Chapter

Giants on an Island: Threats and Conservation Challenges of Elephants Due to Herbivorous Diets

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Abstract

Elephants are highly generalized herbivores with a wide dietary range encompassing natural vegetation and cultivated crops. Their foraging strategies vary across different temporal and spatial contexts, as well as among distinct social groups. A significant number of elephants in Asia and Africa reside beyond the boundaries of national parks, nature reserves, and protected areas. Consequently, many elephants face elevated risks of mortality or injury while seeking essential nutrients. This chapter provides an overview of the critical role played by dry-zone forests as habitats for elephants. Furthermore, it explores how human-dominated landscapes influence elephant feeding behaviors and foraging strategies, emphasizing the need to enhance our current understanding of these behaviors and their implications for the future.

Keywords: elephants, foraging strategies, crop-raiding, human-elephant conflict, elephant conservation

1. Introduction

Herbivores play vital roles in maintaining the ecosystem functions and vegetation community through various processes such as grazing, browsing, trampling, and defecation [1–3]. The large (>5 kg) terrestrial mammalian herbivores are considered 'keystone' species in many ecosystems that help define an entire ecosystem. Therefore, without keystone herbivores, the ecosystem would be dramatically different, cease to exist altogether, or could collapse [2, 4]. Therefore, studying many fields of biology, ecology, and conservation of large herbivores has been an essential topic debated by environmental conservationists, ecologists, and management authorities for over a century in many parts of the world. However, current data show that large herbivores face considerable population declines due to various reasons and home range contractions, such that ~60% are threatened with extinction [5].

In the realm of large herbivore research, South and Southeast Asia hold a unique position due to the Indo-Malayan biogeographic realm supporting more than twice the number of large herbivore species per unit area compared to Africa [6]. However, despite this abundance, our understanding of Asian large mammalian herbivores' behavior, population dynamics, community ecology, and ecosystem impacts remains inadequate for effective conservation and management when compared to other

regions such as North America, Europe, and Africa [6, 7]. Notably, significant research efforts have been dedicated to understanding the Asian elephant (*Elephas maximus*) and its contribution to the conservation and preservation of its habitats [8].

As the largest living herbivorous animal in Asia, the Asian elephant is distributed across South and Southeast Asia, inhabiting diverse ecosystems, including grasslands, tropical and subtropical forests, marshes, and human-dominated landscapes. However, over the latter half of the twentieth century, the Asian elephant population in the wild has undergone a significant decline [9, 10], resulting in its current endangered status [11] and listing in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). The remaining wild population of Asian elephants is estimated to be less than 50,000 individuals [8, 10, 12, 13], with three recognized subspecies: *E. maximus indicus* on the mainland, *E. maximus sumatranus* in Sumatra, and *E. maximus maximus* in Sri Lanka, which holds particular importance for elephant conservation efforts [14].

The Sri Lankan elephant (*E. maximus maximus*), referred to as the "Sri Lankan elephant" or simply "elephant" henceforth, holds immense symbolic, cultural, and economic value within Sri Lanka (**Figure 1**). This country boasts one of the highest densities of wild Sri Lankan elephants in South Asia, with a remaining wildland area of 4102 km^2 dedicated to their habitat [15]. However, the rapid growth of the human population, the expansion of agricultural lands, along with the implementation of development projects, especially in the dry zone, have led to a significant decline in elephant populations compared to historical levels. This decline has been exacerbated by the adoption of agro-civilization practices, which involve the use of irrigation systems with reservoirs and canals. The estimated population, once reaching 12,000 individuals [16], has now dwindled to 7000 elephants across the entire island [17].

The progressive encroachment of human-dominated landscapes into the shrinking habitats of Sri Lankan elephants has brought about a pressing issue: the human-elephant

Figure 1.
The Sri Lankan elephant walking on a tank bed at Minneriya National Park Sri Lanka.

conflict (HEC) [18]. This conflict arises from competing demands for space, time, and resources, leading to dire consequences for both elephants and humans, including loss of life. As such, the HEC has emerged as a critical socio-economic and political challenge within Sri Lanka [19–21], posing a significant threat to local biodiversity conservation efforts. The gravity of the situation becomes apparent when considering the staggering number of HEC incidents recorded between 2010 and 2019, reaching 14,516 in total [22]. Tragically, these conflicts have resulted in the death of 2631 elephants during the same period, with potentially numerous unreported casualties due to inadequate incident management [22]. Furthermore, the human death rate has experienced a 50% increase in the past two decades [20, 23], culminating in 121 human fatalities in 2019 alone [22]. Managing this immense conflict has become a primary objective for elephant conservation, and Sri Lanka, as an island nation, holds a distinct position in the conservation and management of these magnificent, large herbivores.

