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Guardians of giants: a bibliometric analysis of mahout-elephant relationships and management takeaways for the Nilgiris

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The study presents a systematic bibliometric review of mahout-elephant relations and management with specific applications for the Nilgiris region. Asian elephants face significant survival threats including habitat loss and captivity-based exploitation, with approximately 15,000 individuals in captivity across their range countries. Effective conservation strategies require a deep understanding of captive elephant management and welfare issues. Through a systematic review of 63 peer-reviewed articles from 2014-2024, spanning disciplines including animal welfare science, conservation biology, and veterinary medicine, this study identifies critical trends and knowledge gaps. Bibliometric analysis revealed two distinct research clusters with minimal overlap: elephant welfare/management studies and computational approaches. Thailand, particularly Chiang Mai University, emerged as a key research hub with strong international collaborations. Research output has increased significantly since 2016, with a notable acceleration around 2020. Thematic analysis identified concerning shifts in mahout demographics, with younger, less experienced individuals replacing traditional mahouts, compromising vital knowledge transmission. Tourism significantly impacts elephant welfare, with 82% of surveyed Thai camps chaining elephants for extended periods. Health concerns include tuberculosis, with seroprevalence reaching 36% in some populations. Research gaps include limited studies on long-term training effects, elephant psychology, rewilding outcomes, and technological applications in welfare assessment. This review highlights the need for interdisciplinary approaches

targeting both elephant and human welfare, emphasizing collaborative efforts among mahouts, local communities, researchers, and conservation agencies to ensure sustainable Asian elephant conservation. The findings and recommendations provide a framework for evidence-based management strategies at the Theppakadu Elephant Camp in the Nilgiris and other similar facilities.

KEYWORDS

elephant-mahouts interaction, captive wildlife management, cultural knowledge transfer, ethnozoology, zoonotic disease prevention

1 Introduction

Asian elephants (Elephas maximus) represent one of the world's most iconic and culturally significant megafauna, yet they face unprecedented challenges to their survival in the 21st century. As keystone species, they play critical ecological roles in forest ecosystems across South and Southeast Asia, influencing vegetation structure, seed dispersal, and habitat maintenance for countless other species (Campos-Arceiz and Blake, 2011). Despite their ecological importance and protected status, Asian elephant populations have declined by an estimated 50% over the last three generations, with current wild populations numbering approximately 40,000-50,000 individuals (Williams et al., 2020). The relationship between humans and Asian elephants spans millennia, with documented evidence of captive management dating back to the Indus Valley Civilization (Sukumar, 2006). Traditionally, this relationship was mediated through mahouts who are specialized elephant handlers possessing deep intergenerational knowledge of elephant behavior, psychology, and management. This traditional knowledge system evolved over centuries through experiential learning and oral transmission of knowledge between generations of mahouts, belonging to specific communities or families who are specialized in elephant care (Hart and Sundar, 2000). In contemporary contexts, approximately 15,000 Asian elephants live in captivity across their range countries, representing about one-third of the total population (Sukumar, 2006). These captive elephants live in places including temples, tourism camps, and conservation centers. Sometimes they are used for logging operations. There are crucial challenges in the management of these captive elephants and these challenges pertain to the intersection of animal welfare, conservation biology, cultural heritage preservation, and sustainable livelihoods for their human caretakers.

Recent decades have witnessed transformations in mahout-elephant relationship which is a direct outcome socioeconomic changes, shifting tourism demands, regulatory frameworks, and evolving welfare standards (Mumby, 2019). The greatest effect of these transformations is upon the traditional knowledge transmission. The transmission of traditional knowledge was disrupted and the changes altered the dynamics between mahouts and elephants affecting both elephant welfare and conservation outcomes (Crawley et al., 2019).

We know that there is cultural, ecological, and conservation significance for mahout-elephant relationships. Despite this, systematic research examining this dynamic interface remains fragmented across disciplines including zoology, anthropology, veterinary science, and tourism studies. There is no extant comprehensive bibliometric analysis mapping the research landscape in this field. Besides this, there are no identified key research clusters, or synthesized emerging trends and knowledge gaps.

Therefore this systematic review addresses this gap by:

1. Examining relationship between mahout and elephant, and its evolution over time through bibliometric and thematic analysis
2. Assessing the impact of diverse management practices on elephant welfare based on evidence from the literature
3. Analyzing rewilding programs with their potential applications and similar conservation approaches
4. Identifying research gaps that direct future study
5. Synthesizing bibliometric trends in Asian elephant research that helps to guide evidence-based conservation strategies

The findings are relevant with regard to the Nilgiris region of Tamil Nadu, India, which hosts the historic Theppakadu Elephant Camp, which was established in 1972 and currently housing 25 captive elephants which are managed by traditional and contemporary mahouts. To successfully execute this study, bibliometric analysis and thematic synthesis are used. With an aim to enhance both elephant welfare and mahout livelihoods in this specific region, the study furnishes an evidence-based framework. The study thus contributes to the broader conservation goals for Asian elephants.

2 Materials and methods

2.1 Search strategy and data sources

By using the large amount of data spread across Scopus database, a large compendium of peer reviewed multidisciplinary academic journals, we could find that there are relevant literatures pertaining to elephant management and conservation. In the review

which is based on this database, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009; Page et al., 2021) are used to ensure methodological rigor and transparency. To capture relevant literature, we developed a search strategy using the following keyword combinations:

- "mahouts" OR "livelihood" OR "elephant trainers" OR "elephant keeper" OR "elephant workers"
- AND "livelihood" AND "tribes" OR "tribal"

This search strategy was designed to identify studies examining the relationship between elephants and their human handlers, with particular attention to traditional knowledge systems and socioeconomic aspects of mahout communities.

2.2 Inclusion and exclusion criteria

Studies were selected based on predefined inclusion and exclusion criteria to ensure relevance and maintain quality standards. The criteria were established before the search process and are detailed in Table 1.

The selected timeframe (2014-2024) ensured currency of findings while providing sufficient breadth to identify trends over the past decade. We focused on peer-reviewed journal articles to maintain scientific rigor, excluding gray literature, conference proceedings, and book chapters. While this approach may exclude some valuable information, it ensured that all included studies had undergone peer review.

2.3 Study selection process

The study selection process followed the PRISMA framework and involved multiple stages:

1. **Initial search**: The search query returned 416 potentially relevant articles from the Scopus database.
2. **Screening by parameters**: Articles were screened against the predetermined inclusion/exclusion criteria (publication date, document type, language, publication status, source type).
3. **Full-text assessment**: The remaining 63 articles were assessed through full-text review to confirm their relevance to mahout-elephant relationships, management practices, and conservation approaches.

TABLE 1 Inclusion and exclusion criteria for the systematic review.

CRITERIA	INCLUDED	EXCLUDED
Time limit	2014 – 2024	<2014
Document type	Articles	Conference papers, Book chapters, review, Editorial
Languages	English	Non-English
Publication stage	Final	In Press
Source type	Journal	Trade journal
Open access	All open access	Restricted access

The entire selection process is illustrated in Figure 1 (PRISMA Flow Diagram), which documents the number of studies identified, included, and excluded at each stage, along with the reasons for exclusions.

The PRISMA Flow Diagram included studies that underwent bibliometric analysis focusing on keyword frequency and co-occurrence networks, institutional production trends, geographical distribution of research, and international collaboration patterns. Statistical analyses included Chi-square tests for keyword distribution, ANOVA for publication rates among institutions ($F = 12.37$, $P < 0.001$, LSD = 4.21), and network centrality metrics for collaboration assessment, revealing Thailand's significance as a research hub (betweenness centrality = 0.62 ± 0.08, $P < 0.01$).

