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Younger semi-captive Asian elephants constitute suitable repository for conservation translocation

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Abstract

Interdisciplinary efforts are fundamental for achieving successful conservation translocations. However, behavioral information is usually lacking to guide conservation translocations for social animals. This is particularly significant for the conservation of endangered Asian elephants. Therefore, by tracing the long-term behavioral logbook records in the southern central part of Myanmar, our study highlighted that younger semi-captive elephants (male ≤21 years old; female ≤42 years old) were identified as suitable candidates for translocations since they were more easily accepted by the wild population, with fewer fighting events and higher mingling probability. Furthermore, we recorded 136 present data combining field surveys and collection from literature, and we identified 4349.69 km^2 of suitable habitat in this region located around 10 km away from the villages, closer to managed forests and water. This study integrated ecological and behavioral information to support reinforcement conservation for Asian elephants in Southeast Asia, where most of the semi-captive elephants are distributed. These insights could guide more effective reinforcement projects by considering age and sex for improved success in integration. Additionally, our study emphasizes the importance of habitats near human-dominated areas, which are preferred by elephants, offering practical implications for habitat management and human-elephant conflict mitigation efforts. Further research efforts from the behavioral perspectives, such as using camera trappings or video recordings, are encouraged to facilitate social animal conservation.

KEYWORDS

Elephas maximus, habitat suitability, intraspecific interaction, reinforcement conservation, social behavior

1 | INTRODUCTION

Conservation efforts represent a profound and enduring commitment, requiring a thorough gathering of comprehensive data about the target species. Especially, understanding the population figures, habitat preferences, and social and reproductive behaviors is essential in animal conservation (IUCN/SSC, 2017). For instance, the giant panda (*Ailuropoda melanoleuca*) has been successfully downlisted from Endangered to Vulnerable in the IUCN Red List due to the multi-party conservation and interdisciplinary research efforts since 1974 (Swaisgood et al., 2016). The comprehensive research covering various ecological domains in foraging (Pan et al., 2014; Rideout et al., 2012), movement (Pan et al., 2014), landscape (Rivers et al., 2014), and behavior (Utta et al., 2008), contributes to the conservation success of giant pandas. The findings from these studies have been instrumental in informing policy decisions, shaping management plans, and improving overall conservation outcomes for giant pandas. These same interdisciplinary methods, integrating ecological, behavioral, and landscape-level research, offer valuable lessons that can be applied to other species facing similar conservation challenges.

In the context of conservation-based activities, the first documented conservation translocation occurred in 1895, when kakapos (*Strigopas habroptilus*) were relocated to offshore islands in New Zealand (Lloyd & Powlesland, 1994) to safeguard the remaining individuals and create insurance populations. Since then, translocation has played a pivotal role in achieving some of the most celebrated conservation successes (Morris et al., 2021). Collen et al. (2006) noted that species with longer dispersal distances face an increased risk of local extinction. To mitigate this risk and prevent population decline, the implementation of reinforcement is deemed a crucial and initial conservation measure, particularly for endangered species (Kletty et al., 2020). According to the Species Survival Commission of IUCN/SSC (2013), conservation translocation includes four types: reinforcement, reintroduction, assisted colonization, and ecological replacement. Reinforcement refers to the intentional movement and release of individuals into an existing population of the same species to boost its viability. Reintroduction involves releasing individuals within their indigenous range from which they have disappeared. Assisted colonization is the release of a species outside its indigenous range to prevent extinction, and ecological replacement is the release of a species outside its range to fulfill a specific ecological role. Among these, reinforcement is defined as the intentional movement and release of an organism into an existing population of conspecifics aiming to improve population viability (IUCN/SSC, 2013). However, behavioral information is usually lacking to support the reinforcement (Champagnon et al., 2012), especially for social animals, for whom integration into the recipient wild population could be key to the success of the reinforcement project.

As an endangered social mega-fauna, Asian elephants (*Elephas maximus*) serve as vital ecosystem engineers in forest habitats. They facilitate seed dispersal, enhance biodiversity, create microhabitats, influence forest dynamics, and provide valuable ecosystem services, all of which contribute to the overall health and functionality of their ecosystems (Tan et al., 2021). However, their survival is jeopardized by significant threats, primarily from human-induced habitat loss (Leimgruber et al., 2011). The decline of their suitable habitat began in the early 1500s due to human activities such as the expansion of agriculture, logging, and settlement. This situation worsened during the colonial era in the 1700s, as land-use practices further degraded their environment. By 2015, their habitat had shrunk to one-third of the original size (de Silva et al., 2023). Consequently, their population has been confined to diminishing forest patches surrounded by human-dominated lands, while their migratory routes have been blocked (Easa, 2017). As a result, there has been a substantial decline in the population, with an estimated 48,323–51,680 wild individuals and a captive population ranging from 14,930 to 15,130 in South and Southeast Asia (Menon & Tiwari, 2019).

