Human-Wildlife Conflict of Sri Lanka

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Preface

Sri Lanka is internationally recognized as one of the world's biodiversity hotspots, endowed with remarkable biological richness and a high degree of endemism. The country's diverse ecosystems support a wide array of wildlife species that have coexisted with human societies for centuries. However, rapid population growth, changing land-use patterns, agricultural expansion, infrastructure development, habitat fragmentation, climate change, and increasing pressure on natural resources have significantly altered this relationship. As a result, human–wildlife conflict (HWC) has emerged as one of the most complex environmental, social, and economic challenges facing Sri Lanka today.

Human–wildlife conflict extends far beyond the well-known issue of human–elephant conflict. It encompasses a wide range of interactions involving birds, monkeys, crocodiles, carnivores, rodents, and numerous other wildlife species that affect agriculture, livelihoods, public health, human safety, biodiversity conservation, and rural development. Addressing these conflicts requires a multidisciplinary understanding that integrates ecological, biological, social, cultural, economic, technological, and policy dimensions.

Recognizing this need, the Postgraduate Institute of Agriculture (PGIA), University of Peradeniya, initiated the preparation of this volume, *Human–Wildlife Conflict of Sri Lanka*, to provide a comprehensive and up-to-date account of the causes, consequences, and management of human–wildlife conflicts in the country. This publication brings together contributions from leading researchers, academics, practitioners, and experts representing diverse disciplines and experiences.

The book begins with fundamental perspectives on the biological, ecological, social, and ethnobiological dimensions of human–wildlife conflict. It then explores the economic implications and policy responses required to address these challenges. Several chapters examine specific conflict situations involving birds, monkeys, crocodiles, fishing cats, and wildlife impacts on traditional chena cultivation, coconut production systems, export agriculture, and urban environments. The volume further addresses the human dimensions of conflict, including injuries, fatalities, and public health concerns.

Importantly, the book highlights emerging approaches and future directions for conflict management. Chapters on modern technologies, climate change and its influence on wildlife interactions, and strategic pathways for effective human–elephant conflict management provide valuable insights into developing sustainable and evidence-based solutions. The inclusion of case studies on Kandyan homegardens and the ecological role of jackals in controlling rodent populations illustrates the complexity of human–wildlife relationships and the importance of understanding local contexts.

One of the major strengths of this volume is its multidisciplinary nature. The chapters collectively demonstrate that human–wildlife conflict cannot be understood solely as a wildlife conservation issue or as an agricultural problem. Rather, it represents a dynamic interaction between ecological processes and human systems that requires integrated approaches balancing biodiversity conservation with human well-being and sustainable development.

It is our hope that this publication will serve as a valuable resource for students, researchers, policymakers, conservation practitioners, development professionals, and all stakeholders engaged in managing human–wildlife interactions. We believe that the knowledge presented in this volume will contribute to informed dialogue, evidence-based policymaking, and the development of innovative strategies that promote coexistence between people and wildlife.

The Editorial Board expresses its sincere appreciation to all authors who contributed their expertise and experiences to this volume. We also acknowledge the reviewers for their constructive comments and recommendations, which significantly enhanced the quality of the chapters. Our gratitude is extended to the Postgraduate Institute of Agriculture, University of Peradeniya, for providing the institutional support necessary to bring this publication to fruition.

As Sri Lanka continues to seek sustainable pathways for conservation and development, understanding and effectively managing human–wildlife conflict will remain a national priority. We trust that this book will contribute meaningfully to that endeavor and inspire further research, collaboration, and action toward achieving harmonious coexistence between humans and wildlife.

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Dr. K.P.P. Kopiyawattage
Dr. D.S. Weerasekera
Dr. R.M.S.R. Chamara

Editorial Board

Panel of Reviewers

Acknowledgements

On behalf of the Postgraduate Institute of Agriculture (PGIA), University of Peradeniya, I am pleased to express my sincere gratitude to all those who contributed to the successful publication of this book on *Human–Wildlife Conflict in Sri Lanka*. Human–wildlife conflict has emerged as one of the most pressing challenges affecting biodiversity conservation, rural livelihoods, food security, and sustainable development in the country. This publication represents a collective effort to compile and disseminate scientific knowledge, practical experiences, and policy perspectives to support informed decision-making and sustainable solutions.

I extend my heartfelt appreciation to all contributing authors for sharing their expertise, research findings, and valuable insights through their respective chapters. Their commitment to advancing knowledge on this important subject has made this publication possible.

I also wish to acknowledge with gratitude the reviewers who generously devoted their time and expertise to critically evaluate the manuscripts. Their constructive comments and recommendations greatly enhanced the scientific quality, accuracy, and relevance of the chapters.

My sincere appreciation is extended to the Editorial Board for their dedication and hard work throughout the editorial process. I particularly acknowledge the leadership of Dr. R.H.G. Ranil, Editor-in-Chief, and the valuable contributions of the editorial board members, Dr. K.P.P. Kopiyawattage, Dr. D.S. Weerasekera, and Dr. R. M.S.R. Chamara, whose commitment and professionalism ensured the successful completion of this publication. I also acknowledge the academic and administrative staff of the PGIA who provided various forms of support during the preparation, editing, formatting, and publication processes. Their contributions behind the scenes were instrumental in bringing this work to fruition.

Finally, I express my gratitude to all researchers, conservation practitioners, policymakers, government agencies, non-governmental organizations, community members, and stakeholders whose work and experiences have contributed to a better understanding of human–wildlife conflict in Sri Lanka. It is our hope that this publication will serve as a valuable resource for students, researchers, practitioners, and policymakers, and will contribute to developing effective, science-based, and socially acceptable approaches for promoting coexistence between people and wildlife.

Prof. D.K.N.G. Pushpakumara
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Contents

Chapter 01

The Root Causes of Human-Wildlife Conflict in Sri Lanka: Historical Perspectives, Underlying Divers, and the Role of Ecology in Managing Conflict Over Time

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Abstract: Human–wildlife conflict (HWC) has become one of the most significant challenges to biodiversity conservation, rural livelihoods, and sustainable development in Sri Lanka. This paper examines the historical evolution of HWC, identifies its principal underlying drivers, and explores the role of ecology in understanding and managing conflict over time. Drawing on scientific literature and policy documents, the analysis shows that human–wildlife relationships have shifted from a largely coexistence-based system to increasingly conflict-prone interactions as a result of habitat loss and fragmentation, agricultural expansion, settlement and infrastructure development, declining ecological connectivity, changing human behaviour, weak land-use governance, and climate change. The paper argues that these drivers are the cumulative outcome of historical land-use transformations that have progressively increased overlap between human activities and wildlife requirements. It further demonstrates that population ecology and landscape ecology provide essential insights into wildlife distribution, movement patterns, habitat requirements, and conflict dynamics, thereby offering a scientific basis for more effective management interventions. The paper concludes that sustainable conflict mitigation requires moving beyond reactive approaches towards integrated land-use planning, habitat conservation, ecological restoration, community participation, and evidence-based governance that promote long-term coexistence between people and wildlife.

Keywords: Human-wildlife conflict, Sri Lanka, wildlife conservation, population ecology, landscape ecology, habitat fragmentation, colonial hunting, traditional coexistence.

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1. Introduction

Human–Wildlife Conflict (HWC) is one of the most significant environmental and socio-economic challenges facing the world today. It occurs when the needs, behaviour, or presence of wildlife negatively affect human livelihoods, safety, or well-being, or when human activities adversely affect wildlife populations and their habitats (Conover, 2001). Although interactions between humans and wildlife have existed throughout human history, their frequency and severity have increased substantially in recent decades due to expanding human populations, agricultural development, urbanization, infrastructure expansion, and environmental change. These processes have reduced and fragmented natural habitats, increasing the spatial overlap between wildlife and human activities and intensifying competition for land, water, food, and other resources.

Sri Lanka, despite its relatively small land area of 65,610 km², is recognized as one of the world's biodiversity hotspots due to its exceptional species richness and endemism. However, this biodiversity is increasingly threatened by habitat loss and fragmentation, overexploitation of biological resources, invasive alien species, pollution, climate change, and escalating HWC (CCS, 2022). HWC in Sri Lanka involves a wide range of species, including elephants, monkeys and toque monkeys, crocodiles, peacock, wild boar, porcupines, leopards, giant squirrels, fruit bats, and several deer species (Cabral et al., 2018; Danasekara, 2020; Dela, 2011; Dela et al., 2018; Fernando, 2015; LaDue et al., 2021; Nahallage and Huffman, 2013; Uluwaduge et al., 2017; Wijesundara, 2021). Among these, Human–Elephant Conflict (HEC) remains the most severe and widely documented form of conflict due to its substantial impacts on human lives, livelihoods, property, and wildlife conservation.

The consequences of HWC extend far beyond crop damage, livestock losses, property destruction, injuries, and fatalities. Conflicts generate high economic costs, psychological stress, social tensions, and negative attitudes towards wildlife conservation, often resulting in retaliatory killings and further threats to vulnerable species. Consequently, HWC has emerged as a major obstacle to biodiversity conservation, rural development, food security, and sustainable development in Sri Lanka (CCS, 2022; Fernando et al., 2005; Gunawansa, 2023; Madhusudan, 2003; Perera, 2009; Redpath et al., 2013; Woodroffe et al., 2005).

The underlying causes of HWC are deeply rooted in historical and contemporary changes in land use, resource management, and human behaviour. Forest clearance, habitat fragmentation, agricultural expansion, settlement schemes, infrastructure development, poor waste management, and weak governance have progressively altered wildlife habitats and movement patterns, increasing interactions between people and wildlife. As a result, a relationship once characterized largely by coexistence has increasingly shifted towards conflict (Anuradha et al., 2019; Calabrese et al., 2017; CCS, 2022; Fernando et al., 2005; Gunawansa et al., 2023; Köpke et al., 202; Mumby & Plotnik, 2018; Mongabay, 2020; Thouless et al., 2016).

Although considerable research has examined the impacts, spatial distribution, and mitigation of HWC (Li et al., 2018; Palei et al., 2013; Ram et al., 2022; Sanare et al., 2022; Thant et al., 2023; van de Water and Matteson, 2018), many management interventions have focused on addressing immediate symptoms rather than the underlying drivers of conflict. Sustainable solutions require a broader understanding of the historical processes, ecological mechanisms, and governance factors that shape interactions between people and wildlife as suggested by Dela et al. (2018).

Ecology, particularly population ecology and landscape ecology, provides valuable insights into wildlife distribution, abundance, movement patterns, habitat requirements, carrying capacity, and landscape connectivity (Fu and Jones, 2013; Lui and Taylor, 2002). These disciplines offer a scientific foundation for understanding why conflicts occur and for designing effective, long-term management strategies that promote coexistence.

This paper examines the historical evolution of human–wildlife conflict in Sri Lanka, identifies its principal underlying drivers, and explores how ecological principles can contribute to more integrated, adaptive, and sustainable approaches to conflict management. The paper argues that effective solutions require moving beyond reactive interventions towards landscape-level planning, ecological restoration, community participation, and evidence-based governance that balances biodiversity conservation with human well-being.

2. Historical Perspectives on Human-wildlife Conflict in Sri Lanka

HWC in Sri Lanka is the outcome of long-term socio-ecological transformations that have progressively altered relationships between people, wildlife, and landscapes. The historical evolution of HWC can be broadly divided into three phases: a period of relative coexistence before colonial rule, a period of ecological disruption during colonial occupation, and a post-independence period characterized by rapid development, land-use change, and escalating conflict. Understanding these phases provides important insights into the root causes of contemporary HWC.

2.1 Pre-Colonial Period (Before 1505): Coexistence within a Socio-Ecological Landscape

The pre-colonial period was characterized by relatively low human population densities, extensive natural habitats, and land-use systems that accommodated ecological processes. Cultural and religious values, particularly the Buddhist principle of non-violence, encouraged respect for wildlife and promoted tolerance towards nature. The ancient hydraulic civilization created a multifunctional landscape consisting of forests, reservoirs, paddy fields, chena lands, and settlements. Traditional agricultural systems, especially shifting cultivation, maintained habitat heterogeneity and enabled seasonal resource sharing between humans and wildlife. While conflicts undoubtedly occurred, they were moderated by abundant natural habitats, lower resource competition, and land-use practices that supported coexistence. Consequently, human–wildlife relationships during this period were largely shaped by adaptation and coexistence rather than exclusion and conflict (Anuradha et al., 2019; Geekiyanage and Pushpakumara, 2013; Gunasena and Pushpakumara, 2015).

2.2 Colonial Period (1505–1948): Ecological Transformation and the Foundations of Conflict

The colonial period marked a fundamental shift in human–wildlife relationships. Natural resources increasingly became commodities for economic exploitation, resulting in extensive wildlife extraction, large-scale forest clearance, and major land-use transformations. Commercial elephant capture, sport hunting, and organized culling significantly reduced wildlife populations, while the expansion of coffee, tea, and rubber plantations caused widespread deforestation and habitat fragmentation. These changes reduced ecological connectivity and displaced wildlife from many parts of the wet zone and central highlands. For elephants in particular, colonial land-use changes concentrated populations within the dry zone while simultaneously expanding human activities into these landscapes. This spatial reorganization of people and wildlife established many of the ecological conditions that continue to drive conflict today. Wildlife increasingly came to be viewed as an impediment to economic development, further altering societal attitudes toward conservation. Thus, the colonial period laid the structural foundations for modern HWC through habitat loss, fragmentation, wildlife exploitation, and changing human perceptions of wildlife (FAO, 1999; Köpke et al., 2021).

2.3 Post-Independence Period (1948–Present): Development, Fragmentation, and Escalating Conflict

Following independence, inarguably, national development priorities focused on food security, economic growth, rural development, and poverty alleviation. Large-scale irrigation projects, settlement schemes, agricultural expansion, infrastructure development, and urbanization transformed extensive areas of the country. The Mahaweli Development Programme and related settlement initiatives accelerated the conversion of wildlife habitats into agricultural and residential landscapes. Thousands of families were settled in areas that historically functioned as wildlife habitats and movement corridors, increasing spatial overlap between people and wildlife. At the same time, traditional land-use systems that had supported coexistence were replaced by permanent cultivation and commercial agriculture, often involving crops highly attractive to wildlife. Although a new sanctuary (i.e. the VRR Sanctuary) has been established, the underlying issue remains unresolved.

Since the 1980s, HWC, particularly HEC, has intensified substantially. The civil conflict temporarily altered human occupancy patterns in parts of the Northern and Eastern Provinces, allowing elephants to reoccupy abandoned areas. Subsequent resettlement and development following the end of the conflict created new interfaces between people and wildlife, generating additional conflict hotspots.

Today, HWC has become one of Sri Lanka's most significant conservation and rural development challenges. Habitat loss and fragmentation continue through agricultural expansion, infrastructure development, urbanization, tourism development, and encroachment into natural ecosystems. Additional pressures arise from improper waste management, changing livelihood systems, climate change, and weaknesses in land-use governance. Consequently, conflict now extends beyond elephants to include monkeys and toque monkeys, crocodiles, peacocks, wild boar, porcupines, leopards, and several other species.

The contemporary pattern of HWC therefore reflects the cumulative effects of historical land-use decisions, habitat fragmentation, development interventions, governance failures, and changing socio-economic and environmental conditions. These historical processes have progressively reduced ecological space for wildlife while increasing interactions between people and wildlife, transforming coexistence into conflict across much of the country.

3. The Root Causes of HWC

Human–Wildlife Conflict (HWC) in Sri Lanka is the result of interacting ecological, social, economic, and institutional processes that have progressively increased overlap between human activities and wildlife requirements. Rather than being caused by a single factor, HWC emerges from a combination of landscape transformation, resource competition, human behaviour, governance failures, and environmental change. These drivers operate at multiple spatial and temporal scales and collectively influence the frequency, intensity, and distribution of conflicts across the country.

3.1 Habitat loss, fragmentation, and landscape change

Habitat loss and fragmentation are widely recognized as the most fundamental drivers of HWC. The conversion of forests and other natural ecosystems into agricultural lands, settlements, infrastructure, and industrial developments reduces the availability of habitat while disrupting ecological connectivity. As habitats become smaller and increasingly isolated, wildlife populations are forced to utilize human-dominated landscapes to obtain food, water, shelter, and breeding sites (Collinge, 2009; Inskip and Zimmerman, 2009; Marker et al., 2003; Woodroffe and Ginsberg, 1998).

In Sri Lanka, forest cover has declined substantially over the past century, while roads, irrigation systems, settlements, and other development projects have fragmented many remaining habitats. These changes have disrupted wildlife movement corridors, particularly for wide-ranging species such as elephants, and increased contact between wildlife and people. Fragmentation also creates extensive edge habitats where encounters between humans and wildlife become more frequent. Beyond increasing conflict, habitat fragmentation reduces genetic exchange, alters animal behaviour, lowers ecosystem resilience, and increases wildlife vulnerability to environmental change. Consequently, habitat loss and fragmentation should be viewed not only as conservation concerns but also as the primary ecological drivers of HWC (Collinge, 2009; Inskip and Zimmerman, 2009; Marker et al., 2003; Woodroffe and Ginsberg, 1998).

3.2 Agricultural expansion, settlement development, and infrastructure growth

The expansion of agriculture, human settlements, and infrastructure has significantly increased human–wildlife interactions. Large-scale irrigation and settlement programmes, particularly the Mahaweli Development Programme, transformed extensive forest landscapes into mosaics of agricultural lands, settlements, roads, and fragmented forest patches. These developments expanded human activities into areas that historically functioned as wildlife habitats and movement corridors. The replacement of traditional shifting cultivation systems with permanent cultivation and commercial agriculture further reduced habitat heterogeneity and increased competition for resources. The cultivation of highly palatable crops such as paddy, maize, banana, and sugarcane attracts elephants and other wildlife, thereby increasing crop damage and conflict. Infrastructure development, including roads, railways, and transmission lines, further disrupts wildlife movements and increases wildlife mortality. Although population growth contributes to land-use pressure, the spatial overlap between humans and wildlife in Sri Lanka has been influenced largely by development policies, settlement schemes, and land-allocation decisions rather than demographic growth alone.

3.3 Declining natural resources and wildlife food availability

The availability of natural food, water, and other resources strongly influences wildlife behaviour and movement. Habitat degradation, drought, overexploitation of resources, and ecological disturbance can reduce the availability of natural forage and prey species, forcing wildlife to seek alternative resources in human-dominated landscapes. For herbivores such as elephants, shortages of forage and water increase the likelihood of entering agricultural areas. For carnivores such as leopards, reductions in wild prey populations can increase livestock depredation and other forms of conflict. For species such as wild boar, the loss of natural predators disrupts ecological population regulation mechanisms, leading to population increases and greater conflict with agriculture. Resource scarcity therefore acts as an important ecological mechanism linking environmental degradation to human–wildlife interactions.

3.4 Human behaviour, attitudes, and waste management

Human behaviour plays a central role in shaping both the occurrence and severity of HWC. People's attitudes towards wildlife are influenced by cultural values, economic losses, risk perceptions, education, and previous experiences. Communities experiencing repeated wildlife damage often develop negative perceptions of wildlife, which can lead to retaliatory actions and reduced support for conservation. Certain human activities directly increase the probability of conflict. These include cultivating crops in wildlife movement areas, entering forests for livelihood activities, feeding wildlife, and poorly managing waste. Open garbage dumps and improperly managed waste disposal sites attract elephants, monkeys, wild boar, crocodiles, and other species by providing easily accessible food resources. Over time, wildlife may become habituated to human presence and increasingly dependent on anthropogenic food sources, leading to more frequent and severe conflicts. Consequently, behavioural change, public awareness, responsible waste management, and community engagement are essential components of long-term conflict mitigation.

3.5 Policy gaps and institutional weaknesses

Weak governance and inadequate institutional coordination are major underlying causes of HWC. Wildlife conservation, forestry, agriculture, land administration, infrastructure development, and local government are often managed by different institutions with overlapping mandates and limited coordination. As a result, land-use decisions are frequently made without sufficient consideration of ecological connectivity, wildlife habitats, or movement corridors. The absence of integrated land-use planning, weak enforcement of environmental regulations, limited stakeholder participation, and inadequate institutional capacity often result in reactive responses that address symptoms rather than root causes. Effective HWC management therefore requires stronger policy integration, cross-sectoral coordination, and landscape-scale planning that balances conservation and development objectives.

3.6 Climate variability and climate change

Climate variability and climate change are emerging drivers of HWC. Changes in rainfall patterns, prolonged droughts, increasing temperatures, and extreme weather events affect the availability of water, forage, and suitable habitats. These changes can alter wildlife distribution and movement patterns, increasing the likelihood of wildlife entering agricultural lands and settlements. Climate change may also intensify existing drivers of conflict by reducing ecosystem productivity, increasing resource scarcity, and creating additional pressures on both wildlife and rural communities. As climatic conditions become increasingly unpredictable, climate-adaptive approaches must be incorporated into HWC management and conservation planning.

3.7 Spatial and ecological determinants of conflict

The occurrence of HWC is strongly influenced by landscape configuration and species ecology. Conflicts are more common near forest edges, wildlife corridors, wetlands, water sources, and other habitats that facilitate wildlife movement. The distribution of crops, settlements, infrastructure, and natural habitats determines where interactions between humans and wildlife are most likely to occur. Species-specific characteristics such as home-range size, movement behaviour, feeding ecology, social structure, and adaptability also influence conflict patterns. Consequently, understanding landscape structure, habitat connectivity, and wildlife ecology is essential for predicting conflict hotspots and designing effective mitigation strategies. Collectively, these drivers demonstrate that HWC is not merely a wildlife problem but a broader socio-ecological and governance challenge. Addressing the root causes of conflict requires integrated approaches that combine ecological restoration, sustainable land-use planning, improved governance, community participation, climate adaptation, and science-based wildlife management.

4. The Role of Ecology in understanding and managing HWC

Ecology provides the scientific foundation for understanding why HWC occurs and how it can be managed sustainably. The root causes of HWC identified in this paper, habitat loss and fragmentation, agricultural expansion, declining natural resources, climate change, and changing land-use patterns, are fundamentally ecological processes that influence wildlife populations, behaviour, and movement. Consequently, effective conflict management requires an ecological understanding of both wildlife and the landscapes they inhabit.

4.1 Ecology and the drivers of conflict

Ecology explains how wildlife responds to changes in habitat availability, food resources, water availability, climate, and human activities. As habitats become fragmented and resources decline, wildlife increasingly utilize human-dominated landscapes, leading to greater interactions with people. Understanding species-specific ecological requirements, including habitat preferences, feeding behaviour, home-range size, and seasonal movements, helps explain why some species are more prone to conflict than others. Ecological knowledge is therefore essential for identifying the underlying causes of conflict rather than merely addressing its symptoms. It enables managers to determine whether conflicts arise from habitat degradation, resource scarcity, population pressures, landscape barriers, or other ecological factors.

4.2 Population ecology and conflict management

Population ecology examines the abundance, distribution, structure, and dynamics of wildlife populations. It provides critical information for understanding how population size, density, reproduction, mortality, and movement influence conflict patterns. Knowledge of population distribution and habitat use helps identify conflict hotspots, wildlife corridors, and areas requiring conservation intervention. Population monitoring also helps determine whether conflicts are associated with increasing wildlife populations, shrinking habitats, changing resource availability, or altered movement patterns.

Population ecology further contributes to understanding carrying capacity, seasonal movements, demographic structure, and species behaviour. Such information is essential for designing effective management interventions, evaluating the success of mitigation measures, and avoiding inappropriate actions such as poorly planned translocations that fail to address the ecological causes of conflict.

4.3 Landscape ecology and human–wildlife coexistence

Landscape ecology focuses on the spatial arrangement of habitats, land uses, and ecological processes across landscapes. Because most HWC occurs in fragmented environments where human activities and wildlife habitats overlap, landscape ecology plays a particularly important role in conflict management. Landscape ecological approaches help identify habitat corridors, movement pathways, ecological bottlenecks, and areas of high conflict risk. Maintaining habitat connectivity allows wildlife to move between resource areas without entering settlements and agricultural lands. Similarly, the design of buffer zones, multifunctional landscapes, agroforestry systems, and wildlife-friendly land-use practices can reduce direct competition between people and wildlife. Landscape ecology also supports the integration of biodiversity conservation into broader development and land-use planning, helping to balance economic development with ecological sustainability.

4.4 Applying ecology to policy and practice

Ecological knowledge provides a basis for evidence-based decision-making and long-term conflict mitigation. Rather than relying solely on reactive measures such as fencing, translocation, or compensation, ecological approaches emphasize addressing the underlying drivers of conflict through habitat conservation, ecological restoration, corridor protection, sustainable land-use planning, and adaptive management. The integration of ecological science into policy, development planning, agriculture, infrastructure design, and community-based conservation can help reduce conflict while maintaining ecosystem functions and biodiversity. However, achieving this requires stronger ecological research, long-term monitoring programmes, improved data sharing, and closer collaboration among scientists, policymakers, conservation agencies, and local communities. Ultimately, ecology provides the framework for moving from conflict management to coexistence management. By understanding wildlife populations, landscape dynamics, and human–environment interactions, it becomes possible to develop more sustainable solutions that support both biodiversity conservation and human well-being in Sri Lanka's increasingly human-dominated landscapes.

5. Conclusion and implications for management

HWC in Sri Lanka is the outcome of long-term socio-ecological transformations that have progressively altered relationships between people, wildlife, and landscapes. Historical evidence demonstrates a transition from traditional systems that largely facilitated coexistence to increasingly fragmented and human-dominated landscapes where interactions between people and wildlife have become more frequent and intense. Although HEC remains the most visible manifestation, the problem now extends to multiple wildlife species and represents a broader challenge to biodiversity conservation, rural livelihoods, and sustainable development.

The analysis presented in this paper shows that HWC is driven by a combination of interrelated factors, including habitat loss and fragmentation, agricultural expansion, settlement and infrastructure development, declining natural resources, changing human behaviour, weak governance, improper waste management, and climate change. These drivers have reduced ecological space for wildlife, disrupted movement patterns, increased competition for resources, and intensified human–wildlife interactions across the country.

The paper further demonstrates that ecology provides a critical framework for understanding and managing conflict. Population ecology contributes to understanding species distribution, abundance, movement patterns, resource requirements, and population dynamics, while landscape ecology explains how habitat fragmentation, connectivity, and land-use patterns influence wildlife behaviour and conflict occurrence. Together, these disciplines provide the scientific basis for identifying conflict drivers, predicting conflict hotspots, and designing effective mitigation strategies.

The findings suggest that long-term conflict reduction cannot be achieved solely through reactive measures such as fencing, translocation, compensation, or population control. Instead, sustainable solutions require addressing the underlying ecological and socio-economic drivers of conflict through integrated land-use planning, habitat conservation, ecological restoration, corridor protection, and improved governance. Wildlife conservation objectives must be incorporated into national, regional, and local development planning to ensure that future land-use decisions maintain ecological connectivity while supporting human well-being.

Effective management also requires stronger institutional coordination, stakeholder participation, and evidence-based decision-making. Local communities, conservation agencies, researchers, planners, and policymakers must work collaboratively to develop solutions that are ecologically sound, socially acceptable, and economically viable. Public awareness, responsible waste management, wildlife-friendly agricultural practices, and climate-adaptive planning should form integral components of conflict mitigation strategies.

Finally, future progress depends on strengthening ecological and socio-economic research, long-term monitoring programmes, habitat and wildlife assessments, and the integration of scientific knowledge into policy and practice. HWC is unlikely to be eliminated entirely; however, a deeper understanding of its historical origins, underlying drivers, and ecological dimensions can support more effective management approaches that promote coexistence between people and wildlife while safeguarding both biodiversity and human livelihoods.

Conflict of Interest

The authors have declared that no competing interests exist.

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Chapter 02

Human–Wildlife Conflict: Biological and Ecological Perspectives

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Abstract: Human–wildlife conflict (HWC) arises when human activities encroach on wildlife habitats, leading to competition for resources and negative interactions. From biological and ecological perspectives, understanding biodiversity, population dynamics, life table parameters, animal behavior, dispersal limitations, and ecological control measures is essential for effective mitigation. Biodiversity underpins ecosystem resilience and enhances stability and proper energy flow across the ecosystem. Population dynamics drive conflict intensity; species with high reproductive rates and rapid growth, reflected in life table parameters like net reproductive rate (R_0) and generation time, expand into human-dominated landscapes. For example, elephants or primates follow K-selected strategies, with low juvenile mortality and long lifespans, which can increase crop-raiding problems when their populations recover after applying control measures.

Animal behavior plays a pivotal role, with habituation to human food sources fostering bold foraging tactics. Dispersal limitations, constrained by habitat fragmentation and barriers like roads or fences, trap wildlife in shrinking ranges, forcing proximity to settlements. Ecological control measures prioritize non-lethal interventions: habitat restoration enhances carrying capacity, reducing pressure; corridor creation facilitates dispersal; and behavioral deterrents. Translocation targets surplus individuals, while fertility control adjusts population trajectories via immunocontraceptives. Integrating stable isotope analysis of diets and telemetry tracking informs targeted strategies, balancing conservation with human needs. Ultimately, HWC reflects anthropogenic pressures on ecological processes. Sustainable solutions demand interdisciplinary approaches, fostering coexistence through community incentives and policy reforms.

Keywords: Biological diversity, habitat degradation, life table, population regulation, survivorship curves

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1. Introduction

Human–wildlife conflict (HWC) has emerged as a pressing issue worldwide, increasingly recognized not only for its ecological consequences but also for its socio-economic and cultural implications. It reflects a complex intersection between environmental degradation, species conservation, and human development. Both globally and locally, the nature of such conflicts is diverse and ranges from crop raiding and livestock predation to human injury or fatalities. This makes the search for solutions complex and often specific to species or locations. These conflicts are not uniform; instead, they are shaped by ecological contexts, human behavior, socio-economic conditions, and land-use patterns. Therefore, identifying effective mitigation strategies requires a deep understanding of the ecological systems and socio-cultural interactions in which these conflicts occur.

A broader ecological perspective is essential to uncover the underlying causes of these conflicts. Biological and ecological principles, such as species' behavior, population dynamics, resource utilization, and habitat preferences offer valuable insights into how wildlife interacts with the environment and with human activities. For instance, understanding the home range, migratory routes, and foraging behavior of large herbivores like elephants can illuminate why they may intrude into human settlements or agricultural fields. Such knowledge not only supports conservation efforts but also helps in designing conflict mitigation strategies that are grounded in scientific understanding rather than reactive responses.

Rapid human population growth over the last few decades has led to the exceptional exploitation of natural resources. Deforestation, expansion of agricultural lands, infrastructure development, and urban sprawl have drastically reduced and fragmented natural habitats. As a result, many wildlife species, especially large mammals that require extensive ranges such as elephants and leopards, are forced into closer proximity with human settlements. This spatial overlap intensifies competition for resources and escalates the frequency and severity of encounters between humans and wildlife.

Animals, unlike humans, cannot adapt their behavior in response to rapid environmental changes at the same pace. Their actions are largely governed by evolutionary adaptations and ecological needs, which are not easily altered. For instance, migratory paths or seasonal movements are often deeply established and driven by resource availability, and these do not cease simply because human structures now obstruct them. From an ecological standpoint, this inflexibility must be acknowledged and addressed. Expecting animals to modify their instinctual behaviors is unrealistic and biologically unfounded.

Hence, it becomes urgent for humans to adjust their practices and infrastructure in ways that accommodate and even compensate for wildlife behaviors. This may include the development of wildlife corridors, community-based conservation initiatives, improved land-use planning, and sustainable agricultural practices. Technological interventions such as early warning systems, bio-fencing, and use of deterrents can also help mitigate risks without harming the animals. Equally important is community engagement, where local people are made active stakeholders in conservation through education, economic incentives, and participatory governance.

In conclusion, human–wildlife conflict is not just an ecological dilemma but a socio-ecological challenge that requires multi-faceted and context-specific approaches. While the root causes are often tied to human development pressures, the solutions lie in harmonizing ecological knowledge with human adaptability. Recognizing the biological and ecological traits of wildlife and designing human systems that respect those traits is a fundamental step toward sustainable coexistence.

2. Biological Diversity and the Demographic Traits of Animal Populations

Biological diversity refers to the variety of living organisms found in all environments, land, marine, and freshwater systems as well as the ecological networks they form (UNEP, 2007). It encompasses diversity within species, between different species, and across ecosystems. Biological diversity in a broader context provides insights into ecosystem viability and the patterns of species assemblages in ecosystems. As ecological integrity is highly dependent on biodiversity, it provides robust stability for the ecosystem and strengthens the interaction between biotic and abiotic component. Biodiversity combines all structural and functional units of the ecosystem. Biodiversity can be conserved in two main ways: (1) by assessing and managing functional biodiversity, and (2) by using biodiversity surrogates (Heywood, 1995; Gitay et al., 1996; Faith et al., 2003).

In ecology, a surrogate refers to a part of the overall biodiversity that is easier to measure and serves as a representative or indicator of broader biodiversity in a specific region. Examples of surrogate species include keystone species, umbrella species, indicator species, and flagship species. Wildlife contributes significantly to various ecosystem services that benefit human society, including supporting, regulating, cultural, and provisioning services. The decline in biodiversity and wildlife negatively impacts these services, which in turn can harm human livelihoods and overall quality of life (Millennium Ecosystem Assessment, 2005; Cardinale et al., 2012; Díaz et al., 2019).

Biologist E.O. Wilson (1988) and Anne E. Magurran (1988; 2011) offered a more comprehensive definition of biodiversity, it is the variety of life observed at all levels of biological organization and across different spatial scales. This includes genetic variation within populations, populations within species, species within communities, communities across landscapes, landscapes within biomes, and biomes that together form the biosphere. An individual organism as a fundamental unit of the ecosystem plays a major role in sustaining the ecosystem viability. As an example, individual organisms make robust ecological networks with interactions and maintain proper energy flow within ecosystems. This is in turn highly important to manage proper ecological balance when all the biotic and abiotic components are linked together. Therefore, conservation and management systems may adopt in population level to achieve the targeted outcomes. However, management options entirely depend on the nature of the ecosystem and/or species composition.

2.1 Species diversity

Species diversity represents the most fundamental level of biological diversity. Species occur in large groups, each exhibiting distinct physical and biological characteristics. They function either independently or collectively within the food web. Through various interactions such as competition, mutualism, and other species contribute significantly to the dynamics of ecosystems. This diversity is typically assessed using two main components: species richness and relative abundance (White et al., 2018). Considering the human–wildlife conflict, it is important to study about the diversity of the conflict prone species. In Sri Lankan context the key species involved in human–wildlife conflict are primarily large herbivores (e.g. Asian Elephant), large carnivores (e.g. Saltwater crocodile, Sri Lankan leopard), herbivore and omnivore mammals (e.g. Wild boar, Giant squirrel, Indian porcupine) birds (e.g. Indian peafowl, Rose ringed parakeet, Munias etc.) and primates (e.g. Grey languor, Toque monkey, Purple faced leaf monkey). Among them Asian elephant and Sri Lankan leopard now being considered as endangered according to the IUCN conservation criteria. Also, species such as toque monkey listed as endemic to Sri Lanka. Hence, some animals show unique national importance, and all the animals show scientific importance in the wellbeing of the ecosystem. Hence management options should thoroughly adhere to scientific evidence.

2.2 Genetic diversity

Genetic diversity refers to the total range of genetic traits present within the gene pool of a species. It is different from genetic variability, which describes how likely these traits are to differ among individuals (Frankham et al., 2010; Allendorf et al., 2013). Genetic diversity plays a crucial role in helping species adapt and survive in changing environmental conditions. The more diverse the gene pool, the greater the chances that some individuals will possess traits enabling them to cope with new challenges. These genetic differences can lead to anatomical or physiological changes across generations that contribute to a species' long-term survival. Species with high genetic diversity have a wider range of traits that allow them to respond to stressors in different ways. This diversity becomes especially important when facing external pressures such as natural disasters, diseases, pollution, and the impacts of climate variability or climate change (Frankham et al., 2010; Hoffmann and Sgrò, 2011).

Generally, large populations maintain more genetic diversity, while small populations are more prone to losing it over time due to genetic drift a random process where some gene variants (alleles) become fixed while others disappear (Allendorf et al., 2013; Lande, 1999). Mutations, which are random changes in DNA, generate new genetic variations. These mutations can be harmful, neutral, or beneficial, but those that improve survival or reproduction tend to persist under natural selection (Futuyma and Kirkpatrick, 2017; Lynch, 2007). Larger populations typically produce more mutations simply due to their size. Another key factor influencing genetic diversity is gene flow, the transfer of genetic material between populations through the movement of individuals (Slatkin, 1987; Frankham et al., 2010). This process introduces new alleles into a population, increasing its genetic variability.

In fragmented habitats, corridors or planned translocations help facilitate gene flow by allowing movement between isolated patches, thus maintaining or enhancing genetic diversity across the landscape. Therefore, it is important to identify how genetic variability influences adaptability in conflict-prone species. Specially, the animals which have wide range expansion such as Asian elephant and Indian peafowl. Genetic variations among the population describe the future adaptability of the species. It also highlights the proper management options such as maintaining corridors and keep the connectivity between populations. This allows species to adapt in changing environments such as habitat decline and disease transmission.

2.3 Ecosystem diversity

An ecosystem comprises a community of living organisms, their physical environment, and the interactions between them. Ecosystems can exist at various scales—from tiny microhabitats to the entire biosphere. For example, a forest, a river, a mountain, a pond, a dead tree trunk, a sea, or even the entire Earth can each be considered an ecosystem (Odum and Barrett, 2005; Chapin et al., 2011; Tansley, 1935). Ecosystem diversity refers to the variety of ecosystems within a particular area. The greater the number and variety of ecosystems, the higher the potential for species diversity in that region (Gaston 2000; CBD, 2006). A community within an ecosystem is made up of different populations of plants and animals that live together and interact with one another as well as with their surroundings (Odum and Barrett, 2005; Chapin et al., 2011).

The term habitat describes the natural environment where a particular organism or population lives. Habitat diversity refers to the range and abundance of different habitat types in a specific geographic area. Areas with a rich variety of habitats tend to support a wider range of species than those with limited habitat types (Hunter, 1999; Tews et al., 2004; CBD, 2006). Each habitat type also supports distinct species with their own genetic variations. Ecosystem diversity encompasses both community and habitat diversity. Increasing the number or complexity of habitats within an area generally leads to greater diversity. Each ecosystem supports unique cycles of materials and energy and is often interconnected with neighboring ecosystems and habitats (Odum & Barrett, 2005; Chapin et al., 2011). Preserving the diversity of ecosystems and habitats is therefore vital for maintaining the overall balance, function, and resilience of the natural world (Loreau et al., 2001; CBD, 2006). Habitat diversity directly connects with the food availability of the conflict prone species. For example, the littoral area of the reservoir provides tender and more palatable leaves for the elephants. Hence, understanding food preference of the animals and it's connectivity with ecosystems/habitats is important to understand to keep animals' original habitats and not to trespass over the human settlements. This also highlights the impacts of habitat fragments and loss of connectivity of animals with their original habitats.

2.4 Why does biological diversity matter in ecosystem stability?

Biological diversity is crucial for ecosystem stability because it enhances resilience and the ability of ecosystems to withstand environmental changes. Diverse ecosystems have a wider range of species performing similar functions, ensuring that critical processes continue even if some species are lost. This redundancy and interconnectedness make ecosystems more stable and less vulnerable to disturbances.

Human-induced (anthropogenic) environmental changes are expected to drive continued biodiversity loss in the coming decades (Sala et al., 2000), adding to the already high global extinction rates (Stork, 2010). Species diversity as one component of biodiversity plays critical roles in ecosystems, and both local and global losses can undermine the stability of the ecosystem services that humans rely on (McCann, 2000). For instance, plants capture solar energy through photosynthesis to fix carbon, forming the foundation of the food chain for numerous animal species. At the ecosystem level, the total biomass produced by plants is known as primary production. As this article explores, the number and combination of plant species in a community can significantly influence rates of primary production. This key ecosystem function affects both primary production and climate regulation, as it reflects how quickly carbon dioxide, a major greenhouse gas, is removed from the atmosphere. Given the widespread environmental changes underway, concerns about the stability of both natural and managed ecosystems are increasing. Ecosystem stability can be defined in several ways, but it is most understood as low variability meaning the system remains relatively constant despite changing conditions. This characteristic is known as resistance. Another aspect, resilience, refers to the ability of an ecosystem to recover and return to its original state after a disturbance.

3. Species Identity, Functional Traits, and Resource Use

Species diversity consists of two key elements: species richness, the number of species within a community and species composition the specific identity of those species (Magurran, 2004). While much research on ecosystem diversity and stability has emphasized species richness, it is the variation in species composition that provides the underlying mechanisms linking biodiversity to ecosystem functioning. This is because species differ in their resource requirements, environmental tolerances, and interactions with other organisms, all of which influence ecosystem processes and stability.

The characteristics that define a species' ecological role are known as functional traits (Violle et al., 2007). Species with similar traits are often grouped into functional groups. When species from different functional groups coexist, they may exhibit complementary resource use that is, they either use different resources or utilize the same ones at different times (Díaz and Cabido, 2001; Petchey and Gaston, 2006). For instance, if domestic cattle and elephants two herbivores feed on different grass species, reducing competition and supporting greater overall herbivore biomass. This also supports two species to coexistence within the same habitat. However, this example does not particularly happen in nature. As they both feed on same food varies, elephants might shift their feeding ground more particularly towards human croplands. This is just a single example with implications for wildlife management.

Increasing species diversity can enhance ecosystem functions like productivity by boosting the chance that species will either use resources in a complementary way or include particularly efficient or productive species (Tilman et al., 1997; Loreau and Hector, 2001). For example, high plant diversity often results in greater overall productivity by more fully or efficiently accessing soil nutrients and water. While primary production is the main ecosystem function discussed here, others such as decomposition and nutrient cycling are also strongly shaped by species diversity and the specific traits of species present.

3.1 Diversity–stability theory

Theoretical models indicate that the relationship between biodiversity and stability can take different forms, depending on how stability is defined (Ives and Carpenter, 2007). At the ecosystem level, stability might refer to the ability of an ecosystem to maintain functions over time despite environmental variability. For example, a park manager may be concerned with whether a park can sustain consistent levels of primary production for herbivore grazing across years with differing temperatures and rainfall.

As illustrated in Figure 1, the presence of multiple species within a plant community can help stabilize ecosystem processes when species respond differently to environmental changes. If one species declines in abundance under certain conditions, another may increase, thereby compensating for and maintaining overall function. In this way, species diversity can act as a buffer against environmental fluctuations.

Biodiverse ecosystems are also more likely to include species that contribute to resilience. As species accumulate, the likelihood increases that some will possess traits that enable them to tolerate or adapt to environmental changes. These species can help sustain ecosystem function even if others are lost. This idea forms the basis of the insurance hypothesis (Yachi and Loreau, 1999), which proposes that biodiversity enhances stability by ensuring that some species can compensate for the decline or loss of others. In such cases, it is not simply the number of species (species richness) that matters, but the identity and traits of the species present that play a crucial role in maintaining ecosystem stability.

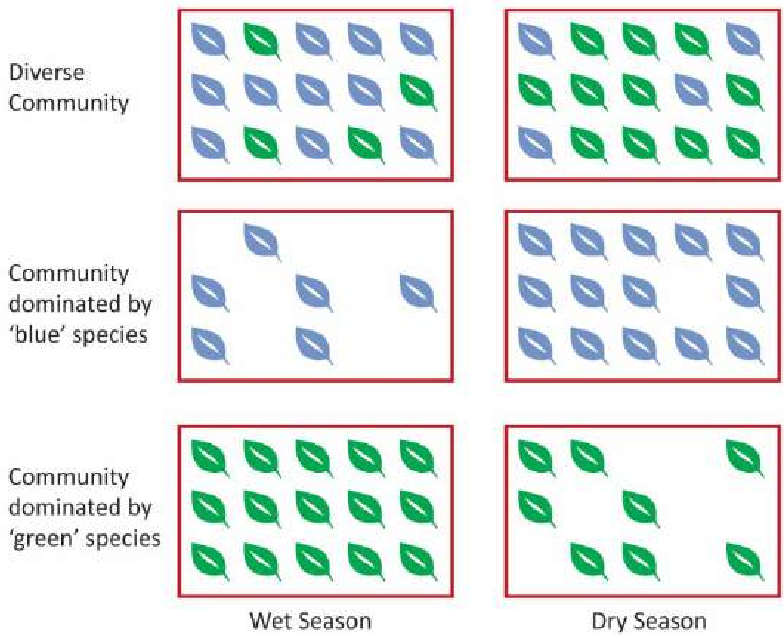

Fig 1. Conceptual illustration of how greater diversity can stabilize ecosystem functioning. The blue species thrives in dry periods, while the green species performs better in wet periods. As a result, communities containing only one species show significant fluctuations in biomass due to annual climate variation.

However, in mixed-species communities containing different species (e.g. both blue and green species in Figure 1), declines in one species during unfavorable conditions are offset by increases in the other (Figure 1). This compensatory dynamic leads to greater stability in productivity across years. Additionally, the mixed-species community tends to have higher average productivity than single-species community. This may occur because the two species are active at different times, reducing direct competition and allowing more efficient, complementary use of resources, a process known as complementary resource utilization. The application of this theory is important to maintenance foods for the large herbivores within the area of inhabitants (e.g within the park of forest). This is crucial to keep conflict-prone large herbivores within the protected areas without trespassing human dwells.