Crop-raiding by elephants is a significant factor contributing to human-elephant conflict (HEC) in Sri Lanka, leading to considerable losses in agricultural produce during individual raiding incidents. This issue carries profound implications for elephant conservation, directly impacting the physical and psychological well-being of farmers, their economic stability, food security, and various social and cultural aspects within Sri Lanka [21, 24–26].

Research conducted by De Silva [27] and Jayawardene [28] has shed light on the annual average crop and property damage caused by wild elephants, ranging between Rs. 6000 and Rs. 30,000 per farming family. These cumulative damages amount to approximately Rs. 560.71 million per cropping season or an average of Rs. 1121.42 million per year, encompassing the entire elephant habitat in Sri Lanka [29]. However, it is important to consider that this estimate may lean toward the higher end, as it might include a significant number of farms that experience substantial elephant-related damage, thereby introducing an upward bias. Consequently, comprehending the general feeding behavior of elephants, their herbivorous dietary patterns, and the resulting HEC from crop-raiding becomes crucial in evaluating its impact on conservation efforts. Addressing these challenges is essential for effective conservation and management of elephants in Sri Lanka.

Exploring the intricate feeding behavior of large herbivores on an island is a vast and challenging topic that cannot be adequately covered in a single chapter. Thus, in the subsequent sections, we provide a general background on the significant role played by dry-zone forests in providing a home for elephants (Section 2). Following this, in Section 3, we delve into the interaction between megaherbivores and human landscapes while also discussing the broader aspects of man-made feeding grounds for elephants. Section 4 focuses on the specific issue of crop-raiding behavior by elephants, shedding light on its implications for the HEC. Additionally, in Section 5, we explore the impact of garbage dump sites on elephants' feeding behavior. Finally, in Section 6, we investigate how the herbivorous diet of elephants influences their habitats. This chapter concludes by presenting emerging threats to elephants, providing a comprehensive overview of the various factors affecting their conservation and management.

2. The dry zone: dry evergreen forests are home to most of the Island's elephants

The dry evergreen forests in the dry zone of Sri Lanka, covering nearly two-thirds of the island, provide crucial habitat for the majority of the country's elephant population.

With 76% of these forests located within the dry zone, they serve as a reliable food source for approximately 5879 elephants [30]. Particularly during times of reduced grass availability, these forests play a significant role in sustaining the elephants [31, 32]. A study conducted in the north-western region of Sri Lanka revealed that elephants consume a diverse array of plant species, including both trees (47%) and non-tree species like shrubs, herbs (including grass), and climbers (53%) [33].

Due to their large size, elephants have substantial dietary requirements, consuming around 150 kg of food daily [13]. The availability of food within the dry zone forests plays a critical role in shaping the home range and movement patterns of Sri Lankan elephants. Sri Lankan male elephants exhibit home ranges that span from 53.6 to 346 km^2, while females have home ranges ranging from 29.6 to 160.7 km^2 [34]. Research by Kumar et al. [35] indicates that elephants exhibit transient foraging behavior, rarely staying in one area for an extended period. Instead, they constantly move between different locations to fulfill their dietary needs. These movement patterns vary throughout the seasons, and their food selection also changes accordingly as they are mixed feeders.

The presence of elephants in dry evergreen forests holds immense ecological significance, as emphasized by the scientific literature [36, 37]. Elephants contribute to the structure and composition of these forests through their feeding habits. By consuming a variety of plant species, elephants facilitate seed dispersal, which promotes forest regeneration and the growth of diverse vegetation [38–42]. Furthermore, their browsing behavior affects the understory vegetation, stimulating the growth of grasses while reducing the dominance of woody plants. Additionally, elephants act as ecosystem engineers by modifying their habitat through activities such as uprooting trees and creating water holes, which benefit other wildlife species [43]. These interactions between elephants and their environment have far-reaching effects on forest dynamics and contribute to the conservation of biodiversity.