2.4 Data extraction and analysis

2.4.1 Bibliometric analysis

For the bibliometric analysis, we extracted the following data from each included article:

- Publication year
- Authors and institutional affiliations
- Country of study
- Journal/source
- Keywords
- Citation metrics

This data was analyzed using R Studio (version 4.1.0) with the 'bibliometrix' package (Aria and Cuccurullo, 2017) to identify patterns, trends, and relationships within the literature. Specific bibliometric analyses included:

1. **Keyword frequency analysis**: Using text mining techniques to identify the most frequently occurring terms in the corpus, visualized through tree maps. Chi-square tests were employed to determine whether the distribution of keywords across major categories showed significant differences ($\alpha = 0.05$).
2. **Institutional productivity assessment**: Tracking the publication output of the most active research institutions over time. Analysis of variance (ANOVA) was used to test for significant differences in publication rates between institutions ($\alpha = 0.05$), with *post-hoc* least significant difference (LSD) tests to identify specific differences between institutions.
3. **Geographical distribution and collaboration network analysis**: Mapping the global distribution of research and

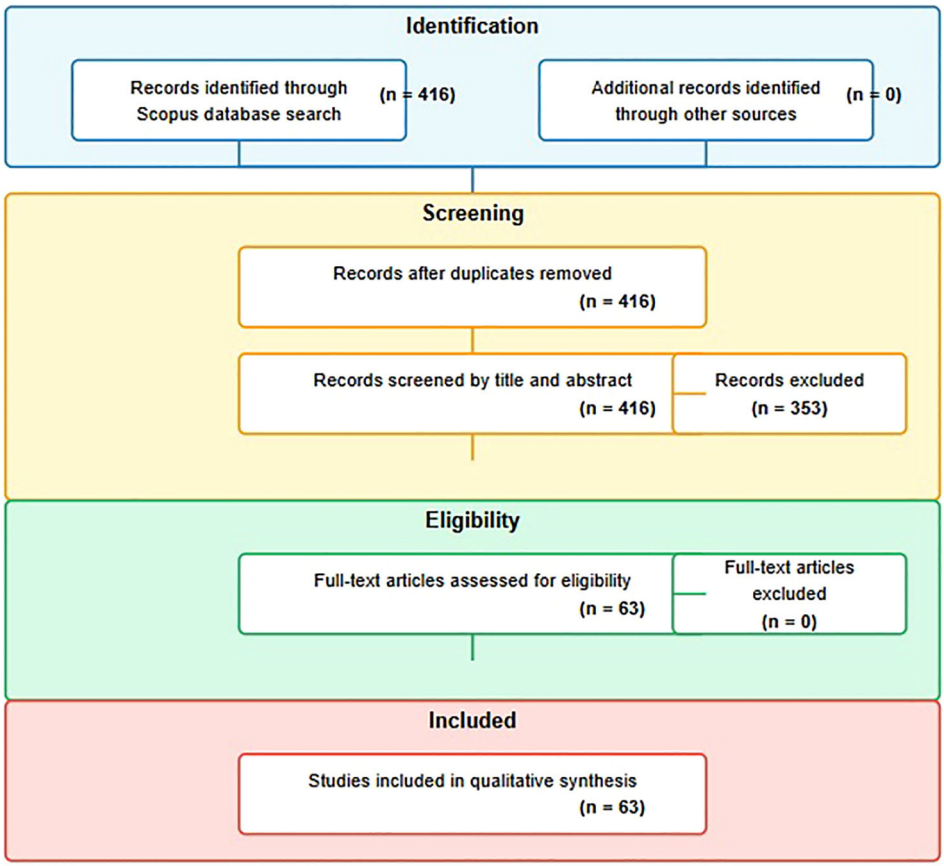

FIGURE 1
PRISMA flow diagram.

identifying international collaboration patterns. Network metrics including betweenness centrality were calculated to quantify the importance of different countries in facilitating research collaboration.

4. **Publication trend analysis:** Source based examination of temporal trends in publication output. To identify potential changes in research momentum, paired t-tests were used to compare publication rates before and after 2020.
5. **Co-occurrence network analysis:** Based on co-occurrence of keyword, this analysis creates a network visualization of research topics to identify thematic clusters. Modularity analysis was conducted to confirm the cluster structure, and t-tests were used to compare inter-cluster versus intra-cluster connection density.

2.4.2 Thematic analysis

It was found that the best framework for the thematic analysis is the framework approach described by Ritchie and Spencer (1994) and further developed by Gale et al. (2013), which is particularly suitable for analyzing qualitative data, especially when the objectives of the investigation are set in advance. So, this framework is chosen for the study. This approach involves five key stages:

1. **Familiarization:** Identifying recurring themes by reading all 63 articles to gain an overview of the content.
2. **Developing a thematic framework:** During familiarization research objectives and emergent themes were identified. Based on this an initial coding framework is created.
3. **Indexing:** Systematically applying the thematic framework to all articles, coding relevant sections according to the identified themes.
4. **Charting:** Reorganizing the data according to the appropriate thematic references, creating thematic matrices to compare information across studies.
5. **Mapping and interpretation**: Analyzing the key characteristics as laid out in the charts, identifying patterns, associations, concepts, and explanations in the data.

The thematic framework was structured around four primary domains:

- Historical context and traditional knowledge

- Shifts in mahout practices
- Management practices and elephant welfare
- Conservation approaches and technological innovations

Within each domain, we identified subthemes through an iterative process, refining the framework as analysis proceeded. Two researchers independently coded a subset of articles to ensure consistency, achieving an inter-coder reliability of 87% (Cohen's kappa = 0.84).

3 Results

3.1 Bibliometric analysis findings

3.1.1 Keyword frequency analysis

The analysis of keyword frequency revealed significant patterns in research focus within the field of mahout-elephant studies. As illustrated in Figure 2, the term "elephant" was the most frequently occurring keyword, appearing in 25 articles (7% of total keyword occurrences). Other prominent terms included "article" (18 occurrences), "female" (17 occurrences), "male" (16 occurrences), and "human" (16 occurrences).

The keyword distribution demonstrated a notable balance between biological/behavioral terms (such as "animal welfare" and "veterinary medicine") and computational terms (including "big data" and "data mining") (Bakirarar et al., 2022). Chi-square analysis confirmed significant differences in the distribution of keywords across major categories (χ^2 = 37.45, P < 0.01), indicating distinct research priorities within the field.

This keyword analysis reveals the multidisciplinary nature of mahout-elephant research, spanning traditional welfare concerns and emerging computational approaches. The prominence of terms related to both elephants and humans underscores the relationship-focused nature of much of the research, while the presence of computational terms suggests growing interest in applying advanced data analysis techniques to elephant conservation challenges.

3.1.2 Institutional productivity trends

Analysis of institutional publication output from 2014–2024 identified Chiang Mai University as the most productive institution in mahout-elephant research, with a projected total of approximately 50 publications by 2025 (Figure 3). The University of Turku ranked second with an estimated 18 publications, followed by Mahidol University (12 publications), Universitas Gadjah Mada (10 publications), and Chiang Mai University Animal Hospital (8 publications).