3.2 Resilience

Biodiversity helps ecosystems resist and recover from disturbances, such as climate change, natural disasters, and human activities (Elmqvist et al., 2003; Isbell et al., 2015). In a network of complex trophic relationships ecosystems are in robust connection regarding energy flow (McCann, 2000; Thébault and Fontaine, 2010). Therefore, with high level biodiversity it can be expected to be fast recovery of disturbances due to maintenance of proper energy flow across ecosystem. Ecosystems with diverse species have multiple options for performing essential functions like pollination, nutrient cycling, and decomposition. If one species is lost, others can often step in and maintain the ecosystem's function. This is known as functional redundancy (Walker, 1992; Naeem, 1998; Rosenfeld, 2002). Also, diverse ecosystems have complex webs of interactions between species, creating a network of support where one species can benefit from another, even if that interaction is not immediately obvious. Therefore, Interconnectedness is important factor to be considered in management. Diverse ecosystems are more likely to contain species with traits that allow them to adapt to changing environments, increasing the ecosystem's ability to adapt and evolve over time. So, the variety of species in a diverse ecosystem allows for a greater range of responses to environmental changes, making the overall ecosystem more stable and less susceptible to collapse (Tilman and Downing, 1994; Yachi and Loreau, 1999; Isbell et al., 2011). This is important to maintain food web complexity of the ecosystem. Biodiversity increases the complexity of food webs, where a greater variety of species and their interactions can prevent a large-scale collapse if one species is lost.

4. Population Dynamics and Understanding Life History Strategies of Animals

Ecologists strive to understand the factors that shape where organisms are found and how many individuals exist in a given area. This can be a complex task because populations are not static, their sizes and locations can shift dramatically over time and across regions. These fluctuations can influence various aspects of biological communities, including species interactions and ecosystem functions. Therefore, our ability to predict such changes is a key indicator of how well we comprehend natural processes.

Understanding what drives the distribution and abundance of organisms also has significant practical value. It helps inform the management of conflict prone species (e.g. Asian elephants, Indian peafowls, Toque monkeys etc.), harvested species like fish and trees, as well as the conservation of threatened species. Effective protection or management relies on a solid grasp of these underlying ecological patterns. To build this understanding, it is critical to study about dynamic nature of populations.

4.1 Populations

A population refers to a group of individuals of the same species that live in a specific area and interact with one another. But what do we mean by "interact"? In sexually reproducing species, interaction often refers to interbreeding among individuals. Other than sexual interactions, populations are better defined by other interactions, such as competing for shared resources like food. In such cases, interspecific (among difference species) and intra specific (between two individuals of the same species) interactions are highly recognized to shape the population stability. Generally, there are four factors which contributed to population fluctuations such as Natality (birth rate), mortality (death rate), immigration (arrival of individuals from other populations) and emigration (departure of individuals from the population). These interactions often can be recognized in large herds or troops such as in elephants and monkeys. Hence, understanding these population interactions are crucial to understanding the population stability of the conflict prone species.

The definition of the population also includes the geographic area within which these interactions occur. When the boundaries of this area are clear, such as for a population of elephants living and moving across the small island, we can quantify population abundance in two ways: by population size (the total number of individuals) or population density (the number of individuals per unit area). For instance, if there are 500 elephants in Yala National Park, Sri Lanka (approximately 1,518 km^2), and the population size is 500, and the population density is 0.32 elephants per square kilometer. In other cases, however, it may be difficult to determine the full extent of a population's range. This is especially true when the distance that sexually reproducing individuals can travel is unknown. Without this information, defining the boundaries of a single, interacting population becomes challenging.

4.2 Abundances change across time and space

The number of individuals within a population is not constant, it changes over time. This variability occurs whether we're examining a small-scale area, such as the number of monkeys along a specific stretch of riverbank, or a broad-scale region, like the population of saltwater crocodiles across the Nilwala Basin, Sri Lanka. At any given moment, population abundance can also vary from one location to another. In some cases, populations show relatively stable numbers over time and space, while in others, abundance can fluctuate significantly. In Sri Lankan context unfortunately, there were not robust studies to identify the population status of conflict prone species other than Asian elephants. This creates critical issues when finding management implications for the distinct population. For example, toque monkeys have four different sub species across the island and information about sub species level population is not readily available. In such cases it is difficult to identify the endangered populations and abundance of the species within the protected areas and outside from the protected areas. This highlighted the dynamic nature of the population status which is dependent on the ecological and environmental conditions.

4.3 What defines an individual?

As discussed earlier, a population may occupy a single continuous area determined by how far the species can disperse or it may exist across several isolated patches connected by occasional movement between them. However, for many species, especially those with poorly understood dispersal abilities, identifying the full spatial extent of a population can be difficult. Complicating matters further, it's not always straightforward to define what an individual organism is. For certain species, distinguishing one individual from another can be challenging due to their unique growth forms or reproductive strategies. Hence, the distribution and abundance of organisms are shaped by a variety of factors. These influences can be broadly categorized into three main groups: habitat suitability, historical influences (such as evolutionary background and continental drift), and dispersal ability (Brown et al., 1996; Lomolino et al., 2017). Moreover, species abundance and dispersal are limited by habitat suitability and resource availability. Habitat suitability is a limiting factor, every species has environments where it thrives and others where it cannot survive (Gaston, 2003; Krebs, 2009). For example, a dry zone species would struggle in wet conditions, and the reverse is also true. Even subtle differences in environmental conditions such as temperature, moisture, or food availability can significantly impact how well individuals survive and reproduce. As a result, suitable habitat plays a critical role in determining where a species is found and how abundant it is. But what exactly makes a habitat suitable for a given species? In this case abiotic factors in the environment play a major role in making the environment a livable place**.** The physical, non-living components of the environment such as climate, soil pH, salinity, and nutrient availability play a key role in determining whether a habitat is suitable for a particular species. While some species are adaptable and can tolerate a wide range of abiotic conditions, others have very specific environmental needs and can only thrive within narrow limits.

5. Biotic Factors in the Environment

Living components of the environment also significantly influence species distributions and abundances (Bronstein, 1994). Species that depend on specific other organisms for survival, reproduction, or growth will not be found in places where those key partners are absent. Moreover, the presence of herbivores, predators, competitors, parasites, or disease-causing organisms can limit a species' ability to survive and reproduce, thereby restricting its distribution. In many situations, both abiotic and biotic factors work together to shape a species' distribution and abundance (Gaston, 2003). Take the barnacle *Semibalanus balanoides* as an example: it cannot survive in areas where summer air temperatures exceed 25°C, and it requires winter temperatures to stay below 10°C for at least 20 days to reproduce. Along the Pacific coast of North America, the climate conditions suggest that this species could potentially exist up to 1,600 km farther south than its current range. However, it is absent from that region, likely because competition from other barnacle species prevents it from establishing, even though the physical environment is suitable. Farther north, its range is limited by increasingly harsh cold temperatures.

5.1 Dispersal limitation

Dispersal limitation occurs when a species is unable to reach areas of suitable habitat simply because of barriers to movement. For instance, in Sri Lanka *Pseudophilautus* species (Shrub frogs) range across many montane regions. *P. femoralis* is inhabiting in central hills and absent from Knuckles, further, *P. mooreorum* inhabits in Knuckles but absent in central hills, this is not because the environment is unsuitable, but because they have no means of dispersing there. Another example is the Hawaiian Islands, which naturally host only one native land mammal the Hawaiian hoary bat (*Lasiurus cinereus*) capable of flying to the islands. Other terrestrial mammals have not reached Hawaii on their own, although many, such as cats, pigs, wild dogs, rats, and goats, have been introduced by humans (Atkinson, 1985; Simberloff, 2000).

Dispersal limitation doesn't only occur across large distances it can also prevent species from spreading to nearby areas that appear suitable for survival. For example, endemic Agamids in montane of Sri Lanka has very limited distributions in short distances (E.g. *Ceretophora* sp. and *Cophotis* sp.). Both environmental factors and biological competition may reduce their distribution. Hence, these sensitive species show restricted distribution corresponding to elevation from the mean sea level. This evidence indicates that dispersal limitation likely prevented the animals from naturally colonizing areas where they could have successfully established and grown. When individuals move from one population to another, they reduce the density of the population they live in and increase the density of the one they join.

Population density itself can also influence dispersal behavior. For instance, in many aphid species, crowding triggers the development of winged individuals capable of dispersing. In the bean aphid (*Aphis fabae*), the proportion of offspring that develop wings rises as population density increases (Harrison, 1980). A similar pattern may be observed in the fish populations in Villus system, in Mahaweli basin in Sri Lanka. After heavy rainfall, the isolated pools where they live become temporarily connected by streams, creating opportunities for movement. While dispersal in such opportunity may offer benefits under certain conditions.

5.2 Geographic range

As discussed previously, a species' distribution is shaped by a combination of factors, including habitat suitability, geological and evolutionary history, and dispersal ability. Often, multiple factors work together to determine where a species can be found. The combined influence of these factors results in some species being restricted to very small areas, while others occupy much broader regions. A species' geographic range refers to the full area across which it is naturally found. Although no species occur everywhere, the size of geographic ranges varies widely. For an example, the montane elephants in Sri Lanka have extremely limited distributions, while dry zone elephants have wide range of migrations. Similarly, some bird species such as Indian peafowl occupy vast areas from dry zone to wet zone of the country. Recently this trend has increased in many more folds than observed several decades ago. Coyotes, for instance, are found across most North America, and gray wolves inhabit parts of both North America and Eurasia (Hody and Kays, 2018). In Sri Lankan context some related species such as Golden jackal shows decreasing trend and proven no conflict with humans. Therefore, understanding about population trends and fluctuation factors is highly important to implement ground level management options.

Even within a species' geographic range, much of the habitat may not be suitable for that species. Consequently, populations often have a patchy distribution, a pattern that can be observed at both large and small spatial scales. On a broad scale, climate plays a key role in determining where populations can thrive. On a more localized level, factors like topography, soil type, and the presence or absence of other species limit how evenly populations are spread across the landscape.

A clear example of this patchiness at different scales comes from purple leaf monkey of the country. Four subspecies of *Semnopithecus vetulus* have been identified (Phillips, 1935; Groves, 2001; Brandon-Jones et al., 2004; Roos et al., 2014), each distinguishable by differences in fur coloration (see illustrations in Pethiyagoda et al., 2012). *S. v. vetulus* (Erxleben) is found in the southern and southwestern parts of the wet zone, south of the Kalu River; *S. v. nestor* inhabits the lowland wet zone north of the Kalu River; *S. v. monticola* (Kelaart) occurs in the central mountainous regions; and *S. v. philbricki* (Phillips) occupies the dry zones in the north and east (Molur et al., 2003; Roos et al., 2014). Distribution of different subpopulations serve as vital tools for representing a taxon's range, aiding in communication and conservation planning, and form an essential part of a species' spatial data (IUCN, 2018). The clusters of *S. vetulus* individuals found across the country serve as an example of dispersion, or the spatial arrangement of individuals. There are three primary patterns of dispersion observed in populations (Figure 2). In some instances, individuals are regularly spaced, resulting in a regular dispersion, where individuals are evenly distributed across their habitat. In other cases, individuals may exhibit random dispersion, where their positions are determined by chance, without any predictable pattern. Finally, in species like *S. vetulus*, individuals may form a clumped dispersion, where they are grouped together in certain areas. These distribution patterns are highly crucial to understanding their behavior and resource utilization.

A variety of factors can shape the dispersion of individuals within a population, leading to regular, random, or clumped patterns. For example, even conflict prone species that require specific resources and environmental conditions (such as a particular nutrient, humidity, temperature etc.) to thrive. In this case, the spatial distribution of individuals would likely reflect the availability of those conditions. Since environmental factors often vary in a random or clumped manner, the species' distribution might also be random or clumped. Dispersal can also play a role; for instance, short dispersal distances may lead to individuals clustering together. In certain cases, competition for resources or space can lead to regular dispersion, where individuals are spaced more evenly. Therefore, understanding population distribution plays a vital role in taking management options into account.

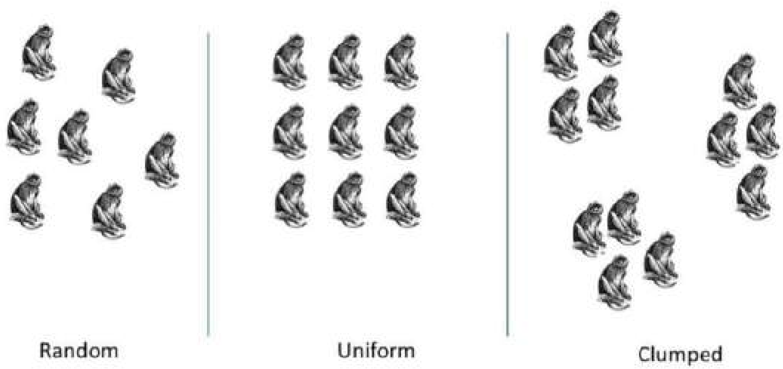

Fig 2. Patterns of population dispersion are seen in *Semnopithecus vetulus*. Random distribution (left) occurs when individuals are spread unpredictably, often in habitats where environmental conditions and resources are uniform. Regular (uniform) distribution (center) is characterized by evenly spaced individuals, typically due to territorial behavior or competition for resources. Clumped distribution (right) is the most common pattern in nature, where individuals group together in patches, often around resources or due to social behavior.

5.3 Individual behavior and dispersion patterns

The behavior of individuals also affects spatial arrangement within populations. Organisms may either repel each other, leading to regular dispersion, or attract one another, resulting in a clumped dispersion. These behaviors are exemplified by the Seychelles warbler (*Acrocephalus sechellensis*), an endangered songbird. In the 1950s, the species nearly went extinct, with only 26 individuals remaining on Cousin Island in the Seychelles (Komdeur, 1992). After the warbler received legal protection in 1968, the population grew to about 300 birds, and the species was successfully introduced to two other islands. Seychelles warblers are territorial, and a breeding pair defends its territory against other birds (Komdeur, 1994). This territorial behavior results in a relatively regular dispersion within the population. However, not all territories are of equal quality. Some provide more food, such as insects, and individuals living in these territories tend to live longer and produce more offspring. Furthermore, pairs in high-quality territories often receive help from offspring born in previous years when rearing their young. As high-quality territories attract additional offspring and tend to cluster toward one end of the island, this variation in territory quality leads to a more clumped dispersion than would otherwise occur (Komdeur, 1992; Richardson et al., 2002).

The above example provided how territoriality shapes the distribution of the species. In Sri Lanka among the conflict prone species, the males show this behavior which is important to recognize. The saltwater crocodile, Asian elephants, Indian peafowls etc. show this behavior. Hence, the regular distribution can be expected among alpha males in species abundance locations.

6. Population Growth and Regulations

One of the core ecological principles is that no population can grow indefinitely. Since the earth has finite resources and space, it simply cannot sustain unlimited growth of any species. This reality places a ceiling on what often appears to be a common trait among living organisms, the ability to reproduce rapidly. As an example, such as the giant puffball fungus, demonstrates an even more astonishing reproductive potential (Starr & Taggart, 2004). A single puffball can release up to 7 trillion spores; if every spore survived to adulthood, the offspring of just two individuals would outweigh the entire planet within two generations. Clearly, this doesn’t happen, earth isn't blanketed in puffballs or any other single species (Krebs, 2009).

The real challenge for ecologists, whatever the species they are studying, is to uncover what factors drive population increases and what factors curb them. The insights they uncover are often surprising. For instance, every species has vulnerable life stages where they are more subjected to predation or diseases. Some species (e.g. Sea turtles) have high vulnerability in their early life stages while other have later stages (e.g. Asian elephants). Accordingly, the application of early or later conservation efforts depending on the species focused on improving survival of the individuals of vulnerable life stages will provide better strategies for supporting the species and understanding about population fluctuations.

6.1 Life tables: types and uses

Understanding patterns of birth and death within a population is crucial for analyzing current population dynamics and predicting future changes in population size. To gather this information for a plant species, for instance, researchers might tag many seedlings shortly after germination. By monitoring these tagged individuals over one or more growing seasons, tracking who survives and how many seeds each plant produces, they can determine how survival and reproduction change with age. Life tables summarize how survival and reproductive rates vary across different stages of an organism's life. They can be constructed based on age, size, or distinct life cycle stages (Begon et al., 2006; Krebs, 2009). Scientists have developed life tables for a wide range of species, including plants, sea turtles, and humans, using detailed data on births and deaths (Caughley and Sinclair, 1994). The total number of individuals in a population, the age distribution of those individuals, the sex ratio of adults, probabilities of survival (or mortality), and rates of fecundity are key traits of population structure. An ecologist can collect two very different types of life history data for individuals in a population, which can lead to two kinds of life tables. Both dynamic and static observations of population structure can be used to create a life table.

Using a life table for a particular species ecologist can quantify the structure of a population, estimate an optimal age of sexual maturity and predict population growth rates (Krebs, 2009; Begon et al., 2006). For example, Table 1 shows life table data for the hypo-ethical species. The "Sample / age class" column, denoted as s(x), shows how many individuals are samples at each age (measured in one day intervals). As time passes and individuals die, s(x) decreases until reaching zero. From this data, two important survival metrics are calculated (Table 1).

Using data collected at a single time in the field, we can determine how many individuals are alive in each age class (n(x)). The assumption stands that each individual sampled was alive in the first age class (x = 0). For example, if you sample 759 individuals, all of them had to have been alive at the first age class. So, n(0) = 759 or the sum of the s(x) column. If 130 of the individuals in your total sample were between 0 and 29 days old (age class 0), then 629 individuals in your sample were alive in the second age class (x = 30). Once you have calculated the number alive at each age class (n(x)), you can determine the survival rate (l(x)) for each age class. Survival rate for a specific age class (l(x)) is the number alive in that age class (n(x)) divided by the number alive in the first age class (n(0)), or l(x) = n(x) / n(0). In the above static life table example, the survival rate at age class 0 (l(0)) = 759/759 = 1.000, l(30) = 629/759 = 0.829, and so on. Once the horizontal life table is completed, we can calculate the: net reproductive rate (R_0), mean generation time (G), and intrinsic growth rate (r**)** of the population. Net reproductive rate (R_0) is the sum of the l(x)*b(x) column. It represents the expected number of offspring an individual will produce over its lifetime in the population. If $R_0 > 1$, then population size increases. If $R_0 < 1$, then population size decreases, and if $R_0 = 1$, then population size does not change.

In the population described by the horizontal life table above, an individual is expected to produce 7.19 offspring over its lifetime. Mean generation time (G) is the sum of the l(x)*b(x)*x column divided by the net reproductive rate (R_0) which is here equal to 98.17 days. The intrinsic growth rate (r) is an estimate of population growth (0.02 ind/day); it is equal to the natural log of the net reproductive (R_0) divided by the mean generation time (G):

$$r = \ln(R_0) / G.$$

The optimal age for sexual maturity in the population corresponds to the age class with the greatest age-weighted fecundity (l(x)*b(x)*x) in this example it is equal to 90 days. Therefore, using life table information scientists can evaluate population dynamics with time space which crucial for conservation implications.

Table 1. The Static life table for a hypothetical species

Age class (days) (x)	**Sample/ age class s(x)**	**Number/ age class n(x)**	**Survival rate L(x)**	**Fecundity b(x)**	**Offspring / Ind l(x)*b(x)**	**Age weighted fecundity I(x)*b(x)**
0	130	759	1.000	0.00	0.00	0.00
30	190	629	0.829	0.00	0.00	0.00
60	240	439	0.578	0.00	0.00	0.00
90	120	199	0.262	24.00	6.29	566.32
120	60	79	0.104	0.00	0.00	0.00
150	15	19	0.025	29.00	0.73	108.89
180	3	4	0.005	32.00	0.17	30.36
210	1	1	0.001	0.00	0.00	0.00
240	0	0	0.000	0.00	0.00	0.00
Sum	**759**				**7.19**	**705.57**

6.2 Cohort and static life tables

Table 1 illustrates a static life table which records the survival and reproductive data of individuals from various age groups during a single point in time. Static life tables are appropriate for species that are highly mobile or live for many years such as long-lived where impractical to follow individuals from birth to death. To create a static life table, researchers must estimate the ages of the individuals being studied. While this can be difficult for some species, others have reliable age indicators, such as annual rings in tree wood or fish scales, and tooth wear in deer. With age estimates, researchers can determine age-specific birth rates by counting the number of offspring produced by individuals of each age. Age-specific survival rates can also be inferred from static life tables, but this requires the assumption that survival rates have stayed the same throughout the lifetime of the individuals, which may not always be true. This information is important in management of conflict prone species such as primates, elephants, peafowls etc. Moreover, the cohort life table, which tracks the survival and reproductive patterns of a group of individuals (a cohort) born at the same time, following them from birth until all have died. Cohort life tables are commonly used for plants and other non-mobile (sessile) organisms because it's relatively straightforward to mark individuals and monitor them over time.

6.3 Survivorship curves

Information from life tables can be visually represented using a *survivorship curve*. This type of graph plots survivorship data to show how many individuals are from a hypothetical cohort/population. Research on various species has revealed that survivorship patterns generally fall into three broad categories, each reflecting when during the life span the highest mortality rates tend to occur (Figure 3).

A **Type I survivorship curve** represents species where individuals have a high likelihood of surviving through early and middle stages of life but experience a sharp decline in survival during old age. In other words, most individuals reach adulthood, but only a few live to old age. On a graph, this curve appears convex in shape.
A Type II survivorship curve indicates a species with a fairly constant death rate throughout its life span. This means that the risk of dying is relatively equal at all ages. On a graph, this is shown as a straight diagonal line that slopes downward.

A Type III survivorship curve describes species where most individuals die at a young age, with only a few surviving to adulthood and old age. The highest mortality occurs early in life. On a graph, this curve is typically concave in shape.

7. Population Growth Rates Respond to Environmental Changes

Population growth rates, as well as birth and death rates, can shift in response to changes in environmental conditions. As demonstrated in life table in F_1 , any alteration in age-specific birth or death rates can impact both the growth rate and age distribution of a population. Understanding this, ecologists and resource managers often aim to modify biotic or abiotic factors in the environment to influence these rates either to reduce the size of particular populations or to help recover populations of threatened species. A strategic approach involves identifying which age-specific birth or death rates have the greatest effect on population growth. For instance, life table analysis showed that improving the survival of specific life stages would be more effective in boosting their population growth than focusing on protecting individuals in all age classes, which is the effective conservation strategy.

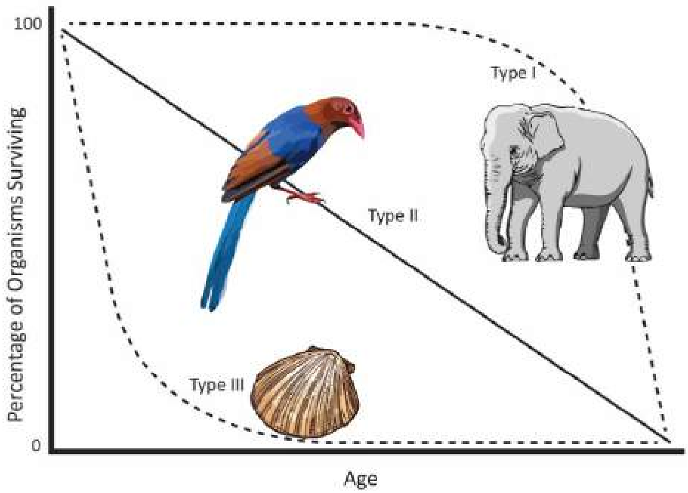

Fig 3. Survivorship curves representing three types of life history strategies across species. Type I (e.g., elephant) shows high survival in early and middle life, with mortality increasing in older age, typical of species with low offspring numbers and high parental care. Type II (e.g., bird) represents a constant mortality rate across all ages, meaning the chance of death is roughly equal throughout life. Type III (e.g., clam) displays high early mortality, with only a few individuals surviving to adulthood, common in species that produce many offspring with little to no parental care.

Even when precise age-specific data is unavailable, long-term monitoring programs can reveal what factors are driving changes in population size. In one example, a cause-of-death reporting system was established at 45 locations across Africa in 2002 to track elephant mortality. Wittemyer et al. (2014) used these data, along with other demographic information, to evaluate trends in elephant population growth (Figure 4). Their research revealed that elephant populations across Africa have been declining, falling below a growth rate of **λ** = 1.0 largely due to a surge in illegal poaching after 2009. Between 2010 and 2012 alone, approximately 100,000 elephants were killed for their ivory, underscoring the significant impact of this threat. Such high levels of elephant poaching are unsustainable. To ensure elephants do not disappear from the wild, their population growth rate must rise and consistently stay above **λ** = 1.0. Achieving this will require stronger actions to combat illegal poaching and reduce global demand for ivory.

More broadly, a population's birth and death rates can be influenced by a wide array of biotic and abiotic factors. Environmental changes, whether abrupt or gradual, can significantly alter these rates. For example, a sharp rise in habitat destruction or a severe drought may trigger sudden, widespread mortality, while other changes may lead to more gradual shifts in reproduction or survival over time.

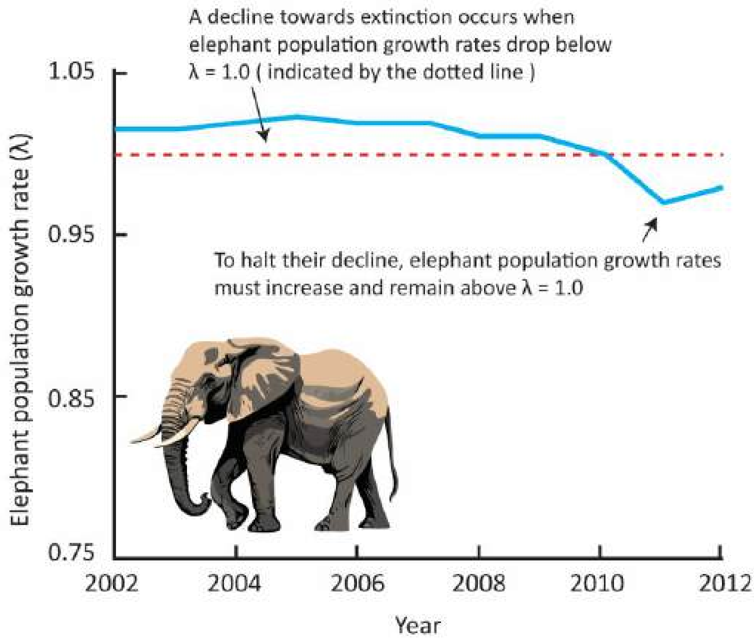

Fig 4. Population growth rates (λ) for 306 elephant populations show that elephant have been in decline across the African continent since 2010 (After Wittemyer et al., 2014).

7.1 Density-independent and dependent factors can influence population size

To understand why growth rates, fluctuate, researchers often examine whether changes occur independently of population density. In one example, Davidson and Andrewartha (1948) studied populations of the rose pest *Thrips imaginis* in Adelaide, Australia, over a 14-year period. They found that variations in temperature and rainfall could accurately predict yearly changes in thrips population size. Environmental variables like temperature, precipitation, or extreme events (e.g., floods, hurricanes) are termed density-independent factors because their effects on birth and death rates do not depend on population density. When population growth rates (λ or *r*) remain unaffected by density, they are said to be density independent (Figure 5). As the thrips data show, density-independent factors can cause substantial shifts in population size from year to year. However, these factors do not inherently regulate populations meaning they don't consistently push growth rates up when populations are small or down when populations are large.

In contrast, density-dependent factors do adjust population growth in relation to population size. When resources like food or space become limited, birth rates often decline, while death and emigration rates rise especially as population density increases (Figure 5). These effects reduce population size. Conversely, when population density decreases, birth rates tend to rise, and death and emigration rates fall, allowing the population to grow. When one or more density-dependent factors cause a population to grow when numbers are low and decline when numbers are high, this process is known as population regulation. As the population density of any species increases, density-dependent influences such as limited food, space, or other critical resources—eventually act to reduce population size.

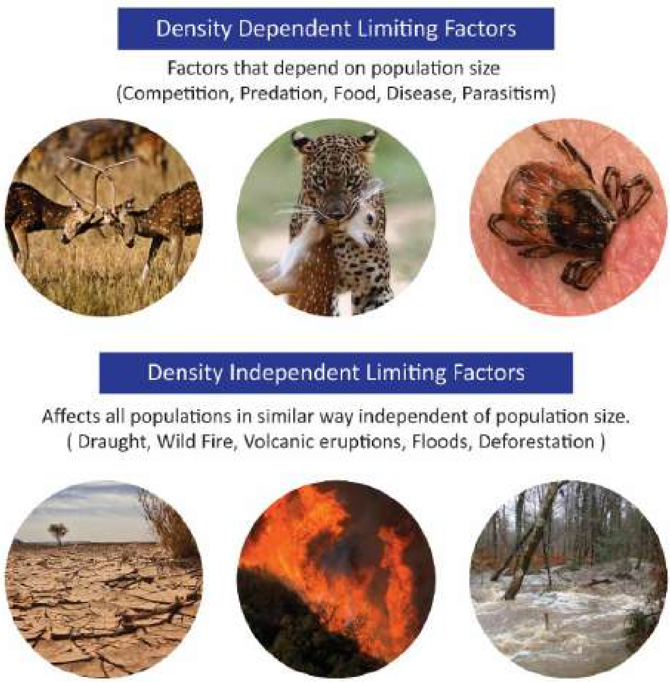

Fig 5. Density-dependent versus density-independent limiting factors that regulate population size. Biotic pressures whose impact intensifies as a population becomes more crowded illustrated by (a) intraspecific competition between antelope, (b) predation by a leopard, and (c) disease/parasitism transmitted by a tick. Abiotic disturbances that strike populations regardless of their density—shown here as (d) prolonged drought, (e) wildfire, and (f) flood events. Together, these factors shape population growth and survival across ecosystems.

In this context, regulation has a specific meaning, it refers to factors that raise the growth rate (λ or r) when the population is small and lower it when the population becomes large. While density-independent factors (such as weather or natural disasters) can significantly impact population size, they do not regulate it because their effects do not vary with population density. Therefore, only density-dependent factors are considered true regulators of population size. For example, in song sparrows (*Melospiza melodia*) on Mandarte Island, the number of young reared to independence decreased as the number of breeding females increased demonstrating density-dependent reproduction. In a 1985 experiment, when the population was dense, nesting pairs that received supplemental food raised younger to independence than unfed pairs, highlighting how limited resources can constrain reproductive success

8. Integrated Biological and Ecological Management of Conflict-Prone Species in Sri Lanka

Understanding HWC in Sri Lanka requires an integration of both biological characteristics of species and ecological dynamics. Several key species involved in conflicts such as the Asian elephant (*Elephas maximus*), Toque macaque (*Macaca sinica*), Saltwater crocodile (*Crocodylus porosus*), and Indian peafowl (*Pavo cristatus*) display distinct biological traits that directly influence the nature and intensity of these conflicts.

For instance, Asian elephants have large home ranges and require continuous access to food and water, often leading them to raid crops when their migratory corridors are disrupted. Their matriarchal social structure and strong memory capacities influence movement patterns, making fixed electric fencing only partially effective. Management options should include the preservation and restoration of elephant corridors and buffer zones with low-conflict crops.

Toque macaques and other primates are highly adaptable omnivores with complex social hierarchies. Their success in anthropogenic landscapes is often driven by access to human food waste, resulting in increased crop raiding and property intrusion. Ethical population management may include sterilization, habitat enrichment, and community waste control programs rather than translocation, which often fail due to strong territorial behavior.

Saltwater crocodiles, territorial and solitary by nature, show conflict behaviors mainly when human activities (e.g., fishing or bathing) overlap with basking or nesting areas. Seasonal awareness programs and crocodile-safe enclosures for riverine communities are critical interventions (e.g. Nilwala River basing).

Indian peafowls, with a broad diet and high reproductive potential, are expanding their range across agro-ecosystems in Sri Lanka. This shift is likely supported by grain-based monoculture farming. Agro-forestry models using less palatable crops, combined with buffer vegetation, can reduce the attractiveness of farmlands to these birds.

Overall, an integrated approach to HWC must consider population dynamics, dispersal limitations, and genetic variability. Conservation corridors, ecological connectivity, and adaptive management strategies grounded in species-specific biology are essential. Further, stakeholder engagement, local knowledge integration, and long-term monitoring are crucial to achieve sustainable coexistence between humans and wildlife in Sri Lanka.

8.1 Managing population growth in conflict-prone wildlife species

In the context of HWC, managing the population dynamics of key species is a critical but complex task. Overabundant or spatially concentrated wildlife populations often increase the frequency and intensity of conflict events (Woodroffe et al., 2005; Dickman, 2010). Effective population management should not be misconstrued as eradication or population reduction for convenience; instead, it should be seen as a conservation tool aimed at promoting long-term coexistence between humans and wildlife while maintaining ecological integrity (Treves et al., 2006).

One primary approach is non-lethal population control, especially suitable for species that exhibit high reproductive rates and thrive in human-modified landscapes. For example, toque macaques (*Macaca sinica*) are prolific breeders and frequently invade human settlements in search of food. Techniques such as immunocontraception and surgical sterilization can be employed selectively in high-conflict zones to gradually stabilize their numbers (Fagerstone et al., 2010; Massei et al., 2010). However, these biological controls must be implemented with community awareness, veterinary oversight, and strict ethical standards (Levy et al., 2003).

In parallel, modifying human practices plays an equally important role. The availability of anthropogenic food sources opens garbage food waste and crop residue—often fuels the growth of animal populations near human dwellings. Mitigating these attractants through improved waste management fencing and secure crop storage can indirectly regulate wildlife numbers without directly intervening in their reproductive cycles (Bateman and Fleming, 2012).

Large-bodied long-lived species like the Asian elephant (*Elephas maximus*) create a different challenge. Fertility control in elephants is biologically demanding, logistically difficult and ethically contentious (Delsink and van Altena, 2015). Therefore, managing population density through spatial reallocation is more practical. This includes establishing and maintaining functional migratory corridors and restoring habitat which enable elephant herds to disperse more evenly across their historical range, reducing overuse of specific patches and lowering human conflict (Fernando et al., 2005).

In the case of the Indian peafowl (*Pavo cristatus*), which shows high reproductive potential and wide ecological tolerance, population control is best achieved by altering landscape-level attractants. The expansion of peafowl populations into farmland is largely due to the cultivation of grain-rich monocultures. Transitioning to agroforestry systems with less palatable crops, or integrating buffer zones with native vegetation, can make the landscape less inviting without harming the birds or compromising agricultural productivity (Sankaran, 2004).

Ultimately, population control should be adaptive, science-based, and species-specific, balancing ecological roles with human safety and livelihoods. It must also be implemented with a strong ethical foundation, community participation, and transparency to ensure long-term public support (Nyhus, 2016).

8.2 Conservation perspectives: toward a coexistence framework

In areas where conflicts between people and wildlife are common, we need to rethink old conservation methods. Instead of trying to keep animals and people separate, a better approach is to focus on living together by connecting habitats, managing wildlife more flexibly, and involving local communities in protecting nature (Woodroffe et al., 2005; Treves et al., 2006).

First and foremost, conservation strategies must recognize the biological and ecological value of conflict-prone species. For example, elephants and leopards are not just icons of biodiversity they serve as umbrella species, whose conservation indirectly protects numerous other organisms sharing their habitats (Roberge and Angelstam, 2004). Preserving these species requires maintaining genetic flow between fragmented populations, which is only possible through the protection and re-establishment of wildlife corridors. These linkages help reduce inbreeding, support meta-population dynamics, and enhance species' resilience to environmental changes (Hilty et al., 2020).

Secondly, ecosystem restoration should be a priority in areas where degradation has disrupted wildlife movement and habitat availability. Rehabilitating degraded forests, reforesting buffer zones, and restoring wetland systems can provide ecological niches and alternative resources, easing pressure on adjacent human landscapes (Chazdon, 2008).

Third, involving local communities in conservation is very important. In the past, many projects failed because they ignored or left out the people living near wildlife. When communities are included—by helping monitor animals, joining eco-tourism efforts, or receiving payments for lost crops, they feel responsible and are more willing to protect wildlife. This makes conservation efforts stronger, more lasting, and better suited to each area (Berkes, 2004; Brooks et al., 2013).

Good policy integration is also essential for solving human–wildlife conflicts. When planning land use, farming, or development, we need to consider how animals move and where conflicts might happen. Technologies like GIS-based risk mapping, real-time animal tracking, and automated early warning systems (e.g., SMS alerts when elephants approach villages) can support proactive decision-making and reduce sudden confrontations (Sitati et al., 2003; Van Eeden et al., 2018).

Finally, educational outreach must reshape the narrative around conflict species. For instance, repositioning the Indian peafowl from a pest to a cultural symbol or ecological ally can shift perceptions and tolerance levels. Conservation communication should use storytelling, traditional knowledge, and empirical science to foster coexistence at the grassroots level (Jacobson et al., 2006; Sutherland et al., 2004).

Thus, conservation in human–wildlife conflict landscapes must be both ecologically grounded and socially informed. A multidimensional, adaptive framework built on connectivity, community empowerment, and ecosystem health offers the best chance for sustainable coexistence.

9. Conclusion

Human–wildlife conflict is both a biological phenomenon and an ecological challenge. Addressing it requires interdisciplinary strategies that respect wildlife ecology, protect biodiversity, and empower communities. Only by combining ecological understanding with inclusive management can we build a future where both humans and wildlife can succeed together.

Furthermore, sustainable solutions demand the integration of ecological science with community-based conservation, land-use policy, and education. Local people must be involved as partners in conservation, and technological tools such as GIS tracking and early warning systems can support proactive strategies. Ultimately, the path forward lies in harmonizing human needs with ecological processes to ensure coexistence.

Ecologically, HWC is closely linked to the degradation and fragmentation of habitats. Conservation efforts must therefore emphasize restoring landscape connectivity, maintaining genetic flow through corridors, and protecting ecosystem functions that support biodiversity. Recognizing the roles of keystone and conflict-prone species in ecological networks is crucial, not only for mitigating conflict but also for sustaining ecosystem resilience and stability.

A biological and ecological perspective helps uncover the root causes of these conflicts. Understanding species-specific traits such as home range size, feeding behavior, reproductive strategies, and dispersal ability are essential for designing effective, ethical management interventions. Population-level analyses, including life tables and survivorship curves, provide insight into growth trends and vulnerable life stages, offering tools to predict and prevent conflict hotspots.

HWC in Sri Lanka represents more than isolated encounters between people and animals it is a symptom of deeper ecological and biological imbalances. These conflicts emerge from a complex interplay of species behavior, habitat loss, population dynamics, and human land-use practices. As human activities continue to modify natural environments, wildlife must either adapt, relocate, or come into conflict with people.

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Conflict of Interest

Authors declare no conflict of interest

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Chapter 03

Conflict and Coexistence: A Social Perspective on Human–Wildlife Relations

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Abstract: Human–wildlife relations have evolved from coexistence and competition in prehistoric societies to complex socio-ecological conflicts in the modern era. This chapter explores the social dimensions of Human–Wildlife Conflict and the transition toward coexistence, emphasising that these interactions are deeply embedded in historical, cultural, psychological, and institutional contexts. Drawing on global and Sri Lankan perspectives, it examines how social inequities, livelihood losses, gendered vulnerabilities, and psychological distress shape community responses to wildlife, while cultural beliefs, trust, and collective action influence attitudes toward coexistence. The discussion integrates behavioural and socio-psychological factors with policy and governance dimensions, underscoring that sustainable coexistence depends on participatory management, equity, and adaptive learning. Through a synthesis of empirical evidence and policy frameworks, including Sri Lanka's national directives, the chapter highlights the need for inclusive, culturally grounded, and ethically informed approaches that balance human well-being with ecological integrity. Ultimately, the concept of coexistence extends beyond technical solutions, representing a fundamental shift towards approaches grounded in empathy, resilience, and shared responsibility between humans and wildlife

Keywords: Behavioural factors, conservation policy, governance, psychosociological factors, social dimensions

1. Introduction

The relationship between humans and wildlife has evolved over millennia, profoundly shaping both human societies and ecological systems, where animal behaviour and human decision-making mutually influence and shape one another. As societies developed, these interactions evolved into complex relationships that often gave rise to Human–wildlife conflict (HWC) (WWF, 2021a). According to the World Wildlife Fund (WWF), HWC is defined as negative interactions in which the presence or actions of wildlife generate

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actual or perceived, recurrent threats to human needs or interests. These conflicts have grown significantly due to agricultural expansion, infrastructure development, and climate change, resulting in increased contact between people and wildlife. Such conflicts frequently result in disputes among human groups and can produce adverse consequences for both people and wildlife, including loss of property, livelihoods, and even life.

Globally, HWC is escalating, with 64% of governments reporting it as a major or serious concern (World Bank, 2023) . Worldwide, thousands of injuries and hundreds of deaths are attributed annually to HWC, especially in areas with large mammals like elephants, tigers, and lions. Retaliatory killings now account for up to 50% of tiger mortality and 55% of snow leopard mortalities each year (WWF, 2021a) . Similarly, in Tanzania, human–lion conflict leads to the deaths of around 60 people and 150 lions each year, reflecting the ongoing challenges of coexistence between rural communities and large carnivores (WWF, 2021a) . Beyond these species-specific conflicts, snakebite envenoming remains a major but often neglected cause of mortality across Asia and sub-Saharan Africa, with the World Health Organization (WHO) estimating between 81,000 and 138,000 deaths annually worldwide (WHO, 2023).

In 2019, human–elephant conflict (HEC) in Sri Lanka resulted in the deaths of approximately 125 people and 370 elephants, marking one of the highest annual tolls ever recorded in the country (Gunawansa et al., 2023). In Sri Lanka specifically, elephants are killed annually via gunshots, poisoning, electrocution, or explosives, in addition to natural causes. These figures highlight the severity of HWC, which has escalated due to multiple interacting factors.

2. Evolutionary and Historical Perspectives

HWC can serve as a potent driver of evolutionary change, where survival and adaptation are guided by the principles of natural selection (Schell et al., 2021). Human survival amid competition with other species played a crucial role in shaping human's early evolution and contributed to humanity's emergence as a dominant global "super predator" (Nyhus, 2016).

Encounters with wildlife played a critical role in influencing the formation of social groups for collective protection, the invention of tools and weapons, and the emergence of cultural norms and taboos regarding dangerous species (Madden, 2004; Nyhus, 2016) . These early interactions fostered the development of cooperative behaviour and symbolic systems that defined how humans perceived and managed risk in their natural environments.

The advent of agriculture marked a pivotal transformation in human–wildlife relations. As humans transitioned from hunter-gatherer to agrarian lifestyles, wildlife increasingly became viewed as competitors or pests that threatened crops and livestock. Historical evidence from multiple civilizations documents the use of traps, poisons, and barriers to mitigate wildlife damage (Redpath et al., 2013). For instance, records from Ancient Egypt describe the use of repellents and trapping systems to control agricultural pests, representing some of the earliest organized attempts at wildlife management (Nyhus, 2016).

During the colonial era, the scale and intensity of HWC intensified by significant changes in land use and governance. Widespread deforestation and the conversion of forests into plantation agriculture disrupted natural habitats, while colonial wildlife management policies prioritised economic profit and game hunting over conservation. These policies institutionalised the displacement and suppression of wildlife, often through extermination campaigns and restrictive land laws that sidelined local ecological knowledge (Adams and Mulligan, 2003).

Sri Lanka's historical experience mirrors these global trends. As an instance, colonial and post-colonial land development schemes, most notably the Mahaweli Development Programme led to large-scale habitat fragmentation and displacement of both humans and elephants. Between 1990 and 1999, studies in the Mahaweli region recorded 316 elephant mortalities and 105 human deaths resulting from HWC (Bandara and Tisdell, 2004; Fernando, 2015). These figures reflect the ecological and social costs of poorly integrated land-use planning in regions of rapid agricultural expansion.

In recent decades, urbanization and infrastructure development have introduced new dimensions to HWC. Expanding road and railway networks have disrupted elephant migratory corridors, leading to a rising number of collisions and fatalities (Fernando, 2015) . Such incidents exemplify the continuing consequences of historical land-use transformations, underscoring the necessity of integrating ecological connectivity and historical context into contemporary conservation and development planning.

3. Social Impacts of HWC

HWC affects not only ecosystems and economies but also human communities, social dynamics, and psychological well-being of people. Around the world, and in Sri Lanka, these conflicts bring economic hardship, psychological stress, and social inequality. They also shape how people think about and interact with wildlife (Barua et al., 2013; Nyhus, 2016).

3.1. Economic and livelihood impacts

Economic losses are among the most tangible social consequences of HWC, particularly for rural and agrarian communities whose livelihoods depend on crop cultivation and livestock rearing. In India, households impacted by elephants or large carnivores often face far greater costs from injuries and deaths than from direct crop or livestock loss alone (Gulati et al., 2021). In Sri Lanka, macaques cause substantial crop damage in districts such as

Kurunegala, with seasonal fluctuations in economic losses linked to crop type (Jayarathne et al., 2025) . These economic stresses reduce household resilience, often forcing adaptation strategies such as migration, changes in livelihood practices, or reliance on informal credit, disproportionately affecting marginalized or resource-poor households (Barua et al., 2013; WWF, 2021a).

3.2. Social equity and community dynamics

The impacts of HWC tend to be unevenly distributed. Smallholder farmers, Indigenous peoples, and marginalized groups often bear the brunt of crop losses, livestock predation, and human casualties, while possessing limited capacity to adapt or access compensation schemes (Treves et al., 2006) . Unequal distribution of impacts can magnify communal tensions, erode trust in local authorities and conservation agencies, and create conflicts over resource allocation or land use (Redpath et al., 2013) . In Sri Lanka and elsewhere, inequities in compensation or mitigation measures often produce perceptions of injustice, fueling resentment and, in some cases, retaliatory killings of wildlife (Barua et al., 2013; Jayarathne et al., 2025)

3.3. Gender-differentiated risks and impacts

Women often face heightened risks from HWC due to their daily subsistence activities such as collecting water, gathering firewood, and managing small livestock that increase exposure to wildlife encounters. In contrast, men are more commonly involved in agricultural production and in protective or counter-offensives against problematic animals (Galley and Anthony, 2024; Li et al., 2023). These differentiated exposures reflect structural gender roles that define access to land, labour, and safety within rural economies.

3.4. Psychological and emotional impacts

Beyond material losses, human casualties, injuries, and psychological harm are seen in many contexts. Chronic exposure to wildlife threats such as repeated crop raids by elephants or attacks by large carnivores, commonly results in persistent fear, anxiety, sleep disturbances, and heightened vigilance, which disrupt daily routines and overall well-being (Inskip et al., 2016).