Research has demonstrated that the decline of elephants in dry forests can have profound, cascading effects on the ecosystem [44]. Reductions in elephant populations disrupt seed dispersal patterns, leading to diminished tree regeneration and alterations in vegetation structure. Without the influence of elephants' browsing and trampling, the understory vegetation may become denser, impacting the abundance and diversity of plant species. Moreover, the absence of elephants as ecosystem engineers hamper critical ecological processes, including the formation of water sources and the creation of microhabitats for other animals. The overall health and resilience of the dry forest ecosystem are intricately linked to the presence and conservation of elephants.

The dry zone of Sri Lanka has witnessed significant forest losses in recent decades due to various human activities such as resettlements, agricultural encroachments, infrastructure development, and the construction of reservoirs and dams. While these endeavors aim to benefit local communities, they have unfortunately led to the fragmentation of wildlife habitats. As a result, a considerable portion of elephant home ranges now overlaps with human settlements, agricultural lands, and croplands. The construction of development projects that disrupt elephant corridors has further exacerbated the human-elephant conflict (HEC) on the island. The loss of natural habitat not only impacts wildlife but also gives rise to numerous human-wildlife conflicts, including the HEC. Therefore, it is imperative to prioritize the preservation and conservation of the existing dry zone forest cover to protect the natural habitat of Sri Lankan elephants. This necessitates comprehensive land use planning and political stability to ensure the long-term coexistence of elephants and humans on the island.

In order to maintain the ecological integrity and long-term viability of the dry evergreen forests, the conservation and protection of the Sri Lankan elephant population in the dry zone are of the utmost importance. Effective conservation strategies should not only focus on mitigating human-elephant conflicts but also prioritize the preservation of suitable habitats and corridors that facilitate elephant movement. It is crucial to implement measures that reduce habitat fragmentation and secure protected areas within the dry zone. One approach is the establishment of wildlife corridors, which would connect fragmented forest patches and enable elephants to traverse their natural ranges without frequent encounters with human settlements and agricultural activities. By creating and reconnecting these corridors, we can effectively address the challenges posed by habitat fragmentation and promote the coexistence of elephants and humans in the region. Such initiatives should be supported by robust monitoring systems, stakeholder engagement, and the involvement of local communities to ensure the success of conservation efforts in the dry zone of Sri Lanka.

3. Megaherbivore in human landscapes

Over the past few decades in Sri Lanka, rapid spatial and temporal changes in land use by human activities have affected natural landscape structure, patterns, and dynamics. In the island's central dry zone, natural landscape has changed over since the last 2000 years mainly due to man-made tanks and their cascade system, chena cultivation, croplands, and agriculture. These activities reduce the availability of elephants' natural habitats, impacting their movement patterns and home ranges. The cultivated fields with various crops within the home ranges of elephants attract the elephants.

3.1 Tank beds

The dry zone of Sri Lanka is characterized by the presence of numerous man-made lakes known as Wewa or tanks. These reservoirs were constructed by the ancient kings of Sri Lanka to store rainwater and surface runoff during the monsoonal periods [45]. Ranging from small seasonal ponds to vast perennial reservoirs spanning thousands of hectares, these tanks serve as favored habitats for elephants, especially during the dry season [46]. They offer vital water sources to elephants when the water level recedes, revealing fresh green short grass beds that elephants prefer grazing on, as opposed to long grasses.

In the dry zone where elephants reside, it is common to witness elephants congregating in these tank beds in the afternoon, ranging from small family groups to large herds. Throughout the day, elephants are typically found in the *Megathyrsus* grasslands [47]. However, during the evening, they migrate to the seasonal grasslands found on the tank beds. One remarkable gathering of elephants, known as the "greater elephant gathering," takes place in Minneriya-Kaudulla National Park (**Figure 2**). In locations like Wasgamuwa, Sri Lanka, elephants transition to these tank beds at around 15:00 hrs from their daytime refuge, where they begin feeding on short grasses. Elephants rely on bulk feeding of short grasses and a diverse diet to meet their nutritional needs. It is noteworthy that the dietary patterns of Sri Lankan elephants, similar to African elephants, do not solely reflect the availability of grass in tank beds but also involve browsing trees and shrubs in forests [47, 48].

Figure 2.
The Sri Lankan elephant gathering at Minneriya National Park.

These observations highlight the importance of tank beds as a crucial resource for elephants during the dry season. Preserving and conserving these habitats is essential for the well-being of Sri Lankan elephants and for maintaining their dietary diversity. By ensuring the protection of the tank beds and their associated grasslands, we can support the natural foraging behaviors and nutritional requirements of elephants in the dry zone.