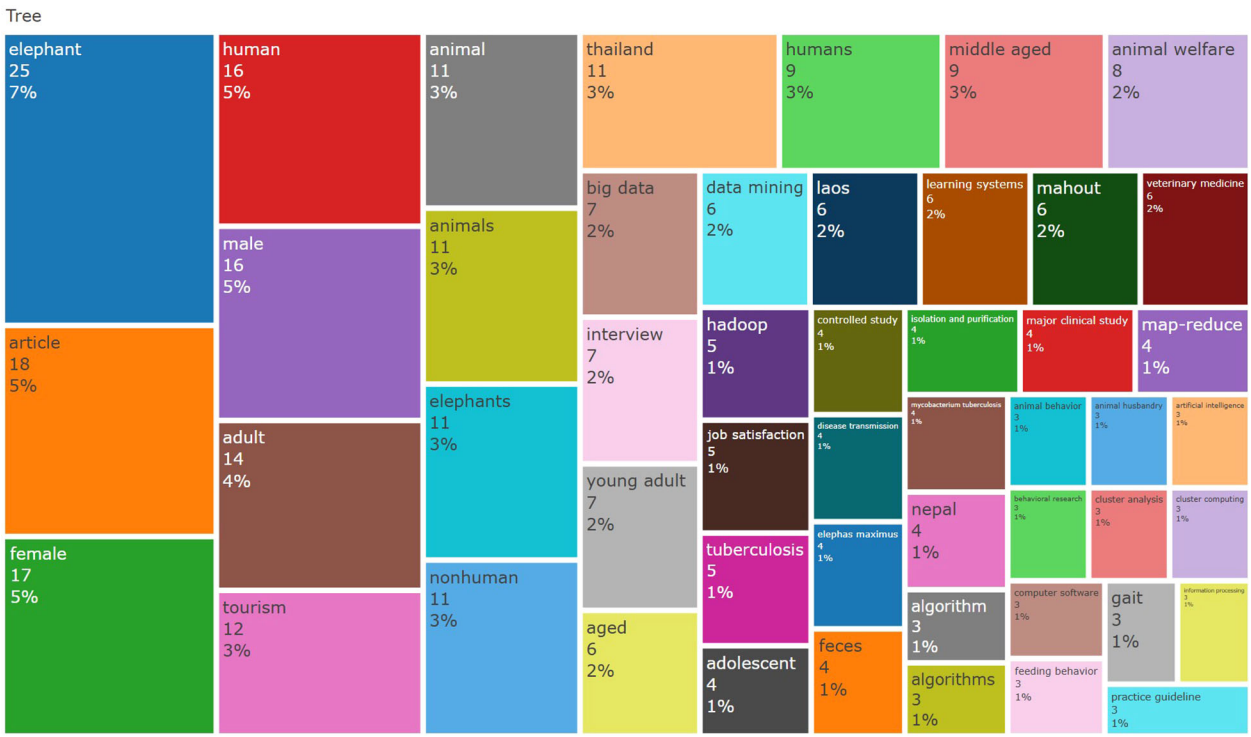

FIGURE 2
Tree map visualization of keyword frequency in mahout-elephant research literature (2014-2024). The size of each rectangle is proportional to the frequency of keyword occurrence in the analyzed literature (n=63). "Elephant" is the dominant term (25 occurrences, 7%), followed by "article" (18), "female" (17), "male" (16), and "human" (16). The visualization demonstrates the balance between computational terms (big data, data mining) and biological/behavioral terms (animal welfare, veterinary medicine) in the research landscape. Chi-square test for keyword distribution showed significant differences among major categories (χ^2 = 37.45, P < 0.01).

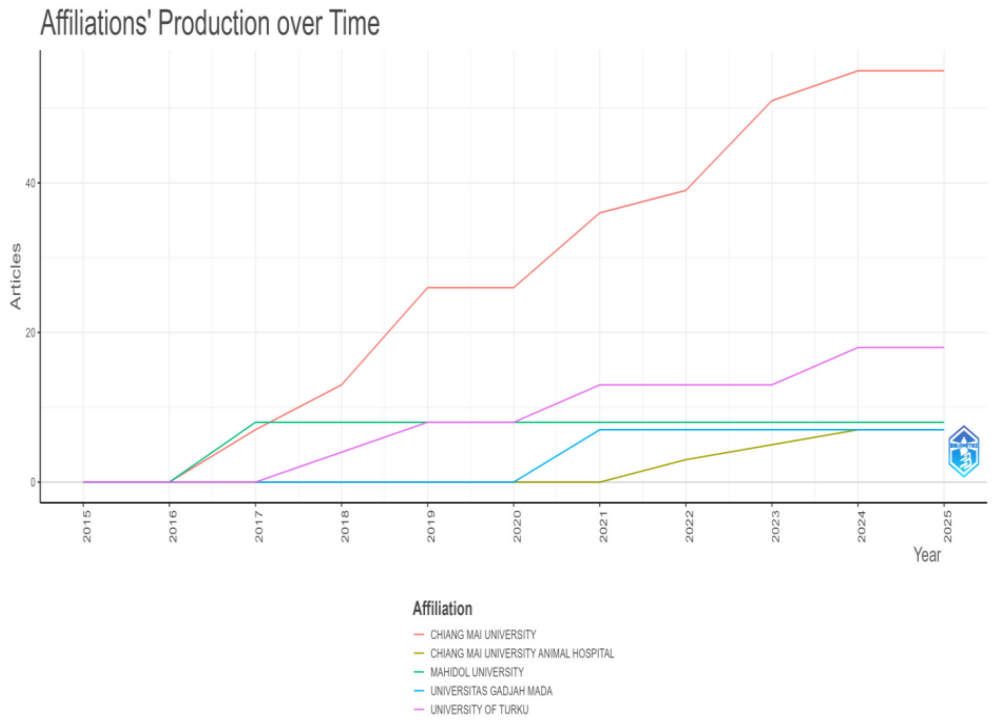

FIGURE 3
Institutional publication output on mahout-elephant research from 2016-2025. Data represent cumulative number of publications by top five contributing institutions over a 10-year period. Chiang Mai University demonstrated the highest productivity (50 articles), followed by University of Turku (18 articles), Mahidol University (12 articles), Universitas Gadjah Mada (10 articles), and Chiang Mai University Animal Hospital (8 articles). Analysis of variance showed significant differences in publication rates between institutions ($F = 12.37$, $P < 0.001$, $LSD = 4.21$).

ANOVA testing revealed significant differences in publication rates between institutions ($F = 12.37$, $P < 0.001$, $LSD = 4.21$). Chiang Mai University demonstrated significantly higher productivity compared to all other institutions, while the University of Turku showed significantly higher output than the three lower-ranked institutions. These findings highlight the concentration of research expertise in specific institutional centers, particularly in Thailand.

Temporal analysis of institutional productivity showed consistent growth in publication output from Chiang Mai University since 2016, with accelerated production beginning around 2019. The University of Turku demonstrated more modest but steady growth throughout the period, while the other institutions maintained relatively consistent output levels.

3.1.3 Geographical distribution and international collaboration

The analysis of international research collaboration patterns (Figure 4) revealed Thailand as a central hub in the global network of mahout-elephant research. The strongest collaborative relationship existed between Thailand and the USA (7 joint publications), followed by Finland-Myanmar (3 publications) and Laos-France (3 publications). Additional notable collaborations included USA-Finland (2 publications) and USA-Myanmar (2 publications).

Network centrality analysis confirmed Thailand's pivotal role in the collaboration network, with the highest betweenness centrality (0.62 ± 0.08, $P < 0.01$), indicating its function as a key connector between different research communities. This position reflects Thailand's importance both as a range country with significant captive elephant populations and as a center of research excellence in this field.

The geographical distribution of research showed a concentration in Southeast Asia, particularly Thailand, with secondary clusters in South Asia (India, Sri Lanka) and connections to research institutions in Europe and North America with emerging research contributions from the middle east region (Nasir et al., 2023). This pattern aligns with the distribution of captive Asian elephant populations but suggests potential gaps in research coverage for some range countries.

3.1.4 Publication trends by source

Temporal analysis of publication sources (Figure 5) identified PEERJ as the journal with the highest cumulative publication count in mahout-elephant research. The journal showed a particularly marked increase in publications around 2020, contributing significantly to the overall growth in research output during this period.