3.5. Cultural and spiritual dimensions

Cultural beliefs, religious values, and symbolic associations with wildlife also intersect with social impacts. Many species affected by HWC hold cultural, spiritual, or heritage significance, meaning that damage to wildlife populations can have repercussions for cultural identity, community cohesion, and social norms (WWF, 2021a) . In Sri Lanka, elephants and other iconic species are embedded in religious and national heritage, so conflict-induced mortality not only diminishes biodiversity but can also disrupt cultural practices and community identity. Cultural factors often mediate responses to conflict, influencing whether communities adopt tolerance, avoidance, or retaliatory behaviors (WWF, 2021b).

3.6. Adaptation, resilience, and social change

Communities frequently develop adaptive strategies in response to HWC, including changes in agricultural practices, livestock management, and settlement patterns, as well as collective action to mitigate conflict (Barua et al., 2013; Carter and Linnell, 2016). While adaptation can enhance resilience, prolonged exposure to conflict can also lead to social fragmentation, migration, and altered demographic patterns, particularly when institutional support and compensation are inadequate (Madden and McQuinn, 2014) . Incorporating psychosocial support and trauma-informed approaches into mitigation strategies has been increasingly recognized as critical to promoting both individual recovery and broader community resilience (Inskip et al., 2016).

4. Human Behavioural and Socio-psychological Factors Influencing HWC

While ecological, economic, and technical dimensions of HWC have received significant attention, the socio-psychological dimensions are equally crucial in determining how such conflicts arise or are managed. Human attitudes, perceptions, and cultural belief systems shape behavioural responses toward wildlife and influence the degree to which communities support or resist conservation interventions (Madden and McQuinn, 2014; Nyhus, 2016).

4.1. Perceived threats and risk perception

Perceptions of risk are often socially constructed rather than empirically grounded. Individuals tend to overestimate the likelihood or severity of wildlife-related harm based on their psychological status (Marchini and Macdonald, 2012). Media coverage that dramatises attacks or fatalities can amplify fear and moral panic, promoting demand for lethal or exclusionary responses (Lute et al., 2016; Mutanga et al., 2017). The discrepancy between perceived and actual risk frequently limits the acceptance of coexistence strategies such as electric fencing, deterrent systems, or translocation programs (Redpath et al., 2013).

4.2. Beliefs, myths, and religion

Beliefs also shape how societies perceive and interact with wildlife, influencing whether species are respected, tolerated, or persecuted (Nyhus, 2016) . In South Asian contexts, elephants hold sacred status in both Buddhist and Hindu traditions, symbolizing wisdom, prosperity, and divine presence (Bandara and Tisdell, 2003; Fernando et al., 2008) . These beliefs can encourage protectionist attitudes; however, when elephants damage crops or pose safety risks, communities often experience cognitive dissonance, the psychological tension between cultural reverence and livelihood insecurity (Gore et al., 2005). Similarly, myths surrounding snakes, leopards, or other predators can influence human behavior ranging from exaggerated fear and indiscriminate killing to fatalistic acceptance due to beliefs in karma or destiny (Dickman, 2010; Nyhus, 2016). These belief systems embed moral and spiritual values into human–wildlife relationships, functioning as informal governance mechanisms that guide acceptable behavior toward nature.

4.3. Values, cultural orientations and world views

Empirical studies have identified two broad cultural worldviews shaping human–wildlife relationships. Domination orientation, which conceptualizes wildlife primarily as resources to be controlled or threats to be eliminated, typically supports lethal control or retaliatory killings. By contrast, a mutualism or coexistence orientation, which views wildlife as integral members of the broader community with intrinsic, ecological, or cultural value, is associated with greater support for non-lethal interventions and coexistence-based policies (Dietsch et al., 2016; Manfredo et al., 2009). Cultural divides between these worldviews can fuel social conflict over wildlife management strategies, particularly when conservation policies challenge traditional livelihoods (Nyhus, 2016).

5. Human-wildlife Coexistence

Coexistence represents a central paradigm in contemporary HWC management, emphasizing the creation of conditions that allow humans and wildlife to share landscapes with minimal risk and mutual benefit (WWF, 2021a). The nature of coexistence may vary across contexts, manifesting as contentious, neutral, or mutually beneficial interactions. Rather than seeking the complete elimination of conflict, coexistence approaches aim to sustain tolerance and manage impacts within socially and ecologically acceptable limits over the long term (Stevens et al., 2025).

5.1. Key social factors that enable wildlife coexistence

Social dimensions play a decisive role in facilitating human–wildlife coexistence, shaping how communities perceive, respond to, and manage interactions with wildlife. Trust is foundational for effective collaboration between communities, conservation authorities, and government institutions (Young et al., 2016). Community participation is equally vital, as involving residents in the planning and monitoring of conflict management enhances legitimacy, draws upon indigenous ecological knowledge, and ensures interventions are contextually appropriate (Nkansah-Dwamena, 2023). Equitable sharing of benefits such as ecotourism revenue, compensation schemes, or livelihood diversification builds local support and tolerance for wildlife (Bhattarai et al., 2021; Rashid, 2024). When economic and social costs are distributed fairly, communities are less likely to engage in retaliatory actions. Additionally, cultural and spiritual values often underpin respect for wildlife, with traditional beliefs and taboos serving as informal conservation mechanisms that reinforce coexistence (Pooley et al., 2021).

5.2. Benefits of coexistence

Promoting coexistence yields both ecological and socio-economic benefits. Ecologically, it sustains biodiversity, maintains ecosystem services, and reduces cycles of wildlife decline and habitat degradation. Socially, it enhances resilience by empowering communities through inclusive governance, participatory decision-making, and livelihood diversification linked to conservation incentives (KSAPA, 2025).

From a developmental perspective, coexistence aligns with global sustainability goals advancing food security, poverty reduction, and environmental stewardship, thereby reinforcing the interdependence of conservation and human development (FAO, 2024; WWF, 2021a) . This integrated approach recognises that human–wildlife interactions are inevitable within shared ecosystems and that effective management must balance human safety, livelihoods, and ecological integrity (Carter and Linnell, 2016).

5.3. Achieving human-wildlife coexistence: methods and approaches

Achieving lasting coexistence requires integrated, multi-stakeholder approaches that address ecological, social, economic, and institutional dimensions simultaneously(Carter and Linnell, 2023; WWF, 2019). Holistic management systems that combine prevention, mitigation, rapid response, research, and continuous monitoring are vital to ensuring adaptability and long-term sustainability. Short-term or isolated actions are often ineffective without broader adaptive learning frameworks that align conservation objectives with community needs (KSAPA, 2025; WWF, 2019).

Community empowerment forms the foundation of successful coexistence initiatives. Involving residents through participatory planning, conservation education, and livelihood diversification fosters tolerance and reduces retaliatory actions. Locally adapted practices such as community patrols, early warning systems, and non-lethal deterrents including beehive fences and electric barriers have demonstrated practical effectiveness (Shepherd, 2023; KSAPA, 2025).

Collaborative governance further enhances coexistence outcomes. Partnerships between government agencies, local communities, NGOs, and private-sector actors strengthen shared decision-making, trust, and transparency (Carter and Linnell, 2023; WWF, 2019) . Evidence-based interventions integrating scientific and indigenous knowledge contribute to contextually grounded, empirically validated solutions.

A supportive policy and legal environment is essential for embedding coexistence principles into land-use planning, protected area management, and compensation frameworks. Policies promoting equity, social justice, and gender inclusivity enhance legitimacy and community buy-in (Carter and Linnell, 2023). At the operational level, non-lethal deterrents, early warning systems, and GPS-based monitoring are complemented by livelihood diversification initiatives such as eco-tourism and agroforestry. Landscape-level strategies like buffer zones and wildlife corridors further minimize spatial overlap between humans and wildlife, reducing the frequency of encounters (KSAPA, 2025; WWF, 2019) . As a guiding principle, it underpins the transition from conflict to collaboration, shaping a sustainable and inclusive future for both people and nature (Pooley et al., 2021)

5.4. Attempts to manage HWC and promote coexistence in Sri Lanka

Effective HWC management involves a multidimensional approach integrating ecological, social, economic, and governance perspectives. Six key components, understanding the conflict, mitigation, response, prevention, policy and legal frameworks, and monitoring and adaptive management, are critical (Nyhus, 2016) . Efforts to mitigate HWC in Sri Lanka have encompassed a multifaceted range of strategies (Table 2).

Sri Lanka's *National Policy Directives for the Management of Human–Wildlife Conflict* emphasize humane, scientifically informed, and socio-culturally appropriate responses combining national policy frameworks, technological innovations, community-based approaches, and institutional reforms (Table 1 and 2). The policy underscores the integration of traditional ecological knowledge, participatory governance, and cross-sectoral coordination among government agencies and local stakeholders. Furthermore, it calls for land-use planning that balances conservation and development priorities (DWC, 2018).

Revisions and enforcement of existing legal instruments such as the *Fauna and Flora Protection Ordinance* and the *Forest Ordinance* have sought to clarify institutional roles and responsibilities. Agencies such as the Department of Wildlife Conservation, the Forest Department, and local authorities are expected to collaborate in managing conflict zones and promoting coexistence.

A range of deterrent mechanisms has been implemented to reduce physical encounters between humans and wildlife. These include electric fencing, early-warning systems, rapid response teams, and spatial mapping of conflict incidents. In particular, electric fences have been widely deployed to mitigate elephant intrusions, while innovative measures such as beehive fences and chili-based deterrents have been tested in localized areas (DWC, 2018).

Community engagement remains central to conflict mitigation. Compensation schemes for crops and property losses, along with support for alternative livelihoods such as eco-tourism, have been introduced in high-conflict regions. These initiatives emphasize shared responsibility and co-management of natural resources.

Table 1. Key laws and policies that HWC management in Sri Lanka (DWC, 2018).

Laws	Key Policies
Fauna and Flora Protection Ordinance and its amendments	The National Forest Policy of 1995
Forest Ordinance No. 16 of 1907 and its amendments	The National Wildlife Policy of 2000
The National Heritage Wilderness Areas Act No. 03 of 1988	The National Environmental Policy and Strategies of 2003
The National Environmental Act, No.47 of 1980 and its amendments	National Policy on Elephant Conservation and Management of 2006 as amended by the draft policy directives of 2017
Animals Act Nos. 29 of 1958, and its amendments	The National Policy on Agriculture of 2007
The National Zoological Gardens Act no.41 of 1982	The National Land Use Policy of 2007
	The National Policy on Agriculture of 2007

Educational and knowledge dimensions are central to shaping community responses to HWC. The transmission of local ecological knowledge, including traditional risk-avoidance and adaptive practices, supports coexistence between humans and wildlife. HWC experiences also influence community attitudes and conservation awareness, shaping perceptions of wildlife positively or negatively. Moreover, schools, NGOs, and community education initiatives play vital roles in disseminating knowledge and fostering coexistence-oriented values through participatory learning and awareness programs (Barua et al., 2013; Nyhus, 2016).

Ecological restoration and habitat connectivity form another critical strand of mitigation. Efforts include establishing wildlife corridors, buffer zones, and habitat enrichment programs while managing invasive plant species. Such landscape-level interventions are intended to reduce competition for resources and promote safer wildlife movement (DWC, 2018).

5.5. Challenges to human–wildlife coexistence

Despite progress, several persistent challenges hinder effective coexistence. Psychosocial barriers, including fear, distrust, and trauma arising from repeated wildlife encounters fuel negative attitudes and retaliation (Madden and McQuinn, 2014; Redpath et al., 2013; Treves et al., 2006) . Resource constraints such as inadequate funding, technical capacity, and trained personnel limit the sustainability of mitigation measures. Poor maintenance of fences, insufficient monitoring, and bureaucratic inefficiency further exacerbate conflicts.

Policy gaps and weak enforcement undermine implementation, while limited inter-agency coordination results in fragmented responses (Dickman, 2010). Moreover, inequitable benefit distribution where conservation gains accrue to elites while rural communities bear costs fuels resentment and resistance (Barua et al., 2013) . Finally, cultural and institutional misalignments, including top-down interventions that disregard local knowledge, often alienate communities and erode trust. Addressing these issues requires strengthening institutional accountability, enhancing inter-sectoral collaboration, and embedding culturally sensitive, participatory approaches into conservation policy.

Table 2. Sri Lanka's HWC mitigation efforts: Success and challenges (DWC, 2018)

Attempt/ Policy	Success/ Innovation	Challenges
National Policy Framework	Holistic, multi-agency platform	Implementation gaps, weak coordination
Electric Fencing	Widely adopted deterrent	Misplacement, poor maintenance, low effectiveness
Translocation	Quick removal of "problem" animals	Creates new conflicts, unsustainable outcome
Compensation Schemes	Direct financial support	Delays, inadequate funding, fosters dependency
Community Engagement	Awareness and inclusion	Limited empowerment, top-down processes
Habitat Restoration	Improved ecological connectivity	Continued fragmentation, slow implementation
Rapid Response & Early Warning	Faster intervention	Limited geographic coverage, resource constraints

5.6. Role of animal rights organisations in promoting human–wildlife coexistence and welfare

Globally and in Sri Lanka, animal rights organisations have become pivotal actors in influencing policy, raising public awareness, and advancing ethical, sustainable approaches to human–wildlife coexistence. Their involvement spans policy advocacy, education, research, and community engagement, reflecting a growing recognition that animal welfare is intrinsically linked to environmental sustainability and human well-being.

At the international level, organisations such as the World Wildlife Fund (WWF), World Animal Protection, Humane Society International, American Society for the Prevention of Cruelty to Animals (ASPCA), and the World Federation for Animals (WFA) have played instrumental roles in advancing animal rights and welfare on global platforms. These organisations advocate for the inclusion of animal welfare within international policy frameworks, such as the United Nations Sustainable Development Goals (SDGs) and the UN Ocean Conference, thereby integrating animal welfare considerations into broader environmental and public health agendas.

Their work encompasses several dimensions. First, policy advocacy efforts have shaped national legislation and international conventions aimed at safeguarding wildlife and promoting humane coexistence. Second, education and awareness campaigns including global movements against fur industries, factory farming, and animal testing, have mobilised consumers and corporations to adopt more ethical practices. Third, research and capacity-building initiatives have produced scientific insights, practical toolkits, and training programs that strengthen institutional and community capacities for ethical wildlife management.

In Sri Lanka, the Department of Wildlife Conservation is the main government body responsible for managing HWC. Local organizations including the Wildlife and Nature Protection Society (WNPS)**,** Rally for Animal Rights and Environment (RARE)**,** Wilderness and Wildlife Conservation Trust (WWCT)**,** and Animals' Welfare and Protection Association (AWPA), have contributed significantly to integrating animal welfare into conservation and coexistence strategies. These organisations engage in legal and policy consultation**,** offering expert input to government agencies and advocating for humane, science-based conflict mitigation approaches. Through these collective efforts, animal rights organizations strengthen the ethical foundation of conservation practice, fostering a coexistence paradigm that values empathy, respect, and shared well-being between humans and wildlife.

6. Conclusion

Human–wildlife interactions have transformed over time with increasing conflict, driven by expanding human populations, agricultural intensification, and habitat fragmentation, making HWC, a critical global conservation and development challenge (World Bank, 2023; WWF, 2021a). Understanding the historical, ecological, and socio-political roots of these conflicts is essential for developing sustainable strategies that balance human needs with wildlife conservation (Fernando, 2015; Nyhus, 2016).

The social dimensions of HWC are complex and interlinked, encompassing economic losses, psychological trauma, inequities, cultural disruption, and challenges to social cohesion. Addressing these impacts requires integrated approaches that consider both human well-being and wildlife conservation. Effective strategies must combine equitable compensation, community participation, cultural sensitivity, and psychosocial support to foster coexistence and resilience in human–wildlife landscapes (Barua et al., 2013; Nyhus, 2016; Redpath et al., 2013). Overall, these interconnected social factors, trust, participation, equity, cultural respect, education, cohesion, and inclusivity, create the social foundations necessary for sustainable human–wildlife coexistence, aligning conservation objectives with community well-being and resilience (Carter and Linnell, 2023; Pooley et al., 2021).

Coexistence is a key concept that reflects the human attitude of promoting mutualism. Achieving human–wildlife coexistence is a multifaceted and evolving endeavour that depends on integrative management, participatory governance, community empowerment, scientific evidence, and policy frameworks. Long-term commitment, adaptive management, and equitable benefit-sharing remain critical to ensuring that both human and wildlife communities can thrive within shared landscapes (Carter and Linnell, 2023; WWF, 2021b)

Coexistence surpasses technical mitigation, and it is a holistic vision of shared living that promotes respect, adaptability, and mutual well-being between humans and wildlife. As a guiding principle, it underpins the transition from conflict to coexistence, shaping a sustainable and inclusive future for both people and nature (Pooley et al., 2021).

While Sri Lanka's approach to mitigating HWC demonstrates a progressive policy framework and growing emphasis on participatory governance, its implementation remains suppressed by fragmented institutional structures, infrastructural inefficiencies, and insufficient integration of local socio-ecological contexts. Long-term coexistence requires adaptive management, data-driven monitoring, and the empowerment of local communities to engage meaningfully in conservation and decision-making processes (DWC, 2018; Fernando et al., 2008; World Bank, 2023; WWF, 2021b).

Conflict of interest:

The authors declare that they have no competing interests regarding the publication of this article. No financial, professional, or personal relationships with other organisations or individuals could influence the results or interpretation of this research.

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Chapter 04

Ethnobiological Perspectives on Human–Wildlife Conflict: Lessons from Farming Communities

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Abstract: As a primarily agricultural country, Sri Lanka serves as an important center of knowledge on diverse agroecosystems and rich ethnobiological traditions that have been passed down through generations since ancient times. Among the many challenges faced by farming communities, human–wildlife conflict (HWC) remains one of the most serious, requiring solutions that balance human well-being with wildlife conservation. However, current approaches to HWC mitigation in Sri Lanka are largely fragmented and focused on conservation, with limited cross-sector cooperation and integration of local knowledge systems. This chapter documents the ethnobiological knowledge of Sri Lankan farming communities related to managing human–wildlife interactions across six selected agricultural ecosystems. Drawing on ethnobiological insights, field observations, and documented practices, it illustrates how farmers have historically developed context-specific strategies based on cultural beliefs, rituals, ecological understanding, and lived experience. While some

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traditional methods show variable effectiveness or remain insufficiently documented, many contain adaptive ecological knowledge refined over centuries. By critically evaluating their relevance, limitations, and potential complementarity with modern wildlife management tools and practices, this chapter highlights how ethnobiological knowledge can support more inclusive, community-driven, and sustainable solutions to reduce HWC. Integrating traditional knowledge with modern science, therefore, offers a promising pathway to enhance food security, safeguard rural livelihoods, and promote long-term human–wildlife coexistence in Sri Lanka.

Keywords: Agricultural ecosystems, ethnobiology, farming communities, indigenous knowledge, traditional ecological knowledge

1. Introduction

Human–wildlife conflict (HWC) is increasingly recognized as a critical issue, affecting both conservation goals and the well-being of local communities (Arroyo-Quiroz et al., 2023; Stevens et al., 2025). The increasing overlap between human and wildlife activities has led to frequent conflicts in agricultural lands, urban zones, and at the boundaries of protected areas (Storch et al., 2024). Such encounters endanger human lives and livestock while disrupting crop production, thereby threatening food security and undermining livelihoods and cultural practices in agrarian communities (Trust et al., 2024). Regardless of the scale or type of crop production system, farming communities worldwide face significant challenges in finding solutions to these threats. However, current strategies for managing HWC are often fragmented and primarily conservation-focused, with limited coordination and support from other affected sectors (Abas et al., 2025).

Mitigating HWC requires robust knowledge of ecological, social, and economic dynamics and depends heavily on understanding the patterns, mechanisms, and trends of conflict (Storch et al., 2024). Although most mitigation endeavors focus primarily on technical aspects of conflict reduction, people's attitudes toward wildlife are shaped by complex social factors, including religion, ethnicity, and cultural beliefs, which influence conflict intensity (Dickman, 2010). Therefore, identifying acceptable and sustainable solutions requires a holistic approach that considers the full range of factors contributing to HWC. Achieving sustainable human–wildlife coexistence requires not only technical and ecological interventions but also the active involvement of local communities, whose perspectives and knowledge are essential for shaping effective policies and management practices (König et al., 2021; Nkansah-Dwamena, 2023).

Over the past few decades, ethnobiology has emerged as a vital interdisciplinary field that explores the complex relationships between humans, plants, animals, and ecosystems, and it is increasingly recognized as a key discipline for addressing this research gap (Arrivabene et al., 2024;

Pieroni et al., 2025). The contribution of ethnobiological knowledge, particularly associated with farming communities in the Global South, has been studied to some extent over the past few decades due to its significance in developing strategies to minimize HWC (Storch et al., 2024; Abas et al., 2025; Jolly and Stronza, 2025; Jaishanker et al., 2025).

However, the application of such ethnobiological knowledge in real-world contexts remains limited and requires detailed investigation into its practicality, effectiveness, and potential for integration with modern scientific knowledge. Since most traditional knowledge is transmitted orally across generations through personal experiences and shared practices, the exploration, documentation, and conservation of such knowledge are important. Therefore, this chapter focuses on compiling the ethnobiological knowledge of Sri Lankan farming communities related to managing HWC, which affects them at varying scales.

2. Agricultural Ecosystem Diversity and Crop Genetic Resources

Sri Lanka's agricultural systems are remarkably diverse and dynamic, shaped by its unique geographical location within the Indian Ocean, complex topography, varied climate, and heterogeneous soils (Rajapaksha et al., 2024). This ecological diversity has supported a wide range of agricultural practices and crop genetic resources. Among the key agricultural ecosystems are rice-based farming, upland vegetable cultivation, homegardens, and plantation crop systems, all of which significantly contribute to national food security and economic growth. These systems are also closely tied to local knowledge and are maintained through long-standing ethnobiological practices.

Besides commercially established crop-based agroecosystems, Sri Lanka preserves several traditional farming systems managed by local communities for generations, yet these remain underutilized, largely due to the undervaluation of their economic, social, and ecological value (Lansakara et al., 2024; Ratnayake et al., 2023; Abeywardana et al., 2019). In these systems, farmers have developed and conserved locally adapted crop varieties, cultivation techniques, and seed management practices based on experiential knowledge and cultural traditions, reflecting centuries of ethnobiological understanding. Overall, the collective efforts across diverse agricultural ecosystems support Sri Lanka's economy by ensuring food and nutritional security, conserving crop genetic resources, supporting rural livelihoods, preserving cultural traditions, and enhancing socio-ecological resilience.

Sri Lanka's diverse agricultural ecosystems host a wide array of plant genetic resources, including traditional landraces, indigenous crops, cultivated exotics, and crop wild relatives, all vital for maintaining agrobiodiversity (Rajapaksha et al., 2024; Ratnayake et al., 2023). These genetic resources are central to food security and serve as reservoirs of adaptive traits that can support crop improvement, climate resilience, and sustainable agriculture (Ghimiray and Katwal, 2013; Salgotra et al., 2022).

However, farmers today face mounting challenges in achieving high yields and improving productivity, mainly due to rapid socio-economic shifts, rising production costs, and the adverse effects of climate change. Additionally, attacks by wild animals on cultivated crops have increased HWC, creating severe socio-economic burdens for farming communities through crop losses, income reduction, and heightened food insecurity.

3. Human-Wildlife Conflict

Crop damage caused by wild animals is not a newly emerging problem; however, it has intensified considerably in recent years, largely due to the unprecedented growth of certain wildlife populations (Rudran et al., 2020, 2021; Wijethilaka et al., 2021). This escalation has led to increasingly violent interactions between humans and wildlife, resulting in fatalities on both sides (Thilakarathna and Godage, 2021). To cope with these critical challenges, farming communities employ a variety of wildlife mitigation strategies at different spatial and management scales (Bharathy et al., 2022). However, none of the measures currently in place have proven fully effective in controlling wild animal incursions, and the growing desperation of affected farming communities is having severe repercussions on Sri Lanka's agricultural sector, food security, and national economy. This situation underscores the urgent need for integrated, innovative, cross-sectoral strategies to mitigate this escalating challenge. Alongside modern technological approaches, many farmers continue to employ traditional practices grounded in ethnobiological knowledge to reduce the impacts of wildlife on crops and farmland.

4. Ethnobiological Insight on Human–wildlife Conflict

Across many regions of the world, local communities hold both documented and undocumented indigenous knowledge, accumulated through generations of lived experience and closely tied to their ecological and cultural contexts (Gunaratne and Sylva, 2025). Such ethnobiological knowledge is increasingly applied to address climate change adaptation, forest management, and sustainable agriculture, while emphasizing the practical value of local and traditional knowledge (Ludwig and El-Hani, 2020). There is ample evidence that farming communities worldwide use such knowledge for crop cultivation and farmland management while ensuring the sustainable use of natural resources.

In the context of human–wildlife conflict, this ethnobiological knowledge also provides locally adapted strategies for anticipating, preventing, and responding to wildlife incursions in agricultural landscapes. In Sri Lanka, where agricultural fields frequently overlap with natural habitats, these knowledge systems play a particularly important role in shaping farmers' responses to wildlife-related risks. Accordingly, the following section examines how Sri Lankan farming communities use traditional knowledge to protect their crops and farmland from wild animals, with particular focus on six selected agricultural ecosystems.

Fig 1. (A) Rice-based farming system surrounded by Kandyan home garden ecosystems; (B) upland vegetable cultivation in the dry zone of Sri Lanka.

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4.1 Rice–based farming systems

Rice cultivation is the backbone of Sri Lanka's agricultural economy and cultural identity, shaping landscapes and rural livelihoods for centuries (Senanayake and Premaratne, 2016). As the staple food crop, rice covers more than 15% of the country's land area and makes up 34% of the total agricultural land, involving about 1.8 million family farmers (Rathnayake and Mizunoya, 2024; FAO, 2023). These systems are deeply connected with Sri Lanka's ancient irrigation heritage, especially the "*wewa*" (tank) systems, and cultural rituals, where rice is revered not just as a staple food but also as a sacred symbol of prosperity and community well-being.

However, rice fields are also hotspots for human–wildlife conflict because they are located in fertile lowlands near forests, protected areas, and elephant corridors (Thilakarathna and Godage, 2021; Gunawansa et al., 2023; Köpke et al., 2020). The main wildlife species affecting rice farming include elephants (*Elephas maximus* maximus), wild boar (*Sus scrofa*), porcupines (*Hystrix indica*), toque macaques (*Macaca sinica*), and various bird species like peafowl (*Pavo cristatus*) and parakeets. Among these, elephants are the most destructive, raiding fields during both the vegetative and grain-filling stages (Gunawansa et al., 2023; Thilakarathna and Godage, 2021). In response, Sri Lankan rice farmers have developed a wide range of ethnobiological strategies, shaped over generations that reflect deep ecological knowledge and cultural heritage. These strategies are often combined and adapted to changing environmental and socio-economic conditions, as outlined below:

- Field guarding and watch-huts ("pela"): Farmers build temporary tree-based watch-huts within fields and guard their crops, particularly at night. Common methods include using torches, drums, banging tins, firecrackers, shouting, and throwing objects to scare away elephants and wild boar (Enukwa, 2017; Sajla and Famees, 2022). Chili peppers and fire are also frequently used to frighten elephants and deter them from entering crop fields (Gross et al., 2017; Köpke et al., 2020).

- Plant-based deterrents: Certain plant species are used to discourage wildlife from entering farms. Farmers often cultivate less attractive or unpalatable crops around rice fields, relying on animals' aversion to strong odors and tastes (Kolinski and Milich, 2021; Santiapillai et al., 2010). As part of buffer planting strategies, crops such as chili, citrus, Tithonia, and thorny fence plants are established along the edges of paddy fields to create biological fences. This practice helps reduce crop damage by elephants, wild boar, and porcupines (Fernando et al., 2008; Sajla and Famees, 2022; Dharmarathne et al., 2020).

- Beehive fences: Elephants naturally avoid areas with beehives, as bees can swarm and sting when disturbed. Farmers suspend active or dummy beehives along fences, which swing and release bees if elephants attempt to cross (King et al., 2017). Beehive fences are relatively inexpensive, constructed using locally available materials, and do not cause harm to elephants (King, 2019). In addition to their deterrent effect, they provide supplementary income through the production of "elephant-friendly honey" and other bee products (Enukwa, 2017; Shaffer et al., 2019).

- Noise and light deterrents: Traditional tools such as "rabana" (local drum), bamboo clappers, and kerosene torches are widely used to scare wildlife away from rice fields, particularly during nocturnal crop-raiding events.

- Seasonal adjustments: Using detailed knowledge of wildlife movement patterns and behavior, farmers often adjust planting and harvesting schedules to avoid periods of peak elephant activity.

- Use of "kem krama": "Kem krama" refers to traditional ritual practices that employ charms, mantras, symbolic objects, and folk beliefs to protect people, crops, and households from illness, misfortune, wild animals, and supernatural forces. These practices represent a culturally embedded system of protection and risk management in rural Sri Lankan society. To protect paddy fields from rodents such as rats, traditional farming communities place chopped papaya stems, pineapple leaves, and other plant materials along field bunds and apply extracts prepared from a selected group of seven plant species. Such practices are embedded within ritual, religious, astrological, and cultural traditions, forming part of the broader "kem krama" framework used for agricultural protection (Dalupotha, 2011).

Together, these practices demonstrate how traditional ethnobiological knowledge remains central to rice farming systems in Sri Lanka. Beyond crop protection, they reflect a broader philosophy of coexistence, whereby farming communities adapt their strategies to safeguard livelihoods while minimizing harm to wildlife.

4.2 Upland vegetable cultivation

Upland vegetable cultivation represents one of the most dynamic agricultural sub-sectors in Sri Lanka, providing both nutritional security and economic resilience to rural households. Major crops such as brinjal, beans, cabbage, tomato, and capsicum are widely cultivated in upland regions. Alongside these market-oriented crops, traditional vegetables, including alu kola, anguna kola, waduru mae, kohila, and pathola, are also grown, reflecting subsistence needs and culturally embedded dietary preferences (Chamara et al., 2021; Ranil et al., 2022). Upland vegetable cultivation therefore contributes not only to household income but also to national food security, while promoting nutritional diversity and strengthening the economic stability of farming communities.

Despite these benefits, upland vegetable fields are highly vulnerable to wildlife incursions due to their proximity to forested mountain slopes, scrublands, and fragmented habitats. Problematic species include wild boar, toque macaques, Purple-faced langurs (*Semnopithecus vetulus*), porcupines, parrots, peafowl, and elephants in areas adjoining forests. These animals cause extensive crop losses: wild boar uproot seedlings and tubers such as carrot and beetroot; monkeys pluck and damage fruits before ripening; and porcupines feed on root crops and gnaw through irrigation pipes. To cope with these challenges, upland farming communities rely on a range of traditional, low-cost, and context-specific ethnobiological strategies (personal observations and communications with farmers).

- Physical barriers: Thorn fences or stone walls are constructed around vegetable plots, particularly in hilly terrain, to deter wild boar and porcupines.

- Guarding and watch-huts: Similar to rice-based systems, farmers guard fields at night from temporary huts, often using fire torches and dogs to detect wildlife intrusions.

- Noise and visual deterrents: Hanging reflective tins, plastic strips, or old compact discs (CDs) is a common low-cost practice to scare monkeys and birds. Scarecrows dressed in brightly colored clothing are also widely used.

- Crop diversification and border planting: Less palatable or deterrent crops, such as chili, bitter gourd, or citronella, are planted along field borders to discourage animal entry.

- Traditional repellents: Burning dried leaves, chili powder, or plant resins at field margins is practiced to repel wild boar and porcupines.

- Cultural beliefs and rituals: Some communities perform ritual practices invoking protective deities during different stages of the cultivation cycle, reflecting the spiritual and cultural dimensions of ethnobiological knowledge.

4.3 Chena cultivation

Chena, or shifting cultivation, is one of the oldest agricultural practices in Sri Lanka and is often regarded as a primitive and unsustainable system. However, it has traditionally been a culturally embedded and ecologically adaptive land-use system, with each stage (from land preparation to harvesting) encompassing distinct cultural and ecological practices (Rajapaksha et al., 2024). These practices include site selection, crop combinations, seasonal timing, and deterrent methods informed by long-term observation of wildlife behavior. Because *Chena* cultivation is typically practiced along the margins of natural forests and in close proximity to wildlife habitats, it is among the agroecosystems most vulnerable to HWC. Predominantly undertaken by traditional small-scale farmers in remote and economically marginalized regions, *Chena* cultivation relies heavily on ethnobiological knowledge systems that guide crop protection, risk management, and adaptive responses to wildlife-related threats.

Although the use of traditional practices in *Chena* cultivation has been studied to some extent (Gunathilaka and Herath, 2015; Ranil et al., 2025; Karalliyadda et al., 2020), little information is available on how traditional farmers apply their ethnobiological knowledge and experiential knowledge to minimize crop losses caused by wild animal attacks. However, two distinctive features of traditional *Chena* systems; the wooden fence and the watch hut—are specifically established to reduce damage caused by wild animals. An auspicious time, known as Divi Karana, is selected for the establishment of the fence; it is believed that the fence becomes imbued with the strength of a tiger, thereby protecting the crops from wild animals such as wild boar, rabbits, and deer (Karalliyadda et al., 2020). Watch huts are constructed in trees near the fences, offering farmers a clear view of their fields and surroundings while also providing safety from elephants. Farmers spend the nights in these huts, exchanging folk songs with those in neighboring huts and remaining vigilant to potential threats, particularly from elephants (Karalliyadda et al., 2020).

Farmers consistently strive to maintain a harmonious relationship with their surrounding environment. Before burning the land, they walk around the *Chena* making loud sounds to deter wild animals from the cultivation area. Some farmers set aside small plots of uncultivated land exclusively for wildlife. To reduce crop damage, farmers traditionally use techniques such as making noise, producing smoke, igniting firecrackers, and burning wood or twigs (Ranil et al., 2025; Bandara, 2006). Although some of these methods may appear simple or less effective under contemporary conditions, they represent the ecological knowledge and cultural wisdom of traditional farming communities. Recognizing their value, it is important to examine how selected traditional practices can be incorporated into the development of context-specific, innovative, and sustainable strategies for managing HWC.

4.4 Home garden system

Home gardens (HGs) are a predominant and long-established land-use system in many parts of Sri Lanka, likely second only to shifting cultivation in their historical origin (Pushpakumara et al., 2012). They serve as multifunctional and sustainable food production systems that incorporate various components, such as annual and perennial crops, livestock, and occasionally fish (Weerahewa et al., 2012). Besides meeting household food needs, HGs provide vital environmental services and create opportunities for employment and income generation (Fernando et al., 2016; Weerahewa et al., 2012).

Kandyan home gardens, in particular, showcase a variety of perennial food crops, fruits, vegetables, roots, tubers, medicinal plants, spices, and timber species, forming a complex, multi-layered, and risk-averse production system (Pushpakumara et al., 2012). However, their structural complexity and year-round food availability attract wild animals (Kumara, 2023). Species such as toque monkeys, wild boar, porcupines, and giant squirrels (*Ratufa macroura*) threaten these gardens by damaging crops at any time of the year, regardless of season. To address these ongoing problems, home garden managers employ a range of locally adapted practices learned from elders or developed through long-term experience. These ethnobiological practices include crop selection, spatial arrangement, physical deterrents, and behavioral adaptations aimed at minimizing wildlife damage. Such knowledge is crucial for understanding everyday human–wildlife interactions in home garden landscapes and offers valuable insights for developing culturally suitable and ecologically sensitive strategies to reduce HWC.

Additionally, locals protect their crops using physical barriers like barrel halves, protective covers around seedlings, and live *Gliricidia* fences. However, *Gliricidia* fences often prove ineffective, as porcupines feed on the roots and damage the root systems (Kumara, 2023). A survey by Rudran et al. (2021) shows that firecrackers are the most common tool used to scare monkeys. Some people also use air rifles and face masks (“wes muhuna”) as visual deterrents. To control damage from wild boar, farmers hang sarees and cover fields with white plastic sheets or metal mesh. Traditional methods include using nylon threads to cover cultivated land, spreading human hair waste around crops, removing kitchen waste from gardens, and fencing with *Gliricidia* or bamboo (Kumara, 2023). For flying squirrels and bats, hanging light bulbs in trees is common. During the durian season, when flying squirrel attacks are frequent, people hang bulbs to ward off these animals (Kumara, 2023).

Moreover, locals believe that the decline in fox populations—due to habitat loss and increased use of agrochemicals—has led to their concentration in remaining forests. With fewer foxes, wild boar populations have grown, causing more crop damage. To prevent pigs and other wild animals from entering, some cultivate sisal (*Agave sisalana*) around their gardens. Cultural and religious norms, such as the “kem krama”, are also used to control wildlife damage. For example, pirith-written papers—inscribed with verses and scriptures chanted by Lord Buddha—are hung on trees to protect crops. Some also sprinkle chanted water (pirith pan) around their gardens to deter animals. These ethnobiological practices—guarding, lighting fires, making noise—form an integrated system of crop protection aimed at safeguarding property, livelihoods, and lives while promoting coexistence with wildlife (Kumara, 2023).

In the dry zone of Sri Lanka, especially in the Eastern, Southern, North-western, and North Central Provinces, significant HWC occurs. Farmers rely on traditional methods to reduce elephant incursions, often combining multiple techniques and modifying them over time (Hoare, 1999; Perera, 2009). These methods include physical and biological barriers such as wooden fences, beehive fences, watch towers, and trenches (Enukwa, 2017). Farmers also use chili peppers and fire as deterrents, along with planting citrus trees to form bio-fences (Fernando et al., 2008; Sajla and Famees, 2022). Chili peppers act as irritants that cause elephants to cough and sneeze, discouraging them from entering crop fields.

Beehive fences, with hives suspended approximately 10 meters apart, are used to scare elephants by releasing bees when disturbed (King et al., 2017). These fences are mainly used around small plots in home gardens (Butler, 2016). Additionally, vegetable buffer zones with unpalatable or deterrent crops like Agave, bird chili (*Capsicum frutescens*), cacti, sunflower (*Helianthus annuus*), moringa (*Moringa oleifera*), lemon (*Citrus limon*), ginger (*Zingiber officinale*), mustard (*Brassica nigra*), or oilseed rape (*Brassica napus*), help protect crops. The strong smell from trampled mustard plants, in particular, repels elephants. Although these traditional methods are not well documented and their effectiveness varies, they warrant further investigation to explore potential integration with modern strategies for sustainable conflict management.

Kumara (2023) noted that damage and the population of toque monkeys have increased rapidly compared to other wild animals. Farmers have good knowledge of which crops are vulnerable to toque monkeys, and which are more resistant. Based on their personal experience, they prioritize growing the crops listed in Table 1 to reduce damage caused by toque monkeys.

4.5 Owita ecosystem

The *Owita* agroecosystem is a unique peri-urban land-use system characterized by distinct soil conditions and situated between lowland paddy fields and upland rubber, coconut, cinnamon, or mixed homegarden systems in the Wet Zone of Sri Lanka (Lansakara et al., 2023; Wijesekara and Hunter, 2010). According to Lansakara et al. (2023), wild animal damage is a major challenge for *Owita* farmers, especially from wild boar, rats, porcupines, and peacocks. *Owita* farming mainly relies on subsistence practices, with minimal use of modern technologies and agrochemicals. To address human-wildlife conflicts in the *Owita* system, farmers depend on ethnobiological knowledge passed down through generations and gained through personal experience.

Since paddy fields often border *Owita* fields, bird damage is significant, as paddy fields serve as ideal feeding grounds for birds. To reduce this, *Owita* farmers frequently hang white ribbons, such as polyethylene strips, and reflective objects like compact discs or aluminum plates within their fields. The movement and reflected light from these materials help reduce bird activity. Some farmers also cover vegetable crops with nylon fishing nets, especially to prevent damage from parrots. Additionally, the use of scarecrows is one of the oldest traditional methods to deter birds. Lansakara et al. (2023) report considerable damage to root and tuber crops caused by rats, wild boar, and porcupines. *Owita* lands are typically enclosed by fences and white polyethylene sheets to limit damage from wild boar and porcupines. However, controlling crop damage from large rodents remains challenging. As a result, some farmers resort to using poisonous chemicals, although this practice is generally discouraged due to its environmental and social impacts.

Table 1: Species less susceptible to toque monkey damage.

Species	Common name	Reasons
Capsicum annuum L.	*Miris*	High pungency
Citrus species	*Dehi*	Spines, unique citrus smell of fruits and leaves
Curcuma longa L.	*Kaha*	Pungency and smell
Raphanus raphanistrum subsp. *sativus*	*Rabu*	Unique smell
Solanum insanum L.	*Ela-batu*	Spines, Pubescence in leaves
Solanum torvum Sw.	*Tibbatu*	Spines, Pubescence in leaves
Syzygium samarangense (Blume) Merr. & L.M.Perry	*Jambu*	Dark and shiny red colour fruits
Zingiber officinale Roscoe	*Inguru*	Pungency and smell

Source: Kumara (2023)

Since *Owita* is a subsistence-based farming system, farmers continue to use a variety of traditional methods inherited from elders to minimize crop damage caused by wild animals. While some of these practices are less effective under changing ecological conditions, they are maintained because they cause minimal environmental harm and pose little immediate threat to wildlife. Nonetheless, many traditional practices are gradually disappearing due to shifts in cultivation methods, the adoption of modern strategies, and broader socio-economic changes. Therefore, it is crucial to systematically collect and document these practices to preserve local knowledge systems and support sustainable, community-based human-wildlife conflict mitigation strategies before they are lost from the traditional farmers' knowledge base.

4.6 Coconut plantation

Coconut is one of Sri Lanka's main crops, playing a vital role in the country's economy and supporting rural communities. However, the sector faces increasing challenges from extensive damage caused by wild animals such as toque monkeys, porcupines, wild boar, giant squirrels, and flying squirrels, with toque monkeys responsible for the worst losses. A survey by researchers at the Hector Kobbekaduwa Agrarian Research and Training Institute found that Sri Lanka loses roughly 107 million coconuts each year due to damage by toque monkeys and squirrels (Nizam, 2022), highlighting the scale of the problem faced by coconut farmers.

Many farmers continue to rely on traditional practices they have developed and adapted over time. During early cultivation stages, coconut seedlings are very vulnerable to damage from wild boar and porcupines. To protect young plants, farmers often place large rocks around the base to shield the roots from porcupine damage. Additionally, they sometimes spread human hair collected from barbershops around seedlings to deter wild boar, while cow dung is applied to the leaves to prevent browsing by deer and cattle.

Traditional methods to reduce damage caused by toque monkeys and purple-faced langurs are generally limited in effectiveness and remain mostly undocumented. However, field observations suggest that in some coconut-growing regions, farmers use various practical strategies such as firecrackers, noise-making devices, mirrors to reflect light, high-intensity light beams, and face masks ("*wes muna*") to deter monkeys and protect their crops. Some farmers also continue to use commonly practiced but potentially harmful methods like air rifles. While these approaches demonstrate farmers' adaptive responses to HWC, their inconsistent success and possible ecological and ethical concerns underscore the need to systematically document, evaluate, and incorporate effective traditional practices into more sustainable and non-lethal wildlife management strategies.

6. Way Forward

Today, HWC is a major issue for farming systems and one of the most urgent challenges for sustainable development worldwide (Braczkowski et al., 2023; Green et al., 2024). Despite the creation and implementation of many measures, they have limitations, and most rely on isolated or single-method approaches rather than integrated, system-based solutions. Traditional practices, developed over generations, remain underrecognized and underused in modern HWC management. While governments, academics, and communities are increasingly calling for the acknowledgment of culture in social–ecological systems and for better use of Indigenous knowledge in research, policy, and management, their actual use remains limited (Fisk et al., 2024). Because of its importance today, Indigenous knowledge has also been recognized in the United Nations' Sustainable Development Goals.

The rich diversity of agricultural ecosystems, combined with ethnobiological knowledge, is a valuable resource for tropical countries. In nations like Sri Lanka, strong partnerships with leading international academic and research institutions are crucial to document, evaluate, and preserve this highly vulnerable yet largely untapped knowledge hub in Asia (Ranil et al., 2025). Despite advances in modern agricultural technologies, traditional knowledge systems have often been marginalized and overlooked. Today, these unique Indigenous insights face rising risks due to environmental changes, population pressures, and rapid socio-economic development (Ford et al., 2020; Mdhluli et al., 2021). Since the transmission of this knowledge mainly depends on oral tradition, it is especially vulnerable to extinction. Therefore, it is urgent to systematically document and protect ethnobiological knowledge among diverse farming communities across the island.

Although farmers use both modern and traditional control methods, no single approach has been fully effective in preventing wildlife-related crop damage. However, many farmers depend on locally developed practices based on personal experience or passed down from elders to tackle this ongoing challenge. Such ethnobiological knowledge offers vital insights into the realities of HWC and helps develop context-specific mitigation strategies against damage from wild animals. Hence, it is important to collect, document, critically evaluate, and utilize traditional knowledge related to wildlife damage, with the goal of creating more effective, culturally suitable, and sustainable mitigation strategies. Combining traditional methods with modern scientific knowledge can be a powerful tool for managing wild animal damage in complex agroecosystems, including Kandyan home garden systems.

Furthermore, integrating this unique knowledge with modern technology is crucial for its effective use. Despite major advancements, little is known about how new technological devices, gadgets, and applications are used in managing HWC. Still, these digital tools and platforms hold promising opportunities for monitoring wildlife movement and giving communities early warnings about potential conflicts (Mwonzora and Mwonzora, 2024). Blending traditional wisdom with modern farming practices is therefore key, not only to reduce crop damage by wildlife but also to conserve and sustainably use this priceless cultural and ecological heritage.

Conflict of Interest

Authors have declared that no competing interests exist.