Among Southeast Asian nations, Myanmar possesses the largest estimated population of both wild and captive Asian elephants, with approximately 2000–4000 and 5693 individuals respectively (Menon & Tiwari, 2019). However, poaching, illegal trade, and habitat fragmentation have posed a threat to the wild elephant population. It has been reported that the elephant population in Myanmar is surprisingly lower than expected, even though 51% of their current range has been classified as suitable for their survival (de Silva et al., 2023). To reinforce the wild elephant population in Myanmar, the Myanmar Elephant Conservation Action Plan was launched in 2018 by the Myanmar government, supporting the potential conservation translocation of captive elephants in the future. Since the government-owned elephants are allowed to roam unsupervised in nearby forests to forage, where they encounter both tame and wild elephants at night, they earn the definition of "semi-captive" (Seltmann et al., 2019), making them ideal candidates for reinforcement projects (Thitaram et al., 2020). However, there is a lack of behavioral information to guide a proper selection of semi-captive elephants for the reinforcement project, to guarantee their integration to the wild population. The same conservation concerns arise in Southeast Asia as well, where most of the captive elephants are distributed.

Therefore, to support reinforcement conservation action from both the behavioral and ecological perspectives, the present study explored the factors influencing different interaction types between semi-captive and wild elephants, using a case study in the Bago Yoma region of Myanmar. Additionally, we predicted suitable habitats for Asian elephants in the study area. This study is the first to integrate both environmental and behavioral information to support reinforcement conservation for Asian elephants in Southeast Asia, where 14,930–15,130 semi-captive elephants are distributed. We anticipate that this study will inspire further research into behavioral perspectives, such as social dynamics, herd integration, and foraging strategies, which are crucial for successful reinforcement and conservation to facilitate social animals like elephants.

2 | MATERIALS AND METHODS

2.1 | Study area

The Bago Yoma Region, situated in the southern central part of Myanmar (94°41′-97°11′ E, 16°19′-19°28′ N; Figure 1), is an ecologically significant area known for its rich biodiversity and important role as a watershed between the Irrawaddy and Sittaung Rivers. This forested region provides critical habitat for small, remaining wild elephant populations, estimated to number between 200 and 240 (Leimgruber et al., 2011). The forests of Bago Yoma, predominantly mixed deciduous, support diverse wildlife, including other large mammals like leopards and various bird species (Myint et al., 2024). Alongside the foothills of Bago Yoma, Myanma Timber Enterprise (MTE) operates timber elephant camps, with a total of 416 captive or semi-captive elephants as reported in 2022 (unpublished data from MTE, 2022). Surrounding the mountain ranges, the lowlands support 80% of Myanmar's human population, with vast agricultural lands exerting pressure on the region's ecosystems. In response to these pressures, establishing the North Zamari Wildlife Sanctuary in 2014 represents a key effort to conserve endangered Asian elephants and protect the remaining forests, reflecting the region's growing role in conservation (MONREC, 2015).