3.2 Chena

Chena, also known as slash-and-burn cultivation, holds a significant historical presence in Sri Lanka, dating back as far as 5000 years. It was a prevalent practice among rural villages and early civilizations. To maintain the integrity of the habitat and environment, early Sri Lankans cleared forests specifically for chena practices. The process involved clearing a portion of the forest, cultivating it for 3–4 years, and then abandoning it to establish a new chena elsewhere. Most chena practices were situated near or within natural forests.

The old and abandoned chena lands serve as ideal foraging grounds for elephants [13, 24]. After the chena harvest, a substantial amount of leftover crops remains on the land, attracting elephants in large numbers. According to our observations and conversations with chena farmers, elephants often spend a day or two consuming the leftover crops before moving on to other areas for foraging. Elephants particularly favor excess crops such as millet and beans.

Over time, these abandoned chena lands become colonized by pioneer vegetation, creating rich food sources that attract elephants back to these areas. This behavior confirms that elephants are "edge species" and exhibit a preference for secondary forests [49]. We witnessed this foraging behavior of collard elephants in Lungamwehera, Southern Sri Lanka, as they are annually attracted to these secondary regeneration areas. As the succession progresses, these habitats provide both food and daytime

refuge for elephants. In addition to chena, other local farming activities within human-dominated landscapes also create ideal or sub-optimal elephant habitats [13].

In the mid-1900s, the traditional chena practice underwent significant changes due to rapid development, increasing human population, and changing needs. This shift resulted in an environmentally unfriendly cultivation method as chena started to rely on permanent cultivation lands near natural forests in the dry zone of Sri Lanka [23].

The landscape of the dry zone in Sri Lanka underwent dramatic modifications during the Mahaweli Development Project, an irrigation-based agricultural development program initiated in 1978. This project diverted the longest river, Mahaweli, to irrigate the dry-zone landscapes [50]. Consequently, the landscape transitioned into monoculture plantations, croplands, agricultural areas, and developed regions, greatly reducing available habitats for elephants.

3.3 Cropland and agricultural land

Crop and agricultural lands account for approximately one-third of Sri Lanka's total land area. Numerous studies have demonstrated that Sri Lankan elephants are attracted to the agricultural landscape as a food source. They have the ability to recognize that seasonal croplands offer a substantial food supply for wild elephants. In the dry zone of Sri Lanka, where the majority of elephants reside, rice paddy farming is a prevalent practice. The specific farming practices employed depend on the availability of seasonal water.

Dry-zone agriculture in Sri Lanka encompasses various farming practices, including intensive rice-rice cultivation, rice-vegetable farming, or cultivation of rice along with other field crops such as mungbean, millets, maize, chili, soybean, and seasonal vegetables. Additionally, rice-fallow rotations are also observed in the region [51]. Therefore, within the dry zone, the Sri Lankan elephant benefits from a combination of habitats, including the dry evergreen forests, agricultural lands, and croplands. Elephants utilize the forested areas for cover and browsing opportunities, while farming areas provide accessible and abundant grazing opportunities [25, 33, 47, 52].

Previous research and observations have highlighted the importance of these diverse habitats for the Sri Lankan elephant population. The elephants rely on the mixture of forested and agricultural landscapes, utilizing each habitat for specific purposes. The forested areas offer protective cover and browsing resources, while the agricultural and cropland habitats provide ample grazing opportunities. This interplay between dry evergreen forests and farming areas contributes to the elephants' overall foraging strategies and supports their sustenance in the dry zone.

4. Crop-raiding behavior of elephants

Crop-raiding behavior is a common occurrence among elephants, but it is often misunderstood that elephants resort to raiding cultivated crops due to a lack of natural food sources. In reality, elephants maintain large home ranges that often overlap with human-dominated landscapes, leading them to feed on human-cultivated crops based on seasonality and availability [53]. However, this exposes elephants to various threats from people, particularly in agricultural-dominated landscapes. Consequently, elephants have adapted their behaviors and activities to reduce risks and maximize benefits in human landscapes.

A significant adaptation by elephants to coexist with humans is their transition to diurnal behavior. Elephants are predominantly active from late afternoon to early morning and seek refuge away from human-dominated areas during the daytime. They venture into human landscapes during the cover of darkness and return to forested areas in the morning [13, 25]. Elephants primarily move toward open natural habitats such as grass beds near man-made lakes and scrublands to feed. They approach crop fields only during complete darkness [13, 25, 54, 55], which poses a considerable risk for humans.