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Chapter 05

Economic Implications and Policy Responses for Human–Wildlife Conflicts in Sri Lanka

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Abstract: Human–wildlife conflict (HWC) has become one of the most pressing socio-economic and ecological challenges in Sri Lanka, with rising incidents of crop losses, livestock predation, property destruction, and human casualties. The chapter documents the scale, distribution, and economic burden of these conflicts, presents the policy response and highlights policy gaps. Despite long-standing cultural and ecological significance of wildlife, particularly elephants, escalating encounters expose persistent failures in land-use planning, habitat management, compensation mechanisms and inter-agency coordination. Current mitigation attempts range from community-led deterrents and guarding practices to government investment in electric fencing, compensation schemes, agricultural insurance and translocation. They, however, remain insufficient, inconsistent or unsustainable as many interventions suffer from implementation gaps, weak monitoring systems, inadequate coverage across species, delays in payments etc. Donor-funded projects and NGO-led pilots have introduced alternative approaches such as private insurance models and community-managed fences, yet these remain small-scale and poorly integrated into national policy. The chapter highlights the need for a holistic, evidence-based and multi-stakeholder policy framework that addresses root causes such as habitat fragmentation, unregulated land expansion and poor coordination. Strengthening data systems, developing inclusive compensation and insurance schemes, enhancing community participation, protecting wildlife corridors and embedding HWC considerations into national development planning are essential steps toward reducing the economic burden of HWC and promoting long-term human–wildlife coexistence in Sri Lanka.

Keywords: Agricultural insurance, community-based approaches, crop damage, livestock predation, mitigation strategies

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1. Introduction

Human–wildlife conflict (HWC) has emerged as a serious challenge worldwide, threatening both rural livelihoods and wildlife conservation. It broadly refers to situations where the needs and behaviors of wildlife clash with those of humans, resulting in negative outcomes for both parties. The severity of this issue has drastically grown because the human populations expand into wildlife habitats, causing incidents of crop raids, property damage, and casualties due to wildlife attacks on villages to increase. Climate change is further exacerbating these conflicts by altering the distribution of species and availability of resources (Gayo, 2025). As a result, incidents of crop raiding, livestock predation, and attacks in humans are on the rise, especially in tropical developing countries, where dense human populations live alongside rich biodiversity (Anuruddha et al., 2025).

Recent trends underscore the growing scale and cost of HWC worldwide. Ma et al. (2024) project that by 2070, human populations will overlap with wildlife across 56.6% while decreasing only across 11.8% earths land area which shows an expansion of conflict hotspot in the absence of intervention. Already thousands of HWC incidents where elephants and other herbivores routinely raid farmers' fields while carnivores' prey on livestock are reported annually from Asia, and Africa. According to Gunawansa et al. (2023), in south Asia, conflict with elephants is particularly a significant concern as more than 600 people and 450 elephants are killed each year during crop raiding encounters. It is also noteworthy to highlight that around 80% of these fatalities are from India and Sri Lanka. In Sri Lanka, annual reported human casualty cases are around 125 on average which is a value that far exceeds historical levels (Gunawansa et al., 2023). These rising casualties now give Sri Lanka the distinction of being one of the countries with worst human elephant conflicts globally. A particularly alarming aspect of this tragedy is that most of those who are killed or injured are from the working age rural community which results in loss of income and stability. For many families, such incidents can single-handedly push households into long-term poverty (Prakash et al., 2020).

Although casualties are the most tragic losses to families, crop raids by wildlife also play a significant role in disrupting rural livelihoods. The National Agriculture Information Call Centre of the Department of Agriculture has reported a substantial increase in farmer complaints of crop loss due to wild animal attacks in recent years. An ongoing report by the Hector Kobbekaduwa Agrarian Research and Training Institute on Damage caused to food crops by wild animal's states that the most affected crop is coconut, followed by paddy, vegetables, corn and bananas. While Asian elephant tops the reasons for wildlife attack casualties, toque macaque tops the list of crop raiders, followed by wild boars. Asian elephant, Indian peafowl, giant squirrel and Indian porcupine also play a significant role in crop loss. This situation not only represents the biodiversity issue behind it, but also a tragic socio-economic crisis for rural communities.

Impacts of HWC not only place a substantial burden on rural farming households through direct costs due to crop loss and human casualties, but these negative impacts bleed the national economy as well (Gunawansa, et al., 2023). These conflicts directly affect the agriculture sector through reducing crop output. These losses of crop ripple into food prices, while spending public funds on mitigation and compensation deter investment in rural communities undermining broader development goals (Sherchan et al., 2022). Therefore, recent escalation of the severity of Sri Lanka's HWC calls for a critical review of country's policy framework and mitigation strategies.

For generations, many wildlife species, especially elephants, have held a unique cultural and ecological significance in Sri Lanka. However, in recent decades, the growing tension between humans and wildlife reveals long standing failures in land use planning, natural resource management and response to conflicts. This chapter examines the HWC in an economic and policy-oriented lens, with a focus on agricultural policy measures and governance structures. However, to understand the gaps in the current policy solutions, first the scale and the economic impact should be accurately quantified. Therefore, the first section of the chapter will present the estimates on the economic loss and thereafter the existing management efforts by communities, government and other stakeholders and their shortcomings will be documented. The final section will focus on policy gaps, evidence-based recommendations shaped by both local and cross-country experiences to promote human wildlife coexistence.

2. Quantifying the Conflict

The economic impact of HWC is both direct and indirect (Sampson et al., 2021). Direct impact is narrowed down to physical and economics impact on rural communities, while indirectly these conflicts lead to boarder social impact on the people and society (Nyumba et al., 2020). As stated by Sampson et al. (2021), these indirect costs play an important role in how local people experience and judge the severity of the conflict.

Wildlife causes direct tangible economic damage in agricultural areas by crop destruction, killed or injured livestock, property damage and human casualties. According to an early study conducted by Bandara and Tisdell (2004), the total annual economic losses due to elephant property and crop damage alone stand substantial at a value of 561 million LKR per cropping season and 1121 million LKR per annum. Furthermore, Perera (2009) reports that every year around 150 elephants and 50-70 humans die because of human elephant conflicts. By 2010 this has escalated to a value where a local farmer in human elephant conflict affected areas is estimated to lose over 200 USD annually due to crop destruction (Santiapillai et al., 2010). However, this figure does not include other destructive wild species such as wild boars and toque macaque that inflict far more frequent and intense crop losses than elephants (Anuruddha et al., 2025). Compared to the situation in 2009, the recent data shows that the human casualty rate has increased by approximately 42% in the previous three decades. Given that, by 2019, human casualties due to human elephant conflicts have risen to an average of 125 per year (Gunawansa et al., 2023).

2.1 Agricultural losses

At the household level, HWC is one of the most immediate impacts and results in crop loss, which directly affects farmers' income and rural food security negatively. For instance, a single night raid by an elephant herd can wipe out an entire season's harvest of paddy causing, farming families to go into depths of poverty (Gunawardhana and Herath, 2018). According to preliminary estimates of crop damage caused by wildlife compiled by the Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI), coconut is the most severely affected crop, followed by paddy, vegetables, corn and bananas. The report further identifies that elephants, wild boars and peafowls cause the worst damage to paddy while toque macaques and giant squirrels target coconuts. Young coconut plants and vegetables are damaged by porcupines. The report further estimated that in the first half of 2022, wild animal raids destroyed around 144,989 tons of crops nationwide. Moreover, it reported that the financial loss caused by this crop damage is as massive as LKR 30,215 million.

At present, crop raiding occurs in all 25 districts of Sri Lanka. Crop raids are heavily dependent on the types of crops grown, distance to the village from the forest, availability of natural foods, and the methods of crop guarding (Nahallage, 2022). Although most wild animals raid crops throughout the year, their activities are intensified during certain months. A study conducted by Jayarathe et al. (2025) states that the peak macaque–human conflict is during the rainy season from July to September in Kurunegala district. On the contrary, the damage is less during the dry season. However, in the case of coconuts, dry season showed higher rates of damage, likely due to absence of other crops. HARTI (2021) reports that nearly 100 million coconuts are destroyed by monkeys and squirrels each year, resulting in an economic loss of around LKR 6,638 million. As macaque's raids variety of other crops as well, the total economic losses incurred by farmers account for around 4% of their average monthly income.

Elephants on the other hand, target a variety of nutritious crops like sugarcane, paddy, pineapple and bananas (Gunawansa et al. 2023). Similar to that of macaques, elephants' raiding behavior is also intensified during certain periods of the year. Paddy fields are mostly vulnerable to elephant raids during January, when the grains reach the maturity stage. They continue to target these paddy fields until the harvesting season is completed. Mango trees are commonly targeted during their fruiting season, starting from May to June and again from November to December. Perennial crops like jackfruit and coconuts become vulnerable to elephant raids when seasonal crops are unavailable along their usual raiding routes (Bandara and Tisdell 2004). Banana on the other hand continues to be targeted throughout its life cycle (Santiapillai et al., 2010). Gunawansa et al. (2023), state that the total economic loss incurred by a typical Sri Lankan farmer in elephant-affected areas is estimated to be around 200 USD annually. Given that, it is evident that including macaques and elephants, most wild animals raid crops predominantly target crops during the latter stages of their growth cycle. By this time, crops have already consumed most of the resources such as water, fertilizer, and labor. As a result, any damage inflicted at this stage directly translates to reduction in harvest and complete loss of resources invested throughout the cultivation period. Such losses undermine national food security and threaten the continued agricultural activities in high-risk areas, which result in a direct negative impact on poverty levels and sustainability of rural farming households.

2.2 Livestock losses

Compared to crop losses, livestock losses because of wildlife attacks are comparatively less reported in Sri Lankan. However, several cases of Sri Lankan leopard and jackal attacks on livestock were reported near margins of forest areas and upland tea estates (Anuruddha et al., 2025; Uduman et al., 2022). Uduman et al. (2022), further highlight that, even though the number of livestock lost to leopard predation is relatively low, its impact on economically vulnerable rural communities is substantial. For a household that relies on cattle or any other livestock rearing activity as their primary source of income, even a minimal loss can cause a significant financial challenge.

2.3 Property and infrastructure losses

Incidents of property damage due to HWCs have drastically increased between 1991 and 2021. The species involved in property and infrastructure damage are mainly elephants, macaques and buffaloes (Anuruddha et al., 2025; Rathnayake et al., 2022). Rathnayake et al. (2022) have further highlighted that there have been more than 23,000 property damage incidents reported during this period from elephant attacks alone.

Toque macaques cause the most infrastructure damage by entering houses and damaging household furniture, roofs, utensils and consuming food that is inside the houses (Nahallage et al., 2022). Additionally, damage to public infrastructure such as water pipes, electric and telephone wires were also reported frequently (Cabral et al., 2018). Jayarathne et al. (2025) have estimated that property damage per household averaged between LKR 850–4,000 LKR per month in Kurunegala district households.

Highest number of cases of property damage due to elephant attacks were reported in Polonnaruwa, followed by Ampara, Badulla, Moneragala and Anuradhapura (Gunawansa., 2023). Galappaththi et al. (2020), have mentioned that the extent of damage caused by elephants varies depending on whether the dwelling is permanent or temporary. These dwellings are more vulnerable to these attacks when paddy and salt are stored inside houses. When elephants with keen sense of smell detect these scents, they knock down the walls to feed on them (Gunawansa et al., 2023). It has been estimated that an average person bears a loss of approximately 30,000 LKR annually due to property losses (Center for Environmental Justice, 2024).

2.4 Indirect costs

Indirect costs of HWC are less tangible when compared to direct costs. However, they are equally significant in their socio–economic consequences (Santiapillai et al., 2010). These costs include disruption of livelihoods, communal interactions and routine daily activities due to heightened fear of attacks. Fear of injuries and casualties can severely limit individuals' activities such as collecting firewood, wild fruits particularly among women and children who often undertake these tasks (Dharmaratne and Magedaragamage, 2014).

Beyond the broader socio-psychological impacts, HWCs also divert household resources such as labor and time towards uncompensated activities such as protective measures including guarding of crops (Sampson et al., 2021). During most vulnerable periods, farmers often dedicate both day and night hours to guarding crops leading to sleep deprivation and physical exhaustion. Furthermore, this reduces opportunities for income generating activities, particularly off-farm employment and imposes psychological strain (Parker et al., 2007). Opportunity cost of these mitigation efforts though not typically compensated or accounted for in formal assessments represents a significant economic burden on rural households. However, these can be assessed in terms of income forgone due to the commitment to dealing with the threat of wildlife (Woodroffe et al., 2005). Dharmaratne and Magedaragamage (2014) have identified that these costs can be calculated as a percentage loss of annual income.

3. Mitigation Efforts

The governmental agencies and local communities in Sri Lanka employ a broad range of HWC mitigation measures to protect both the livelihoods of rural framers and biodiversity in highly vulnerable areas. These interventions include both short term defensive actions, damage and loss compensation as well as long-term policy interventions that promote coexistence models. However, the success rates of these strategies are yet to be quantified. This section will draw further into current community-led mitigation efforts and compensation strategies employed by the governmental and private agencies.

3.1 Community and farmer led strategies

Local communities employ a variety of traditional low-cost methods to protect crops and property from wildlife. Although all these strategies safeguard crops and human life from wildlife attacks, some threaten biodiversity, especially the lives of elephants. Many of these community-led strategies rely on limiting wildlife movement into agricultural land through physical and behavioral deterrents. Villagers impose barriers by digging trenches and erecting simple wooden or beehive fences to physically block entry of wild animals. Often these 3 m deep, 2-3 m wide trenches are dug along settlement perimeters. Additionally, farmers stations watch towers or night guards, light fields at night and chase animals by banging on tins or drums to scare wild animals and keep them away from crop fields (Gunawansa et al., 2023).

Trench excavation has often been proposed as an effective measure to divert wild animals particularly elephants from entering agricultural lands and human settlements (Davies et al., 2011; Gunawansa et al., 2023, Nelson et al., 2003). However, this strategy shows potential only in the short run as economic and practical drawbacks become significant in the long run. Due to trenches imposing rigid boundaries that limit how adjacent lands can be accessed, rural communities who rely on maximizing agricultural land use, face a tangible loss in productivity. The opportunity cost of land use is further exacerbated as the land occupied by the trench itself becomes unproductive (Gunawansa et al., 2023; Nelson et al., 2003). Moreover, trench construction and maintenance are capital and labor intensive especially in large scale (Shaffer et al., 2019; Zhang and Wang, 2003). On the other hand, the large wildlife species, particularly elephants, possess the ability to use their body weight to collapse the trenches resulting in a waste of resources employed in constructing the trenches (Gunawansa et al., 2023).

Similarly, acoustic deterrents have demonstrated promising results in efficiently directing wild animals away from agricultural lands (Zhang and Wang, 2003). However, the sustainability and long-term effectiveness of these types of deterrents are not satisfactory (Nelson et al., 2003). Use of light-based deterrents to chase away the wild animals from agricultural lands tends to be relatively inexpensive when compared to most of the other measures. However, this approach becomes labor intensive as it requires controlling the spread of the fire to prevent it from reaching the cultivated lands (Enukwa, 2017). In contrast to these labor intensive and economically costly methods, agriculture-based deterrents provide economic benefits to farmers. By implementing intercropping or alternative cropping of less attractive or palatable crops, farmers can compensate for the reduced cultivation of main crops leading to an increased income (Shaffer et al., 2019). Similarly, beehive fences, especially used to scare away elephants are simple, inexpensive as well as profitable (Gunawansa et al., 2023). However, in Sri Lanka, this method is not widely adopted and is limited to small areas of crops in home gardens.

These community led measures provide immediate relief at the local scale while fostering coexistence. However, as these grassroot strategies only protect limited areas and tend to be labor intensive, in long run, they alone can't fully address the persistent HWC in rural areas. For these strategies to succeed and sustain the effects, a combined multiple approach should be implemented while integrating outside support.

3.2 Government led interventions

The Sri Lankan government plays a central role in mitigation through policy, infrastructure and financial mechanisms. Constructing electric fences along village perimeters and park borders to separate humans and wildlife is a primary strategy implemented by the government to reduce the occurrence of conflicts.

When strategically located and well implemented, electric fences are considered to be the most effective HWC mitigation measure (Gunaratne and Premarathne 2006). According to Fernando et al. (2025), the material costs of a seasonal electric fence using high-quality materials is about 1500 USD. Additionally, USD 1,000 per km of fence length for wire, posts etc. The cost per acre varies widely with fence length and geometry. Gunawansa, (2023) states that Sri Lanka has spent 2.74 million USD constructing electric fences during the period of 2019 to 2020. This corresponds to roughly490 million LKR as reported by the parliamentary accounts committee (Committee on Public Accounts, 2021). This cost was spent on constructing electric fence of 4756km. The Climate Smart Irrigated Agriculture Project (CSIAP) implemented by the Ministry of Agriculture and funded by the World Bank teamed up with the Center for Conservation and Research in 2022 to install mobile elephant electric fences or seasonal electric fences that are entirely powered by solar energy in 8 districts including Anuradhapura, Kurunegala, and Puttalam. These fences can be deployed by farmers at the beginning of the cultivation and removed and stored after harvest. The estimated budget for this is around 475 million for fences of 1109.3km (Ministry of Agriculture, 2022; Department of Agrarian Development, 2022). However, despite these extreme costs, in the areas where fences were erected still large wild animals particularly elephants break these by kicking fence posts or by pulling or pushing them with the truck. Therefore, even in fenced areas, still significant numbers of human deaths are reported while the extent of crop damage remaining unquantified indicating that fencing alone is not foolproof (Fernando et al., 2020; Gunawansa, 2023).

In parallel, the government administers compensation schemes to offset losses from human wildlife incidents. The Department of Wildlife Conservation (DWC) currently administered a compensation scheme for human-elephant conflicts covering cases of death, injury, and property damage. This scheme provides a maximum of 1,000,000 LKR in case of human death and lesser for injury. Between 2011 and 2018, the government disbursed 0.76 million USD as compensation for human fatalities and 0.05 million USD for injuries caused by elephants. Additionally, 1.7 million USD has been paid as compensation for property damage during the period (Center for Environmental Justice, 2024). However, according to Köpke (2023), field level interviews across several households' report receiving little to no compensation after suffering from repeated damages on property and crop. Some complained that they had not received any compensation while some stated that the compensation values were not sufficient to repair the damage.

Additionally, the Center for Environmental Justice's proposal to mitigate the human elephant conflict In Sri Lanka, states that while there have been efforts by DWC to initiate compensation and insurance for crop losses, these initiatives have not proven to be largely successful. This is contradictory to the fact that Sri Lanka has an existing agricultural insurance scheme that covers crop damages. According to data collected by the DWC, in 2022 approximately 4 million LKR were provided as compensation due to wild elephant damage in Vavuniya district for only paddy cultivation. It is also important to note that these agricultural insurance schemes provide coverage for crop losses caused not only by elephants but also by other wild animals. On the contrary, the compensation scheme for injuries, deaths and property damage is only limited to elephant attacks. This creates a gap in perceived and actual coverage that contributes to public dissatisfaction.

Table 1. Compensation paid by Department of Wildlife Conservation

Year	Amount Paid for Death	Amount Paid for Physical Damages	Amount Paid for Property Damages	Total Amount Paid for Compensation
2021	33.20	1.22	40.36	74.78
2022	90.55	9.49	88.16	188.20
2023	154.49	23.34	187.25	365.01

Source: DWC annual performance report

As Prakash et al. (2020) have emphasized, the loss of lives and injuries of the economically active individual of a household not only cause immediate personal tragedy but also drags the entire families deeper into poverty. This is because the death of the primary income provider undermines the household's ability to generate income and meet basic human needs. In addition, the damage caused by wildlife on housing further exacerbates this vulnerability by destroying the roof above their heads, increasing the financial burden on the families.

Another major governmental initiative is the provision of agricultural insurance for rural farmers, which includes coverage for a list of wild animals' damage. Sri Lanka has one of the longest running crop insurance programs in the region. Currently the Agricultural and Agrarian Insurance Board (AAIB) administers formal crop insurance program covering a range of crops including key field crops, plantation and horticultural crops that are cultivated by rural farmers on a large scale. Under the compulsory crop insurance program, farmers are provided with baseline government funded coverage of 40,000 LKR per acre for staple crops such as paddy, maize, potato, soybean, chili and onion against flood, drought and wild elephant damage. With an additional premium of 800 LKR per acre, farmers extend their insurance coverage beyond wild elephant damage to include damages caused by other wild animals as well. Moreover, recognizing the risk of increased cost of cultivation, the AAIB gives the farmer a choice to purchase an additional top-up of 100,00 LKR with a premium of 6400 LKR per acre which provides an "all-risk" coverage. If a farmer wishes to ensure their cultivation land for more than 100,000 LKR per acre, an enhanced "all-risk" option has been introduced by the government effective from 2022/23 Maha season. To get this coverage, a farmer needs to pay a premium of 6.4% for coverage up to 100,000 LKR and for any amount exceeding the 100,000 LKR an additional 9% premium will be charged.

Table 2. Compulsory crop insurance scheme

Nature of Insurance	Risk Coverage	Insurance Premium
40,000 LKR/acre	Floods Droughts Wild elephants	Government Insurance Contribution Insect Damage – 200 LKR Diseases – 200 LKR Fire – 200 LKR Other Wild Animals – 800 LKR
100,000 LKR/acre	All risks	6.4% = 6400 LKR
>100,000 LKR/acre	All risks	Up to 100,000 – 6.4% >100,000 – 9%

Source: AAIB

Other than compulsory crop insurance, AAIB administers several other crop insurances. However, unlike the compulsory crop insurance scheme, which is government funded, these schemes operate on contributory basis where farmers are responsible for paying the full premium. The yams and vegetables insurance schemes require a 7% insurance premium from the sum insured per acre and cover natural calamities, diseases, pests, insects and wild elephant damage. Under this crop insurance scheme, insurance is provided for sweet potato, cassava, tannia, beet, cabbage, carrot, leeks, red onion, brinjal, bean, capsicum, tomato, bitter guard and pumpkin like crops which are most commonly grown in Sri Lanka. This insurance scheme is applicable to lands that are minimum of ¼ acre or more for each crop. Additionally, by paying an extra 1% premium, the coverage can be extended beyond wild elephants to other wild animal damages as well. Similar to the yams and vegetable insurance scheme, field crop insurance schemes are also provided at a flat premium rate of 7% and to extend the coverage beyond wild elephant damage and extra premium of 1% should be paid. Crops such as black-gram, green-gram, black-eyed pea, ground nut, sesame, finger millets and horse gram are covered under this scheme. Other crops such as ginger, turmeric, cinnamon, pepper, pineapple, papaya and banana are also insured under schemes that have similar premium rates. However, the maximum sum assured per acre depends on the crop type and ranges from 30,000 LKR per acre for crops like black gram to 700,000 LKR per acre for turmeric.

The effectiveness of agricultural insurance however has been limited in practice. Only a small fraction of total cultivated area is actually covered by crop insurance. Even when farmers are covered, payouts have often been delayed or insufficient similar to the DWC compensation for HWC which has led to many farmers in high conflict areas perceive the insurance scheme as unreliable. These shortcomings will be examined further in the next section on policy gaps. Nevertheless, the establishment of insurance schemes reflects an important policy approach as it focuses on shifting from purely reactive conflict mitigation to proactive risk sharing.

Other than attempting compensation and risk sharing, the government also attempted various other initiatives such as elephant drives and translocations and deploying civil defense forces in some regions to assist farmers in crop protection patrols at night to chase away elephants. Translocation and drives, however, were proven to be unsuccessful as wild animals frequently return to their original areas or cause conflicts elsewhere. Also, the stress of capture led to mortality of wildlife, especially elephants which negatively affect biodiversity. On policy front, a National Action Plan specifically for Human Elephant Mitigation was developed in 2020 by the presidential committee where they recommended community-based coexistence strategies like habitat enrichment outside parks and ending counterproductive practices such as elephant drives. However, the plan's implementation and continuity were halted with the change in administration. Many of the governmental recommendations and initiatives remain only partially fulfilled, which highlights the challenge of sustaining political will and coordination when attempting to mitigate HWC through governmental interventions.

3.3 Donor funded projects and NGO initiatives

International donors and non-governmental organizations have supplemented Sri Lanka's HWC management through funding and pilot projects. According to Holt and Steele (2019), one notable project was UK government's Darwin funded "LIFE" (Livelihoods Insurance from Elephants) initiative which linked Sri Lanka, Kenya and Malaysia to design innovative insurance schemes for human elephant conflicts. It was devised by Kenya's AB consultants, the Institute of Policy Studies of Sri Lanka (IPS), and International Institute for Environment and Development (IIED). Under this initiative SANASA Life insurance Company offered insurance against elephant damage. This project aimed at providing a private scheme that includes new and additional insurance coverage alongside the existing government scheme. Although ideally the full premium should be paid by the insured farmer, the project incorporated co funding from additional sources to finance part of the premium for the initial period of the scheme. In Sri Lanka as the scheme did not benefit strongly from the government, the IPS engaged with the World bank to pay the premiums to the insurance provider, SANASA Life Insurance Company during the first year of the initiative. As IPS team failed to secure funding from the world bank, they turned to United Nations Development Program. Finally, when the pilot was implemented, 50% of the premium was paid by the famer while the remaining half was covered by the World bank funded Ecosystem Conservation and Management Project (ESCAMP).

This pilot insurance scheme targeted 250 households from Anuradhapura and another 250 households from Kurunegala districts. Crop loss, fatalities, property (grain storage) loss and hospitalization cost caused by injuries are covered by this scheme. Additionally, the damages incurred by community managed electric fences due to elephant attacks were also added to the coverage per the request of ESCAMP. The farmers would get a maximum of 30,000 LKR for crop loss and 1000 LKR per day for maximum of 10 days when the insured is hospitalized due to elephant attacks. Moreover, a farmer would get compensation of 30,000 LKR for damages done to their grain storage units as well. similar as well as for damages done to the farmers grain storage units. According to IPS to get these benefits a farmer should pay a premium of 2410 LKR per year. However, the IIED (2022), reported this value as 3253 LKR (16 USD) per year. This discrepancy could be due to the updates made during the implementation phase or differences in exchange rates. This premium has been designed in a way that it is less than 2% of a famers income as Sri Lanka was recovering from an economic crisis during that time. The premium for community managed electric fence is 30,000 LKR/ per year and may change according to the length of the fence. In the event of an elephant attack, the farming community would receive a maximum of 300,000 LKR as compensation for any damage caused to the fence. Although this was an initiative with potential, information on its progress after 2023 is not documented. However, the SANASA Insurance Company still continue an indemnity based comprehensive crop insurance scheme that continues to provide assurance for many rural farmers.

4. Policy gaps and Recommendations

As a result of Sri Lanka's current policy framework remaining inadequate to meet the complexity of the problem, despite the extensive efforts of governmental, non-governmental agencies and farmers, the issue of HWCs persists. Several critical gaps and needs can be identified in the existing regulations, programs and resource allocations that collectively prevents the effective mitigation of HWCs in Sri Lanka (Dela et al., 2018).

A fundamental issue is the lack of a holistic, coordinated strategy to address the issue. For years, in Sri Lanka, different governmental organizations and non-governmental agenesis have split their responsibilities on HWC mitigation with minimal coordination. Indian government who faced the same issue have considered integrating HWC mitigation into overall development planning through establishing state level coordination committees in each state in their action plan for 2021 to 2026 to solve this issue (MOEF, 2021). They have understood that without a unified approach, each effort often clashes leaving the vulnerable and affected communities caught in the middle (Fernando, 2015). Furthermore, this resulted in ad hoc measures that often focused on a single species, particularly elephants, rather than the broader wildlife community that interacts with rural households.

The broader forces driving conflicts such as poor land use planning, habitat loss and encroachment of agriculture into wildlife habitats remain largely unaddressed in policy. For instance, expanding farms and settlements near forests makes people and wildlife almost inevitably drawn into more frequent contact. However up until now, Sri Lanka lacks strong land use regulations or wildlife corridors to buffer the human wildlife boundaries. Dahal et al. (2025) have reported similar issues in Nepal where the rapid agricultural expansion around protected areas has fragmented the wildlife habitats. The study identifies that the inadequate resource management policies exacerbate human wildlife interactions. Sri Lanka faces many of the same pressure and is in urgent need of policies that balance both development and conservation so that conflicts can be prevented rather than just reacting to the aftermath of the conflicts. Furthermore, in Sri Lanka, the sudden administrative changes in the past years have put a hold to many of the actions taken by different governments resulting waste of resources. This lack of interagency accountability should be addressed through a centralized HWC coordination mechanism like a national task force or dedicated agency with clear responsibilities shared across ministries that function both at national and district level. Such a structure would bring everyone working on HWC mitigation under one umbrella, ensuring that decisions are not made in isolation.

Another major shortfall is the lack of reliable, island wide data and monitoring. Sri Lanka does not maintain a comprehensive database of conflict incidents or losses from wildlife species other than elephants. Without this information, it is difficult to take evidence-based decisions and restrict optimum allocation of resources. In contrast, some counties have taken the initiative to map conflict hotspots using special data which allows them to target interventions where both wildlife and humans are highly vulnerable to conflicts (Pavithra et al., 2025). A relatively similar approach has been used by a study conducted in Nuwara Eliya area in Sri Lanka to identify risk zones near habitat edges which has made conflict prevention more strategic and successful in those areas (Anuruddha et al., 2025). However small-scale studies are not going to solve the HWC issues in Sri Lanka. India in their action plan for 2021 – 2026 discuss about using standardized data collection parameters and methods across states so that results can be compared across states and landscapes overtime. Furthermore, they discuss establishing a HWC mitigation database hosted on web-based platform which supports visualization of HWC hotspots and other information (MOEF, 2021). The government of Sri Lanka should also actively fund in such data collection, damage quantification and monitoring programs to effectively prevent the issue rather than working on compensation after the incidents occur. Investing in digital, GIS enables HWC monitoring system which allow real time reporting through mobile applications would ensure faster responses and more accurate data which can be used into developing effective targeted policies. Furthermore, this information should be made into annual reports summarizing national HWC trends. Making these reports publicly available will increase transparency as well as accountability.

Present compensation and relief schemes predominantly cover elephant related property damages, casualties and crop raids. Similar losses caused by other wildlife species are seldom compensated. This narrow focus concerns other wildlife species such as peafowls, macaque monkeys and wild boars also cause significant losses to crop and property leaving the affected households without compensation most of the time. In contrast, countries like Kenya through LIFE project included coverage for large cats as well as elephants (IIED, 2022). However Sri Lanka's policies have yet to evolve this way, which highlights the need for an inclusive compensation policy that integrates multiple species. The agricultural Insurance for wildlife damages on crops, although technically available through AAIB, remains underutilized due to low awareness, high premium rates for adequate coverage levels, and long delays in claim verification and payments. Furthermore, the payments do not cover the full extent of loss while most of the time it fails to reflect market prices. As a result, many farmers consider crop insurance as a bureaucratic formality than a dependable protection against crop losses which has led to wide distrust and weak enrollment rates among farmers in vulnerable regions.

Similar problems have been observed by Dahal et al. (2025) in Nepal's Tarai region, where they state that over 90% of villagers believe the compensation system to be corrupted and unreliable. The study suggests establishing a simplified, transparent and decentralized claim verification process as the current bureaucratic and inconsistent system causes long delays in compensation. The hidden costs due to bureaucratic inefficiencies such as stress, lost time and opportunity costs are often overlooked by the policy makers. However, without well designed compensation mechanism, even well intended policies can fail to provide timely support to victims pushing them towards long term poverty. Furthermore, to improve trust in compensation programs, Sri Lanka's authorities could conduct audits of HWC compensation and publish the reports on public platforms which will also reduce corruption and favoritism.

The community based grassroot initiatives such as crop protection fences and alternative cropping are often led by the community or NGOs without formal governmental support. Therefore, these measures are not replicated at scale or integrated into national policy structure. The government should collaborate with communities to develop region specific HWC management techniques such as early warning systems for areas prone to elephant crop raiding or novel deterrents such as beehive fences which have shown success in Africa (King, 2024). Anuruddha et al. (2025), has identified that farmers in Nuwara Eliya already improvise methods like natural fences and active guarding with various success depending on species. Therefore, policies can support these efforts by providing technical and financial support like subsidizing effective tools through district level government funds. Furthermore, establishing village level HWC committees with formal roles in planning and implementation of these community led strategies would boost the effectiveness of the strategies against damage.

Rise of HWC is tied to unregulated land use changes which are usually overlooked when enforcing and monitoring HWC mitigation strategies due to corruption in governance. Especially agricultural expansion into wildlife habitats and poor integration of HWC consideration into development approvals are neglected due insufficient monitoring. Reconnecting forest patches and securing wildlife corridors would reduce the pressure on wild animals to travel across agricultural lands (Dahal et al., 2025). These root causes should be addressed through mapping and providing legal protection to wildlife corridors in national land use plans. Furthermore, HWC risk assessments should be made mandatory in Environmental Impact Assessments for development projects. To put a hold to ongoing illegal land use, the development permits should be revised so that critical habitats will be preserved, and habitat fragmentation will be prevented.

Often in insurance schemes and other mitigation strategies, local communities are considered as passive beneficiaries rather than active partners in HWC mitigation. However, involving farmers and villagers who are getting affected by the conflicts to design solution can improve the trust among the affected parties on the mitigation strategy. Study conducted by Dahal et al., (2025) in Nepal clearly shows that the villagers felt both local authorities and central government should jointly manage HWC. Forming village level committees or strengthening existing community-based organizations could facilitate better reporting of incidents and transparency of financial compensation disbursements.

Finally implementing these recommendations will require a strong political will, interagency coordination and sustained funding. The establishment of National Action Plan for the Mitigation of Human Elephant Conflict in 2020 is a step in the right direction. This action plan guides all stakeholders under a unified framework. Although it is focused on elephants, it emphasizes Ulti-agency coordination through district level committees and a proposed national conservation authority which can easily expand into a framework for managing conflicts involving other species as well. In contrast, Bhutanese government has developed a wildlife conflict management strategy where it clearly separates each species impact on human livelihoods and has proposed strategies for each species management (Government of Bhutan, 2008). Both the action plan for Sri Lanka and Bhutan took into account many of the above discussed policy recommendations. However unfortunately Sri Lankan action plan is currently on hold due to administrative changes. Sri Lanka should further develop this action plan including proactive mitigation, community empowerment and scientific management to move away from current reactive stance towards a more preventive and coexistent oriented mitigation of HWCs.

5. Conclusion

HWCs in Sri Lanka is not merely a wildlife management issue but a significant socio-economic challenge. As this chapter has discussed, HWC inflicts heavy on rural communities including loss of lives, destruction of crops, to psychological stress. These costs seep into national economy as loss of agricultural output and waste of agricultural resources. Rapid agricultural expansion, wildlife habitat fragmentation through unregulated land use have intensified the HWCs in many developing countries including Sri Lanka. Without decisive evidence-based actions, both humans and wildlife are prone to negative effects from these encounters. Despite Sri Lankan government's expenditures of millions of rupees on compensation, fences, and translocations, conflicts remain persistent and growing which indicates that the efforts are not fully addressing the root causes or scale of the underline problem. Furthermore, the focus of most of these mitigation efforts being a single species is not sufficient for the complexity of this multi species issue that is deeply disturbing both the rural livelihoods and the wildlife.

Moving forwards, it is clear that no single intervention will fully solve the conflict. Rather a mix of policy instruments that are coordinated among agencies is suitable to address this issue. Robust data collection and monitoring are needed to enable authorities to grasp the true nature of the situation and the magnitude of the conflicts so that they can work on evidence based targeted interventions. Although on the economic front, strengthening safety nets for victims of conflicts is necessary to provide them with short term relief and prevent them from drawing deeper in poverty, reducing communities' reliance on such compensation payments through reducing the incidents is equally important. This is where land use planning, habitat conservation and community level prevention like mitigation strategies should be integrated into rural development. Many International action plans on HWC mitigation show that the best solution for this is all stakeholders working together to develop a holistic approach that fosters coexistence. Although Sri Lanka has also identified this, the implementation of the strategy is on hold for various reasons including sudden administrative changes.

Conflict of Interest

Authors declare no conflict of interest.

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Chapter 06

A Multi–dimensional Perspective on Human–Bird Conflict in Sri Lanka

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Abstract: Human-bird conflict in Sri Lanka is an emerging conservation and socio-economic challenge, rooted in complex interactions among ecological changes, human activities, and historical socio-political events. This chapter summarizes scientific research and reasonings to explore the nature, causes, and consequences of human-bird conflict in Sri Lanka, focusing on its two-way effects, threats to birds and challenges to humans. Habitat pressures, behavioral changes in birds, agricultural impacts, and effects of the prolonged civil war are discussed hereby, providing insights into how coexistence has been complicated. Threats to migratory birds have been emphasized specifically. Case studies from key ecosystems are reported to indicate the urgency of integrated conservation approaches. The need for information and mitigation strategies are discussed in the latter part, advocating for data-driven, ethical, and community-inclusive solutions to leverage biodiversity conservation with human livelihoods. The chapter examines the underlying causes and impacts on both avian populations and human communities, aiming to foster a comprehensive understanding that informs sustainable coexistence between humans and birds in Sri Lanka.

Keywords: Agricultural impacts, conservation, migratory birds, mitigation strategies

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1. Introduction

Sri Lanka, in conjunction with Western Ghats of India, forms one of the 35 biodiversity hotspots in the world, harboring anamusing biodiversity, yet with tremendous levels of threats (Myers et al., 2000; Mittermeier et al., 2011). The island is renowned for its rich avifaunal composition, with 522 bird speciesbelonging to266 genera, 89 families, and23 orders.Of these,34 species are endemic to Sri Lanka, and another 210 species are identified as breeding residents, of which 32 species have both breeding and migratory populations. 147 species are migrants without resident populations, and 87 species are vagrants (The National Red List 2021 – Conservation Status of the Birds of Sri Lanka, 2021).

Even though birds are now increasingly being viewed as a source of conflict, the ancient Sri Lankan culture has treated birds as an intrinsic component of the society. A famous example is the classic literary genre popularly known as ‘Sandesha Kawya’, where birds such as parrots, peafowls, swans, and mynas are illustrated as divine messengers. Moreover, some religions have incorporated birds such as eagles and peafowls into their auspices as chariots of the god. The frequent portrayal of birds in ancient Sri Lankan frescoes and carvings is another testament of their integration into the human culture.

Nevertheless, the increasing overlap between human activities and bird habitats has now led to escalating conflicts. Human population expansion, ecosystem degradation, and socio-political disturbances have altered avian habitats, intensifying interactions that often result in negative outcomes for both birds and humans. Unlike more conspicuous conflicts with large mammals, human-bird conflict is often overlooked, despite its significant impacts on human livelihoods and biodiversity. This chapter provides an extensive scientific overview of the human-bird conflict in Sri Lanka based on empirical research findings and personal communications, to describe the two main dimensions of this issue; anthropogenic threats faced by birds, and challenges imposed by birds on humans. Complexities of human-bird conflict are analyzed hereby, providing insights into its causes, consequences, and potential solutions.

2. Ecological Background of Human-Bird Conflict

Sri Lanka’s diverse ecosystems support a rich assemblage of bird species. However, as a result of being a developing country, human interventions to natural habitats have become increasingly abundant over the past few decades, adversely affecting the local avifaunal diversity (Rathnasiri et al., 2024a). Habitat alteration can be attributed to habitat fragmentation, modification or reduction of vegetation structure and complexity, and introduction of exotic competitors, predators, and pathogens (Beissinger and Osborne, 1982). Habitat fragmentation reduces the connectivity of habitats and increases perforation by humans and infiltration of anthropogenic threats, thereby causing the attrition of natural ecosystems. Modification of vegetation involves the introduction of non-native flora, replacing the native flora. This non-native vegetation might not produce appropriate resources for the native bird species, such as food, nesting sites and roosting areas. This would result in a drastic reduction in native avifaunal diversity.

This phenomenon is elaborated in specialist species. Most of the locally distinct species tend to be specialists. In simpler words, a species becomes locally distinct or confined to a specific locality because it meets its specific requirements in that particular habitat, and nowhere else in the region. Therefore, alterations done to these environments might be disfavored by most of the specialist locally distinct species. These alterations couldexpand into complete habitat destruction as well, wiping out all specialist species, drastically reducing locally distinct biota (Marzluff, 2001).

Further, exotic vegetation might favor exotic fauna, especially those that have co-evolved with, and are better able to exploit them. The conflict arising between these exotics and the native fauna would apparently favor the exotics, resulting in a collapse in native communities. This conflict may take the form of interspecific competition, parasitism, or predation. This can extend into introduction of alien diseases as well. Moreover, the shift in the plant-associated faunal community resulting from the change of the vegetation from native to non-native has the ability to alter the food supply of the native carnivorous birds. Certain birds feed on small vertebrates such as reptiles, and invertebrates such as insects and other arthropods. The change in vegetation would, most of the time, alter the community of this kind of prey species. The increase of this biota would favor the carnivores, both native and exotic, while the decrease of prey species would disfavor them. In either case, the balance existed in the original faunal community would be compromised (Beissinger and Osborne, 1982).

Inoculation of toxic substances into the environment is another serious threat associated with anthropogenic infiltration into natural habitats (Beissinger and Osborne, 1982). The familiar example of the thinning of the eggshells of raptors, reducing the natality rates and thereby decreasing the population size due to the introduction of DDT into the environment as a measure of mosquito control in domestic areas is a testament for this vulnerability. Similar consequences can occur due to the application of agrochemicals such as pesticides, and the release of hazardous wastes from residential, commercial, institutional, and industrial sources into natural environments.

Various studies have shown that a decrease in raptor species (e.g., Figure 1) richness can be observed as the level of urbanization of the habitat increases (Paine, 1966; Rathnasiri et al., 2024b; Wijesundara and Wijesundara, 2014). Raptors are birds of prey and constitute the apex predators in many avian assemblages. They feed on vertebrates such as reptiles, mammals, birds, and fishes. Hence, the presence of raptors can be used as an indication of the presence of those prey species. Vertebrate prey species show a higher diversity in pristine habitats with healthy ecosystems, and a lower diversity in degraded landscapes. This pattern is found to be reflected in raptor species as well. For example, Rathnasiri et al. (2024b) have recorded seven raptor species in a forest patch, only four in a nearby suburban area, and no raptors at all in a close by city, clearly complying with the above pattern. This indicates the increasing levels of habitat degradation from forest to suburban to urban ecosystems.

Fig 1. Changeable Hawk-eagle (*Nisaetus cirrhatus*), a common raptor species in Sri Lanka

3. Case Study: Human-Bird Conflict in Kuruvikkadu Wetland (Sarasalei mangrove)

The Kuruvikkadu wetland in Jaffna District, Sri Lanka, is a biodiversity-rich habitat harboring over 70 bird species, including the charismatic Greater Flamingo (*Phoenicopterus roseus*). Despite its ecological health being vital for maintaining regional biodiversity and ecosystem services, devastative human interventions such as unregulated encroachment, deforestation, fishing and hunting, developmental activities, waste disposal, and mangrove wood-cutting practices have posed a serious threat to the structure and function of this ecosystem. Coupled with the rapid human population growth, this has become worse over the past few years (Balachandran and Thennakoon, 2019).

Habitat loss, fragmentation, and pollution that have been resulted from these anthropogenic activities have begun to compromise the integrity of this ecosystem, thereby adversely affecting its avifauna. Massive bird killings have been recorded from this site during the recent past. Carcasses of Black-crowned Night Herons (*Nyctanassa violacea*, Figure 2A), Great Egrets

(*Ardea alba*, Fig 2B), Black-headed Ibises (*Threskiornis melanocephalus*, Fig 2C), and Gray Herons (*Ardea cinerea*) have been found especially under the uncovered overhead electric power lines laid across the wetland.

The study strongly recommends declaring Kuruvikkadu as a protected area, in order to preserve its rich, yet highly threatened biodiversity. Law enforcement, implementing and promoting sustainable land use and developmental activities, and conducting community-based conservation and awareness programs are required for the effective recovery and comprehensive management of this ecosystem (Balachandran and Thennakoon, 2019).

Fig 2. Bird carcasses at Kuruvikkadu wetland, Jaffna, Sri Lanka. A: Black-crowned Night Heron, B: Great Egret, C: Black-headed Ibis

4. Tourism and Recreational Disturbances

Even though nature-based tourism is economically beneficial and could be used to increase community awareness and attention towards conservation, it has certain downsides as well. A major problem associated with ecotourism is the noise and disturbance caused by vehicles (Figure 3). Increased levels of human presence in wildlife reserves have been found to be linked to altered bird behaviors and distributions.

Fig 3. An Indian Nightjar (*Caprimulgus asiaticus*) resting next to a recreational vehicle path in Wasgamuwa National Park, Sri Lanka.

A study carried out in Sinharaja Forest Reserve in Sri Lanka (Alwis et al., 2016) has recorded a significant reduction of bird species richness along popular trails, compared to the undisturbed areas. The study points out that birds occupying the ground level, understory and sub-canopy are presumably affected the most. Marasinghe et al. (2022) have recommended a minimal of 100 m buffer zone beside vehicle trails, in a study conducted inside Bundala National Park, Sri Lanka, after analyzing the variation of the intensity of birds' response to recreational disturbance with relation to the distance from the trail. It is documented that the behavior of larger bird species is affected more by vehicles. On the other hand, resting birds are recorded to respond more, compared to foraging birds (Marasinghe et al., 2022).

Unregulated playback usage for ecotourism is another threat to the natural systems. Playbacks can cause unnecessary aggression, attraction, and even predation of birds. This is especially evident during the breeding season, where birds show high levels of active communication (Newsome and Hughes, 2016). Hence, even though nature-based tourism has numerous benefits including the provision of livelihood for locals, it is strongly recommended to manage ecotourism practices closely, with timely revised regulations.

