	Studies with only broad conceptual relevance after refined thematic eligibility were excluded from the 31-study focused synthesis, although they could still support context or methodological discussion.

2.2. PRISMA 2020 screening and refined thematic eligibility

The way we picked the studies followed the PRISMA 2020 framework. We started with 200 studies from Scopus. We checked for duplicates based on DOI, title, and author. We did not find any duplicates. We did not automatically throw out any studies. We excluded 24 studies that were of the wrong type. This left us with 176 studies to consider.

Of 41 studies, we excluded those that were not related to elephants, conflict, land use, habitat, or connectivity. We attempted to get 135 studies. We could not get 60 of them. We reviewed 75 studies to determine eligibility.

We did not use the studies we could not get because we could not be sure they were really relevant. This could have introduced a slight bias into our results for studies published in hard-to-access journals. To limit this problem, we recorded the studies we obtained and those we did not. We used the rules to determine whether a study was eligible. We also kept all the information from the studies so we could look at the themes later.

We checked the title, abstract, keywords, type of study, DOI, where it was published, and the full text if we had it. If we did not agree on something, we talked about it. Made a decision together. This is how we ended up with 31 studies to look at closely. We also kept 128 studies with information and themes, so we could use them to make a map with VOSviewer. This way, we could still focus on our studies and also look at the bigger picture.

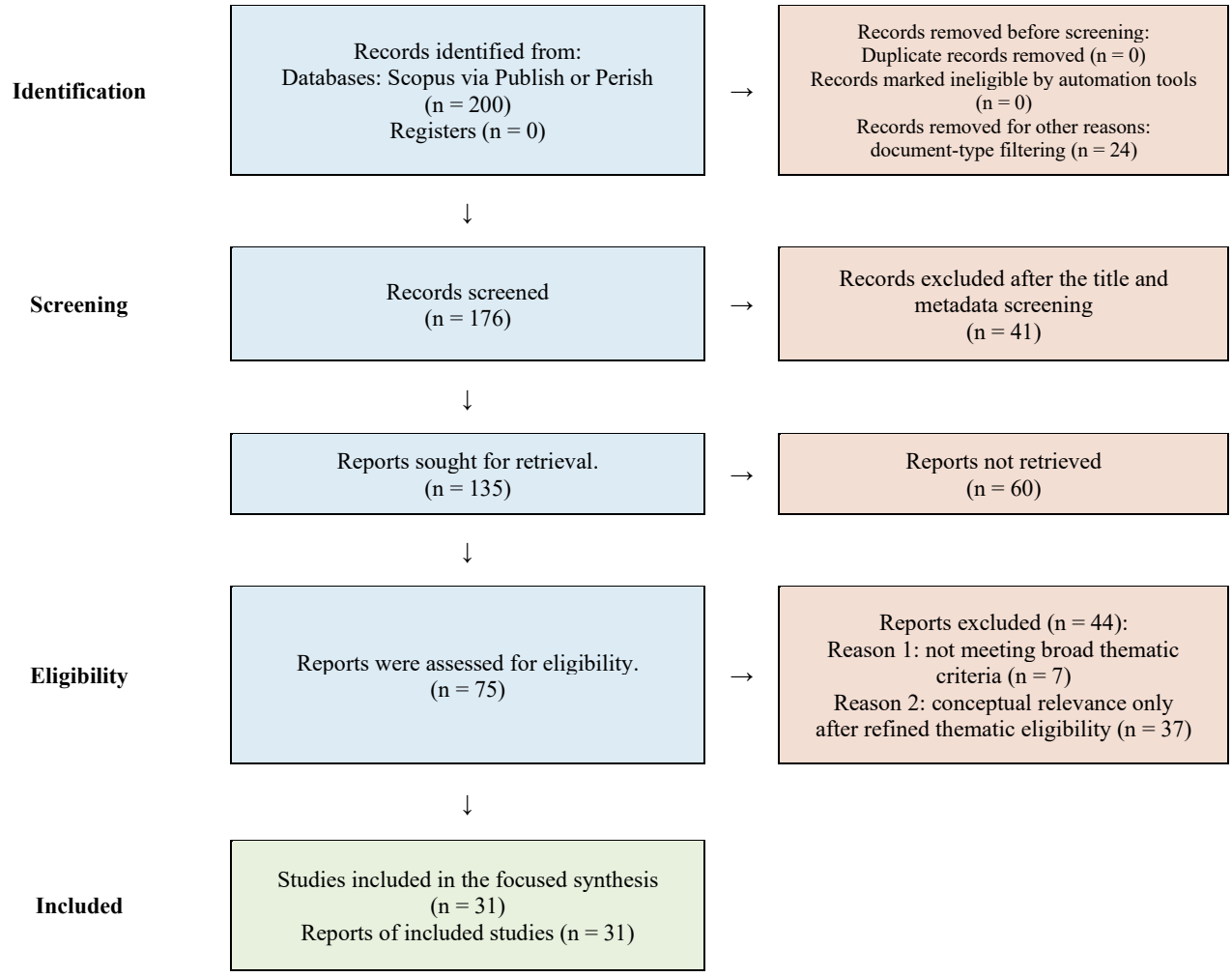

Figure 1. PRISMA 2020 flow diagram for the focused systematic review. The broad thematic eligibility corpus (n = 68) serves as an intermediate audit trail; the final included studies = 31.