Several studies have suggested that feeding on cultivated crops provides elephants with better nutrients compared to foraging on natural food sources [13, 56, 57]. However, the scientific evidence supporting this claim is not yet comprehensive. Nevertheless, Fernando et al. [25] clearly demonstrated that elephant incursions into human landscapes were more frequent during the harvesting periods of rice and other crops, particularly watermelon, banana, and corn. This indicates that elephants are attracted to these crops due to their nutritional value (**Figure 3**). It is important to note that natural fodder for elephants is not scarce during these times. Farmers intensively guard their crops, exposing elephants to high threats. Despite the risks involved, elephants' fondness for crop fields suggests the potential benefits in terms of acquiring nutrients, albeit at the expense of increased interaction with humans [25, 58].

Risk-taking behavior varies among different social groups of elephants [25, 53, 55, 59]. Family groups tend to minimize risks as they are accompanied by juveniles of different ages. For example, we observed a scarcity of mother-calf units entering crop fields and feeding on crops. Consequently, they are less frequently found in crop fields, choosing to sacrifice the gains from cultivated crops to protect their young. Our observations of two-family groups equipped with GPS collars in Southern Sri Lanka revealed that they stayed in small forest patches among crop fields and abandoned agricultural fields more often than entering the crop fields. Additionally, our observations from different locations in Sri Lanka showed that family groups would enter paddy fields immediately after harvest to consume leftover paddy, as these fields are unguarded by farmers, resulting in no human-related risks.

When it comes to the trade-off decision of taking high risks to reap the benefits of foraging on cultivated crops, male elephants are known to be more inclined toward risk-taking behavior. Sexual segregation in movement patterns toward human landscapes, based on crop availability, indicates that males are more willing to take risks [25, 60]. It has been suggested that the high-risk, high-gain foraging behavior of male elephants contributes to their growth and better body condition, ultimately enhancing their reproductive capacity by obtaining cultivated food items [57, 61]. Another possible reason for males to feed on cultivated crops more than females is their larger home ranges, which necessitate more extensive use of human-dominated landscapes, including crop fields while seeking natural resources within their home ranges [62, 63]. Furthermore, according to [53], elephants raid crops not as a foraging strategy but because their natural foraging resources in their home ranges have been depleted due to human activities, leaving them with limited feeding options. This idea is supported by research findings on the ranging patterns of elephants by Fernando [64], which indicate that elephants in Sri Lanka do not engage in long-distance migrations or maintain wet- and dry-season ranges. Consequently, they must find resources within their home ranges. Both scenarios of feeding on crops are equally valid based on our observations.

It is crucial to note that not all elephants engage in crop raiding. However, in rural Sri Lanka, there exists a general perception among farmers that all elephants

Figure 3.
Crop raid by elephants. (A) Crop damage after elephant raid in Sri Lanka, (B) Elephant dung in a crop field after raiding the crop overnight.

raid crops and that all male elephants are crop raiders, considering them a nuisance and serious pests [24]. Nevertheless, this is not the case, as not all elephants are crop raiders; only certain individuals and family groups engage in crop raiding. Desai and Heidi [53] classified crop-raiding elephants into three categories: opportunistic crop raiders, habitual crop raiders, and obligatory crop raiders. Opportunistic crop raiders are elephants that raid crops when they come across unprotected fields. Most

of these opportunistic raiders are family groups. Habitual crop raiders are individuals that develop a liking for crops and become regular raiders, particularly young and mature male elephants. These elephants learn to overcome human-elephant conflict (HEC) mitigation measures implemented by farmers. Male habitual raiders form small bachelor groups when raiding crops, which may serve as a behavioral strategy to collectively face human threats. Young male elephants join bachelor groups with mature males to learn from them. Obligatory crop raiders are elephants that have experienced significant losses of their natural habitats and foraging resources due to habitat clearance, thus being forced to depend to a greater extent on cultivated crops. These elephants frequently encounter humans and are more vulnerable to human retaliations.

Currently, elephants face threats solely due to their status as megaherbivores living within their home ranges. They are compelled to exist in highly fragmented habitats embedded in human-dominated landscapes, leading to increased human actions to control their entry. In Sri Lanka, farmers take invasive measures more frequently than in the past to control elephants that encroach upon and linger around their crop fields.