5. Historical and Political Context: The Legacy of Civil War

Armed battles such as wars can have serious effects on wildlife. The use of explosives, munition, and chemicals can directly affect the ecosystems in the battle zone (Dudley et al., 2002). Additionally, wildlife can be specifically targeted for consumption by soldiers, or to avoid being a food source for the enemy parties (Gnanapragasam et al., 2021). Pollution, deforestation, and draining of wetlands pose adverse consequences for wildlife as well. Meanwhile, people who are withdrawn from the battle zones frequently face food shortages and tend to rely on wildlife for sustenance (Santiapillai and Wijeyamohan, 2003). However, evacuation of human settlements in the proximity of forests can positively affect wildlife by reducing poaching and creating war-zone refuges (Dudley et al., 2002; Santiapillai and Wijeyamohan, 2003).

The 26-year civil war (1983–2009) in Sri Lanka has profoundly altered the natural landscapes and human-wildlife dynamics. Recent research has shown that birds in former war zones in Sri Lanka exhibit significantly longer flight-initiation distances (FIDs) compared to those outside the war zone (Gnanapragasam et al.,. 2021). FID is the distance from an approaching threat at which the animal of interest initiates its escape, which is used as a measure of wariness of wildlife towards humans, or how birds perceive potential anthropogenic threats (Blumstein, 2006; Gnanapragasam et al., 2021). This heightened FIDs recorded from the former war zones of Sri Lanka are attributed to several general postulations. In ecosystems where humans are scarce, birds are generally found to exhibit longer FIDs, as is the case with the war zone when the bordering villages are evacuated (Gaynor et al., 2016; Samia et al., 2015; Santiapillai and Wijeyamohan, 2003). On the other hand, birds tend to increase their FIDs when hunting or killing rate is increased, which might have been the situation in the war zones despite the reduction of general human encounter rates (Daskin and Pringle, 2018; Santiapillai and Wijeyamohan, 2003). In addition, heightened FIDs may be theoretically attributed to the extent of habitat degradation, as in the creation of more open habitats due to armed conflicts (Gnanapragasam et al., 2021; Osorio-Beristain et al., 2018).

The legacy of the civil war in Sri Lanka has compromised human-bird coexistence to a considerable extent, as more ‘traumatized’ bird species seem to exhibit complicated responses to human presence. A strong correlation has been observed between the FID and the body size of birds in the former war zones (Gnanapragasam et al., 2021). Bird species with larger body sizes might have presumably been hunted more often by humans, exerting an elevated survival pressure on them, which has arguably resulted in heightened FIDs (Benítez-López et al., 2017). This might suggest a call for species-tailored management strategies to support recovery and reduce conflict.

Extensive armed battles are found to impose pronounced behavioral changes in avifauna, resulting in long-lasting ‘trauma’, or adaptive plasticity in affected populations. These might cause far-reaching consequences, such as potential influences on feeding, breeding, and habitat use patterns. Understanding such behavioral shifts is crucial for designing effective conservation, management, and post-conflict restoration strategies.

6. Conflict with Migratory Birds

Birds' migration to tropical regions during the winter of the high latitudes of the northern hemisphere has been a research attraction for ornithologists since ancient times. Among the eight major terrestrial bird migratory pathways in the world, the Central Asian Flyway runs down the middle part of Asia (Lovette and Fitzpatrick, 2016). An interesting fact to highlight the importance of Sri Lanka for migratory birds is that Sri Lanka is the terminal main landmass encountered in the Central Asian Flyway, marking the end of the migratory routes. In other words, birds that are migrating southwards from the high northern latitudes have to make their landfall in Sri Lanka, unless they intend to fly all the way to Antarctica over the open ocean, with no major landmass in between.

Sri Lanka receives migratory birds via three main routes; Western Route which lies over the western coast of India, Eastern Route which lies over the eastern coast of India, and Andaman Route which lies over the Andaman Islands. Except the Andaman Route which enters Sri Lanka through the Northeastern coast of the island, both other routes enter Sri Lanka via the Northwestern coast.

Among the migratory waterbirds visiting Sri Lanka, there are a couple of highly threatened species. For example, the Indian Courser (*Cursorius coromandelicus*), which is categorized as Critically Endangered (CR) on the IUCN Red List of Species, is found only in Delft Island and Wedithalathivu Lagoon. This might arguably be the most threatened bird species recorded in the country.

Mannar area, with numerous heterogenous coastal wetlands such as salt marshes like Vankalei Bird Sanctuary (Figgure 4A), mangrove forests like Wedithalathivu Nature Reserve, and lakes such as the Giant's Tank Sanctuary (Figure 4B), is a popular area for migratory birds to make their landfall. However, a major threat to these migratory birds has been imposed by the construction of a windfarm right across an entry point of the routes (Figure 4C). Collisions with the rotating blades have caused numerous bird kills, while other adverse effects such as displacement, and habitat change and loss have significantly affected the migratory birds (Kandasamy et al., 2017). Even though the windfarm concept offers an attractive solution to the power crisis in developing countries like Sri Lanka, rigorous environmental impact assessments should be carried out before implementing such facilities, to properly understand the local faunal community, and to identify any site-specific effects to the natural ecosystem processes and the scale of responses compared to the scale of the intervention (Langston and Pullan, 2003). With the environmental concerns that have been raised, the proposed further extension of this wind farm project in Mannar has been abandoned. However, the ecological threats associated with the existing wind turbines are presumably being continued, and it is strongly suggested to conduct/continue systematic ecological monitoring projects to ensure the safety of local biota. If the threats are found to prevail, relocating the turbines to an area with less sensitive ecosystems might be an option.

Another serious threat affecting Sri Lanka's migratory shorebird community is the unsustainable developmental activities carried out at Vankalei wetland, located in Mannar. Being declared as a Ramsar wetland, Vankalei Sanctuary is designated to be of international importance, in terms of conservation. Thousands of migratory waterbirds populate the Vankalei wetland each year, because of the range of complex ecosystems it houses. Thus, it has become a popular attraction in ecotourism, and hundreds of birdwatchers visit Vankalei during the migratory season. However, the high-voltage power lines laid over the wetland have posed a tremendous threat to the migratory birds, in addition to compromising the natural integrity of the ecosystem. It is prudent to pay serious attention towards managing these ecosystems, both to conserve the associated wildlife, and to continue sustainable ecotourism practices.

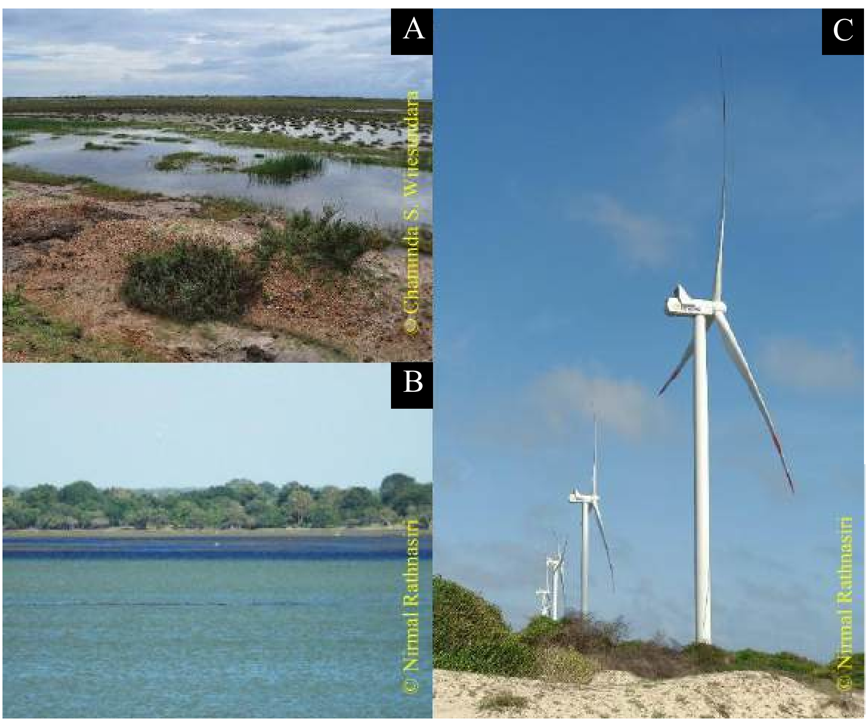

Fig 4. Key areas of concern in Mannar, Sri Lanka. A: Vankalei Bird Sanctuary, B: Giant's Tank Sanctuary, C: Mannar windfarm

A famous example of the conflict between humans and migratory birds in Sri Lanka comes from the Mattala International Airport, constructed in Hanbantota District and opened in 2013. Fobes has dubbed this airport as the 'World's emptiest international airport', due to the extremely low number of flights attracted by it (Malji and Bhatt, 2025). One of the main reasons behind this problem is the fact that the airport is built beneath a bird migratory pathway. Hence, bird strikes with aircraft have been abundant, posing a magnificent threat to the survival of the migratory avifauna, as well as the security of the aerial vehicles and passengers, as a couple of bird strikes can cause an airplane to crash (Peiris, 2019). This is a two-way problem, which harms both wildlife and humans. Rigorous ecological analyses should be carried out prior to the development of such facilities, to avoid this kind of economic-scale issue.

A relatively unspoken aspect of the human-bird conflict until recent years is migratory bird collisions withglass panes; particularlywindows. Around one billion birds are found to die annually due to window collisions in North America alone (Basilio et al., 2020). However, more studies are needed to systematically evaluate this problem in the tropics, including Sri Lanka. Even though the causes of these collisions are not yet fully understood, it is speculated that the landscape-level ecosystem features affect the composition of the collided bird species (Cusa et al., 2015). This is, however, not exclusive for migratory birds.

7. Birds as Agricultural Pests

Crop depredation by birds has been an escalating problem over the past few decades. There are about 13 main bird species which could be considered as pests of important food crops. The population and density, distribution, body size, and quantity of food intake at a time are important factors, when considering them as pests. The following birdspecies could be regarded as agriculturally important pests in Sri Lanka, although some of them might be significant in environmental, ecological, and other aspects as well.

7.1 Indian Peafowl (*Pavo cristatus).* Fig 5A

This is a common bird in most of the dry and intermediate zones and has been increasingly considered as a serious pest. They have recently been reported to spread into new regions, including different areas in the wet zone. The peafowl population in the country was estimated as 4.24 million by the Ministry of Agriculture, in 2025.

Being Omnivores, they feed on, and damage a wide range of plants and animals. Peafowls target newly planted seeds in open fields, seedlings, immature and mature seeds/panicles, and fruits and pods of crops such as paddy and other grain crops, maize, chili,green gram, ground nut, cowpea, bean, yard long bean, cucurbits, leafy vegetables, and many other crops. They are active feeders, and forage for a long period from early morning to late evening as flocks. The quantity of eating/damaging per one Peafowl is higher than that of most other birds, corresponding to the comparatively large body size.

Other than feeding, they physically damage nurseries, and young and mature plants such as paddy, other field crops, and vegetables in open fields by wandering, resting, and other activities. At the same time, it is reported that parasitic ticks on this bird infest humans in some areas, causing heavy fever and long-term allergic reactions. Due to the limitation of natural enemies, lack of human-mediated control measures, high breeding rate, and adaptability to new areas, Peafowls have become an invasive bird species in Sri Lanka.

Fig 5. Major crop depredatory birds in Sri Lanka. A:Indian Peafowl, B: Rose-ringed Parakeet, C: Scaly-breasted Munia, D: Red-vented Bulbul, E: Brown-headed Barbet, F: Spotted Dove, G: Feral Rock Pigeon, H: Common Myna, I: Asian Koel, J: Sri Lanka Hanging-Parrot, K: Sri Lanka Gray Hornbill, L: Large-billed Crow, M: Green Imperial-Pigeon

*7.2 **Rose-ringed Parakeet** (Psittacula krameria).* Fig 5B

This is a common bird in Sri Lanka, and the population is high in all farming areas. They are distributed mainly in dry and intermediate zones, however, can be seen in almost every part of the country. This bird has been considered as a serious pest in agriculture since ancient times. They are herbivores, mainly feed on fruits, pods, and seeds.

They cause serious damage to immature and mature seeds/panicles, fruits, and pods of crops such as paddy, finger millet, maize, chili, green gram, cowpea, bean, yard long bean, tomato, banana, mango, guava, rambutan, and many other crops. They are active and feed the whole daytime in flocks. As they damage maize, legumes, and chili pods, etc. to eat only the seeds, the destruction of a large number of pods is inevitable. They damage silently in a short time resulting in massive yield losses.

*7.3 **Munias** (Lonchura spp.)*

There are four species of Munias in Sri Lanka, *viz.* Black-throated Munia (*L. kelaarti*), Tricolored Munia (*L. malacca*), Scaly-breasted Munia (*L. punctulata*, Fig 5C), and White-rumped Munia (*L. striata*), of which the latter two are considered serious pests. Munia species can be seen in all of the farming areas of Sri Lanka, where high damages occur in areas with high population densities. They are granivores, feeding on and damaging mature seeds such as paddy, in a comparatively short time in large flocks. They damage fields as well as seeds that are spread for drying/processing. Some farmers say that they ‘drink paddy seeds because of the high feeding rate. In some areas in the dry zone, paddy farmers tend to double the seed rate in planting to compensate for this damage. They are active and feed during the entire daytime.

*7.4 **Red-vented Bulbul** (Pycnonotus cafer)* Fig 5D.

This is a common bird species, and the population is high in most parts of the country and can be seen almost everywhere. They are omnivores, feeding and damaging certain vegetable flowers and immature pods/fruits such as bean, yard long bean, winged bean, other legumes, ridge gourd, snake gourd, cucumber, tomato, and ripe and soft fruits like papaw, banana, mango, strawberries, and some minor small-sized fruit crops, etc. They are active and feed throughout the daytime, in pairs or small flocks. Because they forage and damage continuously and everywhere, they are considered as pest birds, causing major yield losses. However, they are important in the dispersal of certain fruit seeds, as an active component of the natural faunal community.

7.5 Brown-headed Barbet (Psilopogon zeylanicus and other Barbets) Fig 5E.

There are four species of barbets in Sri Lanka, *viz*. Yellow-fronted Barbet (*P. flavifrons*), Crimson-fronted Barbet (*P. rubricapillus*), Coppersmith Barbet (*P. haemacephalus*), and Brown-headed Barbet, of which the former two are endemic. Brown-headed Barbet, which is the largest among the four, is a common bird, and can be seen in many regions. They feed on ripe and fleshy fruits such as bananas, mango, guava, and some other minor crops with small fruits. Specifically, their damage is a major problem for ripe papaw fruits in the industry level. They are active and feed the whole day as individuals or pairs. However, they are beneficial in naturally dispersing certain wild fruit-seeds.

7.6 Spotted Dove (Spilopelia chinensis) Fig 5F.

This is a common bird species with populations dispersed in all farming areas, as well as other regions. They are grain-eating birds, and feed on and damage newly sown seeds, mature seeds on the farm grounds such as sesame, paddy, and many other small grains, and seeds that are spread out on the ground for drying and processing. They are active and feed throughout the whole day, individually or as pairs.

7.7 Feral Rock Pigeon (Columba livia) Fig 5G.

This is a common bird species, living in farming areas and human habitats, in large flocks during daytime. They are distributed mainly in the dry zone, however, can be seen almost everywhere. They are primarily granivores, feeding on and damaging paddy and other small-sized grains on the ground, planted seeds, and seeds spread outfor drying and processing.

7.8 Common Myna (Acridotheres tristis) Fig 5H.

They are common birds with large populations in some farming areas and can be seen everywhere. Thay are omnivorous birds that are considered as a pest of ripe and soft fruits like papaw, tomato, banana, mango, and some other minor fruit crops. However, they are considered beneficial birds as well, because they prey on a variety of insect pests including caterpillars on many crops. They are active diurnal feeders and usually encountered in pairs or flocks.

7.9 Asian Koel (Eudynamys scolopaceu) Fig 5I.

This is a common diurnal bird species, living in canopies of fruit trees, as pairs. They have an island-wide distribution and are easily identified by their unique call. They are primarily frugivores, feeding on ripe and soft fruits like papaw, banana, mango, and other small-sized wild fruits. However, they are important in dispersing fruit-seeds.

***7.10 Sri Lanka Hanging-parrot/Sri Lanka Lorikeet (Loriculus beryllinus*)** Fig 5J.

This is an endemic species to Sri Lanka. Their flocks can be seen throughout the daytime in high canopies with flowers and fruits and are distributed island wide. Though they are common birds, it is difficult to spot them because of their green plumage and slow movements in the canopy. They are herbivores, and mainly feed on various fruits, pollen, and nectar. They cause damage to ripe and juicy fruits like mango, rambutan, and starfruit, etc.

7.11 Hornbills

Sri Lanka has two hornbill species, namely Sri Lanka Gray Hornbill (*Ocyceros gingalensis*, Fig 5K), and Malabar Pied-Hornbill (*Anthracoceros coronatus*), of which the former is endemic and distributed throughout the island except in high altitudes. The latter is mainly distributed in the dry zone. It is possible to identify them easily by their distinctive call. They are omnivores, mainly feeding on various fruits and insects. Usually occupying the canopies of fruit trees, they feed on ripe crop fruits such as papaw and mango and physically damage the tender parts of papaw trees due to their heavy weight and sharp claws. They are active and feed in the daytime, in pairs or small flocks.

***7.12 Large-billed Crow (Corvus macrorhynchos*)** Fig 5L.

This is a common bird species, living in association with fruit trees in farming grounds, close to human residences. They occur as individuals, pairs, or flocks, during daytime. Their distribution is island wide. They are omnivores, feeding on and damaging ripe and soft fruits such as papaw, banana, mango, and jack fruit, etc. Ecologically, however, they are important as scavengers.

7.13 Green Imperial-pigeon (Ducula aenea) Fig 5M.

This is the largest pigeon species in Sri Lanka. They live in high canopies of fruit trees, like pairs or small flocks, foraging in daytime. Their distribution is mainly limited to the low country and can be easily recognized by their unique call. They are frugivores, feed on ripe fruits, damaging minor fruit crops and wild fruits (Pers. Com. Chandrasena, S. (Rtd. Additional Secretary, Ministry of Agriculture, Sri Lanka); Makalanda, L. N. (Assistant Director (Research), FCRDI, Horana, Sri Lanka); Ruwanpathirana, K. H. (Rtd. Assistant Director (Research), ARS, Thelijjawila, Sri Lanka); Senannayake, S. (Assistant Director (Research), ARS Rahangala, Sri Lanka); Siriwardhana, H. (District Director (Agriculture), Matara, Sri Lanka).

8. Mitigation Strategies

Sri Lankan culture is primarily based on traditional agriculture, and, except for highly urbanized regions, cultivations are abundantly seen around the country. In ancient times, especially in paddy cultivations, farmers had shown a tendency to coexist with crop-raiding birds by leaving a chosen portion of the field adjacent to the bordering forest for them. This dedicated field stripe was called 'Kurulu Paluwa' in Sinhalese and was not intended to be harvested. However, it is questionable if the farmers still practice this kind of method to deal with wildlife today. Chellappan et al. (2023) have indicated a range of deployable methods to overcome the conflict with birds, of which a few are discussed hereby. These methods can be chosen and modified according to the kind of bird conflict that needs solutions.

Reflective devices could serve as an effective mitigation strategy. An example from Indian croplands is the use of reflective ribbons. These ribbons are suggested to be yellow or red on one side, and silver on the other side, or bear holographic surfaces on either side. The glittering sunlight-reflections of these ribbons are supposed to act as a visual deterrent for birds. When using agricultural lands, it is proposed to lay the ribbons about 45 cm above the crop field, aligned in the North-South direction.

Visual deterrents such as reflective spears and plaques could be used to mitigate the bird problem in facilities like airports and powerplants or areas with exposed electric cables. Additionally, underground cables could eliminate the birds' possibility of getting electrocuted (Bevanger, 1994).

In conjunction with visual deterrents, visual attractants could be deployed to drive the birds to a preferable location. However, the drawback of this method is the possibility of birds becoming habituated to the deterrents. Hence, occasional modifications, randomizations, shifts, and upgrading might be necessary to continue their effective functioning.

Among the several popular strategies employed to mitigate bird-window collisions, one widely used solution is the use of decals. Modern decals are designed to be seen when only observed from the outside, to avoid being a nuisance for humans. Other frequent options include Zen wind curtains, blinders, and external screens, as means of creating visual barriers for birds.

The use of mild explosives as an auditory deterrent is another suggested method for mitigating crop depredation by birds. Propane and acetylene are used in such techniques. The hissing of the device moving swiftly through the air, and the explosion sound are supposed to scare the birds away. If such methods are employed in mature crop fields, precautions should be taken to ensure that the field does not catch fire.

Scarers such as old-school scarecrows, inflatable balloons with eyespots and wavy mannequins, kites resembling hawks or owls, spotlights and flashlights, and laser beams are utilized in various countries to control avian conflicts. The latter can be employed at night as well, if required. The area effectively covered by a single scarer unit could be a limitation here, especially in non-optical methods. The efficiency of scarers can be improved by coupling them with audio devices such as loudspeakers, to broadcast loud noises at random. It is reported that some farmers use the presence of biological scarers such as hawks, by providing raptor perches and/or nestboxes for such predators, elevating their populations, and causing the depredatory prey species to flee.

Physical barriers can be used to keep birds from entering and potentially harming a susceptible resource, such as a cropland or an aquaculture pond. Overhead rope grids and nets can be employed as direct obstacles for birds. The amount of space between ropes, mesh size, extent of net overlapping, and the height and/or orientation at which these barriers should be erected depend on the needs of the resource (such as sunlight intensity), and the body size and habits of the bird species of concern. A traditional example of a simple physical barrier to bird depredation is the practice of wrapping maize cobs with adjacent leaves to hide and camouflage them.

In certain countries, chemical repellants are used to get rid of birds. Primary repellants are those that repel birds directly via fowl tastes or smells, whereas secondary repellants act indirectly on birds, causing diseases or discomfort following ingestion (see Bishop et al., 2003).

Even though lethal methods such as shooting and poisoning are practiced in certain countries, they are relatively less popular in Sri Lanka, probably due to religious influence. It is important to note that except five species, *viz.* Rose-ringed Parakeet, White-rumped Munia, Scally-breasted Munia, Large-billed Crow, and House Crow (*Corvus splendens*), all other bird species found in the island are protected under the Flora and Fauna Protection Ordinance of Sri Lanka and killing them without a valid permit is prohibited.

Ecological mitigation strategies can be viewed as a more environmentally friendly way to moderate human-bird conflict. Creating attractive habitats for birds in the periphery of the perishable resource can potentially reduce the bird density in affected areas. This includes forming forest corridors and/or marginal vegetation enriched with fruit trees. Such approaches can be employed to minimize bird occupation in croplands, airports, playgrounds, and urban areas, etc. However, it is important to properly identify the troublesome bird species and their specific niche requirements before implementing such solutions.

9. Conclusion and Future Directions

Human-bird conflict in Sri Lanka is symptomatic of complexphenomena shaped by ecological, socio-economic, and historical factors. The lasting impacts of civil war on bird behavior, habitat pressures, and agricultural expansion demand a holistic approach that integrates scientific research, public awareness and education, timely revision of regulations, and policy reforms that respect both human and avian needs. Strengthening data collection, fostering community participation, and implementing ethical and adaptive management strategies are pivotal to achieving conservation goals. Only a handful of research has been carried out to analyze the human-bird conflict in Sri Lanka, and there are extensive knowledge gaps which need to be filled to devise sustainable mitigation strategies. In particular, rigorous studies are needed to identify the conflict species, their ecology and behavior, niche requirements, physiology, and sensitivity, to figure out effective ways to moderate the conflict without compromising the island's biodiversity. By encouraging coexistence strategies, Sri Lanka can safeguard its rich avifaunal diversity while supporting human well-being.

Conflict of Interest

Authors have declared that no competing interests exist.

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Chapter 07

Human-monkey Conflict in Sri Lanka

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Abstract: Sri Lanka, a developing country with an agriculture-based economy, is globally recognized for its exceptional biodiversity and high levels of endemism. However, this ecological richness now coexists with growing pressures from development and agricultural expansion, leading to frequent and often severe conflicts between humans and wildlife. Among the most pressing of these is the ongoing human-monkey conflict (HMC). Sri Lanka is home to three monkey species: *Semnopithecus vetulus*, *Macaca sinica*, and *Semnopithecus priam*. All three species have increasingly come into conflict with people and are officially recognized as vertebrate pests. This chapter explores the root causes and consequences of these conflicts, including why monkeys are drawn to human settlements and crops, current practices to mitigate the HMC and recommendations with challenges. Key contributing factors to HMC include rapid human population growth, habitat loss and fragmentation, poor waste management, direct and indirect feeding by humans, and seasonal shortages of natural food and water sources. The impacts on people are significant: crop damage, destruction of property and infrastructure, risks of disease transmission, and even physical injuries. Less visible but equally important are the emotional and social burdens, such as fear, disruption of daily life, increased labour, and concern for pets and children. Meanwhile, the monkeys themselves face escalating threats. Two of the endemic species involved *M. sinica* and *S. vetulus* are listed as Endangered, with *S. vetulus nestor* ranked among the world's 25 most Critically Endangered primates according to the IUCN Red List. Given the complexity of this issue, a multi-disciplinary and scientific approach is essential. This chapter presents case studies and lessons from other countries while emphasizing the urgent need for well-structured public awareness programs, science-based interventions, reforestation efforts, reduced deforestation, and effective governance. We also advocate fair compensation

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schemes and insurance support for affected farmers, ensuring that solutions serve the well-being of both humans and wildlife.

Keywords: Human-monkey conflict, Crop-raiding, Endangered primates, Sustainable coexistence

1. Why is it Termed 'Human-monkey Conflict' in Sri Lanka?

'In the increasingly contested spaces where human settlements, agriculture, and infrastructure meet the remnants of the wild, conflict does not erupt in sudden bursts, it simmers, evolves, and entangles'

Human-wildlife conflict, defined as the struggles that emerge when the presence or behaviour of wildlife poses an actual or perceived, direct and recurring threat to human interests or needs, reflects not only the friction between species but also the fault lines within human societies themselves (International Union for Conservation of Nature/IUCN Species Survival Commission, 2022). These conflicts have significant implications for both human livelihoods and wildlife, posing serious threats to conservation efforts and the goals of sustainable development. Importantly, human-wildlife conflicts are not confined to specific regions or limited to animal taxa. According to a 2022 survey conducted by the Global Wildlife Program of the World Bank, the most reported species involved in such conflicts include birds (40%), herbivores including deer, pigs, and hippos (39%), elephants (37%), large carnivores (37%), crocodiles (26%) and primates (34%). Notably, more than 60% of primate-related conflicts were reported from countries in the Asia-Pacific region.

Primates are broadly classified into two main suborders: Strepsirrhines and Haplorhines (Groves, 2021). Strepsirrhines (wet-nosed), considered more primitive, include lemurs, lorises, and galagos, and are primarily nocturnal. Haplorhines (dry-nosed) are more advanced, comprising tarsiers, monkeys, and apes. Monkeys are further divided into New World/Neotropical monkeys found in the south and central Americas, and Old World/Paleotropical monkeys distributed across African and Asian regions. Apes include both lesser apes (gibbons) and great apes such as orangutans, gorillas, chimpanzees, bonobos, and humans. Significantly, a substantial proportion of documented human-primate conflicts involve species within the Old-World monkey and ape clades, whose ecological flexibility and behavioral adaptability frequently lead to interactions with human-dominated environments. In the context of Sri Lanka, however, non-human primate species are limited to monkeys, which is why the occurrence is commonly referred to as 'human-monkey conflict' (HMC) rather than the broader term human-primate conflict.

1.1 Monkey species diversity and distribution in Sri Lanka

Sri Lanka harbours five species of primates: two species of nocturnal lorises (Suborder Prosimii: Family Lorisidae) including grey slender loris (*Loris lydekkerianus*) and red slender loris (*Loris tardigradus*) and three species of diurnal monkeys (Suborder Anthropoidea: Infraorder Catarrhini: Super-families Cercopithecoidea) including grey langur (*Semnopithecus p*riam) (Figure 1a), purple-faced leaf monkey (*Semnopithecus vetulus*) (Figure 1b), and toque monkey (*Macaca sinica*) (Figure 1c). *Semnopithecus priam thersites* is geographically isolated from its mainland conspecifics by the Palk Strait (Dittus, 2013). It inhabits the dry zone evergreen forests of northern, eastern, and southern Sri Lanka, ranging from Jaffna to Matara, at elevations up to 350 m, and is also present in the drier parts of the intermediate zone, though absent from the wet zone (Dittus, 2020). The World Conservation Union (IUCN) Red List classifies it as Vulnerable (A2cd+3cd), with an unknown population size. Habitat loss exceeding 50% over the past 30 years has likely contributed to a population decline estimated at over 30% across three generations (Molur et al., 2003).

Semnopithecus vetulus is the only endemic colobine in Sri Lanka and is represented by four subspecies: *vetulus*, *monticola*, *nestor*, and *philbricki*. These subspecies exhibit distinct geographic distributions: the Southern Purple-faced Langur (*vetulus*) occupies the southern wet zone from the Kalu Ganga to Ranna, up to 1,000 m; the Highland subspecies (*monticola*) is found in the central highlands between 1,00-2,200 m; the western form (*nestor*) occurs in the wet zone north of the Kalu Ganga, up to 1,000 m; and the northern subspecies (*philbricki*) inhabits the northern dry zone, up to 1,500 m. The species is classified as Endangered (A2cd+3cd) by the IUCN Red List, with an estimated population decline exceeding 50% over the past three generations (Rudran et al., 2020). *Macaca sinica,* an endemic primate species restricted to Sri Lanka, occupies a wide range of habitats from forests to urban areas across the island (Dittus, 2020). It is currently listed as Endangered (A2cd+4cd) on the IUCN Red List and is included under CITES Appendix II. The species comprises three subspecies with distinct distributions: *M. s. aurifrons* inhabit the wet zone and central highlands, *M. s. opisthomelas* is restricted to the montane rainforests around Horton Plains, and *M. s. sinica* occurs throughout the dry zone. Despite its conservation status, *M. sinica* remains the only endemic primate in Sri Lanka not protected under national legislation.

1.2 Driving forces behind the HMC

There is no single underlying cause for the increasing incidence of HMC; rather, it stems from a complex interplay of multiple factors that similarly drive human-wildlife conflicts across the globe. Many of these contributing elements are common to other countries facing comparable challenges. In this discussion, we focus on the primary drivers of HMC, which can be broadly categorized into several key areas: human population growth, land use transformation, habitat loss, degradation and fragmentation, inadequate waste management practices, intentional or unintentional food provisioning, and seasonal scarcity of food and water in natural habitats, particularly during dry periods.

According to the 2025 report by the Department of Census and Statistics, Sri Lanka's population stood at 21,763,170, based on findings from the 2024 Census of Population and Housing. This marks an increase of 1,403,731 individuals (6.9%) compared to the 2012 census. During the inter-census period from 2012 to 2024, the average annual population growth rate was 0.5%, reflecting a deceleration in growth; nevertheless, the population continues to rise. With this demographic increase comes an escalating demand for land expansion to support housing, industry, agriculture, and recreational infrastructure. This demand drives land use changes, often resulting in the conversion of forests and other natural ecosystems into agrarian or urban landscapes to meet the growing needs for land, food production, energy, and raw materials. Consequently, the mounting pressure on land resources poses a significant threat to wildlife through habitat loss, fragmentation, and degradation.

In Sri Lankan context, habitat loss has exceeded 50% over the past 27 years (1994-2020), equivalent to two generations, and ongoing development projects continue to endanger these habitats and the monkey populations that depend on them (Dittus, 2020). This issue has become particularly pronounced since 2009, when the conclusion of the civil war opened the Northern Province to extensive land conversion for economic development. Since then, the Northern dry zone forest habitat has declined by at least 15% and is projected to diminish further (Mattsson et al., 2012). Moreover, the prolonged conflict in the north and east also had detrimental effects on wildlife populations (Santiapillai and Wijeyamohan, 2003). Notably, the dry zone, which supports all three monkey species, has undergone substantial forest cover changes from 1992 to 2019, exhibiting a clear trend of forest loss. Over this 27-year period, the dry zone lost approximately 246,958.4 hectares of forest at an average rate of 9,146 hectares per year (Ranagalage et al., 2020). On the other hand, Sri Lanka's Western Province, one of the most densely populated and economically active regions, is home to *S. vetulus nestor*, a subspecies listed among the world's 25 most endangered primates (Mittermeier et al., 2024). The rapid urbanization and expansion of human settlements in this region place immense pressure on the remaining natural habitats. Consequently, monkey populations are facing severe threats due to the loss of their native ecosystems, ultimately resulting in the encroachment of humans into their natural grounds.

Alternatively, inadequate waste management practices are another key driver of escalating this problem in Sri Lanka. The country experiences high levels of food waste, much of which ends up in unsecured garbage dumps or poorly managed disposal sites. This readily accessible anthropogenic food source attracts monkeys, particularly *M. sinica*, who adapt quickly to these novel foraging opportunities. During dry seasons, when natural food availability within forest habitats is limited, this dependence intensifies. However, the increased foraging pressure in human-dominated landscapes not only fosters habituation but also pushes monkeys, leading to aggressive behaviors such as home intrusions and crop raiding. These interactions are further exacerbated by intentional feeding practices, often rooted in cultural or religious traditions which reinforce the presence of monkeys in urban and peri-urban areas and disrupt their ecological foraging patterns.

2. Extent of HMC

Humans and monkeys have coexisted for thousands of years, but with the increasing expansion of human activities and desires over the past 50 years, this long-standing harmony has shifted toward a state of conflict. However, HMC in Sri Lanka is neither limited to a particular monkey species nor confined to specific cities or villages. Rather, its occurrence and intensity are closely linked to the geographic distribution of different monkey species across the country. Depending on the species involved, the nature and severity of the conflict can vary significantly. Importantly, just as humans are affected by these conflicts, monkeys too experience adverse consequences. Therefore, it is essential to highlight not only the negative impacts on human communities but also the threats posed to monkey populations because of this ongoing conflict.

All three monkey species contribute to HMC across Sri Lanka. As documented by Cabral et al. (2018), based on complaints received by the Department of Wildlife Conservation (DWC), HMC was reported in 21 out of the country's 25 districts, with all three species identified as responsible. Notably, four districts, Colombo, Kandy, Badulla, and Kalutara accounted for over 50% of the total complaints. Among the species, *M. sinica* was implicated in 53.6% of reported conflicts, followed by the *S. vetulus* at 30%.

2.1 Crop and property damage caused by monkeys

The long history of HMC in Sri Lanka can be traced back to the 17th century, with one of the earliest documented accounts provided by Robert Knox, a British captive of King Rajasinghe II of Kandy between 1659 and 1679 (Nijman and Nekaris, 2010). In his *Historical Relation of the Island Ceylon*, published in 1681, Knox described instances of such conflict, highlighting a problem that continues to persist and intensify in modern times (Nijman and Nekaris, 2010). Today, human communities are economically affected through the destruction and damage of property and infrastructure including agricultural crops, domestic crop and ornament plantations, grain stores, water installations, fencing, roofs and pipelines as well as by exposure to zoonotic diseases and the risk of physical injury. In addition to these tangible losses, negative socioemotional impacts are common, nuisance encounters with monkeys can lead to missed work, increased labour costs, fear, restricted mobility, and even the injuries to pets and children.

It is difficult to quantify the amount of damage due to crop raiding, both in actual yield and economic terms (Sillero-Zubiri and Switzer, 2001). Recent events in Sri Lanka underscore the broader economic consequences of HMC, particularly in agricultural communities. For instance, the sharp increase in coconut prices has drawn national attention, with many farmers attributing the shortage in supply to extensive crop damage caused by monkeys. In regions where coconut plantations are a primary source of income, widespread destruction by monkeys has led to significant reductions in harvest yields. However, there has been no systematic survey on this issue, and the claims of crop losses by affected communities are primarily documented in media reports rather than in peer-reviewed scientific publications. However, this decline in productivity not only lowers individual farmers' incomes but also disrupts local economic systems by reducing the flow of goods to markets and limiting household spending. As demonstrated in similar contexts, such localized economic stress can ultimately compromise the overall stability and resilience of rural economies.

Few studies have systematically documented crop and property damage caused by monkeys. An island-wide survey reviewing complaints received by the DWC found that crop damage was the most frequently reported issue, accounting for 70% of cases, with 9% of farmers unable to benefit from government agricultural programs as a result. Other significant sources of conflict included infrastructure damage (35%), nuisance behaviors and injuries (20-25%), and food theft (14%) (Cabral et al., 2018). In the Western Province (Panadura and Piliyandala), a study reported that bananas were the most frequently consumed human-edible fruit by *S. v. nestor*, comprising 26.2% and 22.7% of observations in two groups, respectively (Dela, 2011). Roof damage was observed in only 9.2% and 4.5% of conflicts at Panadura and Piliyandala, respectively. A survey in Gampaha district by Wijethilaka et al. (2021) found that 93% of households experienced damage to commercially valuable fruits, leaves, and buds, while 76% reported broken roof tiles and 43% reported frightful encounters with monkeys. The average household losses from crop and property damage ranged between 1,500 and 2,700 Sri Lankan rupees, with greater losses occurring during the dry season compared to the wet season. In the dry zone of Sri Lanka, where all three monkey species inhabit agricultural landscapes, a survey in the Polonnaruwa district revealed that crop damage was the predominant form of HMC (70.9%), followed by damage to property and infrastructure (34.9%) and food theft from homes (28.0%). Less frequently reported issues included human health risks and negative impacts on local businesses, each accounting for 5.3%, as well as nuisance behaviors such as defecation in public areas (2.6%) (Poornima et al., 2022).

On the other hand, health risk caused from the proximity of monkeys who are acting as reservoirs for gastrointestinal parasites could transmit diseases to humans who are dealing with the HMC frequently. Higher parasite prevalence was observed in monkeys with frequent human contact, indicating increased zoonotic risk in such environments. A coprological survey conducted in the Kandy area analyzed 105 samples from *Macaca sinica* for zoonotic pathogens (Mendis, 2016). The study identified four protozoan cysts (*Entamoeba coli*, *E. histolytica/dispar*, *Giardia spp.*, *Balantidium coli*), four helminth egg types (*Strongyle/Strongyloides spp.*, *Trichuris spp.*, *Enterobius spp.*, *Bertiella spp.*), and one bacterial species (*Shigella sp.*). Similarly, another island wide study on the gastrointestinal parasites of *S. vetulus* found that this species also poses considerable health risk to humans. The most prevalent helminths detected were *Trichuris* *trichiura* and *Ascaris lumbricoides*, alongside protozoan parasites, further highlighting the potential for cross-species transmission in shared habitats (Weerasekara et al., 2021).

2.2 Why do monkeys forage on crops?

Primates are among the most successful groups of crop raiders, with macaques (*Macaca* spp.), baboons, vervet monkeys, and tantalus monkeys dominating the literature on primate crop foraging (Hill, 1997). This prominence is largely attributed to their intelligence, adaptability, aggression, broad dietary range, complex social organization, and cooperative behaviors (Sillero-Zubiri and Switzer, 2001). These traits provide them with an advantage during crop raiding, as they can collaborate to maximize their foraging success. However, crop raiding poses significant survival risks due to human and human-induced deterrents, including electrocution and the use of hunting dogs. Despite these risks, engaging in high-risk foraging appears to be predominantly a male strategy aimed at accessing high-quality food resources necessary to sustain larger body size, which in turn confers reproductive advantages (chimpanzees; Wilson et al., 2007). Another perspective suggests that primates use crops as ‘fallback’ foods, consumed in response to the scarcity of preferred natural foods or to optimize nutritional intake (Lambert and Rothman, 2015). However, understanding the parameters that drive crop foraging behavior is essential to elucidating its dynamics (Hill, 2017).

2.3 Threats to monkeys arising from HMC

Although there is widespread concern regarding the decline of wildlife populations, public perception often contrasts with this trend, particularly in the case of monkeys, which are frequently viewed as increasing in number. In Sri Lanka, most reports highlighting a rise in monkey populations originate from mass media sources. The IUCN report highlights that the locally concentrated populations of pest monkeys near towns or temples is not representative of the very low *M. sinica* population densities in undisturbed natural habitats for this species or its subspecies (Dittus, 2020). For another instance, 82% of the people believed that monkey population had increased over the years from an island wide survey on human perception (Nahallage et al., 2008). However, there is currently no accurate and updated systematic, island-wide monkey survey that provides reliable estimates of population sizes or trends for the three monkey species, making it difficult to draw definitive conclusions.

Species most exposed to conflict are also shown to be more prone to extinction because of human induced injuries or deaths where these can be either accidental, such as road traffic and railway accidents, electrocution or intentional, caused by retaliatory shooting, poison or capture (Ogada et al., 2003). Such human-induced mortality affects not only the population viability of some of the most endangered species but also has broader environmental impacts on ecosystem equilibrium and biodiversity preservation (Distefano, 2005). This perception may be further intensified when the species in question are considered a pest, such as monkeys. Nahallage et al. (2008) reported that the most cited causes of primate deaths included predation by dogs (26%), leopards (18%), crocodiles (8%), and pythons (8%). Additionally, 21% of interviewees indicated that there were no natural predators of monkeys in their areas. Other reported causes of mortality included electrocution from power lines (13%), hunting (8%), and roadkill (3%).

However, recent IUCN reports indicate that all three monkey species in Sri Lanka are threatened by population declines. Among them, *S. vetulus* is experiencing the most severe decline. S. *v. nestor* is frequently observed in small, widely scattered groups, suggesting a decreasing population and local extirpations in parts of its range (Rudran, 2007). It is confined to a highly fragmented area of approximately 1,900 km² in the western wet zone in early 2000 (Molur et al., 2003). But if this trend continues unchecked, it could eventually lead to extinction across its entire range. Further, Molur et al. (2003) identified key threats to this taxon, including habitat encroachment from crop plantations, grazing, shifting agriculture, timber extraction, road development, soil erosion, deforestation, poisoning to prevent crop raiding, and hunting for traditional medicine and food. Occasional hunting for meat and the use of pelts for drum-making also threaten *S. v. vetulus*. Meanwhile, *S. v. monticola* suffered extensive habitat loss when 80% of the hill country forests were cleared for tea plantations in the 19th century. *S. v. philbricki* has faced persistent threats from deforestation due to shifting agriculture and colonization schemes, which were further intensified by the Mahaweli Agricultural Development Scheme initiated in 1978, leading to additional habitat loss for this subspecies. Alternatively, solutions for the HMC could turn out as threat to the populations. Particular to *M. sinica* population size concerns are the translocation of pest macaques to ecologically unsuitable habitats which cannot support the survival of translocated macaques (Dittus, 2012).

3. Current Practices and Mitigation Plans

It is evident that current practices and mitigation plans are not fully success but they are addressing the HMC and managing to a certain level. These traditional practices can be categorized into two categories namely active methods and passive methods (Hill, 2018). Active methods include guarding and chasing animals using dogs, slingshots, firecrackers, bells and other noisemakers, and even culling. Whereas passive methods such as barriers, traps, poisons and visual and olfactory repellents (Hill, 2018). Guarding is more common in wildlife conflicts with elephants unlike in HMC, but farmers who are involved in commercial scale do involve in guarding against the monkey raids to their land. However, guarding is costly in terms of people's time and labour and may conflict with other household labour needs (Hill, 2004). most employed strategy for HMC is lighting firecrackers (99%: Wijethilaka et al., 2021; 37%: Nahallage et al., 2008, 66.7%: Dela, 2011), throwing stones (41%: Wijethilaka et al., 2021;16%: Nahallage et al., 2008; 27.9%: Dela, 2011) and making loud noises (26%: Wijethilaka et al., 2021; 8%: Nahallage et al., 2008), shooting with pellet guns or catapults (18%: Wijethilaka et al., 2021; 6%: Nahallage et al., 2008).

On the other hand, people used to have physical barriers who are more frequently suffer from monkey invasions, where their home garden or farmland is used to be a part of home range of monkeys. Because Barriers have the function of preventing spatial overlapping among wild animals and local communities; they are usually man-made may be a mettle mesh to block the path. Sometimes this mesh can be equipped with electricity (4%: Wijethilaka et al., 2021). As visual repellent methods, most farmers use coloured flags, umbrellas and cloths, mirrors, different masks, scarecrows and traditional bali roopa and applying black oil (Nahallage et al., 2008). An experimental approach involved testing leopard urine as an olfactory repellent; however, the results were inconclusive. Additionally, sound-based repellent devices have been employed to alter monkey movement patterns. These interventions were conducted by the Faculty of Veterinary Medicine, University of Peradeniya, Sri Lanka (pers. comm.).

Furthermore, various population control measures for monkeys have been explored in Sri Lanka (Mendis and Dangolla, 2016). These include medical castration of males through formalin injections (Samal et al., 2014), the insertion of human intrauterine loops in females (Samal et al., 2014), and surgical ovariohysterectomy combined with rabies and tetanus vaccination, followed by rehabilitation into the wild (Mendis and Dangolla, 2016). However, the effectiveness of implementing these interventions on only a subset of individuals within a troop in curbing overall population growth remains uncertain. Additionally, translocation of selected monkey troops has been tested as a management strategy. For instance, in Mahakanda village, Kandy, a capture program was implemented where a significant proportion of individuals from several troops were captured, surgically treated, and translocated (Jayalath, 2011).

Despite this effort, monkeys from adjacent areas infiltrated the region within 6-7 months. Although these newcomers were initially non-destructive, they gradually began exhibiting crop-raiding behavior (Jayalath and Dangolla, 2011). Another recent practice involves the capture and translocation of so-called ‘troublesome’ monkeys from urban areas to forested regions, such as Yala National Park in Sri Lanka. This activity is often carried out by individuals with limited scientific training but is conducted with the support or approval of authorized bodies and organizations. Thence this sort of translocation of monkeys from low-forest areas to forested regions seems to be politically popular but goes against ecological principles (Dittus et al., 2021). However, these efforts may offer short-term relief, they risk ecological imbalance and, in essence, result in relocating the HMC rather than resolving it.