Table 3. Summary of PRISMA 2020 screening.

PRISMA item	n
Records identified from Scopus through Publish or Perish	200
Duplicate records removed	0
Records marked ineligible by automation	0
Records removed through document-type filtering	24
Records screened by title and metadata	176
Records excluded after title and metadata screening	41
Reports sought for retrieval	135
Reports not retrieved	60
Reports assessed for eligibility	75
Reports excluded for not meeting broad thematic criteria	7
Reports were excluded for conceptual relevance only after the refined eligibility	37
Broad thematic eligibility corpus	68
Studies included in the focused synthesis	31

2.3. Controlled thematic co-occurrence mapping using VOSviewer

Thematic co-occurrence mapping was conducted using VOSviewer Online, accessed during the analysis period. The input came from Scopus metadata exported through Publish or Perish and was processed through the screening workbook. The unit of analysis was a controlled thematic term set derived from titles, abstracts, and available keyword fields, then harmonized through documented coding. The resulting maps should therefore be read as VOSviewer-assisted thematic co-occurrence maps, not as a stand-alone author-keyword or citation-performance bibliometric analysis. Co-occurrence analysis used full counting at the document level and VOSviewer association-strength normalization. Before mapping, non-substantive labels, screening-status labels, and truncated-text artifacts were removed. Synonymous or truncated terms were standardized through a thesaurus file. The minimum occurrence threshold was set at three. From 128 documents, 24 controlled thematic terms met the threshold and formed 205 co-occurrence links in four thematic clusters. Reported indicators include occurrence, number of links, total link strength, average publication year, cluster membership, temporal publication trend, geographic distribution, and overlay visualization.

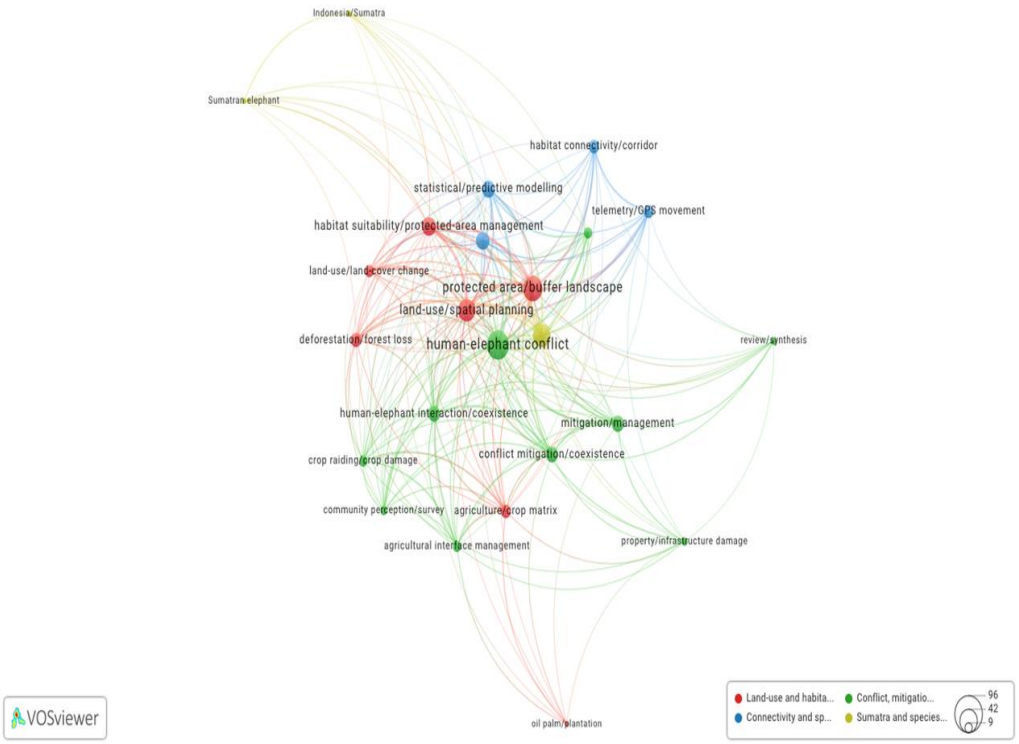

Figure 2. Network visualization of controlled thematic co-occurrence in the literature on human-elephant conflict, land-use change, and habitat connectivity.

Table 4. Cluster summary of VOSviewer-assisted controlled thematic co-occurrence.