5. Elephants eating garbage

Human activities have exerted significant pressure on elephants, leading to extreme changes in their food preferences. In Sri Lanka, some elephants have shifted their feeding habits from foraging on natural food sources to consuming food items found in garbage sites. These garbage dumps offer a plentiful supply of both organic and inorganic waste. Organic waste includes discarded fruits, vegetables, and cooked food, while inorganic materials consist of plastics, glass, metals, and other synthetic items. Elephants are primarily attracted to easily accessible organic matter but may accidentally consume inorganic substances.

Our observations of elephants at various garbage sites indicated that only mature and sub-adult males were present at the dumps, while female groups with juveniles did not visit these locations (**Figure 4**). The only published study on garbage site observations in Bundala, Southern Sri Lanka, conducted by Liyanage et al. [65], supports these findings. Once elephants become accustomed to feeding at these sites, they establish a permanent presence in the vicinity of the garbage dumps. Consequently, their reliance on natural food sources diminishes, and their home range becomes significantly reduced compared to other elephants. These elephants obtain sufficient food quantity and essential nutrients from the items found in the garbage dump, which is reflected in their healthy body condition score. There is a common perception that these elephants should be deterred from consuming garbage due to potential harm to their well-being and the unpleasant sight of elephants in such environments. However, conservationists argue that if these elephants are prevented from accessing garbage sites, they will resort to frequent crop raiding, exposing them to life-threatening injuries and potential retaliatory actions by humans. Therefore, it is preferable to allow these elephants to feed at the garbage sites, with authorities taking measures to separate them from inorganic materials before disposal to minimize accidental ingestion.

In addition to feeding on garbage, elephants in Sri Lanka have adopted another foraging strategy, which involves soliciting food from people along roadsides. These elephants are known as "road elephants" (**Figure 5**). They can often be observed along the Buttala-Kataragama road in Southern Sri Lanka. The elephants select

Figure 4.
A wild elephant waiting for hands outs of food from passing traffic, blocks the Kataragama road Buttala Sri Lanka.

Figure 5.
Sri Lankan wild elephant herd eating garbage at Wellawaya, Sri Lanka.

specific spots near the road and wait for passing traffic to request food. Initially, this behavior was primarily observed in a few mature males, but recently, in 2019, we observed a family group, including females and juveniles, imitating the males and engaging in begging behavior only during the late afternoon due to their fear of humans and traffic. Several family groups have permanently stationed themselves by the road with juveniles, raising significant conservation concerns. The begging behavior exhibited by male elephants is learned by other elephants and transmitted to different populations.

These unique feeding strategies, involving garbage consumption and begging from people, highlight the adaptive behavior of elephants in response to human-altered landscapes. Similar patterns of garbage feeding and road begging have been observed in other parts of the world, indicating the widespread nature of these behavioral adaptations These observations emphasize the urgent need for comprehensive conservation measures to address the underlying causes of these behavioral changes, mitigate human-elephant conflicts, and develop effective strategies for protected area management and conservation biology of elephants. Understanding and managing these adaptive behaviors is crucial for the long-term survival and coexistence of elephants and humans in shared landscapes.

6. Impact on habitats

Larger herbivores play a crucial role as ecosystem engineers, modifying habitats through their feeding behaviors and exerting scale-dependent effects on natural environments [66–68]. Elephants, as one of the largest herbivores, have significant impacts on habitat composition, particularly on woody plants, by breaking branches, toppling trees, and reducing the recruitment of new vegetation [69]. These modifications are essential drivers of habitat dynamics and can lead to the generation of new habitats that support ecological restoration.

The impact of elephants on woody plants is influenced by various factors, including overall food availability, food preferences, spatial and temporal weather conditions, social interactions, and the physical status of elephants [70–72]. For instance, in Gonarezhou National Park in Zimbabwe, the browsing behavior of elephants resulted in the degradation of woodland patches dominated by *Acacia tortillis* [73]. Research indicated that bull elephants, particularly those of higher density, were responsible for more significant damage to trees compared to family groups [74]. High population densities of elephants can exert severe pressure on the survival of threatened plants and disrupt plant community structures, as observed in Addo National Park in South Africa [75]. Efforts are being made in Greater Kruger National Park to protect keystone tree species like marula (*Sclerocarya birrea*) from elephant impact.