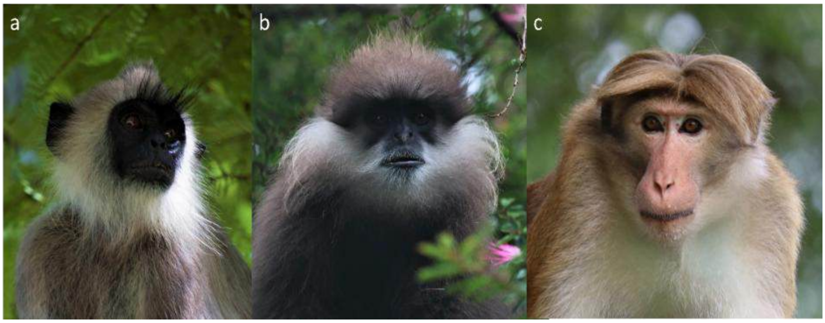

Fig 1. Three species of diurnal primates in Sri Lanka: a. *Semnopithecus priam*, b. *Semnopithecus vetulus*, c. *Macaca sinica*.

4. Recommendations and Challenges

People's hostility is typically inconsistent and tends to surface primarily when individuals experience direct damage to crops or property from the HMC. For instance, Dittus et al. (2019) reported that 50% of residents in the Polonnaruwa, Dambulla, and Matale districts expressed fondness for monkeys appreciating their playfulness and intelligence yet preferred that the animals not to enter their property due to the associated damage. In such instances, people may respond aggressively, sometimes even resorting to harming or killing the animals. Nevertheless, more recent survey data from Polonnaruwa District reflect more favourable public attitudes. According to Poornima et al. (2022), 63.6% of residents viewed monkeys as an integral part of nature, 27.3% believed they enhanced the beauty of the environment, and 9.1% emphasized the importance of coexistence. These findings suggest that despite ongoing conflicts, a positive baseline perception of monkeys persists, offering potential for conservation through community-based engagement and conflict mitigation.

In this context, raising public awareness and cultivating a coexistence-oriented mindset, especially regarding monkeys, is essential. Equally important are community-level reforestation efforts, which form a foundational, long-term strategy for mitigating HMC. Although such initiatives have been launched in the past such as The SPEARS Foundation's community conservation project for *S. v. nestor* (Rudran et al., 2020), such programs must be sustained and expanded. Additionally, they should begin at the school level to educate younger generations and extend to community members, including farmers and residents who experience HMC firsthand. Reforestation can also be linked to the concept of encouraging monkeys to return to forested habitats. One relevant technique is enrichment planting or diversionary feeding, which has proven effective at various sites (Hill, 2018). For example, in the Curú Wildlife Refuge in Costa Rica, fruit trees were planted to divert capuchin monkeys from commercially valuable crops (Baker and Schutt, 2005). In Japan, similar methods were employed to attract Japanese macaques away from fields, turning the initiative into a wildlife tourism opportunity (Knight, 2011). Such approaches could be adapted in Sri Lanka, provided they are guided by sound scientific knowledge. Likewise, establishing monkey corridors in fragmented habitats such as rope bridges or arboreal pathways may facilitate safe movement and reduce encounters with agricultural land. Dittus et al. (2021) suggested implementing buffer zones of 100-200 m devoid of trees as an effective deterrent. However, these measures have limitations, especially since both *S. priam* and *M. sinica* are comfortable moving terrestrially as well as arboreally.

A scientifically informed foundation is critical for all such community-based interventions. Comprehensive data on island-wide monkey population sizes, temporal fluctuations, conflict-prone groups, seasonal variation in pest behaviors, crop cycles, dietary flexibility, and ranging patterns are essential for evidence-based management. For instance, insights into dietary preferences and foraging patterns could help farmers adjust crop rotations or substitute monkey-attractive crops with less palatable alternatives. Strategic planting of buffer crops or positioning vulnerable crops in less accessible parts of farms are additional recommended practices (Hill, 2018). In a recent attempt to address these issues, the Sri Lankan government, with support from the Ministry of Agriculture, conducted a "five-minute survey" on March 15, 2025, aiming to identify agricultural pests. Despite its good intentions, the effort failed due to its poor methodology, resulting in substantial financial and human resource waste. This highlights the need for scientifically grounded approaches. Instead of rapid visual surveys, the government could invest in drone-based monitoring systems, which have proven effective and reliable. Drones equipped with thermal imaging and camera systems can monitor vast agricultural landscapes in real time, detect wildlife intrusions, and even deter animals through integrated deterrent mechanisms. A compelling case study involved the Sichuan snub-nosed monkey in China's Qinling Mountains, where drone-mounted thermal cameras achieved detection precision rates between 85.14% and 97.60% (He et al., 2025). Similar technology could be employed in Sri Lanka, contingent upon sufficient funding and technical capacity.

Such monitoring systems could also serve as platforms for initiating population control mechanisms such as for culling. Culling is a wildlife population management strategy, and its effectiveness depends on accurate baseline data. Without accurate population size data, culling could disrupt ecological balance, especially since all three Sri Lankan monkey species play crucial ecological roles, such as seed dispersal, nutrient cycling, pollination, and invertebrate population control. Nevertheless, selective culling has shown success in a few other countries. In Mauritius, macaque culling protected native bird species and reduced agricultural damage, while in Singapore, it reduced habitat degradation and interspecies competition. Despite these successes, culling remains controversial in Sri Lanka due to strong cultural and religious beliefs. Alternatively, immunocontraception offers a less invasive and potentially scalable method for population control. Pilot studies could help evaluate its feasibility in the Sri Lankan context.

Emerging technologies for monkey deterrence also offer promising solutions. Given monkeys' high cognitive abilities and adaptability, novel methods such as detection and repellent systems are crucial. One example is a system that uses passive infrared sensors to detect presence, sound analysis to identify species, ultrasonic repellents, light-emitting diode deterrents, and Global system for mobile communication alerts to notify farmers (Dissanayake and Tennakoon, 2023). Although such innovations are gaining popularity in media outlets, their efficacy and scalability require systematic testing and refinement. Another critical factor contributing to HMC is poor waste management. Inadequately managed garbage and open waste disposal sites attract monkeys to human settlements, increasing their dependence on anthropogenic food sources. A comprehensive waste management strategy should address everything from collection to disposal, and this must be implemented to mitigate this issue.

Furthermore, compensation schemes and agricultural insurance programs should be introduced as part of a broader mitigation strategy. Poornima et al., (2022) reported that only 8.8% of respondents in the Polonnaruwa District received any form of intervention support, with most lacking both advisory and instrumental assistance (air-riffles). Developing schemes to compensate for crop and property losses and encouraging innovative insurance mechanisms could substantially improve local engagement and tolerance.

Ultimately, the successful resolution of HMC in Sri Lanka depends on strong commitment and collaboration among diverse stakeholders; local governments, wildlife and forestry departments, NGOs, scientists and academics, conservationists, the tourism industry, and communities who are suffering from the conflict. Establishing partnerships, fostering compliance, and ensuring coordinated efforts can enhance the success of mitigation strategies. Crucially, the Sri Lankan government must assume a more proactive role, as it is the central policymaking authority responsible for implementing effective, science-based solutions to this pressing issue.

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Conflict of interest

Authors declare no conflict of interests.

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Chapter 08

A Brief Review of the Human–Crocodile Conflict in Sri Lanka: Past, Present and Future

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Abstract: There is a long history of conflicts between humans and crocodiles in Sri Lanka. During an island-wide survey on human-crocodile conflict (HCC) conducted from 2008 to 2010, 131 cases of attack were investigated. These cases ranged from Matara (Southern Sri Lanka) to Mankulum (Northern Sri Lanka). Of the 131 cases, 107 victims (82%) were males. Fifty-eight (45%) of the attacks took place in tanks (freshwater reservoirs), 45 (35%) in small rivers (Oya), and 22 (17%) in large rivers, and a large number of attacks, (65;50%), occurred when people were bathing. There were 31 (24%) fatal attacks, most (90%) had the body of the victim recovered. Most attacks were not the result of a casual encounter with potential prey but rather reflected deliberate predation at a location where "prey" was known to gather. Methods to prevent attacks by crocodiles are given and consider the changing face of human-crocodile conflict.

Keywords: Agricultural ecosystems, farming communities, holistic approaches, traditional knowledge

1. Introduction

Crocodiles belong to the order *Crocodylia*, with extant species classified into three families: *Alligatoridae*, *Crocodylidae*, and *Gavialidae*. Within the family *Crocodylidae*, the genus *Crocodylus* comprises 13 recognized species that are widely distributed across tropical, subtropical, and warmer temperate wetland regions of the world (Brazaitis and Watanabe, 2011; Uetz et al., 2025).

Two species of crocodiles are found in Sri Lanka. The first is the Mugger or Marsh Crocodile, *Crocodylus palustris* (Lesson, 1831) (Fig 1A & 1B). In Sinhala, it is commonly known as Häla Kimbula or Äle Kimbula. In Pali, the crocodile is referred to as *Kumbhīla*, with *Sumsumāra* as the only recorded synonym. The *Ruwanmal Nigantuwa*, a Sinhala lexicon attributed to King Parākramabāhu VI of Kotte (reigned 1412–1467 ACE) and documented by Wijayasekara in 1914, records several Sinhala names for

De Silva, A. (2026). A Brief Review of the Human-crocodile Conflict in Sri Lanka: Past, Present and Future. In: Ranil, R.H.G., Kopiyawattage, K.P.P., Weerasekera, D.S. & Chamara, R.M.S.R. (eds.). *Human−wildlife conflict of Sri Lanka*. Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka. pp. 136–158.

crocodiles, including Maswā, Awauldethi, and Naku. In English, *C. palustris* is known by a variety of names such as Mugger (derived from the Hindi word *magar*, meaning "water monster"), Tank crocodile, Marsh crocodile, Indian swamp crocodile, Freshwater crocodile, Broad-snouted crocodile (reflecting its characteristically broad snout, the broadest among living members of the genus *Crocodylus*), Stub-nosed crocodile, Ceylon Mugger, and Ceylon swamp crocodile. In Tamil, it is referred to as Kulathi muthelé or Chenganni muthelé, and Santiapillai and Wijeyamohan (2004) note that it is known as Chaanakan in Jaffna. French common names include *Crocodile des Marais*, *Crocodile Palustre*, and *Crocodile Paludéen*, while in Spanish it is called *Cocodrilo Marismeño*.

The second species present in Sri Lanka is the Saltwater or Estuarine Crocodile, *Crocodylus porosus* (Schneider, 1801) (Fig 1C & 1D). In Sinhala, it is known as Gāta Kimbula and Pita Gataya, both names referring to the knobbly texture of the skin, as well as Gorekeya (yellow breast) and Minikana Kimbula, where *Minikana* implies "man-eater." In English, it is commonly referred to as the Saltwater Crocodile, Estuarine Crocodile, or Sea Crocodile. In Tamil, it is known as Semmukhan or Semmukku muthalei, meaning "copper-coloured crocodile" (de Silva, 2024).

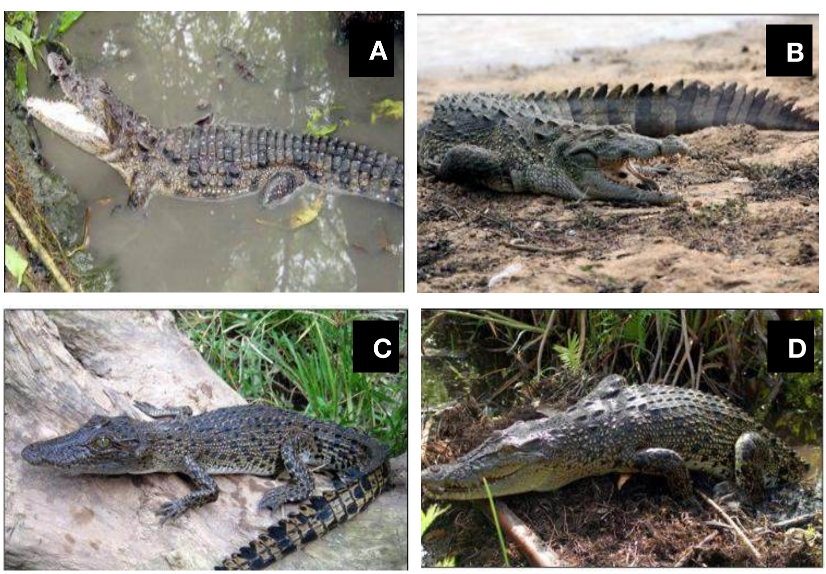

Fig 1. (A) *Crocodylus palustris* Juvenile.Photo © Anslem de Silva; (B) *Crocodylus palustris* Adult. Photo © Luxshman Nadarajha; (C)*Crocodylus porosus* Juvenile. Photo © Anslem de Silva; (D) Crocodylus *porosus* Adult. Photo © Madura de Silva

2. Natural History of Crocodiles in Sri Lanka

The Mugger (*Crocodylus palustris*) spends much of its time in various aquatic habitats such as freshwater tanks (man-made lakes), canals, agro-wells (Fig 2A), and other waterways, including occasionally hyper saline lagoons. It comes on land for several activities, such as to migrate to other aquatic habitats or to find a sheltered place deep in the jungle, usually when a tank water dries out during drought season. I have observed 'migration' many times at Yala National Park between 21:00-23:00 hours during the peak of the dry season (June to October). Movement over open land is usually undertaken in groups of up to seven crocodiles.

The Saltwater crocodile (*Crocodylus porosus*) inhabits mainly rivers, estuaries, lagoons, and the sea (most often having drifted out during floods or migrating from one canal to another canal) (de Silva, 2024). It was reported from Colombo Port. Crocodilians possess a wide array of communication capacities in the acoustic, visual, tactile, and olfactory domains, although the actual communicative function of these behaviours is still a topic of active research (Reber, 2018). Both species lay eggs, as do all crocodilians.

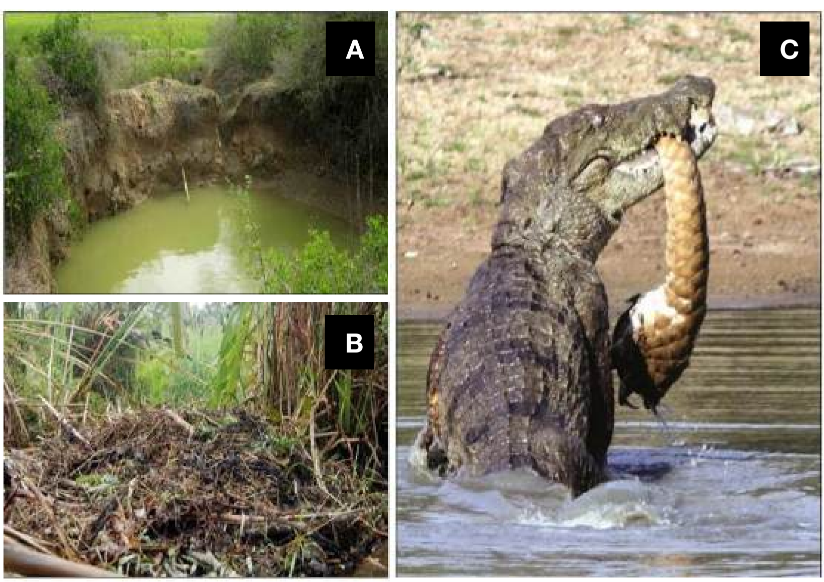

Fig 2. (A) Agro-well in Anuradhapura North Central province. Photo © Anslem de Silva; (B) Mound nest of Saltwater crocodile at habaraduwa, Southern province. Photo © Madura de Silva; (C) Pangolin (*Manis crassicaudata*) attacked by Mugger crocodile in Yala NP. Photo © J.M. Probst

There are two main nest types: the gravid Mugger digs a hole at a suitable place, lays the eggs in it, and covers the nest with soil. The

Saltwater crocodile builds a mound nest composed of scraped-together or mouth-carried organic, aquatic, or forest debris materials, into which they excavate a chamber and deposit their eggs. De Silva and de Silva (2008) observed mound nests approximately 45 cm tall and 90 cm in diameter (Fig 2B).

Crocodilians are apex predators in the reptile world. Hatchlings will hunt and consume a variety of appropriately sized prey such as insects, frogs, snails, and fish. Adults opt for larger prey, including fish, birds, snakes, chelonians, crabs, and mammals (rodents, deer, primates, including humans). We have observed two interesting prey items: 1) In Yala National Park, on December 29, 2016, at approximately 13.55 hours, a large Mugger crocodile about four meters long, situated in the middleof Siyambalagaswala (a water hole, 30m long by 20m wide), brandished a large prey item out of the water, twisted it violentlyand smashed it against the surface of the water by holding on to the tail. The prey was a large pangolin (*Manis crassicaudata*); about one metre long (Fig 2C) (de Silva, et al*.,* 2018). After a brief period, and ensuring that the prey was dead, it swallowed the pangolin. 2) On May 19, 2018, around 0950 hours in Block 1 of Yala National Park, in a small waterhole (unnamed, possibly seasonal) by the main road close to Buthuwa Plains,we observed a sub-adult (approximately two metres long) Mugger crocodile with a large Russell'sViper (*Daboia russelii*) in its mouth. The viper was thick-bodied and appeared to be at least as long as the Mugger. For about half an hour the crocodile continued biting and thrashingthe viper on the water and land before finally devouring it (Gunasinghe and de Silva, 2022).

3. Patterns of Crocodile Attacks

3. 1. Crocodile attacks in the world today

For the period 1 January 2011 to 31 December 2020, Sideleau (2021) reported 3602 attacks on humans by crocodilians worldwide, resulting in 1716 deaths. These attacks occurred in 66 countries and involved 16 crocodilian species. Fatal attacks were recorded for 10 species, although only three species were responsible for more than 100 deaths. Of these 10 species, only 2 are considered regular man-eaters: the Saltwater crocodile (*C. porosus*) and the Nile crocodile (*C. niloticus*). The Mugger crocodile (*C. palustris*) ranks in third place. The Saltwater crocodile (*C. porosus*) too is found in Sri Lanka.

Figures from the crocattack.org database for the period 2015-2024for Sri Lanka alone show that there were 91 attacks recorded:66 fatal and 25 non-fatal. From the data collected we can extract the following information for our two species (Table 1).

For the ten-year period in question, in Sri Lanka, the Mugger crocodile was responsible for a significantly higher number of both total attacks and fatal attacks than the Saltwater crocodile. This can be explained. In Sri

Lanka, the Dry zone, the biggest climatic zone which covers 65 % of the country, contains several thousand of freshwater tanks (reservoirs) which are the main habitats of the Mugger. These tanks are widely used by people for their daily activities – thus making them vulnerable to Mugger attacks. \

Table 1: Crocodile attacks in Sri Lanka 2015-2024

	Mugger			**Saltwater**			**Both species**		
Year	Fatal	Non-Fatal	All	Fatal	Non-Fatal	All	Fatal	Non-Fatal	All
2015	8	3	11	2	0	2	10	3	13
2016	4	4	8	6	1	7	10	5	15
2017	4	1	5	2	4	6	6	5	11
2018	0	0	0	2	2	4	2	2	4
2019	2	1	3	2	0	2	4	1	5
2020	4	1	5	3	1	4	7	2	9
2021	2	1	3	1	0	1	3	1	4
2022	7	1	8	4	0	4	11	1	12
2023	4	2	6	1	1	2	5	3	8
2024	6	2	8	2	0	2	8	2	10
Total	41	16	57	25	9	34	66	25	91

The data is also consistent over the longer period and regionally, although sometimes collection of accurate data is fraught with difficulty. Sideleau (2021) reported, “Within the Indian subcontinent, *C. palustris* was responsible for the highest number of reported attacks. Most of these attacks were reported from India, followed by Sri Lanka and Nepal. Low numbers of attacks were also reported from Iran and Pakistan. It is likely that some attacks went unreported in every country within the range of the species. In Sri Lanka, many attacks were reported from Eastern Province, particularly from around Batticaloa Lagoon. Both *C. palustris* and *C. porosus* are present in this area and thus far we have been unable to determine which species were responsible for most of these incidents.”

3. 2. Historical accounts of crocodile attacks in Sri Lanka

From the following accounts we can infer that negative human-crocodile interactions have been happening in Sri Lanka for many millennia. The *Sārārtha Sangrahaya*, written by physician King Buddhadāsa around 337-365 ACE, which is considered the first Sri Lankan medical treatise (Attygalle, 1917; de Silva and Uragoda, 1983), records the application of a mixture of juices of *Thikulu*(*Thikulu*is three kinds of ginger: a mixture of *Piper longum*, *P. nigrum,* and *Zingiber cylindricum*) for crocodile bite wounds. The ancient chronicle *Culavamsa*(1:70.4) records perhaps one of the first accounts of the danger posed by crocodiles to humans in the country. It records that the army of King Parākramabāhu (1153-1186 ACE) could not pass deep waters at Yatthikanda and Dumbara due to the presence of man-eating crocodiles (Geiger, 1912). The following are a few published reports of crocodile attacks in Sri Lanka listed chronologically: **(1)** Saar (1672) records the abundance of man-eating crocodiles he encountered in Negombo; **(2)** Baker (1853) reports accounts of crocodiles attacking animals and humans; **(3)** Clark (1901) states that every year a number of men, women, and children are killed by crocodiles; and **(4)** Deraniyagala (1939) reports that the Government Agent of the Southern Province had informed him that a crocodile at the Piladuva area of the Nilwala River had killed about 10 to 12 people over a period of 20 years. It had been shot on 14th June 1927. It is of interest to note that the author recorded some crocodile attacks from the same area while conducting his first survey of the crocodiles at the Nilwala River in 2008, almost 70 years after the above record (de Silva, 2008). Deraniyagala (1939) further reports that the Government Agent of the Eastern Province had informed him that fifty-three people had been devoured by crocodiles in Batticoloa district and 9 in Trincomalee between 1900 and 1925.

4. Epidemiology of Crocodile Attacks in Sri Lanka

During his island-wide survey of crocodile attacks undertaken from 2008 to 2010, the author recorded 150 attacks, 50 of them fatal. Of these, 131 cases were personally investigated by the author at locations ranging from Matara in the south to Mankulum in the north (de Silva,2010). Of the 131 attacks, 31 (24%) were fatal. Of these 31 the body was not recovered in three attacks, whereas in the other 28, the body was recovered within periods ranging between a few hours and three days. When the corpses were recovered, body parts, including legs, arms, and viscera, were found missing. Fifty-eight (45%) of the attacks took place in tanks (freshwater reservoirs), 45 (35%) in small rivers (*Oya)*, and 22 (17%) in large rivers. A large number of attacks, 65 (52%), occurred when people were bathing. Twenty-five victims (19%) were attacked while engaged in fishing activities. 107 victims (83%) of crocodile attacks were male.Ninety-eight victims (75%) had been dragged into the water by the crocodile.The anatomical part of the body (Fig 3A) of the victim attacked by the crocodile is given in Table 2 and the occupation of the victim in Tab1e 3.

Table 2. Anatomical site on the body the crocodile first attacked

Body parts	Frequency	Valid Percent
Head	10	10.4
Trunk	12	12.5
Right arm	16	16.7
Left arm	9	9.4
Buttocks	4	4.2
Right leg	25	26.0
Left leg	20	20.8
Total	96	100.0

During our study (de Silva, 2010, and de Silva et al., 2013), ninety percent of the victims of crocodile attacks interviewed by the author admitted that they were aware of the presence of crocodiles suggesting lack of such knowledge was not a primary factor, but an underestimation of risk was.

Table 3. Occupation of the victims

Occupation	Frequency	Valid Percent
Fisherman	19	19.6
Labourer/farmer	49	50.5
Housewife	5	5.2
Student	19	19.6
Others	5	5.1
Total	97	100.0

Three 'SAMEs'

The information received from the victims or the people accompanying them was that they observed crocodiles present on the opposite side of the bank 'looking' at people engaged in water-based activities, i.e., bathing, washing clothes, or some similar activities (fishing, cattle drive through water by men, over a period of time before the attack. This implies that most attacks were not the result of a casual encounter with potential prey but rather the culmination of a hunt by a crocodile at a location where prey was known to gather. The most important finding of the study was that crocodile victims visited the same place in the river or tank at the same time and did the same activity, allowing crocodiles to observe and plan their attack over a period.

5. How to Define Human-Crocodile Conflict?

Negative human-crocodile interactions are as old as humanity, as is evident from the fossil records that show that our ancestors were attacked over one million years ago. The National Geographic News, published on February 25, 2010, reported on fossil evidence of hominid bones with crocodile bite marks. These bones had been discovered in 2007 in Tanzania's fossil-rich Olduvai Gorge, the site that was home to early humans and the 1.84-million-year-old crocodile species, dubbed *Crocodylus anthropophagus*, which means "eater of humans" in Latin.

However, the everyday use of the term Human Crocodile Conflict which focuses almost exclusively on the damage crocodiles can cause to humans is a part of the problem. News headlines of "crocodile attacks" are a seller of newspapers, but their reports of an event are often scant on detail, sensational in character with headlines such as, 'Killer crocodile has taken another human victim', and light on scientific understanding and analysis. Managing the coexistence of humans and crocodiles in a mutually beneficial way is a task that requires a clear strategy, mutual respect and understanding, stakeholder buy-in and education.

The IUCN Crocodile Specialist Group use the term HCC to refer to: “any interaction which results in negative effects on human social, economic or cultural life, or on the conservation of crocodilian species and/or their habitats”. They, rightly, make the point that Crocodilians do not “make war” on humans, and using the language of conflict implies malicious intent and influences peoples’ attitudes and behaviour towards the species in question, reducing options for solutions. Framing interaction as a conflict can polarize a situation where previously a level of tolerance for occasional negative interactions was the norm.

This is important. No one can ever diminish the importance of a crocodile attack or other direct impacts, and they must be properly dealt with. The point is that they are best dealt with by shifting the emphasis away from emotional reactivity and into productive solution-finding. It also enlarges the list of causes and dynamics to consider beyond direct HCC impacts, because human-human conflicts over crocodilians may have important socio-economic, cultural and historical dimensions not directly related to crocodilians at all.

This broader understanding of HCC inevitably brings to the fore questions around the ever- increasing population of Sri Lanka, the spread of human settlements into areas that crocodiles once called home, deforestation, the increase in the road network, the higher number of vehicles, the pollution of waterways and the impact of climate change with its attendant increase in the occurrence of flooding and drought. We also see increases in the populations of wild buffalos and wild pigs (Fig 3B) in National Parks which, when they walk on bunds, they damage mugger nests and crush eggs. It seems inevitable that all these man-made impacts and more, will impact on HCC. An urgent task is to understand how.

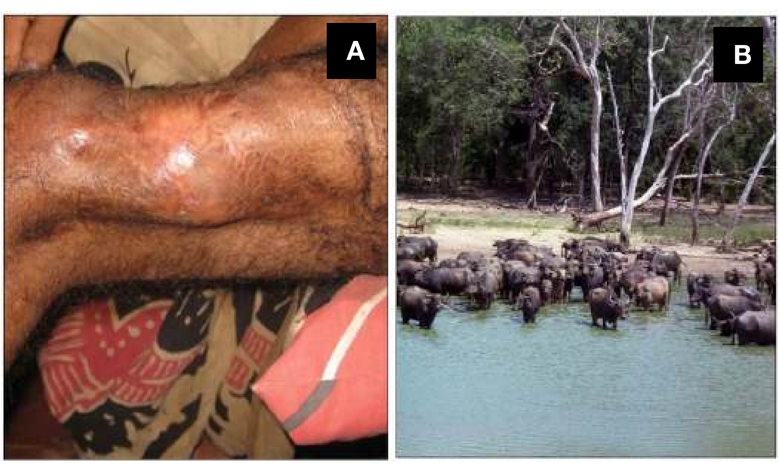

Fig 3. (A) The leg is the part of the body most often targeted. Photo © Anslem de Silva; (B) Wild buffalo at Yala NP. Photo © Anslem de Silva.

6. Is the Face of Human-Crocodile Conflict in Sri Lanka Changing?

Since the first survey of human-crocodile conflict was conducted on the island (de Silva, 2008), there have been approximately a dozen further studies. Each new survey can provide us with fresh insights, and it is through this process of continual surveying that we can better understand the changing pattern of human crocodile conflict in the country. It can also tell us whether any current strategies in use are fit for purpose.

A case in point is the 5-year (January 2008 to December 2012) study undertaken by Amarasinghe et al., (2015) into HCC and conservation implications as they relate to the Saltwater crocodile. Their report contains a wealth of information on 33 cases of Saltwater crocodile attacks on humans (of which eight were fatal and 25 non-fatal) but also on the killing of 17 crocodiles out of fear, 200 incidents of killing for meat and skins, over 800 eggs collected annually for consumption and 10 incidents of crocodiles being run over by trains/vehicles or electrocuted. However, a vitally important part of their report is its in-depth look at the results of the translocation of "problem" Saltwater crocodiles. They conclude that "the effectiveness of translocation as a suitable management option for the mitigation of HCC with Saltwater Crocodiles within a Sri Lankan context. We suggest that only 'problem' crocodiles which have been involved in attacks or which pose a real threat to humans and livestock be captured and translocated, and that this be to captive facilities."

Another groundbreaking piece of work is the report produced by Dinal J.S. Samarasinghe of the Young Zoologists' Association, on HCC in the Nilwala River, Matara (Samarasinghe, 2014). The report shows the importance of structuring a project effectively and identifying what you want to achieve.

Its "Main Objective" is boldly stated and ambitious: "To understand root causes of the human-crocodile conflict, identify the barriers to overcome the problem, identify conservation strategies and propose recommendations to conserve crocodiles, to enhance human well-being in the area and minimize conflict between the two."

Its "Specific Objectives" provide a route-map to the goal:

- Identify the possible causes of the conflict
- Assess the attitude and knowledge of villagers about the crocodiles they coexist with
- Gather information from villagers about their recommendations on solving the conflict
- Understand villagers' attitudes towards proposed recommendations and solutions to responsible government authorities for implementation

The report ends with a set of short- and long-term solutions and recommendations that are prioritized by importance with likely implementers identified.

Short-term solutions with a high priority are awareness programmes, provision of public bathing places and construction of Crocodile Excluding Fences (CEFs) and Type 3 Crocodile Excluding Enclosures (there are 3 main types of CEEs in the Nilwala river, Type 1 – small, approximately 2m x 3m, wooden enclosures for personal use built by the householder(Figure 10), Type 2 – built by people for communal use and constructed of thick Kitul palm (*Caryota urens*) planks or long hard wooden poles firmly driven into the riverbed (Fig 4B), Type 3 – large public CEEs erected using metal wire and galvanized pipes by the Disaster Management Coordination Unit, Matara and Village Councils) (Fig 4C).

Longer term solutions with a high priority are firstly, provision of alternative water sources - dug wells in appropriate areas, piped drinking water supplied by the National Water Supply and Drainage Board. Also, the systematic study on population, ecology, home range utility, territoriality and site fidelity of both male and female crocodiles inhabiting the Nilwala River to be conducted to identify highly populated locations, breeding sites, problem crocodiles and seasonal variations of crocodile populations.

There are a host of other practical solutions and recommendations reported to address the HCC issue in this one location – but the methodology used is repeatable. Rohan Pethiyagoda had this to say in the *Foreword* to the Report: "Applying a repeatable methodology…he assessed the problem from both the human and crocodilian points of view and developed simple solutions that, importantly, are also practical and inexpensive to implement. If put into practice, there is no doubt that the interventions proposed in this work will drastically reduce human-crocodile tensions wherever they occur" (Pethiyagoda, 2014).

Another study based on the Nilwala area by Uluwadugeet al. (2018) also recognised the scale of the problem in this locality. In seeking to address the root cause of the problem – use of the river for daily needs such as drinking, bathing, washing clothes and fishing, population rise, sand mining, unauthorized buildings in the riverbank, scrub jungles, slow flowing of river – they recommended that whilst awareness and more CEE's were necessary, the solutions needed to go further. Their research also showed that introducing alternative long term water sources such as government water supply to households, bathing tanks, dug wells etc., is required. They also recommended the implementation of poverty alleviation and community development programmes as well as a national mitigation plan.

Each of the above studies pointed to the negative impacts of sand mining which has resulted in the changing of rivers physically, geologically and chemically. In the Nilwala river case, mining and its associated changes have enabled the entrance of seawater further upstream and to tributaries and the spread of crocodiles into inhabited areas where they did not previously thrive. Another common feature of the studies is danger associated with the dumping of garbage into rivers, particularly products associated with slaughterhouses or farms. We suggest informing slaughter houses and farms to bury their garbage.

In my 145-page monograph "Crocodiles of Sri Lanka" published in *Wild Lanka* journal in 2024, I dedicated a section to climate change and outlined some of the ways that this global threat might negatively impact crocodiles in Sri Lanka. This research area is at an early stage but possible outcomes including more flooding, higher temperatures, changes in water salinity, reduced water flows, changed water levels, more crocodile migration due to changed habitat conditions and others are all going to affect HCC. Early this year (2025) we saw how Yala National Park was flooded. With the water taking some days to subside, we do not yet know the impact of the water covering the Mugger nests.

The most recent study has been undertaken by Wijesundara and Karawita (2024). It investigates the patterns and underlying factors contributing to human-crocodile conflicts in Sri Lanka with a focus on identifying conflict hotspots, evaluating the approximate body size of crocodile in relation to age, habitat characteristics, and proposes strategies for mitigation and coexistence. Importantly, it covers the period 2010 to 2024, thus covering the period since my own study.

To date their detailed findings have not been published but a conference paper produced indicates that the conclusions will be exceedingly interesting. Without, so far, producing supporting numbers they reference an increasing frequency of human-crocodile conflicts in Sri Lanka, and they also highlight the Nilwala River as a particular conflict hotspot. Of particular interest are these findings:

- Their spatial analysis revealed that 40% of conflicts occurred in suburban areas, such as residential outskirts and semi-urban neighbourhoods. Another 40% were documented in urban environments including cities and densely populated regions, while 20% occurred in rural settings, such as villages and croplands. We think the point is that the animals have not come to the people, but the people have come to the animal habitats i.e. increased urbanization, people moving into crocodile habitats.

- Conflict-prone water bodies included rivers and estuaries, accounting for 46% of the recorded incidents with a notable concentration along the Nilwala River, highlighting it as a conflict hotspot. Lagoons accounted for 28%, while stagnant water bodies were involved in 26% of cases.

- The approximate size of crocodiles in relation to their age was a critical factor in conflict occurrence, with adult crocodiles (≥2.5 m) implicated in 40% of incidents, sub adults (1.5–2.5 m) in 50%, and juveniles (<1.5 m) in 10%. The presence of juvenile crocodiles in high-conflict areas suggests that these regions may also serve as breeding habitats, potentially increasing the risk of future conflict.

- A rise in incidents in post-2015 correlates with habitat loss and human encroachment into crocodile habitats. This underscores the importance of developing comprehensive conservation strategies focused on habitat protection, conflict mitigation, and raising public awareness, especially in high-risk areas near rivers and estuaries. Proactive measures, such as safeguarding breeding grounds and implementing community-based monitoring programs, are essential for reducing human-crocodile encounters and fostering peaceful coexistence.

When I conducted my first crocodile survey, I described crocodile attacks on humans as a "rural occupational hazard" but, as Wijesundara and Karawita report, where, how and why any negative interactions with crocodiles occur has and will change. As shown by their spatial analysis, it is no longer mainly a "rural" issue. Our goal is to monitor these changes to ensure the strategies we have in place always are, and will remain, fit for purpose for the time and place.

7. Managing HCC Effectively

Crocodile attacks on humans mainly occur because people who live beside rivers, streams, and in the vicinity of tanks depend on these water bodies for their domestic needs, such as bathing, drinking, and washing clothes. Some water bodies also provide opportunities for a livelihood, such as fishing or harvesting aquatic and semi-aquatic edible and non-edible plants for their own consumption or for sale. The water courses are also used by the livestock or pets of the local people. Crocodile attacks result in injuries that range from minor to major, including disfigurement, loss of limbs, and even death. There are reports of crocodiles consuming their human victims, with no recovery of any body parts. In addition to the risks to life and limb, conflict with crocodiles has social, economic and emotional ramifications for the local people.

It is important, however, to understand that HCC is much more than crocodile attacks. Other causes listed by the IUCN Crocodile Specialist Group include:

1. Competition for fish – real or perceived (subsistence, recreational or commercial fishing);
2. Damage to fishing gear, notably nets.
3. Reduced access to aquatic habitats because of the danger posed by crocodilians or through exclusion by conservation efforts.
4. Opportunity costs of avoiding or going around crocodilian habitat.
5. Lost income (or potential income) from tourism and other aquatic activities, including aquaculture, made risky by the presence of crocodilians (there are of course benefits to the presence of crocodilians too); and,
6. Structural damage caused when crocodilians burrow into dam walls and under roads or other structures.

It is also vital that we never forget the other side of the same coin, that is the causes of HCC relating to human behaviour impacting on crocodilians (i.e. of conservation concern). These include:

1. Risky behaviour in crocodilian habitat resulting from poverty and lack of resources, and/or ignorance of crocodilian behaviour, intelligence and biology.
2. Alcohol- or drug-fuelled irresponsible behaviour including deliberate provocation of crocodilians.
3. Killing or capture of crocodilians for commercial or non-commercial gain: for food, skins (leather), ingredients for medicine or magic, for sale or to keep as pets, pre-emptive killing or retribution because of a real or perceived threat, for sport or "fun", or out of machismo or a desire for media attention.
4. Incidental capture in fishing gear and the resulting unintentional or deliberate killing.
5. Habitat destruction and encroachment into crocodilian habitat (construction, sand mining, tourist activities, etc.).
6. Competition for wild prey; and,
7. Water pollution and ecologically harmful levels of water extraction.

It is natural that over time, people have resorted to various forms of preventive methods, including various forms of spiritual or occult belief and the use of herbal repellents to protect themselves and their livelihoods. Currently these practices are dying out, but two traditional practices are given here.

7.1. Herbal crocodile repellents

The use of herbal pills as crocodile repellents is known in Sri Lanka. The preparation is called *Bhagawath JeewaraGuliya*, and de Alwis (1948) lists all the plants, seeds, and other ingredients needed to prepare this pill. De Alwis also describes the mystical traditions that one should follow when making this type of medicine. Once the mixture is put into the river or tank where crocodiles live, the belief is that no one needs to fear a crocodile attack.

7.2. Spiritual or occult practices

A granite stone artifact with an engraved charm and a talisman (Fig 4D) is presently housed in the *Dutugemunu Temple* at the *SandarawelaRathnasaraPrivena*, in Ganegama at Baddegama (Southern Province). According to Rohanadeera (2007) the charm starts with salutations to Lord Buddha and various deities and then invokes protection for all humans from male and female crocodiles. It ends with a verse that reads '*…this is the crocodile charm that tied the crocodiles and she crocodiles*', suggesting that due to this charm, the crocodiles will not be able to attack humans, cattle, and buffalos in this particular body of water.

This inscribed block of granite (dating from circa 1469-1474 ACE) had been found in the Gin Ganga River at Baddegama (similar granite stone artifact was found at Thelwatta, Peraliya Thotagamuwa temple). Rohanadeera (pers. comm. 2010), suggests that this charm and talisman is the work of Ven. Thotagamuwe Rahula, a high priest. He was a reputed scholar who was well-known throughout the country as being well versed in charms and the occult.

Fig 4. (A) Type 1 Personal CEE at Nilwala river, Matara Photo © Anslem de Silva; (B)Type 2 Kitul palm CEE at Nilwala river, Matara. Photo © Anslem de Silva; (C) Type 3 Metal CEE at Nilwala river, Matara. Photo © Anslem de Silva; (D) Engraved talisman presently housed in the Dutugemunu Temple. Photo © Anslem de Silva.

Currently, it is unacceptable to think of crocodile attacks and resultant injuries to humans as being some sort of occupational hazard. Whilst it is not realistic to say that the dangers can be eliminated, it is realistic to say that given the necessary commitment to action that people can be protected to a degree that is far in advance of anything that has been achieved to date. Equally, our two species of crocodiles are mainly under severe threat, and it is equally true that they need and deserve enhanced protection. Estimates of crocodile numbers in Sri Lanka are hard to discern but a Mugger survey conducted from 2015 to 2017, indicated that *C. palustris* were inhabiting 1673 bodies of water in nine provinces of the country with a total of 7516 adult Muggers counted. The highest number of Muggers observed was in the Eastern Province (1868), followed by the Southern Province (1480) (Rathnasiri et al., 2018). The highest populations were in wildlife protected areas, such as Yala, Bundala, Maduruoya, Gal oyakumana, Chundikulam, Panama, Yodhawewa, and Wilpattu.In a very recent paper Bors et al., (2024) had this to say regarding the Mugger:

"While populations in the two mentioned national parks [Wilpattu andYala] have a high chance of survival, being less threatened by habitat loss, crocodiles inhabiting unprotected areas are considerably more at risk. There seem to be no migration corridors between the national parks, which likely contributes to lower genetic diversity. It would be possible to rehabilitate these populations, considering the number of available habitats in the form of man-made tanks. However, it would require intense education efforts to teach local communities safety measures to coexist with crocodiles and the role of crocodiles in maintaining stable ecosystems.

As regards the Saltwater crocodile, in their 2015 research Amarasinghe et al. (2015) gave what they described as a conservative estimate for the non-hatchling size of the Sri Lankan population of 2000. Effective HCC strategies will benefit both humans and crocodiles.

Listed below are some measures that can form a robust strategy for dealing with HCC in Sri Lanka. Some are short term, some are long term, some can be implemented locally, others have to be managed at a higher level of governance. The art of effective management of the risks is to have local buy-ins and the right measures in the right place at the right time. Perhaps it is better to consider this list as a menu to choose from!

7.3. Awareness programmes

The call for awareness programmes is a regular feature of most reports into HCC but, in truth, there is no "one size fits all" answer to the question "what is a crocodile awareness programme?" It is better to think of it in terms of a strategy of education, research, planning and outreach. It is also best to think about what will work at the local level. It is a truism that long-term coexistence with crocodilians can only be achieved if the community values crocodilians, and the values outweigh any detrimental impacts of coexistence. Value can be either ecological, intrinsic, cultural, or economic (e.g. eco-tourism). The more of these values that can be achieved or leveraged the greater the chance of sustainable coexistence (Amarasinghe et al., 2015).

Samarasinghe (2014) stresses the importance of increasing the public's general knowledge as to the important elements of crocodile ecology (e.g. habitat and micro-habitat selection), behaviour (e.g. hunting strategies), breeding (breeding season and nest sites, etc.). Our studies indicate that it is necessary that target groups are informed during awareness programmes to change the timing and the place of the water-based activities – avoiding the 3 SAMEs. Working with schools is a productive approach as is community involvement. This can include approaches like community monitoring schemes, training in observing and handling crocodilians, as well as educational talks, drama and interactive activities.

As an important component of awareness, it is crucial for *all* stakeholders associated with crocodiles to possess a comprehensive understanding of the importance of these animals. This knowledge is essential for effectively educating the public. During our awareness programs, we frequently encountered questions such as “Are crocodiles important to humans?”, “Why should we conserve crocodiles?” and “How can we escape if a crocodile grab us?” Therefore, equipping these individuals with relevant knowledge is essential in addressing these inquiries and promoting public awareness. We give below just a couple of points to underline the importance of crocodiles:

- A study on the Nile River system in Africa has shown that wherever crocodiles were exterminated, the tilapia *(Tilapia mossambica)* fishery has declined (Cott, 1961). This is because crocodiles feed on the voracious catfish, which feed predominantly on the eggs and youth of the commercially desirable tilapia. Thus, if crocodiles were protected, the tilapia population would increase.

- The maintenance of wet refuges during droughts is important. Mugger crocodile burrows, which are dug into banks of streams, tanks, and rivers, serve as this refugia. They are typically 5 to 10 meters long and have temperatures at least 3 to 5 degrees Celsius lower than the ambient temperature. These burrows provide a cool and sheltered environment for amphibians, and fresh water turtles and insect species during the dry seasons.

However, this area needs much more research. Sri Lankan scientist Ruchira Somaweera and co-authors investigated the ecological importance of crocodylians and concluded that “most claims regarding the importance of crocodylians as apex predators, keystone species, ecosystem engineers, and as contributors to nutrient and energy translocation across ecosystems are mostly unsubstantiated speculation, drawn from anecdotal observations made during research carried out primarily for other purposes. There is a paucity of biological research targeted directly at: understanding population dynamics; trophic interactions within their ecological communities; and quantifying the short- and long-term ecological impacts of crocodylian population declines, extirpations, and recoveries. Conservation practices ideally need evidence-based planning, decision making and justification. Addressing the knowledge gaps identified here will be important for achieving effective conservation of crocodylians” (Somaweera et al., 2020). Some medical benefits have been identified:

- Thailand has produced capsules of freeze-dried crocodile blood, which are effective in managing iron deficiency/anaemia in people. The use of crocodiles for medicinal purposes is beneficial to human health. The effects of Alligator Leukocytic Peptides on antibiotic-resistant human bacterial pathogens have been studied. Clinical isolates of human pathogenic bacteria, known to be resistant to multiple antibiotics, were treated with refined leukocyte extracts from the American alligator (*Alligator mississippiensis*). The results showed a concentration-dependent reduction in bacterial growth. Among the tested bacteria, the alligator leukocyte extract demonstrated the strongest antibacterial effect on *Klebsiella pneumoniae* and *Acinetobacter baumannii*, followed by *Enterococcus faecium* and *Pseudomonas aeruginosa* (Merchant et al., 2008). The first Thai FDA-approved crocodile blood capsule made from freeze-dried, farmed Siamese Crocodile (*C. siamensis*) produced by Sriracha Moda Company Limited and marketed as MODAPLAS® is used as an iron supplement. Protein is purported to "repair body damage, reduce stress, and maintain good body condition" (Temsiripong, 2009). Another study in the Philippines has shown that the serum of *C. porosus* exhibited antibacterial properties against human pathogens *Enterobacter* aerogenes, *Pseudomonas aeruginosa*, *Enterococcus faecalis*, and *Bacillus subtilis* (Subosa et al., 2008).