A paired t-test comparing publication rates before and after 2020 confirmed a significant acceleration in research output across sources ($t = 5.24$, $P < 0.001$). ANOVA testing revealed significant differences in publication rates across journals ($F = 8.76$, $P < 0.01$, $LSD = 1.58$), with PEERJ demonstrating significantly higher output

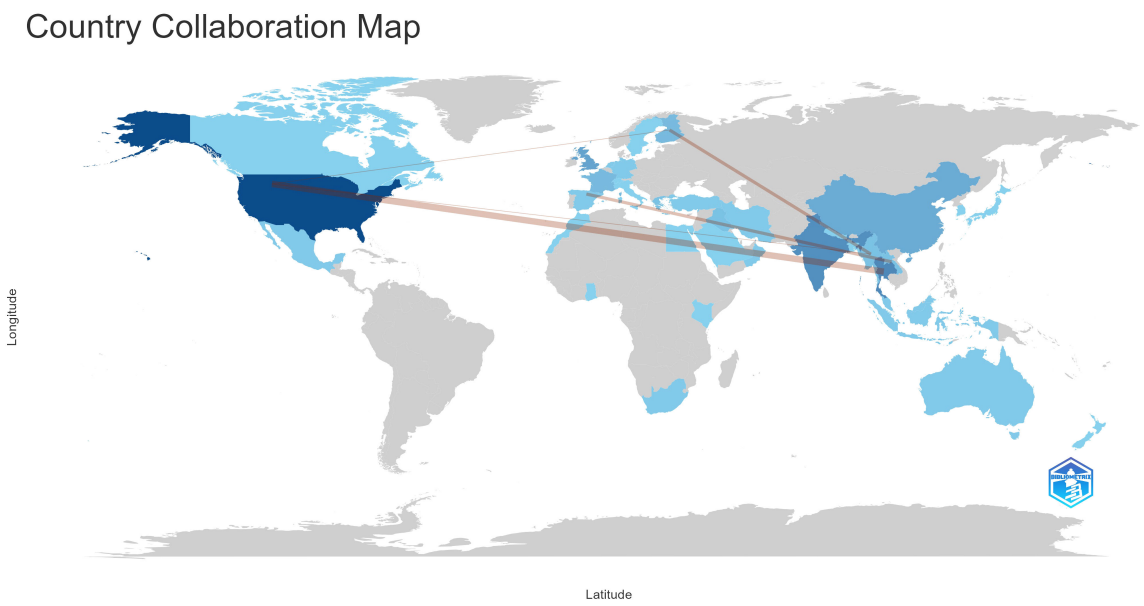

FIGURE 4
Global collaboration network on mahout-elephant research (2014-2024). Network visualization showing collaborative relationships between countries publishing on mahout-elephant dynamics (n=63 publications). Line thickness represents collaboration frequency, with the Thailand-USA collaboration being the strongest (7 joint publications), followed by Finland-Myanmar (3) and Laos-France (3). Node size represents the number of publications from each country. Statistical analysis using network centrality metrics showed Thailand had the highest betweenness centrality (0.62 ± 0.08), indicating its role as a key connector in international research efforts ($P < 0.01$).

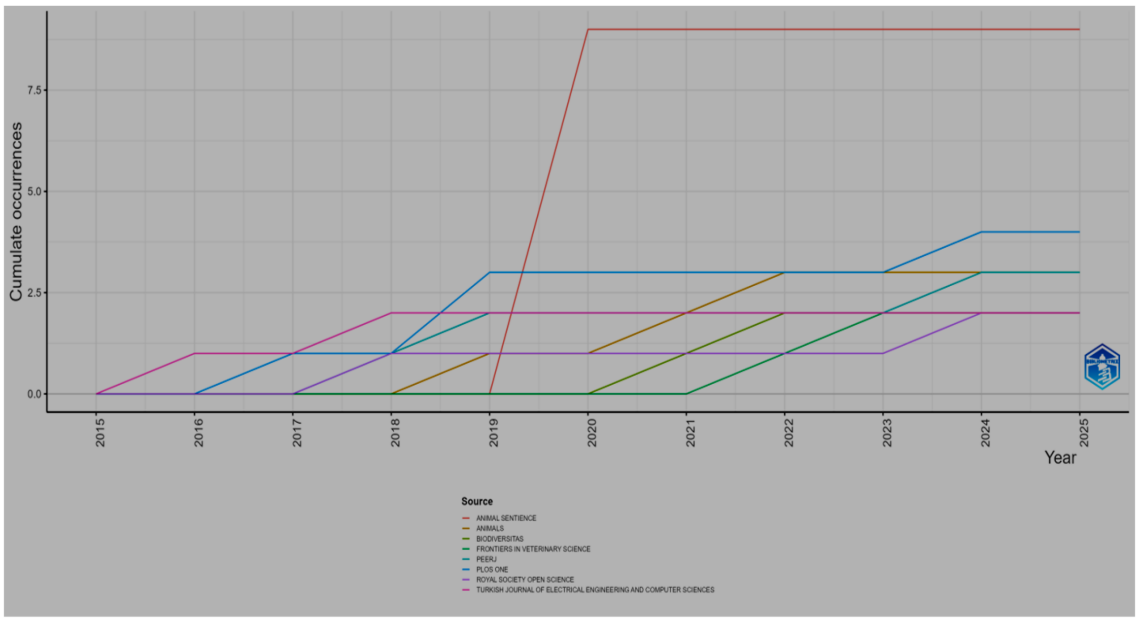

FIGURE 5
Temporal trend of publication sources for mahout-elephant research (2014-2024). Data show cumulative number of publications in top journals over time. PEERJ demonstrated the highest overall publication count with a notable increase around 2020. Analysis of publication rate slopes before and after 2020 showed significant acceleration across sources (paired t-test, $t = 5.24$, $P < 0.001$). The dashed line represents the mean publication trend across all sources, with the gray area indicating 95% confidence interval. Publication rates across different journals were significantly different ($F = 8.76$, $P < 0.01$, LSD = 1.58).

compared to other sources. Most journals began publishing research on mahout-elephant relationships between 2016 and 2019, indicating the relatively recent emergence of this as a distinct research focus. The overall trend shows growing scientific interest in this field, with particular acceleration in the past four years.

3.1.5 Research topic network analysis

Co-occurrence network analysis of research topics (Figure 6) revealed two distinct clusters within the mahout-elephant research landscape:

1. **Welfare and Tourism Cluster (Left)**: This cluster encompassed research on elephant welfare, tourism impacts, management practices in Thailand, interview-based studies, and animal behavior assessment.
2. **Computational Approaches Cluster (Right)**: This cluster focused on big data analytics, algorithms, artificial intelligence, and data mining applications related to elephant research.

The central terms connecting these clusters included "elephant," "article," "female," "male," and "adult," which served as bridge concepts between the two research communities. Modularity analysis confirmed the two-cluster structure (modularity value = 0.43, $P < 0.001$), indicating clear differentiation between these research approaches.

Comparison of inter-cluster versus intra-cluster connection density revealed significantly stronger connections within clusters than between them ($t = 11.32$, $P < 0.0001$). This finding suggests limited cross-disciplinary integration between welfare/management researchers and those applying computational approaches, highlighting a potential opportunity for greater collaboration between these fields.

3.2 Thematic analysis findings

3.2.1 Historical context and traditional knowledge

The thematic analysis revealed the rich historical context of mahoutship and its foundation in traditional knowledge systems. Historically, mahouts established profound bonds with elephants through extended periods of interaction, often beginning from childhood through formal or informal apprenticeship systems (Hart, 1994). This relationship was characterized by several key elements that emerged from the literature:

While analysing the impact of this intergenerational knowledge transfer, it is astonishing to find that this created continuity in