Cluster	Dominantly controlled terms	Final interpretation
Cluster 1 Land-use and habitat transformation Terms: 7; TLS: 641; avg. year: 2023.97	protected area/buffer landscape; land-use/spatial planning; habitat suitability/protected-area management; deforestation/forest loss; agriculture/crop matrix; land-use/land-cover change; oil palm/plantation	Land-use transformation, forest loss, protected areas, and agricultural matrices that shape conflict risk.
Cluster 2 Conflict, mitigation, and coexistence Terms: 10; TLS: 658; avg. year: 2023.76	human-elephant conflict; mitigation/management; conflict mitigation/coexistence; human-elephant interaction/coexistence; agricultural interface management; crop raiding/crop damage; human injury/death or safety risk; community perception/survey; property/infrastructure damage; review/synthesis	Human-Elephant Interaction, Crop Damage, Safety Impacts, Community Response, and Mitigation Strategies.
Cluster 3 Connectivity and spatial modeling Terms: 4; TLS: 306; avg. year: 2023.98	geospatial/GIS/remote sensing; statistical/predictive modeling; habitat connectivity/corridor; telemetry/GPS movement	Habitat connectivity, movement corridors, telemetry, GIS, remote sensing, and spatial risk modeling.
Cluster 4 Sumatra and species focus. Terms: 3; TLS: 193; avg. year: 2024.18	Asian elephant; Indonesia/Sumatra; Sumatran elephant	Species- and regional-focused elements that highlight the relevance of Asian and Sumatran elephants, and the Indonesian/Sumatra context.

Note: TLS = total link strength. The clusters indicate four major streams: land-use and habitat transformation, conflict mitigation and coexistence, connectivity and spatial modeling, and Sumatra/species focus.

Table 5. Top ten controlled thematic terms ranked by total link strength.

Controlled thematic term	Occurrences	Links	TLS	Avg. year	Cluster
human-elephant conflict	63	23	176	2023.63	2
land-use/spatial planning	40	23	173	2024.35	1
protected area/buffer landscape	50	23	166	2023.92	1
Asian elephant	43	20	161	2024.16	4
habitat suitability/protected-area management	28	20	110	2023.96	1
geospatial/GIS/remote sensing	26	21	100	2023.85	3
statistical/predictive modelling	24	20	95	2024.38	3
conflict mitigation/coexistence	21	19	87	2024.00	2
human-elephant interaction/coexistence	21	21	78	2023.71	2
mitigation/management	22	18	70	2023.64	2

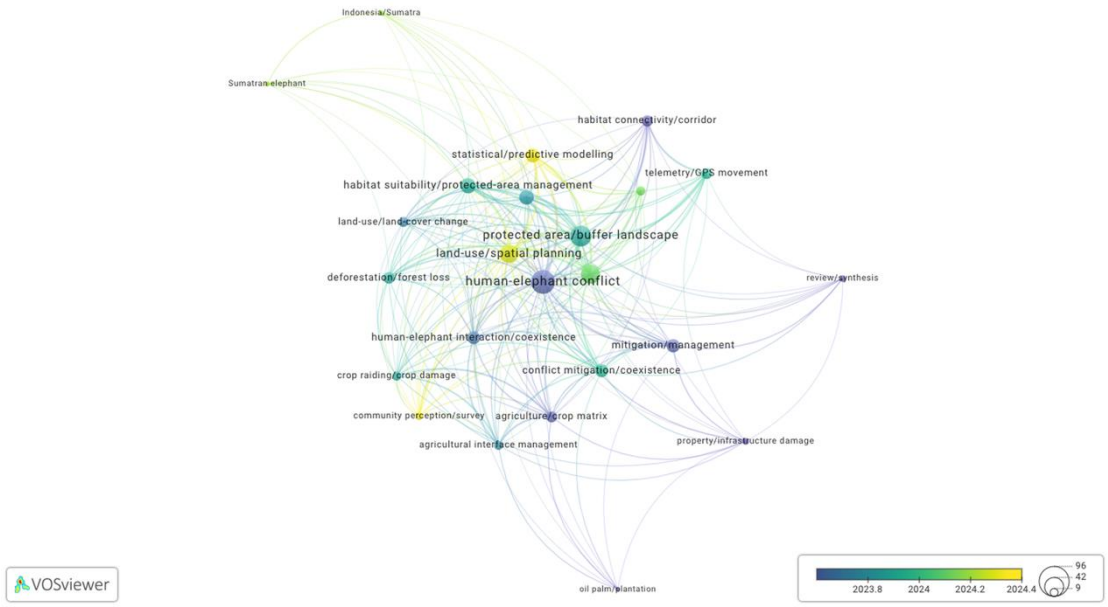

Figure 3. Overlay visualization of temporal development in controlled thematic terms based on average publication year.

2.4. Data extraction and coding procedure

Data extraction used a structured coding workbook. Each record was coded by bibliographic identity, geographic and taxonomic focus, conflict type, land-use driver, habitat-connectivity component, method, data source, analytical scale, conservation implication, contribution to research gaps, citation role, and relevance to Sumatran elephant conservation. The workbook documented one coding decision for each study. Each study had one coding decision recorded in the workbook. Formal inter-coder reliability was not calculated; instead, all decisions were documented in structured fields, checked against the study objectives and inclusion criteria, and finalized through author discussion and consensus to reduce coding bias.

Direct relevance was assigned to studies conducted in Indonesia or Sumatra, or to studies that explicitly discussed Sumatran elephants. Comparative relevance was assigned to Asian elephant studies outside Sumatra when their findings could be cautiously transferred through land-use change, fragmented habitats, protected-area edges, agricultural interfaces, movement corridors, or conflict governance. Thematic synthesis was developed by repeatedly grouping the coding results into: land-use and land-cover change; protected-area edges and buffer landscapes; agricultural interfaces and crop raiding; habitat connectivity and corridor disruption; spatial risk mapping; coexistence governance; and Sumatran elephant evidence gaps.