7.4. Signage

'Warning signs' placed in areas of crocodilian habitat, particularly where attacks have occurred in the past have proven useful in some areas. The design of the sign is important, and it may be useful to use more intimidating photos of crocodiles on them. Reports of attacks along the Nilwala River decreased following the erection of warning signs with a "scary" looking very large Saltwater crocodile on them. Look at the sign used for mugger at Sigiriya (Figure 14) and compare it with the sign used along the Nilwala for the saltwater crocodile (Figure 15). Which would you take more notice of!

7.5. Crocodile-excluding enclosures and crocodile exclusion fences

Crocodile Exclusion Enclosures (CEEs) are enclosures built along the banks of water bodies to reduce the frequency of crocodile attacks on residents (See Fig 4A,4B & 4C). These enclosures are predominantly used in freshwater habitats in areas where people rely on water bodies for bathing, collecting water, washing clothes and utensils. Some of the CEEs are for personal use built by them, some by local village councils and by NGO's and by the author (Somaweera and de Silva, 2013). These enclosures can be VERY effective at reducing attacks, but CEEs MUST be maintained, and, obviously, CEEs must be used! Metal and wire enclosures with gates that can be secured when not in use are the most effective, but if they are not maintained, CEEs can rust and develop holes that can allow crocodiles entry. This has already resulted in at least one attack along the Nilwala River in Sri Lanka, where an 18-year-old young girl was killed by a Salt water crocodile (*Crocodylus porosus*) that had entered a poorly maintained CEE. In this case and in several other CEE's we observed during our survey (de Silva, 2010) the CEE were not maintained by the installation of new poles for missing ones. To address this type of issue Samarasinghe (2014) suggests that a committee of local users be formed to clean and maintain CEEs to a set schedule. This committee can also collect a small amount of money monthly from users and utilize this money to cover costs. Crocodile Exclusion Fences are erected by households living next to a watercourse but are less effective than CEEs (Figure 16).

7.6. Establishment of public/individual bathing facilities on land and alternative water sources

Evidence suggests that these can be popular and effective measures but will often be beyond the means of individuals or many NGOs to provide and they will need the relevant authorities to come on board.

7.7. Sand mining

As noted in the various reports quoted here sand mining has had a range of negative impacts including ingress of saltwater, river level changes, changes of food items (eg. Food fish's species composition, alterations to flood plains and vegetation structure. Illegal mining should be stopped through enforcement actions and permits for legal activity should only be issued after appropriate impact analysis. These need to include impacts on fauna and flora, and in crocodile-rich areas, specific consideration of crocodiles.

7.8. Garbage clearance and pollution control

Dumping of waste, especially from slaughterhouses and other food processing facilities, has been a proven magnet in attracting crocodiles to areas where people work. Local government or NGOs concerned with community development should take a lead in clearing existing river-based garbage dumps and promoting recycling or incineration as alternatives going forward.

7.9. Crocodile vigilance zones

In their study of the Saltwater crocodile Amarasinghe et al. (2015), recognised that different areas of the country have commonalities when it comes to HCC but there can also be important differences. By recognising these important facts, one is better able to develop the correct suite of actions. They identified five zones of high HCC incidence which they referred to as "Crocodile Vigilance Zones" (CVZ). Four of these are within the wet zone (Matara-Malimbada-Akuressa; Beruwala-Bentota-Ambalangoda; Moratuwa-Dehiwala-Wellawatta; Ragama-Hendala-Wattala) and one in the dry zone(Kalmune-Batticaloa-Eravur-Kalkuda). They stress that there is a risk of increasing HCC within these zones and the possibility of it spreading to surrounding areas in the future unless proper management actions are implemented. This approach has merit.

7.10. Translocation

Large Saltwater crocodiles captured around Colombo and the Nilwala River, were released in Udawalawe, Bundala, and Yala National Parks which are the prime Mugger habitats in the country. There is already enough evidence to show the damage these translocated Saltwater crocodiles have done to other crocodiles. Translocated Saltwater crocodiles have previously killed a visitor to the park, they have attacked and killed Muggers, and a few have died, possibly due to the stress of transport or being injured during capture. Additionally, the ‘homing’ capabilities of crocodiles are well-known and have been proved to be detrimental to translocation attempts (Read et. 2007).

Both Amarasinghe et al. (2015) and Samarasinghe (2014) look at the translocation issue. The former state that in the Sri Lankan context any benefits are unclear. The latter, after going through a whole list of poor experiences from translocation, from this country and abroad goes as far as saying, “considering these events, the studies conducted in the past, and also considering the manpower, the cost of capturing and releasing animals and the lack of suitable habitats; translocations of crocodiles must be considered as a futile option for the time being”. This is broadly in line with the thinking of the IUCN Crocodile Specialist Group who say that translocation is not favoured by experienced crocodilian conservationists due to the strong homing instincts of crocodilians and the costs involved. They do, however, add that if crocodilians can be removed legitimately and safely to captive facilities like zoos, which have a conservation and education dimension to them, or crocodilian farms, this may be a feasible option.

7.11. Ex-Situ conservation

Crocodiles provide economic benefits through various means, including ecotourism and income generated from tourism that is shared with local communities. Several foreign media organizations (BBC, National Geographic) have made films on Mugger crocodiles at Yala. This international exposure has attracted many tourists and generated interest worldwide. Such income plays a crucial role in enabling the protection and sustainable development of crocodile populations and their habitats. As well as the opportunities to see crocodiles in the wild via reputable guided safaris and the like, there are several reputable centres across the globe where important conservation and education work is conducted. Perhaps the best known is the Madras Crocodile Bank Trust in Chennai, India (MCBT), which was begun by Rom and Zai Whitaker in 1976. Today, MCBT receives close to half a million visitors a year. Amarasinghe et al*.,* (2015), suggested such a reserve and even suggested a possible location. “A captive or semi-natural reserve could assist conservation efforts for crocodiles in Sri Lanka, as was suggested in the 1970s by Whitaker and Whitaker (1979). Such a reserve or facility would not only provide a site for release of problem crocodiles captured to reduce HCC but could also serve as a centre of public education, training (local and international participants), captive breeding, research and recreation (tourism). Kirala-Kale (Matara District), an 1800ha area, is considered the site with most potential.”

This proposal should be revisited. Many years back a Minister of Wildfire requested me to select a site to where nuisance crocodiles could be moved. In fact, we went as far as selecting a location in Muthurjawela marsh. The Minister, Wildlife Rangers and I went in boats to the area. Another minister suggested Matara, but nothing materialized.

7.12. Lethal control

It might not be palatable to a conservationist, but it must be accepted that lethal control is sometimes necessary when there is imminent danger of the loss of human life, or to prevent a major conflict and controversy detrimental to the cause of conservation. If possible, crocodilians should be captured and killed humanely away from the public and media.

7.13. An International dimension

We are not alone. Studies into HCC have been undertaken right across the world and there is an enormous amount we can learn from them and from international co-operation. We are indeed fortunate that Dr. Simon Pooley produces a regular "Croc Digest: A Bibliography of Human-Crocodile Interactions" which is now in its 5th edition. This "provides a first point of reference for researchers interested in human-crocodile interactions and offers policy makers and practitioners a wide range of information on and approaches to mitigating such conflicts. The material includes papers which include useful information on human-crocodile relations more broadly, but the focus remains problematic encounters" (Pooley, 2024). The current edition lists several hundred papers, including 17 on Sri Lanka.

Dr. Pooley, who is a member of the IUCN Crocodile Specialist Group's Living with Crocodilians Working Group, is in the process of initiating an important "How to Prevent Crocodile Attacks Survey". The aim is "to discover the main management actions, but also the range of kinds of actions, being used to manage negative impacts of crocodilians worldwide." The goal is "to gather information to inform expert guidance on effective strategies for preventing crocodilian attacks for managers, local authorities and others in affected areas." With the results "being analyzed, and a synthesis report written, with management recommendations. This will be published in an Open Access publication." (Pooley, 2025).

8. A Final Remark

Crocodiles will always be crocodiles and crocodiles will always act like crocodiles. That has been the case for millions of years and nothing can change that. If humankind has existed we have lived with crocodiles. We need to find ways that both crocodiles and humans can thrive together in our ever-changing world. It is not "mission impossible". By using our hearts and our minds the goal is attainable.

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Conflict of Interest

Authors have declared that no competing interests exist.

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Chapter 09

Livestock Depredation by Fishing Cat (*Prionailurus viverrinus*) in the Eastern Province, Sri Lanka

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Abstract: Livestock depredation by wildlife poses a major conservation and livelihood challenge in Sri Lanka, particularly in regions where endangered carnivores such as the Fishing Cat (*Prionailurus viverrinus*) inhabit mosaic landscapes comprising wetlands, agricultural areas, and human settlements. This study examines the dynamics of fishing cat–livestock conflict in the Eastern Province through semi-structured interviews with farmers across Trincomalee, Batticaloa, and Ampara districts, documenting 42 predation incidents between April and September 2025. Chickens experienced the highest predation pressure (64.3%), followed by ducks, rabbits, goats, and geese, with most attacks occurring during night (50%) and dawn (19%) hours, peaking at 23:00, 05:00, and 19:00. Structural vulnerability played a major role, with half of all incidents involving broken cops and nearly a quarter affecting free-ranging livestock. Statistical analysis ($\chi^2 = 22.899$, df = 15, $p = 0.086$) indicated a potential relationship between predation timing and enclosure type, highlighting nocturnal attacks on weak structures as a key risk factor. These results suggest that the conflict is localized and manageable through low-cost, targeted interventions such as strengthening enclosures, enhancing night-time security, and improving farmer awareness. Integrating ecological findings with community knowledge offers a practical path toward coexistence, reducing economic losses while promoting positive attitudes toward fishing cat conservation. Effective conflict mitigation at the farm level not only benefits rural livelihoods but also supports the long-term

Weerasekera, D.S., Kodithuwakku, S., Mdushanka, S., Udurawana, K.M., and Ranawana, K. (2026). Livestock Depredation by Fishing Cat (*Prionailurus viverrinus*) in the Eastern Province, Sri Lanka. In: Ranil, R.H.G., Kopiyawattage, K.P.P., Weerasekera, D.S. & Chamara, R.M.S.R. (eds.). *Human–wildlife conflict of Sri Lanka*. Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka. pp. 159–167.

survival of this endangered wetland carnivore and the sustainability of Sri Lanka’s human-dominated landscapes.

Keywords: Fishing cat, Livestock, Sri Lanka, Wildlife

1. Introduction

1.1. Background and context

Livestock depredation by wildlife is a major aspect of human–wildlife conflict in Sri Lanka, especially where agricultural areas overlap with habitats of threatened carnivores (Thilakarathna et al., 2021). Among these, the fishing cat (*Prionailurus viverrinus*), an endangered wetland associated species, illustrates the delicate balance between conservation and rural livelihoods (Ratnayaka et al., 2022). In the Eastern Province, fishing cats persist in fragmented wetlands interspersed with paddy fields and home gardens, where conflict with livestock keepers has become a serious conservation and livelihood concern.

The species is listed as *Endangered* on the IUCN Red List (MOE 2012,), with declines driven by wetland loss, habitat degradation, and persecution (Ratnayaka et al., 2023). Apart from mainland populations, Sri Lanka—being an island stronghold—harbours one of the most important populations of the Fishing Cat (*Prionailurus viverrinus*), where the species occupies a broad range of habitats from coastal and urban wetlands to montane areas reaching up to 1700 m elevation (Reuter et al., 2020). Smallholder farmers in these areas keep mixed livestock—mainly poultry, ducks, rabbits, goats, and geese—for food and income, often in simple or open enclosures made from local materials (Devendra et al., 2002; Perera et al., 2008). While these traditional systems suit rural conditions, their effectiveness in preventing predation by a nocturnal, semi-aquatic carnivore is largely unknown (Ratnayaka et al., 2023).

1.2. Fishing cats in agricultural landscapes

Fishing cats (6–12 kg) are known for their wetland associated lifestyle possessing webbed feet, dense water-resistant fur (Fig 1), and a preference for aquatic prey such as fish and amphibians (Ratnayaka et al., 2022). However, in human-modified landscapes, they show strong behavioral flexibility, feeding on terrestrial prey including rodents and poultry (Jayasekara et al., 2022). This adaptability allows persistence in disturbed areas but also increases conflict risk as cats exploit readily available domestic animals (Mishra et al., 2018).

Fishing cats (6–12 kg) are known for their wetland associated lifestyle possessing webbed feet, dense water-resistant fur (Plate 01), and a preference for aquatic prey such as fish and amphibians (Ratnayaka et al., 2022). However, in human-modified landscapes, they show strong behavioral flexibility, feeding on terrestrial prey including rodents and poultry (Jayasekara et al., 2022). This adaptability allows persistence in disturbed areas but also increases conflict risk as cats exploit readily available domestic animals (Mishra et al., 2018).

Fig 1. Fishing cat (*Prionailurus viverrinus*)

In the Eastern Province, agricultural expansion and wetland reclamation have intensified contact between people and small to medium-sized carnivores. Unlike leopards (*Panthera pardus*), which usually avoid settlements, Fishing Cats (*Prionailurus viverrinus*) frequently forage in home gardens and paddy fields, especially at night when livestock—particularly poultry—are poorly secured. Other mesocarnivores such as civets (*Paradoxurus* spp.) and mongooses (*Herpestes* spp.) also contribute to livestock predation and economic losses in these human-dominated landscapes.

1.3. Method of data collection – interviews with farmers

Primary data on livestock depredation by Fishing Cats (*Prionailurus viverrinus*) were collected through semi-structured interviews with 156 local farmers across the Eastern Province of Sri Lanka, covering Trincomalee (52 households), Batticaloa (61 households), and Ampara (43 households). These sites were selected based on verified records of Fishing Cat presence and reported livestock losses. A purposive sampling approach ensured inclusion of both high- and low-conflict zones, targeting respondents who owned livestock and had experienced or were aware of depredation incidents.

To ensure accurate predator identification, participants were shown color photographs of Fishing Cats and other similar-sized carnivores (e.g., civets, mongooses, domestic cats, and dogs) at the beginning of each interview. Only respondents who could reliably distinguish species based on body size, coat pattern, tail morphology, and behaviour were included in species-specific analyses. Additionally, wherever possible, reported incidents were verified in the field using multiple forms of evidence, including CCTV footage, pug marks, and fur entangled in animal enclosures, which helped confirm the identity of the predator.

Interviews were conducted in Sinhala or Tamil to facilitate clarity and reduce reporting bias. Both quantitative and qualitative data were collected, including livestock types and numbers, housing and protection methods (particularly at night), detailed descriptions of depredation incidents (species attacked, timing, and frequency), and respondent attitudes toward Fishing Cat conservation. While the study primarily focused on Fishing Cat–related incidents, respondents also reported livestock losses attributed to civets, mongooses, and stray dogs and cats, which collectively contribute to significant economic losses in these rural landscapes (Thudugala et al., 2025).

All responses were recorded using pre-tested data sheets, transcribed, and coded for analysis to identify spatial patterns of predation, risk factors, and local perceptions toward coexistence with Fishing Cats and other carnivores.

1.4. Human–wildlife conflict dynamics

Even small livestock losses can have significant economic and psychological impacts on resource-poor farmers. A single chicken may represent several days of food or income, and repeated losses can erode tolerance toward wildlife, leading to retaliatory killing. Despite the conservation importance of fishing cats, awareness and institutional support are minimal, and no formal compensation programs exist. As a result, farmers rely on ad hoc methods that often prove ineffective or harmful to conservation efforts.

2. Overall Predation Patterns

A total of 42 livestock predation incidents were documented during the study period (1st of April to 28th of September 2025). The analysis revealed distinct patterns across species composition, temporal distribution, and structural vulnerability factors that characterize predation dynamics in the study area (Figure 01).

3. Livestock Species Vulnerability

Predation incidents varied significantly across livestock species. Chickens experienced the highest predation pressure, accounting for 27 incidents (64.3% of all cases). This was followed by ducks and rabbits, each with five incidents (11.9%), goats with three incidents (7.1%), and geese with two incidents (4.8%). The predominance of chicken predation was nearly five times greater than the next most affected species, indicating disproportionate vulnerability or exposure of poultry to predation risk. This higher incidence is likely due to the greater availability of chickens compared to other livestock species in the study areas.

4. Age Class Distribution

Age class analysis revealed that adult livestock comprised the majority of predation victims, with 31 incidents (73.8%), while juveniles accounted for 11 incidents (26.2%). This pattern was not uniform across species, however. Among chickens, adults represented 22 of 27 incidents (81.5%), while juveniles accounted for only five incidents. In contrast, ducks showed a different pattern with two adult and three juvenile victims, and all three goat predation incidents involved juveniles. Rabbits and geese predation exclusively affected adults (five and two incidents respectively).

5. Time Period Analysis

Temporal analysis revealed pronounced patterns in predation timing (Figure 01). Night hours (18:00-05:59) represented the critical risk period, accounting for exactly half of all incidents (21 cases, 50%). Dawn (06:00-08:59) emerged as the second highest risk period with eight incidents (19%), followed by evening hours (12:00-17:59) with seven incidents (16.7%), and morning (09:00-11:59) with six incidents (14.3%). The combined nocturnal and dawn periods (18:00-08:59) accounted for 29 incidents, representing 69% of total predation events.

6. Hourly Resolution Patterns

Fine-scale temporal analysis identified specific high-risk hours throughout the 24-hour cycle (Fig. 2). The single highest-risk hour was 23:00, with six recorded incidents. This was followed by 05:00 and 19:00, each with four incidents. Secondary peaks occurred at 00:00, 02:00, and several other hours with three incidents each. The hourly distribution revealed two distinct risk windows: a primary late evening/early night period (22:00-02:00) encompassing 14 incidents, and a secondary dawn transition period (04:00-07:00) with seven incidents. The circular clock plot visualization (Figure 02) clearly illustrated this bimodal temporal pattern, with the concentration of incidents during nocturnal hours visually apparent in the polar histogram format.

7. Species-Specific Temporal Patterns

The relationship between livestock type and time period revealed species-specific vulnerability windows. Chickens were predated across all time periods, with the highest frequency during night hours (13 incidents), followed by dawn (six incidents), evening (five incidents), and morning (three incidents). Duck predation showed concentration in dawn and evening periods, while rabbit predation occurred predominantly during night hours.

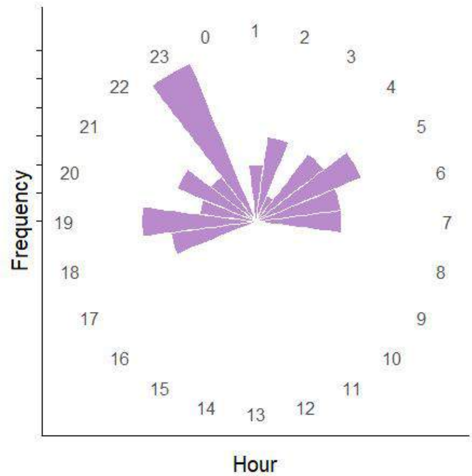

Fig 2. Time period distribution of livestock predation

8. Enclosure Type and Structural Vulnerability

Enclosure type emerged as a critical factor in predation occurrence (Fig. 3). Broken coops represented the most vulnerable housing category, associated with 21 incidents accounting for exactly 50% of all cases. Free-ranging livestock experienced ten predation incidents (23.8%), followed by wooden cages with five incidents (11.9%), weak fences with three incidents (7.1%), open sheds with two incidents (4.8%), and fenced ponds with a single incident (2.4%). The dominance of incidents involving broken coops suggests that structural integrity failure, rather than inherent design inadequacy, represents a primary vulnerability pathway.

9. Vulnerability Matrix: Livestock Type by Enclosure

Cross-tabulation of livestock type with enclosure type revealed species-specific associations with housing vulnerabilities. Chickens exhibited predation predominantly in broken coops (19 incidents) and free-ranging contexts (eight incidents), with no incidents recorded in other enclosure types. Rabbits experienced predation exclusively in wooden cages (five incidents), while all goat predation occurred in association with weak fence enclosures (three incidents). Geese predation was limited to open shed settings (two incidents), and ducks were distributed across multiple enclosure types including broken coops (two incidents), free ranging (two incidents), and fenced ponds (one incident). This matrix demonstrates that vulnerability is not solely determined by enclosure type in isolation, but rather by the interaction between livestock species characteristics and specific housing configurations.

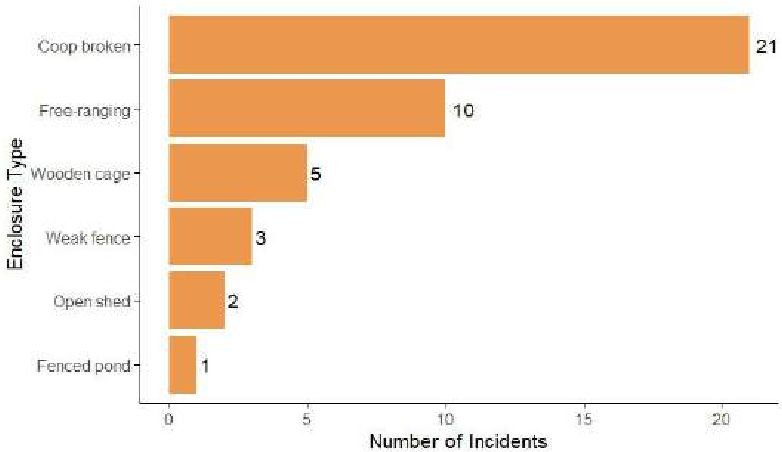

Fig 3. Enclosure Vulnerability

10. Spatial Context

Location characteristics provided additional context for predation patterns. Analysis of home garden versus farmland settings indicated that the majority of incidents occurred in home garden contexts. This spatial concentration suggests that predators may exploit areas of high livestock density in proximity to human habitation, potentially due to higher prey availability, structural complexity providing cover, or habituation to human presence.

11. Statistical Relationships

Chi-square analysis examined potential associations between temporal patterns and enclosure vulnerability and yielded a test statistic of $X^2 = 22.899$ ($df = 15$, $p = 0.086$). While this result approached but did not reach conventional statistical significance at the $\alpha = 0.05$ level, it suggests a potential relationship between temporal patterns and structural vulnerability that warrants consideration, particularly given the limited sample size of 42 incidents.

12. Peak Risk Identification

Integration of temporal and structural data identified compound risk factors. The top five peak predation hours were 23:00 (six incidents), 05:00 (four incidents), 19:00 (four incidents), 00:00 (three incidents), and 02:00 (three incidents). When combined with enclosure data, broken coops during night hours represented the single highest-risk combination, accounting for a substantial proportion of total incidents. This compound vulnerability pattern suggests that interventions targeting specific time-structure combinations may yield disproportionate benefits in predation reduction.

13. Conclusion

Livestock predation by fishing cats in the Eastern Province of Sri Lanka represents a tractable conservation challenge. Unlike conflicts involving large carnivores where spatial separation or landscape-scale interventions may be necessary, fishing cat conflict operates at a scale amenable to targeted, relatively low-cost modifications of existing husbandry practices. The clear temporal patterns, identifiable structural vulnerabilities, and species-specific risks revealed by this analysis provide multiple intervention points that address the mechanisms of driving conflict without requiring wholesale transformation of traditional farming systems.

The path forward requires integration of these empirical findings with participatory approaches that engage farming communities in intervention design and implementation. Farmers possess detailed knowledge of local conditions, constraints, and opportunities that must provide practical solutions. By combining scientific understanding of fishing cat behavior with farmer expertise in livestock management, collaborative approaches can develop context-appropriate interventions that are both effective in reducing predation and feasible within the socioeconomic realities of smallholder farming.

Success in reducing fishing cat-livestock conflict will yield benefits extending beyond individual farmers and predation incidents. Reduced conflict can transform community attitudes toward fishing cats, creating local constituencies for conservation of this endangered species. Improved livestock security enhances household food security and income stability, contributing to rural development objectives. Demonstration of effective, evidence-based conflict mitigation in the Eastern Province can provide models for addressing fishing cat conflict throughout Sri Lanka and the species' broader range, contributing to global efforts to conserve threatened carnivores in human-dominated landscapes.

The empirical patterns documented in this study—clear, consistent, and actionable—offer genuine optimism for fishing cat conservation. By understanding and addressing the specific mechanisms through which fishing cats access livestock, we can work toward a future where wetland agriculture and an endangered carnivore coexist with reduced conflict, supporting both biodiversity conservation and rural livelihoods in the complex, dynamic landscapes of Sri Lanka's Eastern Province.

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Chapter 10

Impact and Consequences of Human–Wildlife Conflict on Traditional *Chena* Cultivation Systems in Sri Lanka

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Abstract: Human–wildlife conflict (HWC) is a pressing challenge across social and agricultural landscapes in Sri Lanka. It is also evident within the *chena* cultivation system. The most immediate impact of wildlife presence in these systems has been crop damage, which undermines farmers' economic stability and fosters broader social and cultural tensions within and among farming communities. Traditionally, farmers have relied on diverse physical and cultural strategies to minimize wildlife intrusion by guarding cultivated areas, maintaining protective watch points, and deterring animals without engaging in direct conflict. Such coexistence practices significantly reduced the intensity of HWC in *chena* systems. Nevertheless, the persistent threat of crop loss has pushed farmers to intensify cultivation cycles and frequently shift to new lands, leading to considerable ecological degradation in Sri Lanka's dry-zone forests. These dynamics ultimately contributed to the nationwide prohibition of *chena* cultivation, underscoring the complex interplay between livelihoods, wildlife, and ecological sustainability.

Keywords: Human–wildlife conflict, shifting cultivation, slash and burn agriculture.

1. Introduction

Among Sri Lanka's traditional agricultural practices, *chena* cultivation, also known as slash-and-burn or shifting cultivation, represents one of the most ancient and culturally embedded systems, with origins dating back to around 400 BC (Panabokke, 2009). These *chena* systems are located near or within dry zone forests of the country, where wild animals are naturally abundant.

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However, compared to the prevailing human-wildlife conflicts (HWC) in other farming systems of the country, *chena* systems have been able to thrive for thousands of years without much harm from wild animals. The use of traditional systems, such as *dandu vata* (wooden fence), for crop protection (Ranil et al., 2025) and watch huts for farmer protection, have been some of the key features in minimizing the human-wildlife conflicts in *chena* systems. This chapter summarizes the information on key wildlife species commonly found near *chena* systems; the techniques farmers have been using to co-exist without leading to human-wildlife conflicts, and the social, cultural, and ecological impacts of HWC connected with *chena* systems in the country.

2. *Chena* Cultivation: A Traditional Agricultural System

2.1 Historical and cultural significance of chena

Historically, *chena* cultivation in Sri Lanka can be traced to early tribal communities and the pre-Anuradhapura period and is widely referenced in chronicles such as the *Mahawansa* (Irangani, 2020). Traditionally, it has been integrated into the tank-cascade village systems of Sri Lanka's dry zone (Abeywardana et al., 2019). *Chena* supported rural subsistence by complementing irrigated paddy cultivation and home gardens. Its cultural grounding is evident in more than 630 Sinhala and Tamil village names, including Ginigathhena and Chenkatpaday, which reflect its historical prevalence (Gelbert, 1988). Practices such as *pel rekeema* (crop guarding), *hoo keema* (shout deterrence), and shared labour for watch-hut construction and land clearing illustrate the communal and spiritual dimensions of the system (Shantha, 2021). Women played a central role in preserving traditional crop diversity through the selection and saving of seeds from crops such as millets, legumes, sesame, and gourds (Irangani, 2020). This practice supported household food security even under unpredictable climatic conditions (Swaminathan and Kumar, 1999). However, many of these traditions are now declining due to technological changes in agriculture, legal constraints, and the expansion of market-oriented farming.

2.2 Ecological principles

Chena cultivation is a rainfed, low-input system that typically involves the clearing and burning of forest patches or scrublands, which temporarily enrich the soil. Traditionally, large trees were left standing to protect the environment. A variety of crops such as finger millet, maize, cowpea, green gram, sesame, and chilli are cultivated on the same land, most often as mixed cropping systems, promoting resilience and reducing soil erosion. When *chena* land is cultivated for several seasons, productivity declines and farmers traditionally abandon the plot, allowing it to recover naturally into forest vegetation. Historical fallow cycles of 15–20 years supported soil regeneration and biodiversity recovery. Over time, however, population pressure has shortened these cycles, leading to reduced fertility, weed invasion, and increased human–elephant conflict due to habitat encroachment (Gunasena and Pushpakumara, 2015). Based on the vegetation present prior to clearing, *chena* lands are commonly classified as *mukalan hena* (primary forest), *nawadali hena* (secondary forest), *landu hena* (scrub), and *illuk hena* (grassland). Soil fertility within these systems is closely linked to the biomass density contributed by the original vegetation (Gunasena and Pushpakumara, 2015).

2.3 Geographic distribution

Chena is primarily practiced in Sri Lanka's dry zone, which covers nearly two-thirds of the country's land area. Districts such as Anuradhapura, Kurunegala, and Polonnaruwa represent key *chena* regions. These areas experience seasonal rainfall and limited access to irrigation, making rain-fed *chena* an essential livelihood practice. Today, *chena* cultivation persists primarily on state-owned lands, often within or adjacent to forest reserves, despite legal restrictions limiting cultivation to 0.8 ha per family per season. In 2014, this policy decision was introduced by the Government of Sri Lanka to address concerns associated with shifting cultivation. Wet-zone regions receive more reliable rainfall and have fertile soils that support plantation crops such as tea, rubber, and coconut. *Chena* is uncommon in these areas and is largely confined to marginal uplands used for short-term cultivation of tubers and vegetables (Perera, 2001).

2.4 Socio-economic role

For resource-constrained households in Sri Lanka's dry zone, *chena* cultivation continues to serve as a vital subsistence strategy. It provides a steady supply of grains, legumes, and vegetables across the farming calendar, thereby supporting household food and nutritional security. *Chena* is a low-input farming system that relies mainly on basic tools, saved seeds, and shared communal knowledge. Crop planting is timed to expected rainfall, with sowing typically occurring from September to October during the Maha season and, in some cases, a second crop grown during Yala using supplemental irrigation (Gunasena and Pushpakumara, 2015). Women play a central role in seed selection, weeding, harvesting, and daytime guarding, while men are primarily responsible for land clearing, burning, and night-time watch duties. These gendered roles reinforce household cooperation and facilitate knowledge transfer, particularly in relation to seed preservation and intercropping practices (Swaminathan and Kumar, 1999). Despite these contributions, *chena* remains marginal within national agricultural policy frameworks. Farmers often lack secure land tenure as well as access to subsidies and extension services, which are largely directed toward paddy cultivation and plantation-based agriculture. In addition, pressures arising from conservation regulations, climate change, and population growth continue to threaten the long-term viability of *chena* systems.

3. Human-Wildlife Conflict in Chena Landscapes

Daytime and nighttime guarding has become an essential component of the *chena* system due to the common wildlife damage to crops. Wildlife damage is in one way quite common because *chena* are mostly situated within or among forest areas where wildlife is abundant.

Key conflict species

3.1 Asian Elephant (Elephas maximus maximus)

The Asian elephant is a keystone species for conservation action and the principal conflict species in Sri Lanka, where expanding human settlement has reduced available habitat and increased overlap with elephant ranging areas (Gunawansa et al., 2023). Long-term patterns of human–elephant conflict (HEC), including crop loss, infrastructure damage, and human and elephant fatalities, have been documented for several decades (Fernando et al., 2005).

Since 2019, an average of approximately 125 people and 370 elephants have been killed annually as a result of this conflict, with human fatalities increasing by about 42% compared with the previous three decades (Gunawansa et al., 2023). HEC is now widely recognized as the most significant threat to elephant populations across their range, highlighting that impacts are not one-sided (Menon and Tiwari, 2019). The expansion of agriculture and human settlements has led to progressive contraction and fragmentation of elephant habitats, often isolating individuals or herds and restricting access to traditional migratory routes (Ram et al., 2021).

As mega-herbivores, elephants require extensive home ranges to meet substantial daily nutritional demands (Koirala et al., 2016; Dharmarathne et al., 2020). Adult elephants forage for 12–19 h per day and consume approximately 150–200 kg of fresh vegetation daily (Sukumar, 2003; Ong et al., 2023). They are strongly attracted to palatable crops such as bananas, maize, and sugarcane, and frequently raid agricultural fields, sometimes causing losses in a single night that exceed a household’s annual food supply (Fernando et al., 2005). Their advanced cognitive abilities, strong spatial memory, and reliance on established migratory routes contribute to repeated crop-raiding, particularly when natural forage becomes scarce within fragmented habitats (Blake et al., 2009; Katupotha and Sumanarathna, 2016). Habitat fragmentation has increasingly forced elephants to traverse agricultural mosaics, especially *chena* fields located near traditional movement corridors (Fernando et al., 2005; Köpke et al., 2021). Studies indicate that elephants may travel more than 10 km in a single night to raid crops, underscoring their adaptive foraging behavior and wide-ranging movement patterns (Leimgruber et al., 2003).

Although elephants exhibit some degree of compatibility with traditional *chena* systems, they are poorly accommodated within permanently cultivated and intensively managed agricultural landscapes. In Sri Lanka, the transition from shifting *chena* cultivation to fixed, sequential farming has intensified HEC by eliminating fallow periods, increasing continuous human presence, and further fragmenting habitats (Anuradha et al., 2019).

Traditional *chena* cultivation involves plots cultivated only part of the year and embedded within forest–agriculture mosaics, often adjacent to elephant habitats. Following harvest, fallow *chena* fields provide seasonal grazing opportunities with limited human disturbance, creating temporal separation that historically facilitated partial landscape sharing between humans and elephants (Anuradha et al., 2019). Consequently, traditional *chena* systems have supported higher levels of coexistence with elephants than permanently cultivated, intensive agricultural systems.

3.2 Wild Boar (Sus scrofa)

The wild boar has emerged as another significant conflict species in Sri Lanka's dry zone, including *chena* cultivation areas. As opportunistic omnivores, wild boars readily adapt to fragmented landscapes (Thalgaspitiya et al., 2023). Their nocturnal foraging behavior, high reproductive rate, and capacity to exploit a wide range of food resources make them persistent agricultural pests. With up to two litters per year, each typically comprising four to eight piglets, wild boar populations can increase rapidly in fragmented habitats (Keuling and Massei, 2021).

Farmers frequently report wild boars digging up newly planted tubers, consuming ripening grains, and damaging vegetables and legumes. Their characteristic rooting behavior, an ecological adaptation for exploiting underground food resources, causes particularly severe damage to root and tuber crops (Massei and Genov, 2004). *Chena* fields located near forest patches are especially vulnerable, as wild boars use surrounding vegetation cover to avoid detection while raiding crops at night. They also exhibit adaptive foraging strategies that reduce exposure to human vigilance. Landscape ecological studies indicate that habitat fragmentation increases wild boar abundance by enhancing access to food resources and reducing predation risk (Thurfjell et al., 2009). Their elusive behavior and rapid movements make deterrence difficult, and traditional protective measures, including fencing and scare tactics, often prove ineffective. Unlike elephants, however, wild boars rarely attract conservation sympathy, and management responses are therefore typically framed in terms of pest control rather than coexistence.

3.3 Toque Macaque (Macaca sinica) and Grey Langur (Semnopithecus priam)

The toque macaque and gray langur have become increasingly problematic in Sri Lanka's *chena* cultivation systems. These species thrive in fragmented environments where forest patches, fallow land, and cultivated fields are closely interwoven. Such mosaic landscapes provide both food and refuge, attracting primates and other wildlife (Dhawale et al., 2020). Toque macaques live in large social groups, often exceeding 50 individuals, and are well known for their intelligence and adaptability. Their complex social organization and cognitive abilities facilitate coordinated foraging, communication, and repeated raids on familiar, food-rich locations (Dittus et al., 2019; Jayarathne et al., 2024).

Toque macaques are highly mobile and consume a broad range of foods, including fruits, seeds, small animals, and cultivated crops. Annual breeding cycles allow populations in fragmented habitats to remain stable or increase. Their ability to move easily between trees and the ground enables access to crops across multiple fields. In *chena* areas, they frequently raid fruit crops such as bananas and papayas, cereal crops such as maize, and vegetables including pumpkins and groundnuts, particularly when wild food resources are limited (Jayarathne et al., 2024).

Gray langurs similarly cause substantial crop loss. These primates primarily feed on leaves, fruits, and young shoots and are commonly observed along forest margins where cultivation begins. Unlike macaques, langurs typically remain arboreal and are more cautious in open fields. However, the early stages of *chena* cultivation, when partial tree cover remains, provide sufficient concealment for them to approach crops with minimal risk. After harvest, many *chena* fields are left unattended or fallow, encouraging wildlife to forage on residual food resources. This can create ecological traps, in which primates perceive *chena* fields as resource-rich habitats, thereby intensifying conflict (Battin, 2004). The absence of physical barriers, such as fencing, combined with limited human activity, makes these fields particularly vulnerable to primate incursions. Under such conditions, both macaques and langurs gain easy access to crops with minimal disturbance, especially during early morning and late afternoon periods when they are naturally most active (Dhawale et al., 2020).

3.4 Indian Peafowl (Pavo cristatus)

Peafowl populations have increased markedly across Sri Lanka's dry zone in recent years. As ground-dwelling birds, peafowl prefer habitats with low vegetation, scattered shrubs, and adjacent forest patches, conditions commonly created through the cyclical clearing and regeneration associated with *chena* farming. Their omnivorous diet, strong site fidelity, and repeated use of food-rich fields amplify their impacts on agricultural landscapes (Ramesh and McGowan, 2009). These open, sunlit environments are well suited to their feeding and nesting behaviors, and regenerating ground cover following harvest and fallow provides particularly favorable conditions.

Peafowl consumes a wide range of plant and animal matter. In agricultural settings, they are especially attracted to sprouting rice, legumes, ground nuts, and leafy vegetables during the early stages of crop growth. Feeding typically involves pecking at tender shoots and scratching the soil surface, which can disrupt germination and damage seedlings. Farmers also report losses to bean and chilli fruits, particularly in home gardens and small-scale *chena* plots. Although the damage caused by peafowl is generally less severe than that inflicted by elephants or wild boars, it tends to be more frequent and persistent. Their diurnal activity patterns and conspicuous presence also result in more immediate and visible impacts, leading to higher levels of farmer complaints compared with less conspicuous crop-raiding species.

3.5. Porcupine (Hystrix indica)

Indian crested porcupines are among the less visible yet most destructive wildlife species in dry-zone farming areas, particularly in and around *chena* fields. They can persist undetected in *chena* landscapes, where fallow patches and scrub vegetation provide extensive cover and shelter (Hafeez et al., 2012). Their presence often becomes apparent only when damage reaches economically significant levels (Ashraf et al., 2021). Porcupines are nocturnal and typically forage alone rather than in groups (Ehtisham et al., 2021). They are largely herbivorous, with a strong preference for underground plant parts, including roots, tubers, and bulbs (Khan et al., 2000). Therefore, porcupines frequently damage crops such as cassava, sweet potato, yam, and turmeric, often uprooting entire plants during foraging (Ashraf et al., 2021).

Although porcupines raid fields less frequently than species such as wild boars or peafowl, the severity of damage per incident can be high, sometimes resulting in the complete loss of individual plants or small crop patches (Tobgay et al., 2019; Ashraf et al., 2021). Unlike diurnal crop raiders, porcupines are rarely observed directly, and damage is typically detected only the following morning (Ehtisham et al., 2021). Their elusive, nocturnal behavior limits opportunities for active deterrence, and porcupine-related damage is therefore frequently underreported or misattributed to other wildlife species (Tobgay et al., 2019; Ehtisham et al., 2021).

3.6. Small mammals, birds, and invasives species

In addition to major conflict species such as elephants, wild boars, and primates, a wide range of small mammals, birds, and invasive species also contribute to crop damage in Sri Lanka's *chena* landscapes. Although often overlooked, these species can cause persistent cumulative losses, particularly during the early growth and ripening stages of crops (Poché et al., 1982; Anuruddha et al., 2025).

Among mammals, civets (*Paradoxurus hermaphroditus*), nocturnal omnivores that forage near forest edges, are known to feed on fruits such as papaya, banana, and guava (Dehaudt et al., 2022). Bandicoots (*Bandicota bengalensis*) and palm squirrels (*Funambulus palmarum*), are both common in dry-zone habitats, dig through soil to consume germinating seeds and young tubers, often resulting in irregular and patchy crop establishment (Poché et al., 1982; Munawar et al., 2022). Rodents, particularly the black rat (*Rattus rattus*) and brown rat (*Rattus norvegicus*), are among the most widespread agricultural pests, feeding on grains, legumes, and stored produce (Witmer, 2022). Their high reproductive rates, adaptability to disturbed environments, and exploitation of both standing and stored crops make them especially difficult to manage in shifting systems such as *chena*, where fields are not continuously occupied or monitored.

Fruit bats, particularly the Indian flying fox (*Pteropus giganteus*), pose increasing challenges to fruit cultivation in *chena* areas. These nocturnal mammals feed on soft, sugar-rich fruits such as bananas, papayas, and guavas, often partially consuming fruit clusters during night foraging, with damage peaking during fruiting seasons. Bird species are also frequent visitors to *chena* fields Parakeets are attracted to millets, maize, and fruit crops and often shred grains before maturity (Rehman et al., 2019). Their flocking behavior and repeated use of the same fields over several days can result in substantial cumulative losses. In recent years, invasive species have further altered the dynamics of human–wildlife conflict in *chena* ecosystems. The Indian myna (*Acridotheres tristis*), an aggressive introduced bird, competes with native species and frequently raids fruit and cereal crops (Orabi et al., 2024).

Although these smaller species may not individually cause damage comparable to those inflicted by elephants or primates, their combined impacts, particularly when occurring simultaneously or repeatedly, can significantly undermine farmer livelihoods. This is especially true for smallholders cultivating high-value or short-duration crops in isolated *chena* plots.

3.7. Sri Lankan Leopard (Panthera pardus kotiya), Sloth Bear (Melursus ursinus), and Jackal (Canis aureus)

Although large carnivores, such as leopards and sloth bears, do not cause direct crop losses in *chena* landscapes, their presence can lead to attacks on humans. Such incidents often provoke retaliatory actions, including the indiscriminate use of snares, poisons, or traps, which may unintentionally harm non-target species and escalate tensions with conservation authorities.

Beyond immediate conflict, the decline or removal of apex and near-apex predators can generate long-term ecological risks. These species play a critical role in regulating prey populations and suppressing smaller predators through trophic interactions. Their loss can disrupt these regulatory processes, leading to phenomena such as mesopredator release, in which medium-sized species, including civets, rodents, and mongooses, increase in abundance due to reduced top-down control. This, in turn, may result in heightened crop-raiding pressure or pest outbreaks (Barua et al., 2013).

4. Consequences of Human-Wildlife Conflict on Chena Cultivation

4.1 Economic impacts

Human-wildlife conflict (HWC) has caused significant economic impacts on *chena* cultivation, especially in the dry zone of Sri Lanka. Crop loss is one of the most common and direct effects of HWC caused by various species, including elephants, wild boars, primates, porcupines, and peafowls. Elephants can wipe out entire fields overnight, and birds, macaques, porcupines, and wild boars can all cause significant losses through repeated, smaller-scale damage (Köpke et al., 2021). Usually, smallholder farmers rely on seasonal harvests for their livelihood, and their yields are affected by these damages. Therefore, farmers invest in preventive measures such as fences, watch-huts, firecrackers, and scare devices. These costly and labor-intensive methods often do not guarantee success. The need for constant vigilance forces families to dedicate time and resources away from other income-generating or social activities. Although compensation schemes are available for damage caused by elephants, there are no formal systems to cover losses from most other species like wild boars or monkeys. Even when compensation is theoretically accessible, bureaucratic hurdles and poor enforcement make it ineffective. Additionally, delayed or denied claims leave many farmers without support (Köpke et al., 2021). The threat of conflict also discourages farmers from cultivating high-value or long-term crops, and it reduces their profitability and changes cropping patterns.

4.2 Ecological impacts

The ongoing conflict between humans and wildlife is driving widespread ecological damage in *chena* landscapes. Farmers, trying to reduce crop losses, often speed up land-use cycles by planting crops more frequently and shortening fallow periods. Traditionally, fallow cycles lasted 10 to 15 years, allowing forests to regenerate, soil to recover, and biodiversity to thrive. However, due to land scarcity and pressure from wildlife, these cycles have shortened to 1–3 years in many areas (Tennakoon, 2010). Shorter fallow periods lower organic matter, soil fertility, and water retention, which ultimately degrades the land and reduces productivity. Repeated land and forest burning not only depletes nutrients but also releases atmospheric emissions and increases the risk of unplanned fires. These practices change vegetation structure, diminish native plant species, and displace pollinators and predators, weakening natural pest control and fertility regulation. Additionally, habitat fragmentation caused by *chena* expansion and retaliatory land-use practices has disrupted migration and foraging routes of many species, not only elephants but also boars, monkeys, and porcupines. This results in more frequent encroachments into farmland and further ecological stress. Retaliatory killings, including the use of snares, poisoning, and electrocution, have unintended harmful effects on non-target wildlife, including predators and endangered species. On the other hand, invasive species, which adapt quickly to disturbed landscapes, are becoming more common in *chena* areas. These species increase competition, disrupt food chains, and further alter the fragile ecosystems' ecological balance.

4.3 Social and cultural impacts

HWC in *chena* landscapes goes far beyond economic or ecological losses; it profoundly affects the social fabric, mental health, and cultural heritage of farming communities. Constant vigilance and fear of wildlife incursions lead to chronic stress and anxiety. Farmers, particularly those living near forest edges, report sleep disturbances, fatigue, and increasing despair. In severe cases, injuries or fatalities from animal attacks worsen psychological trauma and social tension (Köpke et al., 2021). The threat of conflict alters gender dynamics. Traditionally, women played a central role in *chena* farming by managing seed selection, weeding, harvesting, and day guarding. However, rising risks from wildlife have led to a decline in female participation in fieldwork. Women are now restricted to safer home garden activities, while men take on the more hazardous night guarding, resulting in shifts in family roles and an erosion of collaborative farming practices (Swaminathan and Kumar, 1999). Many traditional practices: such as *pel rekeema* (communal guarding), the use of symbolic deterrents, and crop selection strategies based on coexistence are fading. The younger generations, disillusioned by the dangers and declining returns of *chena* farming, are migrating to urban centers. This rural out migration undermines the intergenerational transmission of indigenous knowledge, threatening the continuity of *chena* as a cultural system. HWC has also altered the cultural perception of wildlife. Animals once respected or symbolically integrated into local belief systems such as elephants and monkeys are now increasingly viewed as threats or pests. This shift in perception, driven by frustration and loss, diminishes local support for conservation and breeds animosity toward wildlife protection efforts. Therefore, HWC in *chena* areas is not just a conflict between farmers and animals; it represents a conflict between modern survival and ancestral livelihoods.