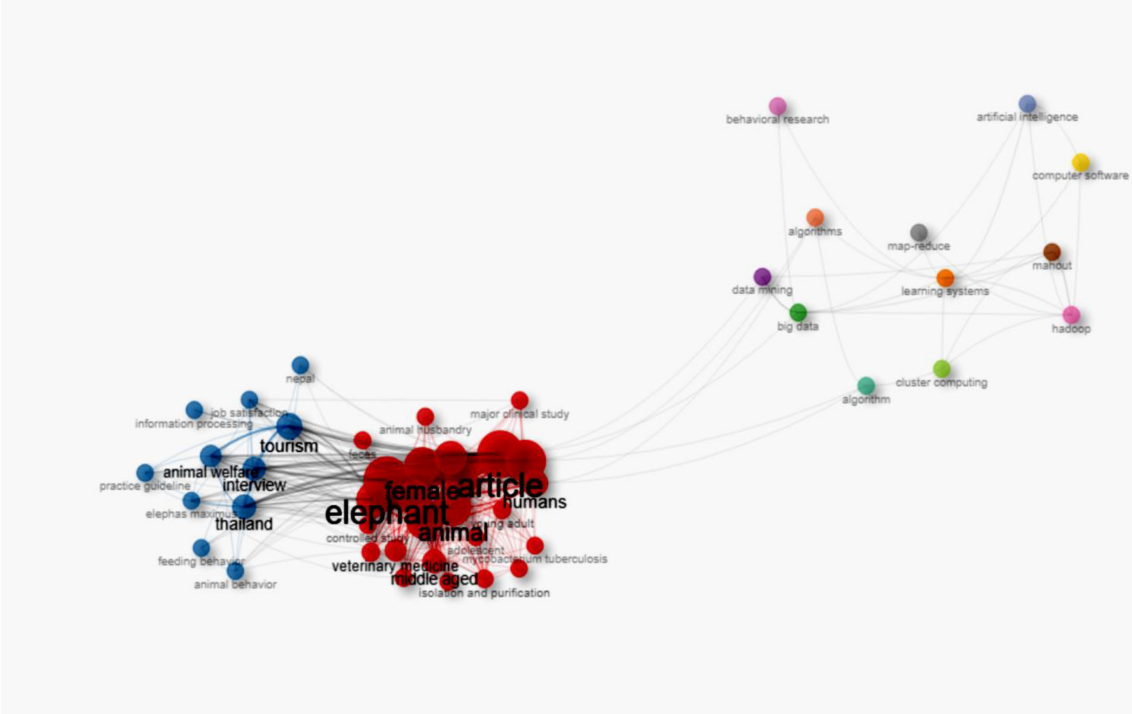

FIGURE 6
Co-occurrence network of research topics in mahout-elephant studies (2014-2024). Visualization of keyword co-occurrence relationships with line thickness indicating co-occurrence frequency. Analysis revealed two distinct research clusters: welfare/tourism cluster (left) and computational approaches cluster (right). Node size represents keyword frequency, with "elephant," "article," "female," "male," and "adult" serving as bridge terms between clusters. Modularity analysis confirmed the two-cluster structure (modularity value = 0.43, $P < 0.001$). Significant differences were observed in inter-cluster versus intra-cluster connection density ($t = 11.32$, $P < 0.0001$), indicating limited cross-disciplinary integration in the research landscape.

management approaches and preserved cultural practices specific to different mahout communities (Crawley et al., 2019).

We can also see that long-term relationship between individual mahouts and elephants, once a standard practice, facilitated the development of deep familiarity and mutual understanding between elephants and mahouts over decades. These sustained relationships encouraged more responsive care for the elephants, since the knowledge gained enabled mahouts to recognize even the subtle changes in elephant behavior and health (Mumby, 2019).

The knowledge acquired from such a long-term relationship is irreplaceable with formal institutionalised training programmes. Mahouts developed embodied awareness and instinctual understanding of elephant needs which is only possible through daily physical interaction with the elephants and their observation. This tacit knowledge allowed experienced mahouts to anticipate elephant behavior and respond appropriately to minimize probable risks (Szydlowski, 2024).

The relationship between elephants and mahouts also has religious and cultural implications in various Asian contexts. The literature also highlighted this. In the Asian context, elephant management was usually part of religious practices, community identity, and local ecological knowledge systems. These dimensions influenced the regional elephant training practices, healthcare approaches, and ethical frameworks for elephant management (Dubost et al., 2019).

3.2.2 Shifts in mahout practices

The research studies in the field shows a significant transformation in mahout demographics, working conditions, and knowledge systems that occurred in recent decades. These changes affected both elephant welfare and the sustainability of traditional mahout knowledge.

One such shift was documented by Crawley et al. (2019) which is the dropping of mahout median age to 22 years and median experience to just 3 years in Myanmar. So the shift marked the transfer of mahoutship to younger and less experienced mahouts. These demographic changes corresponded with increased elephants' rotation between different mahouts. This disrupted the formation of stable human-elephant bonds that was a unique feature of traditional practice.

While analysing economic factors that were crucial determinators of these changes we see Hayward et al. (2022) reporting that there were discrepancies between mahouts in private tourism facilities in Thailand and those in government institutions. In private sector compensations are low. This contributed to high turnover rates and mahoutship as a lifelong career stands unattractive. As per multiple studies the other factors that contributed to the low attractiveness of the profession among the youth include difficult working conditions, including long hours, physical risks, and limited social status.

There was a tradition of intergenerational continuity of mahoutship, but now there is a decline in the intergenerational continuity, with fewer mahouts coming from traditional mahout lineages. According to Mumby (2019) this disruption in traditional knowledge pathways has led to a dilution of specialized skills and cultural practices that once formed the foundation of mahout-elephant relationships.

Commercialization of elephants increased with the growth of Tourism and this fundamentally altered mahout-elephant dynamics in many contexts. Tourism operations give more importance to entertainment value and visitor experience over traditional mahout practices (Baker and Winkler, 2020), which in turn results in changing the nature and purpose of elephant training, daily care routines, and human-elephant interactions.

These shifts reflect broader socioeconomic changes like urbanization, changing educational patterns, and evolving cultural values in Asian elephant range countries. As a cumulative effect of these changes, we can see a potential erosion of traditional mahout knowledge systems. Still for an effective and ethical management of captive elephant populations, traditional expertise remains crucial.

3.2.3 Mahout perspectives and knowledge

The relationship between mahouts and elephants is a notable area of study from which a valuable knowledge system can be derived. Such a study focuses on mahout perspectives on elephant welfare and the human-elephant relationship. But this is often undervalued and understudied. There is a change nowadays as recent research has begun to explore this dimension. If we study this only the traditional knowledge helps improvements and the new knowledge can be integrated to the traditional knowledge. Szydlowski (2024) reported that 96% of mahouts surveyed were very confident about the knowledge on the emotional states of their elephants findings supported by behavioural studies demonstrating mahouts ability to recognize individual elephant characteristics (Chu et al., 2023). They believed that their elephants were "happy" or "very happy." In this study we could find the multiple sensory modalities used by the mahouts to gauge elephant affective states. These include touch, sound, body language, and a sense of emotional distance or connection.

Because of the one to one correspondence between mahouts and elephants, the role of mahouts in understanding elephant behaviours is pertinent. This research highlighted the role of mahouts in understanding elephant communication systems. This serves as the foundation for developing strong human-elephant relationships. Mahouts described their ability to recognize individual differences between elephants, adapting their handling techniques accordingly based on personality, age, sex, and previous experiences with each animal.

By incorporating observation of elephant self-medication behaviors, these traditional pharmacological practices suggest a sophisticated understanding of wildlife health management. An ethnobotanical dimension to mahout knowledge emerged in studies examining traditional health practices. Dubost et al. (2021) documented a form of cross-species knowledge transfer regarding medicinal plants used by elephants and this knowledge helps them to treat man and animals alike.

The attitude of mahouts on changing management practices face some complex attitudes toward innovation and tradition. In spite of holding Traditional knowledge and techniques in high reverence, they were also pragmatic in adapting to new circumstances like

changing tourism demands and evolving welfare standards. This suggests that when mahouts' expertise is valued and incorporated into planning processes, they serve as important agents in the thoughtful modernization of captive elephant management.

3.2.4 Management practices and elephant welfare

It is inevitable to understand the effect of Tourism industry on management practices and welfare outcomes of captive elephants. To study this in the context of Thailand, Bansiddhi et al. (2018) conducted a comprehensive survey of 33 elephant camps housing 627 elephants in northern Thailand. The study revealed substantial variation in management approaches.

This research in the context of Tourism could identify a generational shift. The change observed was that the older camps were more likely to feature riding with saddles and performative shows. On the other hand, newer establishments focused more on personalized and less intrusive visitor interactions with elephants. The study also could find that, these evolving approaches remain futile as 82% of surveyed camps still chained their elephants for the majority of the day, which restricted the elephants' natural movement and behaviors.