Table 6. Data extraction and coding categories.

Coding dimension	Recorded variables
Bibliographic identity	Record ID, authors, year, title, source, DOI, document type, and retrieval source.
Geographic and taxonomic focus	Country or region, geographic coverage, species focus, and direct or comparative relevance to Sumatra.
Conflict and land-use variables	Conflict type, land-use driver, agriculture or plantation interface, protected-area edge, and habitat or connectivity component.
Methodological variables	Geospatial/GIS/remote sensing, predictive modeling, telemetry/GPS/movement analysis, review or synthesis, and survey/interview/community perception.
Synthesis variables	Conservation implications, contribution to research gaps, citation role, reading priority, and focused synthesis status.
Bibliometric and mapping variables	Publication year, country or region, source title, controlled term occurrence, links, total link strength, average publication year, cluster membership, and overlay visualization.

3. Results and Discussion

3.1. Screening results and evidence structure

The final focused synthesis consisted of 31 studies published between 2022 and 2026. The largest contributions appeared in 2023, 2025, and 2022, indicating recent growth in research linking human-elephant conflict, land-use change, and spatial conservation planning. The corpus covered nine country/region categories and a diverse set of conservation, ecology, land-use, geography, and sustainability journals. The studies focused on farm-interface dynamics, range expansion, corridor use, deterrent methods, demography, protected-area assessment, conflict fatalities, feeding ecology, risk perception, and environmental drivers of crop raiding [21]-[39].

The thematic co-occurrence map showed human-elephant conflict to be the most dominant controlled term, with 63 occurrences, 23 links, and a total link strength of 176. The strongest cluster was conflict, mitigation, and coexistence (TLS = 658), followed closely by land-use and habitat transformation (TLS = 641). These clusters dominate because most conflict records are generated where farms, settlements, plantations, and protected-area edges overlap with elephant movement routes. Habitat suitability/protected-area management reflects the growing use of GIS and remote sensing, while mitigation/coexistence reflects the shift from reactive deterrence to planned coexistence strategies. Telemetry/GPS movement and statistical/predictive modeling mark a more recent turn toward anticipatory risk mapping.

The final set of studies was mainly focused on Asian elephant research outside Indonesia. The targeted synthesis included countries such as India, China, Thailand, Malaysia, Nepal, Sri Lanka, Vietnam, and Indonesia. The significant contributions of India and China are justified by their extensive areas with Asian elephant conflicts, extensive monitoring programs, and substantial research capacities in conservation. Studies in Malaysia, Sri Lanka, Thailand, Nepal, and Vietnam on protected areas, plantation settings, corridor planning, and community-based conflict mitigation provide important comparative data. However, these studies do not replace specific evidence from Sumatra, due to the differences in land ownership, plantation histories, decentralized governance, and habitat configurations across different regions [1,2,5,6,17,18].

We identified only 4 focused studies directly relevant to Indonesia, Sumatra, or Sumatran elephants. Kuswanda et al. reviewed human-elephant conflict on Sumatra Island; Abdullah et al. examined habitat characteristics and preferences of Sumatran elephants in Aceh; Syahran et al. developed a habitat-based spatial prediction of conflict risk in Minas, Riau; and Yuningsih et al. reported on negative human-Sumatran elephant interactions in the Gunung Raya Landscape. This difference is an important empirical gap highlighted by the review, which stresses the need for careful interpretation of comparative Asian elephant data when applied to Sumatra [13]-[16].

The temporal distribution shows that the focused synthesis mainly relies on recent publications. The body of evidence peaked in 2023, continued in 2025, and included studies from 2026, a pattern that indicates not a saturated, well-established field, but rather a rapidly evolving literature landscape in which spatial modeling, governance for coexistence, and landscape connectivity are emerging as key areas of analysis.

The temporal distribution shows that the focused synthesis is based on numerous recent publications. The body of evidence peaked in 2023, was still active in 2025, and included studies from 2026. This trend reflects a rapidly evolving literature landscape rather than a well-established, saturated field, with spatial modeling, coexistence governance, and landscape connectivity emerging as key areas of analysis.