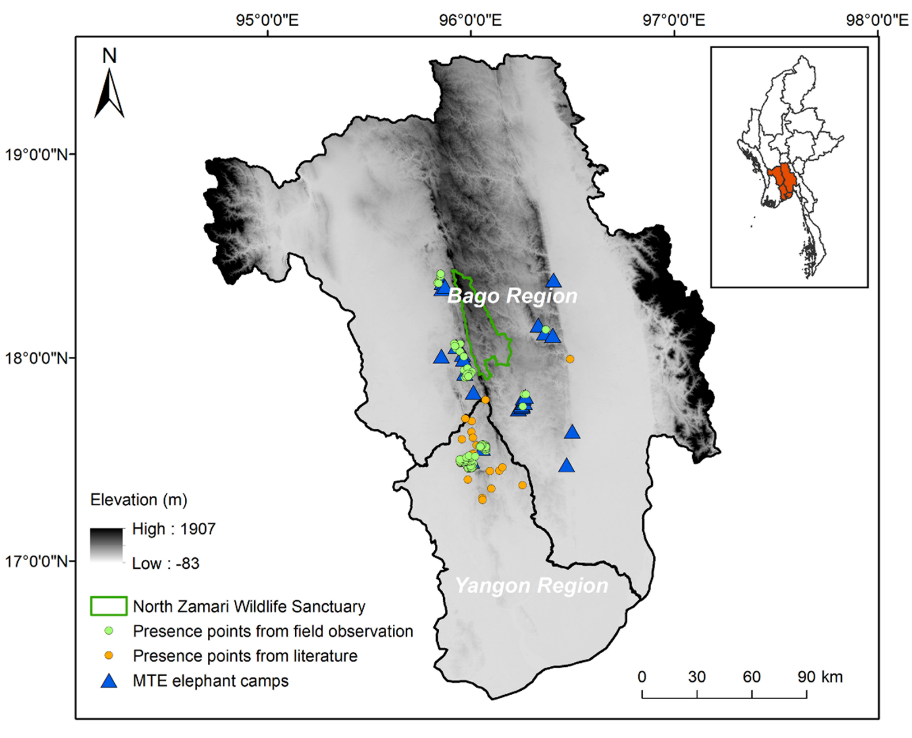

FIGURE 1 Location of the study area, presence points from field observation and literature in the Southern Central part of Myanmar.

2.2 | Conspecific interactions between semi-captive and wild elephants

MTE possesses approximately 3000 semi-captive elephants for timber extraction (Crawley et al., 2020). However, since the nationwide logging ban was launched in 2016, most of the elephants from Bago Yoma retired from their jobs and were kept in elephant camps. These elephant camps are usually located in the forest, overlapping with the distribution of wild elephants. Each MTE-owned elephant has its logbook since the day it was born or caught. In the logbook, the registration number of the elephant, name, origin (wild-caught or captive-born), date of birth, place of birth, mother's registration number, mother's name, year of capture, place of capture, and year or age of taming are recorded. Moreover, it also includes medical treatment schedules, pregnancies, calving events, and social interaction events with wild elephants (including fighting, mating, and mingling events). Mahouts (elephant caretakers) play a key role in maintaining the elephants' health, with daily responsibilities that include retrieving elephants from the habitat, bathing them, and monitoring their physical condition, sleep patterns, and any signs of injury or unusual behavior. If any health issues or abnormalities in the habitat are noticed, the mahouts are required to immediately report to the head mahout and take necessary actions. Interaction events that elephants experience in their habitat are recorded in the logbooks based on the mahout's observations. By collecting data of the interaction event records from the elephant logbooks, we analyzed the conspecific interactions between semi-captive and wild elephants over five decades (1970–2022).

Logbooks displaying partial or missing information ($n = 129$) were excluded from the analysis. We included 216 semi-captive elephants where 99 were female and 117 were male elephants, and 29.16% were calves younger than 5 years old. Specifically, we categorized the events "Fighting" denoted instances where a semi-captive elephant suffered injuries due to attacks by wild elephants. Events were categorized as "Mating" when a semi-captive elephant engaged in mating behavior with a wild elephant. Lastly, we defined the event "Mingling" as a semi-captive elephant grouped with wild elephants regardless of the group number. Altogether, the interaction dataset included 70 events.

To analyze what variables influenced the probability of different interactions, we fitted Bayesian multinomial regression mixed models using R packages *nnet* (Venables & Ripley, 2002), which allowed non-normally distributed data and used categorical variables as response variables. We set elephant identity as a random effect, and year, season, sex, age, origin (wild-caught or captive-born), and feature (classified into tuskless, one-sided tusk, short-tusk, or tusker) as fixed variables. We included interactions ("Fighting", "Mating," or "Mingling") as response variables, with "Fighting" serving as the reference category. Accordingly, we applied *dredge* from the *MuMIn* package (Bartoń, 2023) to generate a model selection table of models with delta corrected Akaike information criteria (ΔAICc). In the interest of the best model with the lowest AIC value, we set the ΔAICc value as less than 2. The analyses were performed in R 4.3.0 (R Core Team, 2023). Based on the model prediction, we then set the threshold by keeping the probability of fighting events less than 50% (and probability of mingling events more than 50%) for male elephants, and the slope of the predicted curve for fighting events less than 1 (and the slope of the predicted curve for mingling events less than 1) for female elephants. We also pinpointed the highest probability of mating events for female elephants.