The study also tried to evaluate the effect of the COVID-19 pandemic on elephant tourism. The pandemic had adversely affected elephant tourism. As per the study by Supanta et al. (2022) a 45% decline in mahout numbers, 30% reduction in elephant populations, and 50% decrease in support staff at Thai tourist camps were observed during this period. These disruptions are important indicators of the vulnerability of current economic models for captive elephant management. They also raised questions about sustainable approaches moving forward.

The physiological impacts of different management practices on captive elephants are examined in several studies. Contrary to expectations, the study found that elephants in "observation only" tourism programs exhibited higher fecal glucocorticoid metabolite (FGM) levels compared to those in riding programs (Bansiddhi et al., 2019a). This counterintuitive finding highlights the complexity of welfare assessment and the need to consider multiple factors beyond activity type, including handling practices, social environment, and individual elephant characteristics.

The effect of environmental contexts was also studied. There were evidences showing how environmental context influences stress responses even during restricted movement periods (Bansiddhi et al., 2019a). One among that was the way in which housing conditions of the elephants significantly affected physiological welfare indicators. Elephants tethered in forested areas overnight showed lower FGM concentrations than those kept in open areas. Bansiddhi et al. (2019b) also found associations between floor substrate and health outcomes, with elephants resting on sand floors showing a lower risk of developing severe skin wounds compared to those on concrete or compacted earth.

While analyzing the traditional taming practices, the literature shows that those practices raised serious welfare concerns. Crawley et al. (2024) documented dramatic physiological changes in elephant calves during traditional training procedures, with markers including FGMs, cortisol, glucose, heterophil: lymphocyte ratios, and creatine kinase showing increases ranging from 50-500% above baseline levels. Some indicators took up to two months to recover, which reflect prolonged stress responses that could have lasting health implications.

Safety risks are found to be the prime motive for the mahouts to stick on to traditional standards. The same study by Crawley et al. (2024) noted that the mahouts who followed the traditional practices, despite knowing these concerns were hesitant to adopt alternative training methods because of perceived safety risks. This highlights the tension between welfare improvements and practical management concerns. If humane training programmes are to be implemented, this tension must be properly addressed.

3.2.5 Elephant health and disease conditions

There are several elephant health and disease concerns to be addressed. Many studies identify that Tuberculosis (TB) is a significant health concern for captive elephants. Research about this in different geographical contexts revealed varying prevalence rates and risk factors. Gautum and Koju (2022) documented demographic and health patterns in captive elephants around Chitwan National park, Nepal, while Rajhans et al. (2021) tested 15 samples from captive elephants in Maharashtra, India, finding that all tested positive using the BacT/ALERT 3D system, though only one sample was confirmed for Mycobacterium bovis via PCR, suggesting potential issues with diagnostic specificity.

In the context of Malaysia, Yakubu et al. (2016) reported a TB seroprevalence of 23.3% among captive elephants, with significantly higher risk for animals assigned to mahouts. With regard to the human infection from elephants, this study also found that 24.8% of Malaysian wildlife staff was tested positive for TB infection, highlighting the zoonotic transmission potential between elephants and their human caretakers.

But, transmission dynamics may vary across different management contexts and geographical regions. Several studies bear testimony to this. Lassausaie et al. (2015) documented that 36% of elephants in Laos tested seroreactive for the ElephantTB STAT-PAK assay. Interestingly, none of the mahouts in this study tested positive for Mycobacterium tuberculosis.

There are also other health conditions that require medical attention. The literature addressed these health conditions beyond tuberculosis requiring specialized veterinary intervention. One such condition is identified by Paul et al. (2018). He described the successful treatment of bilateral corneal opacity in an Asian elephant using a combination therapy approach. From the literature we see that Wijayanto et al. (2021) established a correlation between foot circumference and body size in Sumatran elephants. This provides a safer alternative method for estimating body mass while determining appropriate medical dosages.

All these show the necessity of Innovative approaches to health monitoring. The approaches included application of three-dimensional inertial measurement units (Kongsawasdi et al., 2021) to track gait changes associated with lameness in horse. This technology offers potential for earlier detection of musculoskeletal issues, which are common in captive elephants due to substrate conditions, exercise limitations, and aging processes.

3.2.6 Conservation and rewilding approaches

The conservation approaches for captive elephants can be summarized as follows. As a conservation strategy for captive elephants, rewilding is proposed by many researchers, with varying frameworks and emphases. Notable among them include the study by Baker and Winkler (2020) who advocated for a comprehensive approach, including rescue, rehabilitation, and eventual release of captive elephants, by incorporating traditional mahout skills throughout this process. In this perspective, mahouts are viewed as potential partners of conservation rather than obstacles to elephant liberation.

Rewilding is both a psychological and cultural process (Baker, 2020). This process requires the active involvement of elephants rather than being passive objects of conservation efforts. It requires collaboration across stakeholder groups. This approach emphasizes the need for gradual transition and culturally sensitive implementation strategies.

The above models could provide simultaneous benefits, both for elephants and traditional mahout cultures as evident in the study of Pauketat's (2020) community-based rewilding within elephant-Karen communities in Thailand. This perspective challenges binary distinctions between captivity and wildness, advocating instead for intermediate arrangements that honor both elephant autonomy and human-elephant relationships.

Some researches on elephant conservation are oversimplified. Several researchers cautioned against oversimplified narratives in elephant conservation. Lorimer and Rahmat (2020) warned against conflating elephant survival with their role in human economies, whether through tourism or traditional labor, and argue for recognition of elephant interests beyond their utilitarian value. Conversely, Kopnina (2020) critiqued approaches that maintain elephants under mahout control, suggesting that such arrangements inherently limit elephant freedom and risk perpetuating exploitative relationships.

There are also practical models to emulate as van de Water et al. (2020) proposed a model of co-management with local communities, aiming to balance elephant welfare, human wellbeing, and environmental sustainability. This integrated approach recognizes the complex socioecological systems within which elephant conservation occurs and the necessity of addressing human needs alongside conservation goals.

3.2.7 Technological innovations in elephant conservation

With the changing technology, there are many computational approaches available. The bibliometric analysis revealed a significant interest in computational approaches to elephant-related research. The approaches include big data analytics, data mining, algorithms, and artificial intelligence applications. This emerging field offers promising tools for enhancing conservation and welfare assessment.

Some possible suggestions are seen. Several studies described frameworks that could be applied to elephant conservation challenges, though many were not yet specifically implemented in this context. Trigueroa et al. (2014) outlined the MapReduce approach for prototype reduction in big data classification (MRPR), which could assist in processing large elephant-related datasets such as movement patterns, physiological monitoring, or behavioral observations.

Some models can be seen in the following studies. Building on their own earlier work, Ghadiri et al. (2017) presented BigFCM, a scalable fuzzy c-means clustering model implemented in Hadoop, with potential applications for analyzing elephant behavior or ecological data across large temporal or spatial scales. There is a parallel sentiment analysis method for social networks using Spark, which could evaluate public attitudes toward elephant conservation initiatives or tourism practices (Iqbal and Latha, 2022).

Studies on direct application of technological innovations to elephant-related issues is very rare. There are mahout-based machine learning libraries utilized to construct personalized recommender systems that could potentially support conservation education or stakeholder engagement. Another innovation is by Machorro-Cano et al. (2019) who developed PISIoT, an integrated machine learning and Internet of Things platform for health monitoring, which could be adapted for tracking elephant physiological parameters and welfare indicators. Landset et al. (2015) revealed that, Elephant conservation generates massive datasets from: GPS collar tracking data from multiple elephants over extended periods, Camera trap images and videos, Environmental sensor data, Acoustic monitoring systems, Satellite imagery for habitat monitoring. The survey can cover both batch and streaming processing paradigms, with streaming models designed for projects aimed at finding out what is happening right now with real-time feedback. This is crucial for Anti-poaching surveillance systems requiring immediate alerts. Real-time elephant movement monitoring and Emergency response to human-elephant conflict situations.