In Asia, studies by Sukumar [76] demonstrated the browsing effects of elephants on woody plants, revealing variations in foraging impact across different tree size classes. Unlike in Africa, the specific aspects of elephant foraging ecology and their habitat impacts have received less attention in Asian contexts [25, 53, 60]. In Sri Lanka, we have observed that the elephants have not caused significant habitat changes through their foraging behaviors, as seen in Africa. However, they do exhibit selectivity in targeting certain tree species. In Wasgamuwa, for example, elephants selectively forage on two woody plant species: Maila (*Bauhinia racemose*) and Welang tree (*Pterospermum suberifolium*). Elephants debark Maila trees after monsoon rains, with family groups contributing to much of the damage. Additionally, Maila trees are

selectively targeted during the dry season when mature seed pods are abundant, with elephants breaking branches to acquire the sweet seeds. The impact on Maila trees does not have a negative effect on the habitat; instead, the thinning of Maila trees helps maintain the scrubby nature of the habitat, preventing or delaying the succession from scrubland to forest.

These examples illustrate the significant role of elephants as ecological influencers, shaping habitats through their feeding behaviors and highlighting the dynamic relationship between elephants and their environments. These relationships are of the utmost importance for protected area management and conservation biology. Understanding the ecological effects of elephants' foraging behaviors helps inform conservation strategies aimed at maintaining biodiversity and ecosystem functioning within protected areas. By altering habitat composition through branch breaking, tree toppling, and selective feeding, elephants shape the structure and dynamics of plant communities, which in turn influences the availability of resources for other species. These habitat modifications can have cascading effects on other wildlife, including changes in species composition, plant regeneration, and overall ecosystem resilience.

Therefore, incorporating the knowledge of elephant impacts into protected area management plans allows for the implementation of targeted conservation measures to mitigate potential negative effects, ensure the survival of threatened plant species, and maintain the integrity of habitats. Additionally, understanding the role of elephants as ecosystem engineers and the generation of new habitats through their behaviors provides valuable insights for ecological restoration efforts, guiding the restoration of degraded areas and promoting the establishment of diverse and functional ecosystems. By recognizing and addressing the complex interactions between elephants, their habitats, and other species, protected area managers and conservation biologists can effectively conserve biodiversity and promote the sustainable coexistence of elephants and humans.

7. Emerging threats to elephants

The high-risk foraging strategy of male elephants is identified as the primary cause of human-elephant conflict (HEC) [57, 62, 64]. In Sri Lanka, the majority of elephant deaths occur in landscapes dominated by agriculture [77]. While various measures have been employed to mitigate elephant crop damage, there has been an alarming increase in the utilization of highly destructive methods to control elephants, posing a significant concern for elephant conservation [77]. We aim to provide details on some of these destructive measures to shed light on this pressing issue.

One of the most destructive methods used to control elephants is the deployment of "jaw bombs." These homemade explosive devices, resembling small grenades, are created by combining gunpowder with tightly packed stones or metal pieces. Initially developed to combat agricultural pests like wild boar, jaw bombs are designed to detonate within an animal's mouth when inadvertently bitten. The explosion causes severe damage to the jaws and tongue. Disturbingly, villagers have started hiding jaw bombs inside fruits, such as watermelons, to target elephants. Often, these devices are strategically placed at the periphery of crop fields to deter raiders. It is worth noting that the majority of jaw bomb victims are female and young elephants. This observation suggests that male elephants may have developed a heightened sense to detect and avoid these concealed explosives. However, further scientific investigation is required to confirm this hypothesis.

Sadly, most elephants affected by jaw bombs are unable to eat or drink due to their injuries, leading to minimal chances of survival from a veterinary standpoint. Troublingly, the use of jaw bombs is becoming increasingly prevalent and widespread in Sri Lanka. Farmers and individuals deploy these explosives in nearly all crop fields, predominantly during the night and retrieving them in the morning. Given that elephants are active during the night, they are particularly vulnerable to encountering jaw bombs. Consequently, we strongly recommend that government authorities take decisive action to prevent and combat this illegal activity.