2.3 | Presence data of wild elephants and environmental predictors

To identify suitable habitat for translocation of Asian elephant in this region, we used elephant paths and trails as transect lines and a handheld Global Positioning System (GPS, Garmin 78S) to collect the traits (dung pile, footprints, and signs) of wild elephants. We identified the elephant paths and trails that cover the habitat based on our experienced local MTE head mahouts' supervision. Rangers from the Emergency Elephant Response Units under MTE helped us to collect the presence data and differentiate the dung pile, footprints, and signs of wild elephants from those of semi-captive elephants. For example, the toenails of semi-captive elephants are shorter than wild elephants since they get regular foot care. Dung piles differ based on the content since wild elephants have access to a wider variety of food resources than semi-captive elephants. As the rangers are responsible for patrolling every month and responding to the wild elephants' affairs, they can recognize signs such as broken tree branches and trails. The average transect line length is 6.5 km, and this covered the average daily distance by the elephants in the dry season, which was 3.9 km (range 1.3–7.3) (Chan et al., 2021). We collected 117 presence points of wild elephants from field sampling (from February to April 2022) including old presence points from the previous late winter season (December to January) and the other 19 presence points from published literature, which documented the locations of wild elephant deaths and disappearances, particularly in the Bago Yoma region as secondary data (Sampson et al., 2018).

Based on the previous studies related to elephant habitat utilization, we included 11 different environmental predictors in this study (Table S1; Mohd Taher et al., 2021; Thant et al., 2023). These environmental predictors represented four categories: (1) topographic variables including elevation, slope, and proximity to the water source; (2) climatic variables including mean annual temperature and mean annual precipitation; (3) vegetation variables including land use/land cover (LULC; Chen et al., 2020), proximity to the managed forest (i.e., forests with disturbances since 2000), the natural forest (i.e., forests without disturbances since 2000) and the cropland; and (4) anthropogenic variables including proximity to roads and proximity to villages. Then, we used Pearson correlation coefficients to reduce the multicollinearity and improve model interpretability and performance since they can identify redundant variables, quantify the relationship between predicted and observed data, and support accurate, standardized comparisons across models (Elith et al., 2006; Zeng et al., 2016).

We initially generated each raster layer of environmental predictors at a fine resolution (30 m). Yet we encountered technical constraints in stacking all environmental layers. Therefore, we adjusted the spatial resolution of all environmental variables to 60 m resolution, resampled into the same geographic coordinate system (World Geodetic System 1984). All spatial data preprocessing was conducted in ArcGIS version 10.8 (ESRI, 2020, Redlands, CA, USA) and R Studio version 4.3.0 (R Core Team, 2023).

2.4 | Modeling of habitat suitability

Based on the presence data of wild elephants collected, we used Maxent version 3.4.4 (Phillips et al., 2006) for species distribution modeling (SDM) to analyze habitat suitability of Asian elephants. To minimize spatial autocorrelation, we applied spatial filtering by randomly selecting one GPS location per 1-km^2 grid cell. After data trimming, 72 location points remained for Maxent modeling. We examined correlations among the environmental predictors by using pairwise Pearson's correlation coefficients (Pearson's r) and excluded two predictors that were highly correlated with other predictors ($r \geq 0.7$), which were annual mean temperature and proximity to cropland (Goljani Amirkhiz et al., 2018; Huang et al., 2019).

In Maxent modeling, the output format was set up as a logistic type and default for the features (Phillips & Dudik, 2008). The regularization multiplier and background points were also set up with default settings of 1 and 10,000 points, respectively. We set up 500 iterations and to test the robustness of our model, we fitted 10-fold cross-validation. We used a 10-percentile training presence logistic threshold to identify the binary suitable habitat (suitable versus unsuitable). A Jackknife test was used to detect the most important variables contributing to the prediction of suitable habitats for wild elephants. The presence points were divided into 70% for training and 30% for testing. To mitigate the effects of sampling bias commonly associated with presence-only SDMs, we applied a "bias file" that was generated using all occurrence data. The bias file, created with the ENMeval package in R, represented the density of occurrence records across the study area. This file was incorporated into the MaxEnt model to adjust for uneven sampling effort, ensuring that areas with higher sampling intensity did not unduly influence the model's predictions. By accounting for sampling bias, the bias file helps improve the reliability and accuracy of the SDM by preventing the overrepresentation of heavily sampled areas.