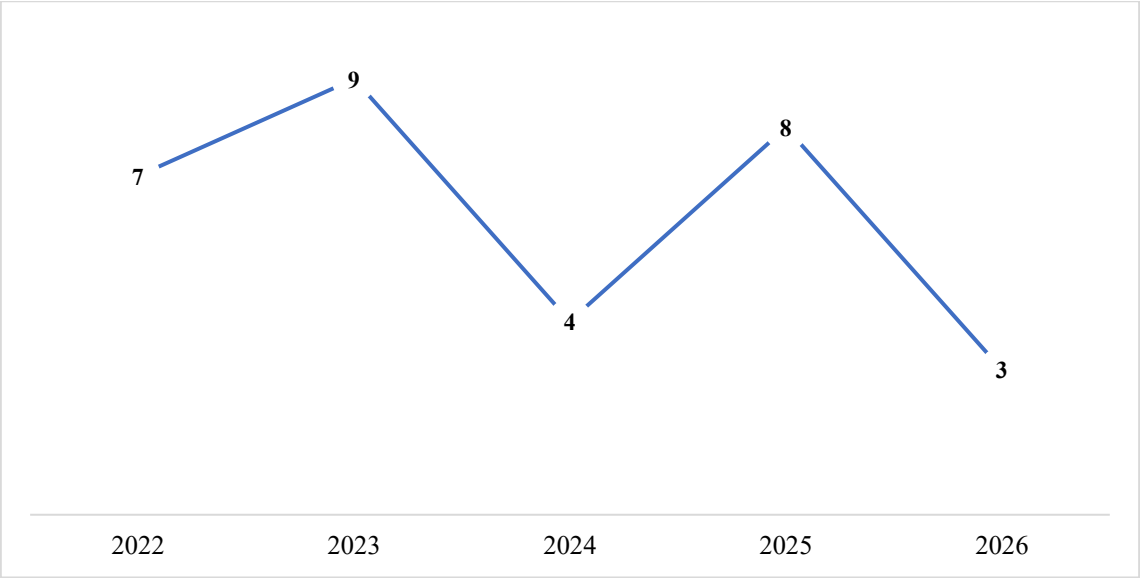

Figure 4. Temporal trend of focused studies included in the systematic review.

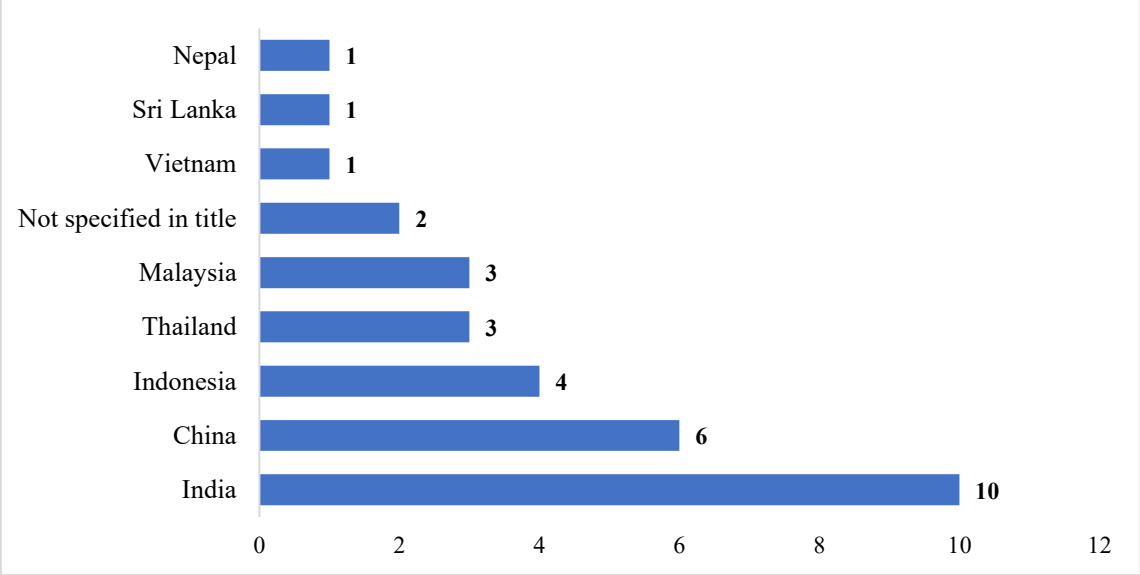

Figure 5. Geographic distribution of focused studies included in the review.

Geographically, comparative evidence is mainly available from India, China, Thailand, and Malaysia, whereas direct evidence from Indonesia is relatively limited. India is well represented because of the high incidence of conflict at the interface of farms and forests and the availability of long-term monitoring data providing useful datasets. China is also important, as the expansion of the elephant range in Yunnan has received considerable spatial and policy attention. Malaysia and Thailand offer examples from plantations and corridors that are particularly useful for understanding the situation in Sumatra, where oil palm plantations, roads, settlements, and fragmented forests often overlap with elephant movements. This pattern highlights the need for more location-specific evidence on conflict risk, habitat connectivity, and land-use governance in areas inhabited by Sumatran elephants.