The second highly destructive method employed to control crop-raiding elephants is electrocution. Farmers and villagers' resort to this method to safeguard their crops and properties. Typically, this involves setting up single metal strings around the targeted fields, connected to electrical power sources from nearby houses. The continuous high amperage running through the metal strings poses a fatal threat to elephants and any other animals, including humans, coming into contact with them. Electric shocks lead to ventricular fibrillation, causing heart failure, burns, and internal organ damage. It is crucial to emphasize that electrocution is an illegal practice. Recognizing its illegality, villagers predominantly set up these lethal traps at night when elephants are active, removing them during the daytime. Male elephants constitute the majority of victims of electrocution. To mitigate the use of such methods, farmers should be encouraged to participate in crop-guarding initiatives, including the establishment of village and crop-field fences. It is disheartening to note that some farmers resort to additional invasive measures, such as shooting elephants with homemade illegal guns, employing gun traps, and setting up metal snares, to harm or kill elephants in agricultural landscapes.

Addressing the issue of destructive measures used to control elephants is paramount within the framework of protected area management and conservation biology in Sri Lanka. It requires a comprehensive approach that encompasses several key aspects. Firstly, there is a pressing need for increased law enforcement and strict regulation to curb illegal activities related to jaw bombs, electrocution, and other harmful methods. Government authorities must take decisive action to halt the production, distribution, and use of these destructive devices, ensuring that those involved in such practices face legal consequences. This includes strengthening patrols and surveillance in vulnerable areas, collaborating with local communities to gather information and intelligence, and establishing mechanisms to encourage individuals to report any instances of illegal elephant control methods.

The island's elephant populations face potential threats from current and future irrigation projects. One such example is the completion of the Moragahakanda Dam, which has had detrimental effects on the elephant population in Minneriya. Unseasonal water releases during the dry season have disrupted the natural water levels in the reservoir, leading to a decline in elephants. Despite the presence of limited grasslands, even a minor increase in water levels prompts several elephant herds to move away from Minneriya. As a result, there has been a significant decrease in the number of elephants observed during the peak of the "elephant gathering" over the years. It is crucial to closely monitor these populations and study their feeding behavior and movement patterns to understand the full impact of these changes.

To safeguard the long-term conservation future of the elephant population and preserve the natural wonders of Minneriya, it is imperative to address the issues arising from the Moragahakanda Dam project. Additionally, it is essential to ensure that future development projects undergo thorough environmental assessments and

planning processes. By taking these measures, we can mitigate the adverse effects on elephants and maintain the ecological balance of this unique habitat.

8. Conclusions and future directions

The historical and ongoing interaction between elephants and humans in Sri Lanka has resulted in significant challenges for elephant conservation. Development projects in the country's dry zone have led to the loss and fragmentation of elephant habitats, pushing them into more marginal areas. As a response, elephants have exhibited both positive and negative behavioral adaptations to survive in human-dominated landscapes, particularly through their feeding habits. However, these adaptations have also contributed to the escalating issue of human-elephant conflict (HEC), which remains the leading cause of daily elephant fatalities in Sri Lanka. It is crucial to prioritize research efforts aimed at enhancing favorable habitats within elephants' home ranges, preserving natural wildlife corridors, and implementing sustainable and effective crop protection measures to mitigate crop raiding and conserve Sri Lankan elephants.

Education and awareness programs play a pivotal role in fostering coexistence and changing societal attitudes and behaviors toward elephants. Public outreach initiatives should focus on highlighting the negative impacts of destructive measures, raising awareness about the ecological importance of elephants, and promoting alternative conflict mitigation strategies that are both humane and sustainable. Engaging local communities, farmers, and landowners through capacity-building programs and providing support for the implementation of effective crop protection measures, such as physical barriers, deterrents, and early warning systems, can significantly reduce reliance on harmful methods while safeguarding livelihoods and ensuring food security.

Additionally, scientific research and monitoring are essential for understanding the complex dynamics between elephants, their habitats, and human activities. Investigating the ecological impacts of elephant foraging behaviors, movement patterns, and responses to various deterrent methods can inform evidence-based management strategies. Close collaboration among conservation biologists, researchers, protected area managers, and government agencies is crucial for generating scientific knowledge that guides conservation efforts and supports the development of sustainable policies and practices.

By integrating these approaches into protected area management and conservation biology, Sri Lanka can make significant progress in mitigating human-elephant conflict, protecting elephants from harmful measures, and promoting a harmonious coexistence between humans and these majestic creatures. This holistic approach not only ensures the survival of elephants but also contributes to the conservation of biodiversity, the maintenance of ecosystem functioning, and the preservation of Sri Lanka's rich natural heritage for future generations to enjoy.

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Conflict of interest

The author declares no conflict of interest.

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