3 | RESULTS

3.1 | Conspecific interaction between semi-captive and wild elephant populations

The result of the multinomial regression mixed model showed that the age and sex of semi-captive elephants significantly influence the probability of conspecific interactions with the wild elephants (Table S2). The result of the analysis of variance showed that both age and sex were highly significant predictors of interaction types, with p-values well below the .001 significance threshold (Table S3). This result underscores the importance of age and sex in influencing interaction behaviors among wild and semi-captive elephants. Compared to female elephants, male semi-captive elephants demonstrated a significantly higher probability of fighting with wild elephants, and the probability of fighting increased with age for both sexes (Figure 2A). In addition, the probability of mating was slightly higher in female semi-captive elephants and reached a peak when they were 46 years old (Figure 2B). The probability of mingling decreased as the age of semi-captive elephants increased in both female and male elephants (Figure 2C). When female semi-captive elephants were younger than or equal to 42 years old, they fought less and mingled more with the wild population. Younger male elephants fought less and mingled more with wild elephants, and to keep the fighting probability under 50% and the mingling probability higher than 50%, they should be younger than or equal to 21 years old.

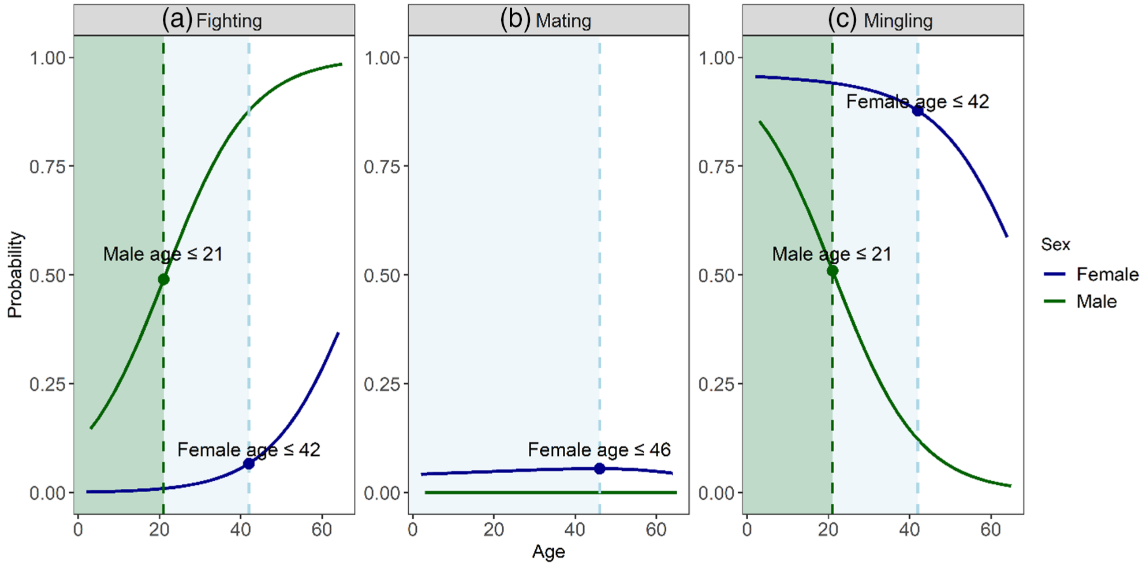

FIGURE 2 The effect of age and sex of semi-captive elephants on the probability of their interaction with wild elephants. The points and shades show the age threshold of selecting suitable semi-captive elephants for conservation translocation.