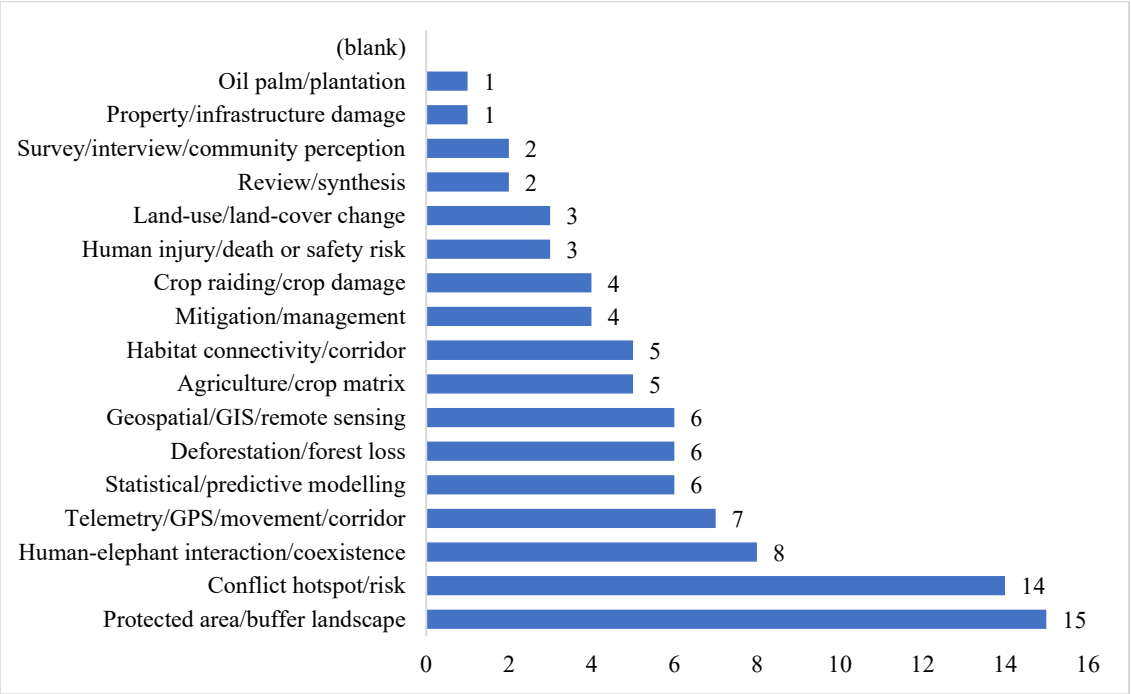

Figure 6. Main thematic and methodological coding categories in the concentrated synthesis.

In the coding profile, it is stated that keyword analysis should be thematic rather than descriptive. Protected areas and buffer zones are prominent since they represent the spatial regions where conservation limits intersect with community land use. Geospatial/GIS/remote sensing and statistical/predictive modeling are prevalent in recent studies because they enable the prediction of conflict before on-the-ground incidents intensify. Human-elephant interaction/coexistence and mitigation/management are commonly mentioned since conservation practices are evolving from mere deterrence to negotiated coexistence, effective risk communication, and institutional collaboration.

Table 7. Overview of the geographical and methodological characteristics of the focused synthesis.

Country/region	n	Dominant species	Relevance to Sumatra	Dominant evidence focus	Dominant method
India	10	Asian elephant	Comparative relevance (10)	Land-use change core (5); Habitat/connectivity core (2); HEC mitigation (2); Supporting article (1)	Geospatial/GIS/remote sensing (2); Telemetry/GPS/movement/corridor (2)
China	6	Asian elephant	Comparative relevance (6)	Land-use change core (3); Habitat/connectivity core (2); Supporting article (1)	Geospatial/GIS/remote sensing (3); Telemetry/GPS/movement/corridor (2)
Indonesia	4	Sumatran elephant	Direct relevance (4)	Land-use change core (3); HEC mitigation (1)	Review/synthesis (1); Geospatial/GIS/remote sensing (1)
Thailand	3	Asian elephant	Comparative relevance (3)	Habitat/connectivity core (2); HEC mitigation (1)	Telemetry/GPS/movement/corridor (2)
Malaysia	3	Asian elephant	Comparative relevance (3)	Land-use change core (1); HEC mitigation (1); Habitat/connectivity core (1)	Telemetry/GPS/movement/corridor (1)

Unspecified Asian elephant study	2	Asian elephant	Comparative relevance (2)	Supporting article (1); Land-use change core (1)	Not explicit from the title metadata
Nepal	1	Asian elephant	Comparative relevance (1)	Land-use change core (1)	Statistical/predictive modeling (1)
Sri Lanka	1	Asian elephant	Comparative relevance (1)	Land-use change core (1)	Not explicit from the title metadata
Vietnam	1	Asian elephant	Comparative relevance (1)	Land-use change core (1)	Statistical/predictive modeling (1); Survey/interview/community perception (1)

The comparative Asian elephant evidence base is larger than the direct Indonesian evidence, as confirmed by the geographic-methodological profile. The direct evidence of Sumatran elephants came from Indonesia, but the majority of comparative studies came from China and India. The primary methods for connecting land-use change, habitat connectivity, and conflict risk were geospatial analysis, predictive modeling, telemetry, and review-based synthesis. This combination is crucial because conflict prevention necessitates both institutional interpretation and spatial prediction: governance analysis explains whether mitigation can be implemented, while maps show where risk concentrates.

3.2. Changes in land use fuel conflict

In the focused synthesis, the most consistent driver was found to be changes in land use and land cover. Research from China, India, Nepal, and Indonesia has linked the risk of conflict to changes in buffer zones, forest loss, agricultural expansion, settlement growth, and broader land-use transitions [1]–[4], [15]. Based on related GFJ data on land-use change in the Gayo Highlands [11], forest cover may decline while agriculture, plantations, settlements, and open land increase over time. These results suggest that conflict hotspots are seldom random. They typically appear where landscapes rearranged for infrastructure, production, and settlement collide with elephants' movement and foraging habits.