However, these technological approaches represent an emerging frontier in elephant conservation. This remains distinct from traditional welfare and management research, as confirmed by the clustering pattern in the co-occurrence network analysis. Bridging this divide presents a significant opportunity for innovation in welfare assessment, health monitoring, and conservation planning.

4 Discussion

4.1 Integration of bibliometric and thematic findings

From the existing studies it is evident that an all-encompassing view is to be developed in mahout-elephant research. The combined findings from bibliometric and thematic analyses provide comprehensive insights into the current state of mahout-elephant research and its implications for conservation practice. The bibliometric analysis revealed a field characterized by two distinct research communities with limited interaction. One community focused on welfare and management, the other on computational approaches. This division represents both a challenge and an opportunity for advancing elephant conservation through interdisciplinary collaboration.

The spatial and temporal dimensions of the research are to be considered. Geographically, research is concentrated in Thailand, particularly at Chiang Mai University, which has established itself as a key hub for Asian elephant studies with strong international collaborations, especially with institutions in the United States. The predominance of Thai research settings interrogates the generalizability of findings to other range countries with different socioeconomic contexts, cultural traditions, and management approaches.

The temporal analysis of research output demonstrates growing scientific interest in mahout-elephant relationships, accelerated since 2020. This trend coincides with increasing public concern about elephant welfare in the context of tourism and broader shifts in conservation paradigms toward more integrated approaches that consider both wildlife and human wellbeing.

While moving to the thematic findings, they highlight several critical developments in mahout-elephant relationships that have significant implications for conservation and welfare. The documented shift toward younger, less experienced mahouts with shorter tenure represents a potential crisis in traditional knowledge transmission at a time when such expertise remains essential for ethical and effective elephant management. This trend appears driven by complex socioeconomic factors, including changing career aspirations among younger generations, urbanization, and inadequate compensation for mahout skills.

A dominant influence on elephant management practices is tourism as seen in both bibliometric and thematic analyses, particularly in Thailand. Tourism prioritizes visitor experiences over natural behaviors and historical human-elephant bonds. The industry's demands have transformed traditional relationships and management approaches. While tourism provides economic justification for maintaining captive elephants and employing mahouts, it often neglects the natural requirements of elephants.

One of the major challenges identified in captive elephant management, was the Health concerns like the infectious tuberculosis. It represents a significant challenge, with implications for both animal welfare and public health due to its potential for zoonotic transmission. The research suggests varying prevalence rates across regions and inconsistent screening protocols. This calls for standardized approaches to disease monitoring and prevention.

4.2 Research gaps and future directions

The integrated analysis identified several significant research gaps that warrant attention in future studies:

Long-term impacts of training methods: While Crawley et al. (2024) documented acute physiological responses to traditional training, there remains limited understanding of the long-term psychological and physiological effects of different training approaches. Longitudinal studies comparing traditional and alternative methods could provide valuable insights for developing welfare-centered training protocols that maintain safety for both elephants and mahouts.

Elephant psychology and cognition: Despite growing recognition of elephant cognitive complexity, relatively few studies have systematically investigated how captivity and management practices influence elephant psychology, decision-making processes, and mental wellbeing. Research integrating cognitive ethology with welfare assessment could enhance our understanding of the psychological dimensions of captive elephant management.

Rewilding outcomes: The literature presents various theoretical frameworks for rewilding captive elephants, but empirical studies documenting outcomes of such initiatives remain scarce. Long-term monitoring of rewilding projects, examining behavior, survival, reproduction, and ecological impacts, would provide an evidence base for evaluating different approaches.

Technological applications in welfare assessment: Despite the identification of a computational research cluster in the bibliometric analysis, there are few studies applying these technologies specifically to elephant welfare monitoring or management. Developing and testing IoT systems, machine learning algorithms, or remote sensing technologies for elephant health assessment represents a promising research direction (Faiz et al., 2017).

Mahout welfare and knowledge preservation: While considerable research focuses on elephant welfare, relatively fewer studies examine mahout welfare, working conditions, and knowledge systems. More comprehensive investigation of the socioeconomic challenges facing mahout communities could inform interventions to support both human livelihoods and animal welfare.

Zoonotic disease transmission: The high seroprevalence of tuberculosis in some elephant populations highlights the need for more systematic research on disease transmission pathways between elephants and humans, particularly in tourism contexts where close contact is common. Studies integrating veterinary epidemiology with human public health approaches could address this critical interface.

Geographical research distribution: The concentration of research in Thailand represents a significant gap in our understanding of mahout-elephant dynamics in other range countries, particularly India, which hosts the largest captive elephant population. Expanding research efforts across diverse geographical and cultural contexts would enhance the applicability of findings to global conservation efforts.

Based on these identified gaps and the integrated findings from bibliometric and thematic analyses, we propose several strategic directions for future research:

Based on these identified gaps and the integrated findings from bibliometric and thematic analyses, we propose several strategic directions for future research:

1. **Integrated welfare assessment frameworks:** Through the integration of physiological, behavioral, and psychological parameters in the evaluation of elephant welfare across different management contexts, a comprehensive approach and validated assessment tool can be developed. The work by Ghimire et al. (2024) represents an important step in this direction, but further validation and refinement are needed.
2. **Alternative training methodologies:** There should be research including both elephants and mahouts as participants. This helps to investigate positive reinforcement-based training approaches that promote welfare while

maintaining handler safety. Such research should addressing practical implementation challenges and cultural acceptability along with welfare outcomes.

3. **Human-elephant relationship studies:** By expanding research on the bidirectional relationship between mahouts and elephants, we can examine how different interaction patterns influence outcomes for both species. This could include cross-cultural comparative studies to identify beneficial practices across different traditional knowledge systems.
4. **Technological integration:** in tracking the behavior of the elephants, monitoring their health, and habitat assessment, technology can be used. Further research efforts to bridge the gap between computational and welfare research clusters could yield innovative approaches to conservation challenges.
5. **Sustainable tourism models:** Tourism approaches that prioritize elephant welfare along with mahouts' employment should be developed. These approaches should be economically viable also. Such a research should include market analysis, visitor education impact assessment, and long-term viability studies.
6. **Disease monitoring systems:** There is a possibility of developing field-appropriate diagnostic tools and evidence-based management protocols for detecting and preventing disease transmission within captive elephant populations and between elephants and humans.
7. **Traditional knowledge documentation:** Before losing the traditional Mahout knowledge, there should be appropriate recording and preservation of traditional mahout knowledge. This includes utilizing digital tools to create accessible repositories that can inform both scientific research and practical management.
8. **Interdisciplinary integration:** Developing collaborative projects that incorporate expertise from animal welfare science, conservation biology, anthropology, computer science, and economics to holistically address the complex challenges of elephant conservation.

4.3 Applications for theppakadu elephant camp in the Nilgiris

The findings from this systematic review have direct relevance for the management of captive elephants at Theppakadu Elephant Camp in the Nilgiris region of Tamil Nadu, India. Based on the evidence gathered, we propose the following recommendations.

4.3.1 Addressing mahout demographic changes and knowledge transfer

The documented decline in traditional mahout knowledge and changing demographics requires strategic intervention at Theppakadu to preserve essential expertise. We recommend the following alternatives:

1. There should be proper formalized apprenticeship program for mentoring the younger mahouts with experienced senior handlers. This enables transfer of knowledge across generations. This program should be designed with structured mentoring sessions, ongoing assessment, and proper recognition of acquired skills.
2. There should be proper documentation of mahout knowledge by conducting systematic interviews with senior mahouts focusing on elephant behavior interpretation. The focus of the interview should be health assessment, and handling techniques specific to the Nilgiris context.
3. The knowledge thus received should be digitized and made available globally Such a digital knowledge repository preserves traditional practices and integrates them with contemporary welfare standards. Even video documentation of handling techniques, medicinal plant identification, and cultural practices important to the local mahout community can be included.
4. Mahoutship often loses its attraction due to low payment. So career advancement schemes should be implemented and appropriate compensation structures should be maintained to make mahoutship more attractive as a long-term profession, reducing turnover and enhancing continuity in elephant care.