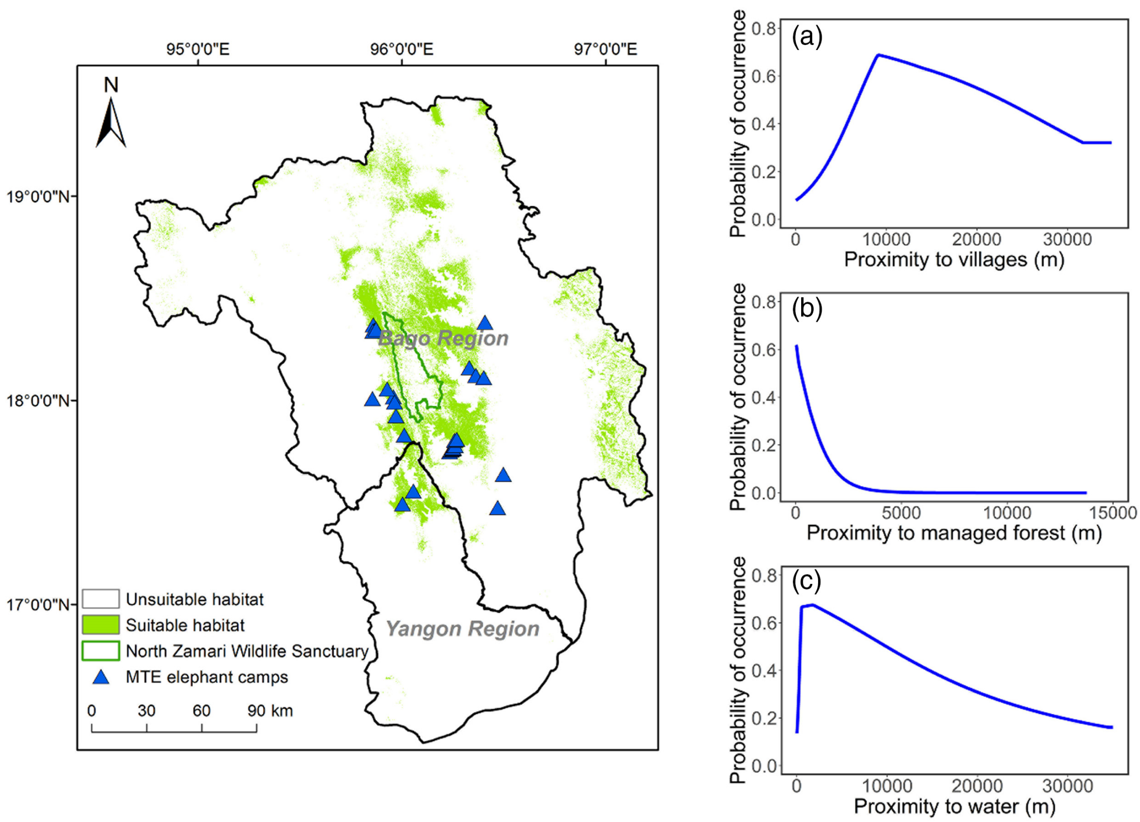

FIGURE 3 Suitable habitat prediction and the response curve of Asian elephants in Bago Yoma region in Myanmar: (a) the correlation of proximity to villages with the probability of occurrence; (b) the correlation of proximity to managed forest with the probability of occurrence; and (c) the correlation of proximity to water with the probability of occurrence.

3.2 | Suitable habitat of Asian elephant

We identified 4349.69 km^2 of suitable habitat in the Bago Yoma region (Figure 3). The mean area under the curve (AUC) value of the SDM was 0.89, indicating a good model performance. The average threshold for the 10-percentile training presence logistic threshold was 0.484 ± 0.038. In the Jackknife test, the proximity to villages had the highest gain when it was used as the only independent predictor in the Maxent model (Figure S1). Contrarily, the Maxent model had the lowest gain when the proximity to villages was excluded from the modeling, indicating that the proximity to villages was the most important factor in habitat suitability for wild elephants. The proximity to villages contributed 46.5% for predicting their suitable habitat. The second-highest gain in the Jackknife test was the proximity to managed forests, contributing 9.2% (Figure S1). Furthermore, when the proximity to water and LULC were excluded from the model, the training gain would be the second and third lowest gains by contributing 15.8% and 13.9%, respectively.

According to the response curves, we found that wild elephants prefer the habitat 10 km away from the villages the most (Figure 3A). Wild elephants inhabit the managed forests (Figure 3B). The results showed that wild elephants lived in habitats close to the water (Figure 3C).

4 | DISCUSSION

Our study combined both behavioral and ecological data and revealed that younger semi-captive Asian elephants constituted a suitable repository of translocation candidates for reinforcing the wild population, especially in South and Southeast Asia, where a majority of semi-captive elephants are distributed. Furthermore, our study has mapped out the areas in the southern central region of Myanmar that serve as suitable habitats for Asian elephants, covering 4349.7 km^2 that accounted for 9.03% of the entire study area. The present study was the first attempt to provide behavioral information to guide conservation translocation of a social mega-fauna.