This interpretation is important in the Sumatran context because elephant ranges frequently cross protected-area boundaries into plantations, agricultural fields, forest fragments, and settlements. Evidence from Indonesia shows that conflict persists where habitat patches are embedded in human-dominated landscapes and where spatial planning fails to accommodate elephant movement fully [13]–[16]. GFJ studies on other land-use areas, buffer-zone wildlife conflict, and community perceptions [9,10,12] suggest that conservation issues concerning protected landscapes are intrinsically linked to livelihood strategies, local attitudes, and land-use decisions. Therefore, zoning, restoration, buffer-zone governance, and control of high-risk land conversion along movement routes must be linked to conflict management.

3.3. Corridors, spatial conflict risk, and habitat connectivity

Of the 31 focused studies, 15 coded habitat connectivity. Comparative studies of Asian elephants [5]–[7], [26] suggest that landscapes dominated by humans may act as imperfect, high-risk corridors or barriers between isolated patches of habitat. This finding is central to the review's novelty, shifting the focus from where conflict occurs to how elephants move in changing environments and why conflict is clustered at certain edges, corridors, and agricultural interfaces.

Geospatial techniques can be employed in support of this interpretation. Habitat suitability modeling, GIS-based multi-criteria analysis, ecological network modeling, circuit theory, telemetry, satellite tracking, and spatial prediction [38,6,26,29,15] can be used to identify conflict-prone areas ahead of incidents escalating. These tools can be used to incorporate land-cover change, crop distribution, road networks, settlements, water sources, known elephant routes, distance to forests and protected areas, and documented conflict events in Sumatra. Anticipatory planning is useful in that it allows managers to prioritize community engagement, early warning coverage, and corridor restoration before conflict becomes chronic.

3.4. Coexistence governance, community reactions, and agricultural interfaces

Crop raiding and agricultural damage remain the most obvious manifestations of human-elephant conflict, but research shows that it also affects livelihoods and governance. Local responses are influenced by perceived losses, trust in authorities, access to compensation, and the concrete costs of deterrents, according to studies on farmers' perceptions, willingness to engage in conflict management, alternative crop strategies, and coexistence practices [17,18,32,39]. Wildlife conflict can cause quantifiable livelihood losses and influence

community attitudes to conservation, as demonstrated by GFJ evidence from Sumatran tiger conflict in a national park buffer area [10,12].

Sumatran elephant conservation requires more than corridor protection alone. Communities living around elephant habitats also need practical deterrents, credible compensation or insurance mechanisms, locally trusted early warning systems, and participation in land-use decisions. Coexistence governance should therefore be treated as a multi-actor process involving conservation agencies, village institutions, land managers, plantation companies, researchers, and affected communities [17,18,32,39].

Table 8. Thematic synthesis of focused studies.

Theme	Synthesis meaning	Implication
Land-use and land-cover change	Forest loss, agricultural expansion, settlement growth, and plantation interfaces repeatedly shape conflict risk.	Integrate conflict prevention into spatial planning, land allocation, and environmental permitting.
Protected-area edges and buffer landscapes	Conflict tends to concentrate along protected-area edges and human-dominated buffer landscapes.	Strengthen buffer zone governance, edge restoration, and local coordination.
Corridors and habitat connectivity	Corridors are shrinking, and pathways for movement are fragmenting as elephant movement overlaps with human land use.	Protect functional corridors, restore degraded corridors, and validate corridors with movement and community data.
Agricultural interfaces and crop raiding	Elephants are attracted to crop fields, which concentrates economic losses on local communities.	Implement site-specific deterrents, early warning systems, compensation mechanisms, and crop-selection strategies.
Spatial risk mapping	GIS, remote sensing, telemetry, ecological networks, and predictive modeling support anticipatory planning.	Create dynamic spatial databases combining conflict incidents, land cover, road networks, water sources, and elephant movement.
Governance of coexistence	Mitigation depends on community engagement, institutional trust, corporate responsibility, and the coordination of actors.	Design multi-actor governance that links conservation agencies, villages, companies, and local government.
Sumatran elephant evidence gap	Only four focused studies provide direct evidence on Indonesia/Sumatra or Sumatran elephants.	Prioritize longitudinal, geospatial, movement-based, and institutional studies specific to Sumatra.

3.5. Conservation gaps and future research agenda for Sumatran elephants

This review has highlighted a major gap in the evidence for conservation. The wider Asian elephant literature provides tools for habitat suitability assessments, corridor modeling, risk mapping, early warning, and coexistence planning; however, little direct evidence exists from Sumatra [13]–[16]. This disparity is important, as conservation decisions in Sumatra must compete with strong land-use pressures, fragmented habitats, competing private and public land claims, plantation expansion, road construction, and ongoing development pressure.

Future research should prioritize a more operational agenda for Sumatran elephant landscapes. First, multi-year land-cover change should be linked with conflict-event records to evaluate how plantation expansion, road development, restoration, or settlement growth alters conflict risk. Second, telemetry, satellite tracking, UAV monitoring, and community-based reporting should be combined to distinguish habitual movement routes from incidental crop raiding. Third, AI-based prediction, machine learning, and dynamic risk maps should be validated with field evidence and updated regularly. Fourth, early warning systems should be linked to compensation procedures, village response teams, and plantation management. Fifth, corridor governance should be studied as a social-political process that involves land tenure, Indigenous and local ecological knowledge, corporate responsibility, climate change impacts, socio-economic valuation, and cross-sector planning [5,6,26,29,15].