4.3.2 Enhancing health monitoring and disease prevention

The high prevalence of tuberculosis and other health concerns in captive elephant populations necessitates improved health management protocols:

1. Using appropriate diagnostic methods regular TB screening should be conducted for both elephants and mahouts, with clear protocols for managing positive cases that balance public health concerns with animal welfare.
2. Establishing comprehensive baseline health metrics for each elephant using standardized monitoring methods, enabling early detection of changes that might indicate developing health issues.
3. Adopting biomechanical assessment tools, such as the 3D inertial measurement unit described by Kongsawasdi et al. (2023), for early detection of lameness and musculoskeletal problems.
4. Developing integrated health monitoring approaches that combine traditional mahout observations with modern veterinary techniques to provide more comprehensive health surveillance.

4.3.3 Balancing tourism with welfare

As Theppakadu serves both conservation and tourism functions, balancing these priorities is essential:

1. Chaining of the elephants for tourism purpose should be reduced. The duration of chaining should be reduced so as to enhance opportunities for natural behaviors, including foraging, social interaction, and environmental exploration.
2. Considering a gradual transition toward observation-based or minimal-contact tourism models. This helps to maintain economic viability while reducing physical impacts on elephants.
3. Designing enrichment activities that promote physical and mental stimulation for elephants while providing engaging educational experiences for visitors.
4. Implementing the welfare assessment tool developed by Ghimire et al. (2024) specifically for tourist camp elephants to systematically monitor and improve welfare standards.

4.3.4 Applying technological approaches

The computational research identified in the bibliometric analysis offers opportunities for innovation at Theppakadu:

1. Developing a digital monitoring system for tracking elephant health parameters, activity patterns, and welfare indicators using sensor technology and data analytics.
2. Implementing IoT devices to monitor movement patterns and physiological parameters, potentially adapting approaches like the PISIoT system described by Machorro-Cano et al. (2019).
3. Applying data analytics to process and analyze behavioral data, identifying patterns and trends that might not be apparent through observation alone.
4. Creating mobile applications for mahouts to record observations and access health information, bridging traditional knowledge with technological tools.

4.3.5 Conservation and rewilding considerations

While full rewilding may not be appropriate for all elephants at Theppakadu, elements of natural living can be incorporated:

1. Assessing individual elephants for suitability for increased autonomy or limited rewilding experiences based on age, health status, and behavioral characteristics.
2. Creating opportunities for elephants to engage in natural foraging in suitable forest areas, balancing freedom with necessary monitoring for safety and health.
3. Adopting the "co-management" conservation approach proposed by van de Water et al. (2020), which balances elephant welfare with human livelihoods and environmental sustainability.
4. Collaborating with local communities to develop conservation initiatives that provide benefits for both human populations and elephants, fostering positive relationships between local residents and the elephant camp.

4.3.6 Research collaborations

To address the geographical research imbalance identified in the bibliometric analysis, Theppakadu should proactively engage with the scientific community:

1. Establishing research partnerships with leading institutions identified in this review, particularly those with expertise in elephant welfare assessment, health monitoring, and conservation approaches.
2. Collaborating with local universities on studies addressing specific challenges facing elephants in the Nilgiris ecosystem, including habitat connectivity, human-elephant conflict, and climate change impacts.
3. Contributing to the literature through participation in comparative studies across different elephant management contexts, helping to address the regional research imbalance.
4. Initiating longitudinal studies of mahout-elephant relationships at Theppakadu to document the impact of management changes over time and contribute to the evidence base for best practices.

4.3.7 Mahout welfare and professional development

Recognizing that mahout welfare directly influences elephant welfare, comprehensive support systems should be implemented:

1. Improving living conditions, healthcare access, and social support for mahouts and their families, recognizing the physical and psychological demands of their work.
2. Providing professional development opportunities, including training in modern conservation approaches, welfare assessment, and health monitoring techniques.
3. Creating forums for mahouts to share knowledge and experiences, both within Theppakadu and with counterparts at other facilities, building professional community and identity.
4. Acknowledging and celebrating the cultural significance of mahoutship in the Nilgiris region through community events, educational materials, and public recognition.

4.3.8 Integrated welfare assessment

Implementing systematic welfare monitoring will enable evidence-based management decisions:

1. Adapting the welfare assessment tool developed for tourist camp elephants (Ghimire et al., 2024) to the specific context of Theppakadu, ensuring cultural relevance and practical applicability.
2. Regularly monitoring physiological indicators such as stress hormones, body condition, and health parameters to detect welfare issues before they become severe.

3. Incorporating mahout observations of elephant emotional states and behavior into formal welfare assessments, validating and integrating traditional knowledge with scientific measures.
4. Taking a holistic approach that considers physical, psychological, and social aspects of elephant welfare, recognizing the complex and interrelated nature of these dimensions.

So many evidence based recommendations are listed, and the implementation of these would position Theppakadu Elephant Camp as a model facility that balances traditional knowledge with contemporary welfare standards. It creates a sustainable approach to captive elephant management that honors both cultural heritage and conservation imperatives.

5 Conclusion

As a conclusion to the study the following findings are derived. The Findings of the systematic review and bibliometric analysis of mahout-elephant relationships reveals a complex and evolving field of study intersecting animal welfare science, conservation biology, anthropology, and technological innovation. By integrating bibliometric mapping with thematic analysis, we have identified significant trends, research gaps, and potential applications that are relevant for captive elephant management globally and specifically within the Nilgiris region.

The bibliometric analysis revealed two distinct research communities with limited interaction between each other. One focused on welfare and management, the other on computational approaches. Geographically, research is concentrated in Thailand, primarily through Chiang Mai University, which has established itself as a key hub with strong international collaborations. This geographical concentration highlights a significant gap in research from other range countries, particularly India, which has the largest captive elephant population.

In the thematic analysis remarkable shifts were identified in mahout demographics and traditional knowledge transmission, with younger and less experienced handlers replacing multigenerational mahouts in many contexts. Tourism has emerged as a dominant influence on elephant management practices, creating both opportunities and challenges for welfare and conservation. Health concerns, like tuberculosis, represent significant challenges for both animal welfare and public health due to zoonotic transmission potential.

The research gaps identified include limited studies on long-term training impacts, elephant psychology, rewilding outcomes, and applications of technology in welfare assessment. These gaps suggest promising directions for future research that could significantly enhance our understanding of mahout-elephant relationships and inform evidence-based management practices.

For Theppakadu Elephant Camp and similar facilities, the findings suggest several key management priorities: preserving traditional mahout knowledge while improving working conditions, enhancing health monitoring and disease prevention, balancing tourism with welfare considerations, applying appropriate technological innovations, and exploring conservation approaches that respect both elephant needs and human livelihoods.

The most promising path forward lies in interdisciplinary collaboration that bridges traditional divisions between scientific disciplines and between scientific and traditional knowledge systems. By integrating insights from animal welfare science, conservation biology, anthropology, veterinary medicine, and computer science, we can develop more effective approaches to ensuring the welfare and conservation of Asian elephants while supporting the communities that have historically lived alongside them.

This review highlights that successful conservation of Asian elephants in captive contexts requires attention to both elephant and human needs, recognition of cultural and historical relationships, and willingness to innovate while respecting tradition. Through collaborative efforts among mahouts, local communities, researchers, and conservation organizations, we can develop sustainable models for captive elephant management that contribute to the species' long-term survival while honoring the rich cultural heritage of human-elephant relationships in Asia.

Author contributions

JP: Conceptualization, Supervision, Writing – review & editing, Investigation, Writing – original draft. HN: Writing – review & editing, Software, Formal Analysis. CF: Methodology, Writing – original draft. SR: Writing – review & editing, Visualization, Resources. RP: Project administration, Supervision, Writing – review & editing, Validation. JS: Software, Validation, Writing – review & editing. SM: Validation, Writing – review & editing. VB: Supervision, Visualization, Writing – review & editing. MS: Conceptualization, Investigation, Writing – review & editing.

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