Specifically, understanding how released animals interact with the wild population is crucial for effective conservation, aiding in the development of better management plans (Blumstein & Fernández-Juricic, 2004), yet this information is lacking in any Asian elephant reinforcement project. Our study highlights that the probability of different interaction types between semi-captive elephants and wild elephants was influenced by the age and sex of the semi-captive elephants, as in other species (bottlenose dolphins *Tursiops truncates*: Lopes et al., 2016; fallow deer *Dama dama*: Pecorella et al., 2018; wild baboons *Papio cynocephalus* and *Papio anubis*: Alberts, 2019; killer whales *Orcinus orca*: Weiss et al., 2021). As the semi-captive elephants get older, the likelihood of interacting with wild conspecifics in aggressive ways increases, especially among males. This finding agrees with a previous study unveiling that male semi-captive elephants tend to be more aggressive and less sociable than females (Seltmann et al., 2019). Interestingly, Allen et al. (2021) revealed that the presence of older male elephants was linked to decreased rates of lone adolescents' aggression toward non-conspecific targets in male African elephants. These behavioral findings highlight the need for further research into the relationship between age and aggression in male elephants, both toward conspecifics and non-conspecifics.

Despite the absence of mating records for male semi-captive elephants, our result indicates a notably low probability of mating with wild bulls in female semi-captive elephants. According to the observation by Taylor and Poole (1988), mating is predominantly believed to occur with the dominant males in specific areas, although females from MTE have access to a greater number of mature males than those in zoos. Our result also suggested that the low probability of mating with wild bulls may depend on the presence of dominant semi-captive male elephants in areas and the need to consider the structure of the semi-captive population in certain areas. It is crucial for improving mating behavior between semi-captive females and wild males. Additionally, it is notable that the probability of mating with wild elephants in female semi-captive elephants steadily increased before 46 years of age and then decreased regardless of fecundity. Comparatively, Hayward et al. (2014) acknowledged that reproductive senescence in female semi-captive elephants from MTE begins early, exhibiting a rapid increase of fecundity to a peak at age 19 and followed by a subsequent decline. These findings match the prediction that in long-lived mammals, senescence should commence at an earlier age relative to the mean lifespan than in short-lived species (Turbill & Ruf, 2010). More studies must clarify the complexities of reproductive senescence in these long-lived giants, considering various factors such as adverse environmental conditions, mate selection, nutrition, and more.

Furthermore, our study showed that younger semi-captive elephants were more easily accepted by wild elephants, indicating that younger individuals could be considered for reinforcement projects. More precisely, we suggest that male semi-captive elephants younger than 21 years old and females younger than 42 years old would be ideal to guarantee better integration into the wild populations and fewer fighting events. This aligns with the recommendation for the giant panda (*Ailuropoda melanoleuca*) conservation translocation by Wang et al. (2023), emphasizing the importance of selecting young individuals and considering the sex based on the community structure of the target population. Particularly, the observation that female semi-captive elephants predominantly engage in mating and mingling behaviors with wild elephants when they are younger than 40 years old, while males exhibit mingling behavior primarily before the age of 20 highlights important aspects related to their sexual maturity, social senescence, and aging.

In terms of sexual maturity, the tendency for these behaviors in younger females aligns with the general understanding of elephants reaching reproductive maturity at a relatively early age 10–15 years old (Mumby et al., 2013; Mendis et al., 2017). Nevertheless, the subsequent decline in these behaviors after those age periods suggests a potential link to social dynamics among female Asian elephants. Previous studies observed that adult females associate only with maternal relatives (Fernando & Lande, 2000; Vidya & Sukumar, 2005), contributing to the survival of calves (Lahdenperä et al., 2016). These factors may drive female elephants to become less engaged with wild populations while prioritizing familial bonds over mating and mingling opportunities.

In contrast, the observation that male Asian elephants predominantly engage in mingling behavior before the age of 20 reflects the complex dynamics of male social behavior and aggression. Males also reach sexual maturity at around 10–15 years of age (Mumby et al., 2013), but their social behaviors differ significantly from those of females (Seltmann et al., 2019). Younger males may seek out mingling opportunities to establish social hierarchies and gain experience in interacting with both conspecifics and potential mates. However, as males age and gain size and strength, they often become more aggressive, especially during musth, a period characterized by heightened reproductive hormones (Rajaram, 2006). The decrease in mingling behavior in males after 20 years of age in our study may suggest, as Chelliah and Sukumar (2013) highlighted, that males with larger body sizes or those in musth prioritize establishing dominance for various reasons, such as gaining reproductive advantages and exerting control over resources.

According to these findings, the social interaction between semi-captive and wild individuals was less as they aged, and it indicated that young individuals could be considered for reinforcement projects as more ideal candidates, and then the gender should be selected according to the structure of the target population. The captive population of Asian elephants in Southeast Asia is approximately 10,000 (Menon & Tiwari, 2019), and based on our results, parts of this population can make ideal subjects for conservation translocation to reinforce the elephant population in the wild. These results could inspire policymakers and conservationists to launch reinforcement projects from both ecological and behavioral perspectives to efficiently achieve successful conservation.