Table 9. Conservation gaps and future research agenda.

Gap	Evidence from the review	Recommended direction
Direct Sumatra evidence	Four studies were coded as direct evidence for Indonesia/Sumatra or Sumatran elephants.	Expand site-specific datasets in Aceh, Riau, Jambi, Bengkulu, South Sumatra, and Lampung.
Landscape dynamics	Many studies address land-use change, but few link land-cover trajectories with longitudinal conflict records.	Combine multi-year land-cover change with conflict-incident databases.
Corridor modelling	Connectivity appeared in 15 of the 31 focused studies, but Sumatra-specific corridor models remain limited.	Use circuit theory, least-cost paths, telemetry, and participatory corridor validation.
Plantation-edge conflict	Oil palm and plantation landscapes are important in Sumatra, but their governance mechanisms remain understudied.	Examine company-community-state coordination and elephant-compatible production landscapes.
Policy integration	Mitigation is often fragmented across conservation, agriculture, spatial planning, and local government.	Integrate conflict mitigation into spatial planning, restoration priorities, and regional development policy.
AI-based prediction and early warning	Newer studies have predictive modeling, but operational warning systems for Sumatra are limited.	Create machine learning risk models linked to village alerts, ranger response, and compensation processes.
Telemetry, UAV, and citizen science	Movement studies and community reports are rarely integrated in Sumatran elephant landscapes.	Combine GPS collars, UAV/thermal monitoring, ranger patrol data, and citizen-science conflict reports.
Climate and landscape connectivity	Climate change and corridor disruption may jointly affect elephant movement and crop-raiding risk.	Model climate-sensitive forage, water availability, habitat connectivity, and future corridor suitability.
Socio-economic valuation and local knowledge	Livelihood costs, Indigenous/local ecological knowledge, and institutional trust are under-represented.	Estimate economic losses, compensation feasibility, and local knowledge contributions to corridor governance.

3.6. Methodological contribution and limitations

The methodological contribution of this article is the use of refined eligibility after broad PRISMA-based screening. This procedure prevents the final synthesis from becoming too diffuse and keeps the title, research questions, and evidence base aligned. At the same time, VOSviewer-assisted thematic co-occurrence mapping provides a transparent summary of how coded themes cluster within the broader literature on human-elephant conflict, land-use change, and habitat connectivity. The article therefore contributes a thematic bibliometric map and a focused synthesis, rather than a full citation-performance evaluation of authors, institutions, or journals.

There are various restrictions on this review. First, relevant studies that are only indexed in Web of Science, Dimensions, CrossRef, Google Scholar, institutional repositories, or local journals might not be covered, it this depends on Scopus metadata exported via Publish or Perish. Second, availability bias may affect the focused synthesis, as 60 reports could not be retrieved. Third, papers using highly localized terms like "elephant damage," "elephant depredation," "conservation conflict," or non-English terminology might have been overlooked even though the search string contained multiple alternatives to "human-elephant conflict". Fourth, when methodological details were scarce, some coding variables were derived from titles and metadata. Fifth, direct research on Sumatran elephants is still scarce. The results should be interpreted as a structured map of recent evidence based on Scopus rather than as a comprehensive account of all research on elephant conflicts, even though these limitations do not invalidate the synthesis.

4. Conclusion

This review shows that conflicts between humans and elephants are closely linked to landscape changes. Land-use change, habitat fragmentation, protected-area edges, agricultural interfaces, and corridor disruption often

cause or facilitate conflict. A larger thematic corpus was refined to meet eligibility criteria, yielding 31 studies for focused synthesis using the PRISMA 2020 process. Although little direct evidence exists on Sumatran elephants, comparative Asian elephant evidence predominates the final corpus.

The main practical and policy implications for Sumatran elephant conservation are that conflict mitigation needs to be integrated with local livelihood protection, habitat connectivity, and land-use governance. Technical solutions such as fencing, deterrents, early warning systems, and compensation are insufficient without corridor protection, restoration of degraded movement routes, participatory spatial planning, coordination at the edges of plantations, and better integration between conservation policy and regional development planning. To develop evidence-based landscape strategies for Sumatran elephant coexistence, future research should integrate geospatial analysis, movement ecology, community-based conflict records, socio-economic valuation, and institutional analysis.

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Author Contributions
A.I. and R. conceptualized the review and designed the methodological framework. A.I., G.F., A.M.P., R.F.N., S., and R. contributed to literature screening, thematic coding, VOSviewer-assisted thematic co-occurrence mapping, data interpretation, manuscript drafting, and revision. R. supervised the study and approved the final manuscript. All authors read and approved the final version of the manuscript.

Data Availability Statement
The screening workbook, coded database, VOSviewer-compatible controlled-term files, and supporting figures generated during this review are available from the corresponding author upon reasonable request. No new field data were collected for this review.

Conflict of Interest
The authors declare no conflict of interest.

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