However, there are limitations associated with longitudinal records of semi-captive elephants, which may impact the depth and generalization of the behavioral analysis. First, the information on the estimated age and sex of the wild elephant counterparts is lacking, which impedes a comprehensive understanding of the dynamics when exploring the conspecific interactions. Second, rather than through methods like all-occurrence sampling, the historical records were recorded mainly by veterinarians and elephant handlers when they encountered interaction events of elephants, which may limit the breadth of behavioral variables that can be studied. Future research could benefit from real-time behavioral observations, such as using camera traps or video recordings to enhance the robustness of the analysis. Regardless of these limitations, the use of longitudinal records of semi-captive elephants serves as an initial step in unraveling the complexities of conspecific interactions between semi-captive and wild elephants.

The result of our predicted suitable habitat is consistent with a previous study stating that North Zamari wildlife sanctuary, despite its considerable size, is comparatively less used by elephants (Sukumar, 2007). Most of the suitable habitats for Asian elephants are located outside of this wildlife sanctuary. We suggest that more attention should be paid to suitable habitats outside the wildlife sanctuary to better conserve this endangered species. The present study found that the proximity to villages was the most influential environmental variable in predicting Asian elephant habitat. This aligns with previous research by Yu et al. (2024), which argued that elephants were quite adaptable to areas shaped by human activities. This preference for human-dominated areas could mostly be driven by food availability, which are not just backup options for elephants but preferred habitats (Fernando et al., 2022). This helps us understand the intricate connection between elephants and areas influenced by humans, explaining why suitable habitats for elephants in our study were found near human-dominated regions outside of the North Zamari Wildlife Sanctuary. In addition, Asian elephants are categorized as "edge specialists" due to their inclination to forage along the edges of forests (English et al., 2014; Li et al., 2023). Consistently, our study revealed that the proximity to managed forests was the second crucial variable influencing elephant distribution, indicating that Asian elephants show a preference for habitats marked by disturbed vegetation commonly found at the boundary between human-altered and natural environments.

As elephants prefer human-dominated environments, the potential for human-elephant conflict rises, particularly when these areas become preferred habitats due to food availability. Conservation strategies must therefore focus on mitigating these conflicts through approaches such as cultivating non-preferred crops in buffer zones (Cao et al., 2020), improving land-use planning (Thant et al., 2021), and promoting coexistence initiatives that reduce competition for resources. Additionally, community-based programs that involve local populations in conservation efforts can help balance the needs of both elephants and humans, ensuring that habitat management supports the long-term survival of elephants while minimizing disruption to human livelihoods.

In conclusion, our study identified suitable habitats for Asian elephants in the southern central region of Myanmar. We argued that most of the suitable habitat is distributed outside of the North Zamari Wildlife Sanctuary, emphasizing the need to consider other forest habitats as essential refuges for Asian elephants in this region. To advance conservation efforts, we advocate for further studies to assess MTE elephant camps as potential translocation sites, utilizing useful tools such as multicriteria decision analysis (MCDA) to ensure that decisions are data-driven and contextually relevant. Secondly, we suggest that younger elephants (male ≤21 years old; female ≤42 years old) should be prioritized as translocation candidates in future elephant reinforcement conservation projects. This targeted approach not only enhances the chances of successful integration into wild populations but also contributes to the genetic diversity and resilience of these populations. Understanding these interactions is crucial, as it can lead to tailored management practices that promote coexistence and reduce conflict with not only conspecifics but also humans. Overall, the findings of our study have significant implications for conservation policy and practice. By emphasizing the necessity of adaptive management strategies that incorporate local ecological knowledge and stakeholder involvement, our research supports the development of comprehensive conservation frameworks. These frameworks can effectively address the complexities of elephant conservation in anthropogenic landscapes, ensuring the long-term survival of Asian elephants and the ecosystems they inhabit.

AUTHOR CONTRIBUTIONS

Hnin Nandar, Li-Li Li, and Rui-Chang Quan designed the study. Hnin Nandar and Zaw Min Oo collected the data. Hnin Nandar, Ye Htet Lwin, and Li-Li Li performed the analysis and graphing. Hnin Nandar, Li-Li Li, and Rui-Chang Quan wrote the manuscript, with all authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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