5. Traditional Methods of Mitigation Strategies

In traditional *chena* cultivation, farmers use various methods to protect their crops from birds and wild animals. In traditional farming systems, crops were mainly protected through fencing and night watches from watch huts. They often build small watch huts, known as *Pela* (Fig. 1, A), where they stay both day and night to guard the fields and chase away intruding animals. To keep away larger raiding animals such as wild boar, Indian peafowl, porcupine (Fig. 1, a,b,c) and deer, a *Dandu Vata* (Fig. 1, B) or fence made of sticks and branches, is constructed around the *chena* (Dilmah Conservation, n.d). Farmers built fences around the fields, usually about 1.5–2.0 m high, using timber and thorny wood obtained from slashing and burning. Watch huts are constructed on top of trees near the fence, giving farmers a clear view of the fields and their surroundings while also offering safety from elephants (Fig. 1, d) since they are usually built in a height out of the reach of elephants (Fig. 1, i). Farmers spend nights in these huts, staying alert for threats, especially from elephants, and often share folk songs with others in nearby huts as they keep watch (Karalliyadda et al., 2021).

In addition to fences and huts, other protective measures included planting pest-prone crops like maize (Fig. 1, ii) and finger millet close to the huts for easier supervision, maintaining fires near the huts (Fig. 1, iii) to ward off animals especially like leopards (Fig. 1, e), who are carnivorous and life-threatening to farmers, and use mechanical devices to scare or trap invaders (Karalliyadda et al., 2021). Farmers also use devices to scare off smaller animals and birds. A *Pambaya* (scarecrow) made of sticks, leaves, or old clothes (Fig. 1, iv) is placed in the field to create the illusion of human presence, while a *Takeya*, a bell-like metal object, is installed to make noise and frighten away pests. Together, these traditional practices form an effective, low-cost system of crop protection that has been followed by farmers for generations.

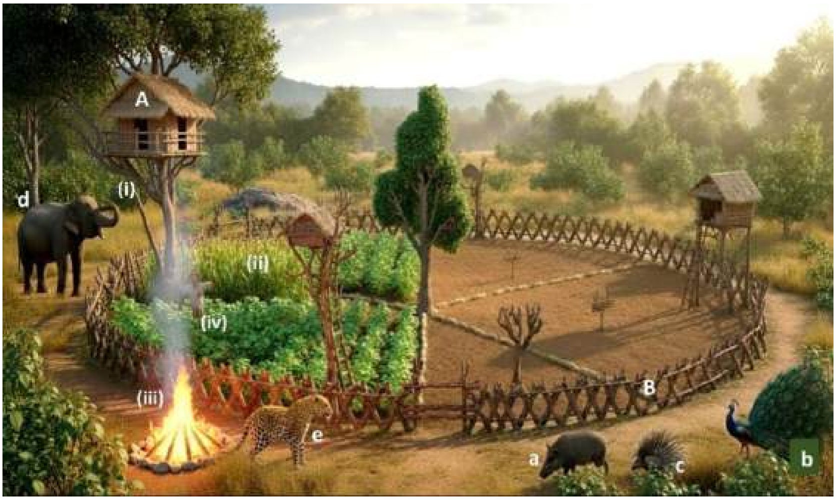

Fig 1. An AI-generated diagram of the traditional *chena* system practiced in Sri Lanka. A; the watch hut, B; wooden fence, a; wild boar, b; Indian peafowl, c; porcupine, d; elephant, e; leopard, (i); watch hut out of the reach of elephants, (ii); maize grown near to watch hut for easy guard; (iii); fires for repelling animals, (iv); scare crow for scaring birds.

In *chena* cultivation, certain crops are grown strategically to protect the main crops from wild animals. For example, coriander (*Coriandrum sativum*) is planted close to fences, not only for household consumption but also because its strong smell repels wild pigs and other animals that dislike it. Similarly, crops like bitter gourd, bottle gourd, and ash gourd are grown along the fences and later directed onto the fence, creating a natural protective barrier. Around the cottage within the *chena*, farmers grow yam varieties, cereals, tomatoes, leafy vegetables, and other essential food crops, mainly to protect them from monkeys and birds by keeping them under closer supervision. These traditional techniques of crop placement and management are unique to *chena* cultivation and play a vital role in maximizing productivity, ensuring food security, and providing natural protection against pests and animals (Irangani, 2020).

In *chena* cultivation, farmers practice a polyculture cropping system, which means they grow a variety of crops together in the same field. This method naturally helps to minimize pest infestations and control the spread of diseases, as the diversity of crops disrupts pest cycles and reduces the chances of large-scale damage. Farmers mainly use indigenous seed varieties that have been passed down through generations. These traditional varieties are not heavily dependent on modern agrochemicals and are naturally more resistant to pests and diseases (Irangani, 2020).

6. The Way Forward: Balancing Conservation and Livelihoods

The persistence of human–wildlife conflict in Sri Lanka's *chena* landscapes underscores the urgent need for approaches that protect both farmer livelihoods and biodiversity (Köpke et al., 2021; Gunawansa et al., 2023). Neither strict protectionist conservation strategies nor unregulated agricultural expansion has proven capable of delivering long-term solutions to this conflict. Instead, experience from Sri Lanka's dry zone suggests that workable responses must explicitly balance ecological connectivity with the everyday livelihood needs of farming communities.

6.1 Integrated land-use planning

A landscape-level approach that combines *chena* cultivation with designated wildlife corridors is critical for reducing conflict while maintaining ecological connectivity. Wide-ranging species such as elephants depend on seasonal movement across forest–farm mosaics, while farmers require predictable and secure access to cultivation areas (Anuradha et al., 2019). Evidence from Sri Lanka shows that encroachment into traditional movement routes and poorly coordinated land-use decisions have intensified conflict rather than reduced it (Bharathy et al., 2022; Köpke et al., 2023).

Research from Tanzania highlights that many tropical wildlife corridors can disappear within a few years under rapid land-use change, emphasizing the urgency of identifying and safeguarding such corridors before they are irreversibly lost (Caro et al., 2009). In Sri Lanka, recent spatial analyses similarly demonstrate that substantial elephant habitat and "de facto wilderness" areas lie outside formally protected areas and remain highly vulnerable to development and infrastructure projects (Withanage et al., 2023; Mudalige and Carver, 2024). As Evans (2007) cautions, corridors are not merely ecological constructs but are also shaped by political priorities and power relations. Consequently, corridor planning in Sri Lanka must balance ecological integrity with community land rights and tenure security if it is to gain local legitimacy.

6.2 Eco-friendly farming incentives

Chena farmers often receive little institutional support for adopting environmentally sustainable practices, despite bearing a disproportionate share of wildlife-related costs. Incentive mechanisms such as Payments for Ecosystem Services (PES) have been promoted globally as tools to reward land users for maintaining habitats and ecosystem functions (Redford and Adams, 2009). However, experience from the Global South suggests that PES outcomes are mixed and highly sensitive to local institutional design, equity considerations, and governance arrangements (Calvet-Mir et al., 2015; Wunder et al., 2018).

Critically, market-based conservation instruments risk privileging easily commodified services, such as carbon sequestration, while sidelining local food security needs and cultural values if applied uncritically (Chan et al., 2017; Wegner, 2016). For Sri Lanka's dry-zone *chena* systems, any incentive-based approach must therefore be embedded within broader rural development and coexistence strategies, ensuring that benefits accrue to smallholder farmers rather than being captured by commercial or external actors.

6.3 Community-based conservation models

Farmer-led initiatives remain central to mitigating human–wildlife conflict in *chena* landscapes. Empirical studies from Sri Lanka document widespread reliance on collective crop guarding, rotational night watches, community fencing, and shared watch-hut systems, particularly during peak cultivation and harvest periods (Gunawansa et al., 2023; Köpke et al., 2021). These practices distribute labour and risk across households and reduce the burden on individual farmers.

At the same time, qualitative research highlights persistent tensions between farming communities and conservation authorities, often driven by top-down interventions that fail to recognize local knowledge and land-use realities (Köpke et al., 2023; De Silva and Srinivasan, 2019). Embedding communities as genuine partners in conservation planning, rather than as passive recipients of externally designed solutions, is therefore essential for sustaining collective action and reducing long-term conflict.

6.4 Toward coexistence, not elimination

The objective in *chena* landscapes should not be the complete removal of wildlife but the management of shared spaces in ways that keep risks tolerable for both people and animals. Recent conservation scholarship emphasizes coexistence as a dynamic process, shaped by governance, social norms, and land-use practices, rather than the absence of conflict altogether (Pooley et al., 2020; König et al., 2020). In Sri Lanka, traditional practices such as seasonal shifting of plots, collective guarding, and culturally embedded deterrence methods historically supported forms of coexistence within forest–farm mosaics (Gunawansa et al., 2023; Köpke et al., 2021).

Blending such locally grounded knowledge with contemporary tools, including spatial planning and incentive mechanisms, may offer more realistic pathways toward coexistence than reactive conflict suppression alone (De Silva and Srinivasan, 2019).

6.5 Research and long-term monitoring

As Caro et al. (2009) note, documentation of wildlife movement and corridor use in tropical landscapes is often fragmented and time sensitive. In Sri Lanka, much existing knowledge on human–wildlife interactions remain anecdotal or localized, limiting its usefulness for policy and planning (Köpke et al., 2021; Gunawansa et al., 2023). Establishing participatory monitoring systems that involve farmers, local officials, and researchers could generate more reliable data while fostering local ownership of conservation initiatives. Such collaborative approaches are particularly important in dynamic *chena* landscapes, where land use, wildlife movement, and livelihood strategies change rapidly over time.

7. Comparative Analysis

Sri Lanka's traditional *chena* cultivation shares many similarities with shifting cultivation systems worldwide. They suffer disproportionately from human–wildlife conflict. As fallow periods shorten, forests fragment, and communal land access decline, such systems become hotspots of ecological and social strain (Mertz et al., 2009; Van Vliet et al., 2012). By analyzing global shifting cultivation systems, valuable and actionable lessons can be drawn for Sri Lanka as well. Some models offer positive inspiration, while others serve as something to prevent or refrain from early warnings.

7.1 Landscape buffering and agro-ecological design

This approach highlights the importance of spatial and cropping design in mitigating crop raiding. The Baranaja system found in India and Nepal, along with the milpa agricultural method in Latin America, are examples of how diversified intercropping and border planting can deter wildlife from agricultural areas (Mishra et al., 2003; Ghosh and Dhyani, 2004). These strategies not only enhance deterrence but also promote soil conservation, facilitate habitat connectivity, and foster resilience over time. Similar design principles could be relevant for *chena* systems in Sri Lanka. By intercropping with unpalatable crops, utilizing native shrubs for buffering, and rotationally employing hedgerows, farmers can lessen both visibility and accessibility for animals that raid crops. In the long run, more organized landscape-level strategies, such as establishing buffer zones or implementing agroforestry mosaics that integrate native trees with crops, may be considered as part of community-led HWC solutions. These ecological designs offer additional benefits, including enhanced biodiversity, improved soil health, and the creation of natural barriers against wildlife, all of which support a more sustainable coexistence.

7.2 Community-based vigilance and shared deterrence

Community cooperation remains a cornerstone of traditional HWC mitigation. In Northeast India, Jhum cultivators use group guarding, scare devices, and ritual practices to manage elephant raids (Choudhury, 2004). Programs like Gaja Mitra in Assam combine local vigilance with institutional support, including solar fencing (Assam Tribune, 2024; India Today, 2025). Similarly, in Ethiopia and Southeast Asia, cultural reverence for wildlife is reinforced through collective norms and group decisions (Tsegaye et al., 2010; Chokkalingam et al., 2006). Though rituals alone may not deter animals, they help foster cooperation and reduce retaliatory killings. In Sri Lanka, village vigilance groups, practices like Pel Rekeema, and participatory fencing could serve as scalable models.

7.3 Learning from global failures

Across the globe, there are failed interventions for managing human–wildlife conflict that provide valuable lessons for Sri Lanka. For instance, in the Congo Basin, the degradation of communal land ownership due to privatization has disrupted traditional cooperation and intensified conflict (Van Vliet et al., 2012; Nasi et al., 2011). Conservation measures that displace traditional farmers often result in unsustainable land practices and retaliatory actions against wildlife. In addition, in India, more than 600 elephants have died because of unsafe electric fencing since the year 2000 (Assam Tribune, 2024). This indicates that implementing fencing without ecological oversight and community involvement can be both dangerous and ineffective. Moreover, relying solely on ritual-based deterrents has not worked in cases where wildlife has adjusted to either symbolic or non-physical barriers. These global shortcomings exhibit a shared characteristic such as top-down, exclusionary, or non-participatory approaches. Such strategies, including forced privatization, militarized conservation, or superficial spiritual interventions, often disregard communities, diminish trust, and undermine both ecological and social outcomes.

8. Conclusion

The human wildlife conflict, as in other areas and social and agricultural systems in the country, can be seen in the *chena* system as well. However, the major effects of wildlife in *chena* systems have been the damage to the cultivated crops. In expansion, the same damage to crops has led to economic instability of the farmers and thereby leading to many more social and cultural conflicts within and among farm families. The farmers have traditionally used many physical and cultural techniques in minimizing the wildlife attacks to *chena* areas as well as have been cautious to be in protective places and chase away the wildlife rather than going into conflicts with them. The co-existence strategies with the wildlife they have followed have been one of the major reasons for minimized HWC in *chena* systems. On the other hand, the HWC and possible crop damage have led farmers to intensify their cultivation cycles and also to move for new fresh lands more frequently. This has caused severe ecological damage to the dry zone forest of Sri Lanka, which has ultimately resulted in banning of *chena* cultivation in the country.

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Conflict of Interest

The authors have declared that no competing interests exist.

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Chapter 11

Beyond the Palm: A Socio–Economic Impact of Coconut (*Cocos nucifera*) Crop Loss–Drivers, Impacts on Livelihoods, and Perspectives

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Abstract: This chapter examines the socio-economic dimensions of human-wildlife conflict (HWC), with a specific focus on coconut (*Cocos nucifera*) cultivation in Sri Lanka. Drawing on region-specific literature, field surveys, and institutional reports, this chapter examines the ecological, economic, and social impacts of wildlife incursions, particularly by elephants, toque macaques, wild boar, porcupines, squirrels and rodents on smallholder and estate-managed coconut farms. The findings indicate that HWC results in significant direct damage, such as tree destruction and lower yields, as well as indirect effects including infrastructure damage, delays in replanting, reductions in household income, and declines in national exports. Socially, the conflict causes psychological stress, rural out-migration, gender-specific burdens, and the weakening of traditional farming cooperatives. Measures such as excessive clearing of buffer zones and overuse of chemical deterrents further harm biodiversity, soil health, and pollinator populations, creating a cycle of ecological degradation that exacerbates the economic and social costs of the conflict. The chapter also records local coping strategies, including traditional deterrents, modern technologies, community patrols, and crop-switching practices. Nonetheless, policy gaps persist, especially the lack of damage estimation tools for perennial crops, fragmented institutional mandates, and the underrepresentation of coconut in conflict monitoring systems. In conclusion, the chapter emphasises the urgent need for integrated coexistence frameworks to address the distinct challenges of perennial agriculture. It advocates for enhanced conflict documentation, insurance innovations, agroecological buffer designs, and the harmonization of wildlife and agricultural policies to support the sustainable future of Sri Lanka's coconut industry and rural communities.

Keywords: Coconut, human-wildlife conflict, mitigation, socioeconomic, yield loss

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1. Introduction

The agricultural sector is a critical pillar of Sri Lanka's economy, supporting rural livelihoods, ensuring food security, and contributing significantly to national export earnings. Within this diverse landscape, which includes paddy, tea, rubber, and a variety of spices and fruits, the coconut (*Cocos nucifera*) industry holds a position of unique and enduring importance not only for its contribution to national exports but also for its deep connections with rural livelihoods, agroecological stability, and food security. Often referred to as the "Tree of Life," the coconut palm plays a vital role in the country's socio-economic fabric. It covers nearly 443,717 hectares (Coconut Development Authority of Sri Lanka, 2024), and the sector provides livelihoods for around 700,000 people and indirect employment for another 135,000, according to the Coconut Research Institute of Sri Lanka.

Sri Lanka ranks as the world's fourth-largest exporter of coconut-derived products (Export Development Board Sri Lanka, 2024), playing a significant role in the global trade of desiccated coconut, coconut oil, copra, coir, and activated carbon. In 2024 alone, coconut exports earned over LKR 257.9 billion (~USD 855 million), accounting for 0.7% of the country's GDP, emphasizing the sector's macroeconomic significance (Coconut Development Authority of Sri Lanka, 2024).

More importantly, coconut cultivation is not just a commercial venture, but also a vital livelihood strategy for subsistence and semi-commercial farmers, especially in the "Coconut Triangle," comprising the Kurunegala, Puttalam, and Gampaha districts (Figure 1). These regions support both monoculture and intercropping systems, integrating coconut with pepper, banana, pineapple, and vegetables (Nuwarapaksha et al., 2022). In many areas, coconut serves as a buffer crop, helping farmers manage income fluctuations and providing year-round food and marketable produce.

Beyond economics, coconut plantations are deeply embedded in the rural landscape, supporting soil stability, carbon sequestration, microclimate regulation, and biodiversity conservation (Nair et al., 2019; Kumara and Kunhamu, 2022). Furthermore, coconut agroecosystems serve as habitat corridors essential for the coexistence of native fauna and flora, making them central to the dynamics of human-wildlife conflict.

However, over the past two decades, coconut cultivation has faced increasing threats from various stressors, including climate variability, pest and disease outbreaks, and, notably, human-wildlife conflict. Incidents involving wildlife intrusions by elephants, monkeys, wild boars, and squirrels have increased in both frequency and severity, particularly near fragmented forest edges and in districts bordering wildlife habitats, such as Puttalam, Anuradhapura, Monaragala, and Polonnaruwa. These encounters often result in the direct destruction of trees and nuts, disrupt farm activities, and have long-term impacts on the productivity of plantations.

The socio-economic impacts of such crop loss are particularly severe due to the perennial nature of the coconut. Unlike seasonal crops, any damage to coconut trees has long-lasting effects that can persist for many years (Aratchige et al., 2025), sometimes diminishing productivity for a decade or more. As a result, smallholder households face not only lower income but also increased food insecurity (Prakash et al., 2020), psychological stress (Dixon et al., 2009), and decreased resilience to future shocks.

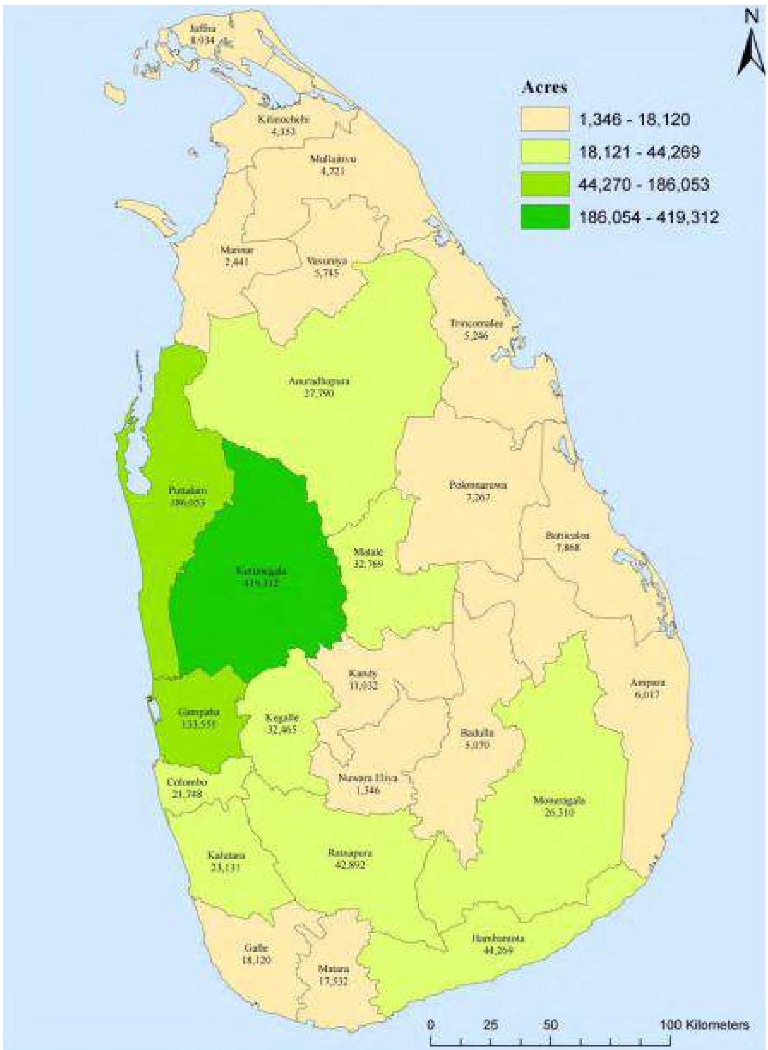

Fig 1. Distribution of coconut cultivation by districts in Sri Lanka. Source: (Department of Census and Statistics, 2017).

Despite the importance of the issue, research specifically exploring the intersection of human-wildlife conflict and ongoing crop losses in Sri Lanka, particularly concerning coconut, remains limited and scattered. This chapter aims to address this gap by systematically analysing the socio-economic impacts of wildlife-related coconut crop loss, incorporating empirical evidence, stakeholder accounts, and policy insights. In doing so, it seeks to enhance understanding of the effects and consequences of human-wildlife conflict within Sri Lanka's perennial cropping systems.

2. Human-Wildlife Conflict in Coconut Agroecosystems

Coconut (*Cocos nucifera*) agroecosystems in Sri Lanka are increasingly affected by human-wildlife conflict, driven by the expansion of agricultural frontiers and the loss of wildlife habitats. Previously, such conflicts were mainly reported from the North Western, Eastern, North Central, and Southern Provinces of Sri Lanka (Jayewardene, 1994; Mathotaarachchi et al., 2021; Santiapillai et al., 2010). However, after the civil war ended in 2009, human-wildlife conflict has also risen in the Northern Province (Bharathy et al., 2022) due to the expansion of agricultural activities, including coconut cultivation. Multiple species, including large mammals and smaller vertebrates, contribute to crop destruction, causing significant economic, ecological, and social impacts.

2.1 Species involved in conflict:

The Indian Elephant (*Elephas maximus maximus*): Sri Lanka's subspecies of the Asian elephant is among the most destructive to coconut plantations. Elephants cause extensive damage by uprooting palms, trampling seedlings, and breaking mature trees (Thennakoon et al., 2017), especially during foraging or when travelling through fragmented landscapes. Incidents are concentrated near wildlife corridors in areas such as Anuradhapura, Puttalam, and Monaragala, where coconut estates intersect elephant migration routes. Most of the human-elephant conflict (HEC) incidents reported in Sri Lanka involve damage to perennial crops, such as coconuts.

Toque Macaque (*Macaca sinica*): Endemic to Sri Lanka, the toque macaque is a notable pest in coconut-growing areas. These primates feed on fruit, especially young coconuts, which they often bite open and leave partially eaten. Macaques, recognized for their sociable nature, frequently interact with humans and are commonly observed near human settlements (Jayarathne et al., 2025). The history of conflict between humans and primates in Sri Lanka is well-documented, as evidenced by Robert Knox, an English traveller who spent nearly two decades in Sri Lanka as a prisoner, who recorded instances of macaques invading home gardens despite human efforts to defend them.

Giant Squirrel (*Ratufa macroura*): Giant squirrels are common in mixed-agriculture landscapes and have been documented to cause damage by gnawing through coconut husks and inflorescences. As a result, they lead to cumulative yield losses, especially in mature trees (Bandara et al., 2012). Their presence is often reported in coconut-based home gardens and smallholder estates in many parts of the country.

Porcupine (*Hystrix indica*): Porcupines are nocturnal pests in young coconut plantations, particularly in fringe areas adjacent to scrub forests or jungles. Its foraging behaviour involves gnawing at the root collars and base of young palm seedlings (Coconut Research Institute of Sri Lanka, 2006). This injury can lead to stunted growth or mortality, and in some areas, seedling loss is so severe that extensive replanting is necessary. While not as geographically widespread as other conflict species, localized porcupine damage is particularly pronounced during the dry season and can be a critical limiting factor in the successful establishment of plantations.

Wild boar (*Sus scrofa*): Wild boars damage coconut ecosystems through their rooting behaviour, which harms soil structure and irrigation systems. They remove the mesocarp (husk) and endocarp from fallen nuts and consume the endosperm, thereby rendering the nuts unfit for sale (Govind and Jayson, 2018). Their intrusions occur most frequently at night and along the edges of uncultivated estates. Farmers in Polonnaruwa and Batticaloa often cite wild boar as a constant threat, especially in estates with inadequate fencing.

Rodents (*Rattus rattus, Bandicota bengalensis*): Rodents are among the most underestimated yet consistently damaging pests in coconut ecosystems. These animals target tender nuts and bore into them for moisture (Kumawat et al., 2016). Their impact is especially severe during droughts or after natural disasters, when coconuts become an accessible source of water and food. The developing nuts are attacked near their point of attachment to the inflorescence, where a hole, usually about 65 by 40 mm, is made. Rats appear unable to penetrate nearly mature and mature nuts, so most damage occurs on nuts aged between three and six months.

2.2 Temporal and spatial patterns of interactions in coconut-growing regions

The above species exhibit temporal and spatial patterns of interactions in coconut-growing regions.

- Spatially, the dry and intermediate zones show the highest conflict frequency, particularly where coconut plantations border protected areas or degraded forest reserves.
- Temporally, conflicts peak during dry inter-monsoonal periods (March–April and August–September), when natural water and food resources are scarce in forests. This encourages wildlife to move into cultivated areas in search of sustenance.
- Conflict escalation is more prevalent in newly expanded coconut zones, where buffer zones and fencing have not kept pace with land use change.

The Northwestern Province (e.g., Kurunegala, Puttalam) and the North Central Province (e.g., Anuradhapura, Polonnaruwa) are among the most vulnerable regions due to a combination of coconut cultivation, high wildlife presence, and fragmented land-use patterns.

2.3 Ecological and land-use drivers of conflict

Various ecological and human-induced factors intensify human-wildlife conflict in coconut ecosystems as follows:

- Habitat fragmentation: The expansion of coconut plantations into buffer zones and forest edges has diminished wildlife corridors, compelling animals into areas dominated by humans.
- Monoculture farming systems: Extensive areas of uniform coconut cultivation offer minimal ecological resistance to wildlife and provide easy access to food.
- Deforestation and land degradation: The loss of dry zone forests due to development or illegal logging has reduced natural food sources for elephants, macaques, and boars.
- Failure of mitigation infrastructure: Poorly maintained electric fences, lack of bio-barriers, and ineffective deterrent systems cause frequent breaches.
- Lack of community coordination: Conflict reporting and mitigation are often handled by individuals rather than through coordinated village-level strategies.
- Climate stressors: Extended droughts intensify resource shortages in natural habitats, leading to more frequent and severe wildlife raids (Suratissa, 2021) on coconut farms.

3. Direct and Indirect Economic Losses

The economic impact of human-wildlife conflict (HWC) on coconut farming in Sri Lanka is complex, affecting yields, infrastructure, household income, and exports. As a perennial crop with a long lifespan, coconut is more susceptible to wildlife damage than short-term seasonal crops. These impacts are especially apparent in the districts of Puttalam, Anuradhapura, Kurunegala, Matale, and Polonnaruwa, which serve as conflict hotspots with frequent wildlife movement and widespread coconut cultivation (Köpke et al., 2024).

Direct crop loss is the most immediate and visible impact. Elephants cause significant damage by trampling or uprooting mature coconut palms, leading to the total loss of productive trees, each capable of yielding 40–60 nuts per year. Toque macaques, endemic to Sri Lanka, contribute to substantial yield losses by consuming immature nuts or damaging the husk and mesocarp, often rendering the fruit unmarketable. Similar cumulative damage is caused by rodents and squirrels, especially during drought periods when they attack nuts in search of moisture.

Human-wildlife conflict causes severe and complex economic losses to Sri Lanka's coconut industry, affecting local communities and the nation as a whole. Direct damages are clearly seen in the systematic destruction of the crop itself. A survey in the key coconut-growing district of Kurunegala measured these losses, showing a clear seasonal pattern driven by food shortages for macaques, the main offenders. During non-fruiting seasons, when there are few other food options, monthly economic losses per plantation ranged from 3,000 to 14,000 LKR, dropping by more than half during fruiting seasons (1,200 to 6,000 LKR). This pattern was most pronounced in plantations near forests, with one site, Deegalla, experiencing monthly losses of up to 13,200 LKR (equivalent to 220 coconuts) during the lean season (Barathy et al., 2022). These local figures align with staggering national data; one study counted the destruction of 93 million coconuts in the first half of 2022 alone, rising to nearly 200 million by the end of the year, primarily due to the actions of toque macaques and giant squirrels (Rodrigo, 2023; Samarawickrama, 2023). This resulted in the destruction of 57,815 hectares of coconut plantations across 21 districts, with Kurunegala alone losing 24,038 hectares. Besides the loss of harvestable nuts, conflict also causes indirect losses by damaging plantations' core assets. For example, in the Polpithigama Divisional Secretariat of Kurunegala District, North-Western Sri Lanka, wild elephants have damaged 36% of coconut palms, with approximately 90% of the damage occurring during germination, resulting in the loss of future yields and necessitating costly replanting (Thennakoon et al., 2017). As a result, these combined direct and indirect losses, from immediate crop raids to long-term asset destruction, cause a significant economic burden, destabilizing livelihoods and threatening the future of the entire coconut sector.

The loss mentioned above affects not only coconut nuts but also income from products such as coconut oil, coir, toddy, and firewood. The labour economy is also disrupted by a shortage of nuts, affecting seasonal employment in harvesting, processing, and transportation.

Infrastructure damage further worsens these direct losses. Electric fences intended to deter elephants are often broken, while wild boars damage irrigation pipes and disturb soil beds around young coconut plants. Access roads to plantations are frequently rendered unusable due to trampling and erosion, increasing the logistical burden on producers. The Department of Wildlife Conservation reported that, during 2021-2022, in high-conflict districts, Rs 1.03 billion was spent on maintaining electric fences and Rs 1.25 billion on construction and related costs, highlighting the financial strain caused by repeated repairs (Auditor General's Department of Sri Lanka, 2022).

Further replanting and recovery impose an additional economic burden. Replacing lost palms incurs costs for seedlings, labour, fertilizer, and weed control, with each tree taking four to seven years to become productive again. Post-conflict replanting of one hectare of coconut land usually costs significantly more, often a sum too high for smallholder farmers without institutional support or insurance. This long-term investment gap delays land recovery and further reduces local income.

At the national level, HWC's impact on coconut cultivation affects foreign exchange earnings. Sri Lanka, a major exporter of coconut oil, desiccated coconut, and activated carbon, has been partly affected by inconsistent nut availability due to wildlife-related disruptions. According to estimates, this shortfall resulted in an annual loss of Rs 6,638 million (approximately USD 19.3 million) in foreign exchange revenue in 2022 (Rodrigo, 2023).

Opportunity costs are another hidden yet significant consequence. Uncertainty about crop security deters farmers from reinvesting, especially in high-yielding varieties or expanding plantations. Additionally, disruptions to harvest cycles affect the flow of seasonal labour and local market dynamics, leading to productive coconut lands remaining underused for years due to fears of repeated wildlife intrusions, which causes a cycle of abandonment and economic stagnation.

A comparative analysis of plantations with and without mitigation measures reveals a significant economic gap. Estates equipped with electric fences, trained watch groups, or coordinated deterrent measures achieved higher yields than unprotected estates (Bandara, 2015), indicating that early and continuous investment in mitigation infrastructure not only protects crop output but also accelerates economic recovery and improves land productivity.

4. Social and Livelihood Implications

The social and livelihood impacts of human-wildlife conflict (HWC) on coconut cultivation in Sri Lanka extend far beyond financial losses, affecting psychological well-being, gender dynamics, community cohesion, and long-term land-use planning. These effects are especially noticeable in districts such as Kurunegala and Monaragala, where coconut farming is crucial for the local rural livelihoods and social systems.

4.1 Psychological stress, fear, and migration

Repeated crop raids by elephants, monkeys, wild boars, and rodents have caused ongoing anxiety among coconut farmers, especially smallholders who rely solely on their plantations for income. It has been revealed that increasing levels of psychological stress, sleep deprivation due to nocturnal watch duties (Suratissa, 2021), and a persistent sense of insecurity. In Monaragala, farmers reported relocation during high-conflict seasons to avoid encounters with elephants. This sense of helplessness and fear has sometimes led to permanent migration, particularly among younger families, highlighting the decline in people’s power in rural areas (Suratissa, 2021).

4.2 Gendered impacts

The burden of conflict does not affect all genders equally. In areas with women-led households that often lack adult male labour, they are particularly vulnerable. These households find it difficult to maintain fences, replant, or participate in community defence groups. Women also hold the primary responsibility for household coping strategies, such as managing food shortages or seeking informal credit after harvest failures. Despite their vital role in coconut-based processing (e.g., coir, oil, sweets), women have limited access to decision-making forums related to HWC management or land-use planning (Homewood et al., 2022).

4.3 Social tensions and breakdown of traditional systems

Conflict pressure also weakens traditional coconut cooperative societies and communal labour exchanges. Repeated crop damage breeds distrust among neighbouring landowners about the maintenance of shared fences or communal mitigation measures. Hence, members opted for isolated, household-level strategies that were often less effective and more costly. These changes undermine local resilience and increase rural inequality.

4.4 Changes in farming behavior

Human-wildlife conflict is beginning to change farming practices and crop selection. Farmers who initially focused on intensive coconut cultivation are increasingly switching to alternative crops such as banana, turmeric, or maize, which are considered less attractive to elephants and monkeys. In various parts of the country, land abandonment is also becoming a coping strategy, particularly among elderly farmers without successors or the physical ability to repair the damage. Others are relying more on chemical deterrents, including pesticides and repellents, which may have unintended environmental effects.

4.5 Community perspectives

Studies conducted in coconut-growing regions reveal a deep-seated frustration among coconut farmers. For instance, a study in the Deegalla, Kabalewa, and Elathalawa Granaseva Niladari Divisions of the Kurunegala district reported a loss of over 50% of their harvest in a single season due to monkey raids (Jayarathne et al., 2025). This raises questions about the sustainability of coconut farming, and community members expressed feelings of neglect by authorities, citing delays in compensation and a lack of training in non-lethal deterrent methods. These localised experiences highlight the importance of context-sensitive, participatory conflict resolution strategies that acknowledge social complexity and empower local communities.

5. Ecological and Agricultural Ecosystem Consequences

Human-wildlife conflict (HWC) not only threatens the socio-economic stability of coconut-growing communities in Sri Lanka but also disrupts ecological and agricultural systems, particularly in areas reliant on coconut-based agroforestry. These agroecosystems, once valued for their diverse, multi-layered cropping patterns involving coconut alongside banana, pepper, and legumes, are increasingly being degraded due to wildlife pressures and human responses aimed at reducing these conflicts.

5.1 Disruption of coconut intercropping and agroforestry models

Some coconut plantations in Sri Lanka are integrated into agroforestry systems. These methods include intercropping with numerous crops, ranging from annuals to perennials, including legumes, ginger, banana, and pepper, which enhance income diversification, soil health, and ecological resilience. However, recurring wildlife damage from elephants, wild boars, and monkeys disrupts carefully planned crop cycles, forcing farmers to abandon intercrops or switch to less profitable, wildlife-resistant species, thereby undermining land-use efficiency and the economic viability of diversified farming systems. Furthermore, the pressure to avoid planting sensitive or high-value species leads to a shift toward monocultures, compromising the ecological integrity and resilience of agroforestry landscapes.

5.2 Impacts on biodiversity and soil erosion

To deter wildlife, some farmers clear buffer vegetation, often removing understorey shrubs, border trees, and groundcover crops. Although these actions aim to improve visibility and eliminate hiding spots for animals, they unintentionally accelerate soil erosion, reduce microbial diversity, and destroy habitats for beneficial organisms such as pollinators and birds. In regions with fragile topsoils, this clearing can lead to increased runoff and declining soil fertility in marginal coconut lands.

5.3 Use of chemical deterrents and impact on agro-ecology

The increasing use of chemical deterrents such as strong-smelling repellents, synthetic pesticides, and unregulated rodenticides has significant effects on non-target species in and around coconut plantations. Pollinators such as bees and wasps, which are essential for the flowering and nut-setting of many intercrops (e.g., chilli, papaya), have been observed to decline in areas where chemical barriers are employed. Furthermore, these deterrents tend to leach into nearby water bodies, posing a threat to aquatic life and the health of domestic animals. This practice also poses long-term contamination risks to Sri Lanka’s coconut value chain, especially for the organic branding segment of coconut exports to international markets.

6. Coping Strategies and Local Responses

Faced with ongoing human-wildlife conflict (HWC), particularly in Sri Lanka's coconut-growing areas, farming communities have adopted various coping strategies. These include traditional deterrents, community efforts, adaptive farming practices, and calls for government support. These methods highlight limited resources and inventive solutions shaped by lived experience.

6.1 Traditional vs. modern deterrents

Traditionally, coconut farmers have employed techniques such as firecrackers, scarecrows, noise-makers, and torches to deter elephants and monkeys (Friesen, 2017; Madhushanka and Ranawana, 2021; Roshan, 2023). Although these techniques are inexpensive and easily accessible, their effectiveness decreases over time as animals become accustomed to them. Such deterrents may only offer short-term relief and are ineffective during peak conflict periods or in areas with high wildlife activity (Wildlife Control Training, n.d).

Meanwhile, some farmers wrap aluminium sheets around coconut trees to prevent macaques from climbing them. Additionally, they sprinkle cow dung mixed with water on coconuts, as some farmers believe macaques dislike the smell of cow dung. Furthermore, farmers cover the young coconut bunches with an iron mesh to prevent macaques from reaching the coconuts. This process is both time-consuming and costly (Jayarathne et al., 2025), and they feel the need to increase their efforts. Farmers also adjust the mesh size as coconuts grow larger; however, this method is not practical to implement in large coconut estates for several reasons.

In contrast, modern mitigation tools, particularly solar-powered electric fencing, sensor-triggered alarms, and early-warning mobile alerts, are gaining popularity (Nepune, 2018; Ronoh et al., 2022). These methods have shown potential to reduce elephant intrusions, especially in Anuradhapura and Kurunegala, where electric fencing has reduced the frequency of conflicts (UN-Habitat, 2023). However, the cost of installing and maintaining such fences remains a significant barrier for coconut smallholders.

Electric fences are used not only to deter elephants but also wild boar and porcupines. Electric fencing for wild boars requires a configuration that accounts for their intelligence and targets their anatomy. A low three-wire setup is most effective, with the bottom wire placed six inches or less from the ground to target their sensitive snouts, and subsequent wires spaced up to shoulder height. A minimum voltage of 2,000–3,000 volts is used to penetrate their thick hide, and training domestic pigs by initially pairing the electric wire with a solid fence ensures they learn to retreat. Porcupines present a distinct challenge due to their insulating fur and quills, necessitating a specialised approach. A significantly more powerful charger, often exceeding 5,000 volts, is therefore used. The fence design specifically encourages contact with their less-protected nose or mouth, achieved by placing a hot wire just inches above the ground or laying it directly on the soil to deter burrowing. For maximum effectiveness, electric wires are integrated with a physical barrier, such as tight wire mesh. However, the need for such high voltage and precise construction can again increase both the initial cost and the complexity of the installation for coconut smallholders.

6.2 Farmers' perspectives on compensation

Although Sri Lanka's government has established compensation schemes for crop damage and property loss, farmers' perceptions of these programmes remain mixed (The Island, 2025). According to Chinthaka (2018), farmers expressed frustration over delays, inadequate assessments, and inconsistent payouts. Coconut growers in Puttalam and Monaragala reported that compensation often fails to reflect the actual market value of lost nuts or trees and is rarely sufficient to cover the costs of replanting or infrastructure repairs. Many farmers also mentioned bureaucratic challenges in submitting claims and securing timely inspections.

6.3 Community-level responses

Faced with the limitations of individual action, several communities have started forming voluntary patrol groups to monitor wildlife activity (Edirisooriya and Bandara, 2022; Köpke et al., 2023). These groups often communicate and alert each other during animal sightings. In some regions, community fencing projects have received support from government organizations, non-governmental organisations or cooperatives, combining labour and materials to set up shared barriers. While maintenance remains challenging, these efforts have encouraged greater collective ownership and greater readiness for responses.

6.4 Adaptation Strategies

Crop switching and agroecological modifications

Farmers are increasingly adopting a variety of adaptation strategies to reduce losses from human-wildlife conflict. These strategies range from crop-level changes to systemic land use modifications. One method involves altering cropping patterns by introducing unpalatable or deterrent crops, such as chilli (*Capsicum frutescens*), sesame (*Sesamum indicum*), and citrus (*Citrus* spp.), or by employing innovative biological deterrents, such as honeybees, to repel elephants. Simultaneously, agroecological adjustments are being made, including the creation of "bio-fences" using thorny species such as agave, cacti, and bougainvillaea as protective barriers (Japan International Cooperation Agency [JICA], 2012). In more severe cases, where certain crops suffer persistent and unsustainable damage, farmers may cease cultivation altogether, as seen with coconut farming ending due to macaque depredation (Jayarathne et al., 2025). To further boost resilience, an additional approach is agricultural diversification, including the integration of livestock such as goats and poultry into farming systems. This not only improves land-use efficiency but also provides an alternative income source, helping stabilise household earnings and buffer against crop losses caused by wildlife.

7. Policy Gaps and Institutional Challenges

Despite the growing impact of human-wildlife conflict (HWC) on perennial crops, such as coconut, policy responses and institutional frameworks in Sri Lanka have remained mainly reactive, underfunded, and focused on annual crops, including paddy and maize. This misalignment creates a series of structural gaps that undermine efforts to mitigate conflict, implement compensation strategies, and support long-term planning in coconut-dominated regions.

7.1 Lack of region-specific loss estimation tools

One of the most persistent challenges is the lack of standardised, region-specific tools for assessing crop loss, especially in perennial systems such as coconut (Köpke et al., 2023). Existing damage-assessment frameworks were initially designed for short-cycle crops and often overlook multi-year productivity losses, replanting delays, and depreciation of tree value (Ceylon Today, 2025). Although tools such as mobile-based field reporting have been tested in elephant corridors, they have not been integrated into Sri Lanka's official compensation infrastructure for tree crops. As a result, coconut farmers in areas such as Kurunegala and Monaragala often receive generic or insufficient loss estimates, leading to compensation that does not accurately reflect the actual economic damage.

7.2 Disconnect between wildlife and agricultural policies

There has been a long-standing disconnect between the conservation goals of the Department of Wildlife Conservation and the livelihood protection mandates of agricultural agencies (Sri Lanka Brief, 2021). Policies prioritizing elephant preservation and habitat corridors often clash with agricultural expansion or replanting programmes. This institutional siloing results in conflicting mandates, where wildlife corridors are designated without fully recognizing the economic importance of coconut plantations, leaving farmers unprotected or unsupported in mitigation efforts (Ministry of Agriculture, 2022). The absence of integrated land-use governance in conflict-prone areas leads to inefficiencies, enforcement gaps, and community distrust of government agencies (Köpke et al., 2023).

7.3 Bureaucratic delays in compensation and damage assessment

Farmers across Sri Lanka consistently highlight bureaucratic delays in the approval of compensation and damage inspections as a major institutional failure (Köpke et al., 2023). Further independent interviews suggest that it often takes inspection teams weeks or even months to visit affected coconut estates. By this time, vital evidence (such as broken trees, footprints, and damaged nuts) may be lost. Additionally, manual record-keeping and the absence of digital claim-tracking systems hinder accountability. Only a small fraction of affected farmers complete the entire compensation claim process, and even fewer receive full reimbursements (Köpke et al., 2021; Köpke et al., 2023), which leads to delays and discourages many smallholders from reporting damage altogether.

7.4 Neglect of coconut in the national HWC data collection

While damage data for crops such as rice and vegetables are routinely collected via seasonal agricultural surveys, no nationwide monitoring system comprehensively captures human-wildlife conflict (HWC) losses in coconut cultivation (Ministry of Agriculture, 2023). This gap may be attributed in part to administrative divisions: coconut cultivation falls under the purview of the Ministry of Plantation Industries, a separate entity from the Ministry of Agriculture. Given that the latter maintains an extensive organizational network for data collection, the administrative separation likely hinders the development of an integrated monitoring framework for coconut systems. Further, coconut's perennial nature and diverse regional planting densities (ranging from smallholdings to large estates) make it more challenging to track damage unless a coconut-specific reporting system is established. The lack of baseline data hampers accurate forecasting, resource allocation, and prioritisation in conflict mitigation policies. As a result, funding and policy measures tend to overlook coconut regions in favour of crops with shorter production cycles or politically sensitive food security issues.

8. Recommendations

To reduce the growing threat of human-wildlife conflict (HWC) in coconut agroecosystems across Sri Lanka, a coordinated, evidence-based approach is essential. These recommendations are based on national research and insights from local stakeholders, emphasising documentation, ecological resilience, insurance innovation, and governance integration.

8.1 Enhance documentation of conflict events specific to coconut

A crucial step in reducing conflict is setting up a dedicated, crop-specific documentation system. Current loss assessments typically focus on seasonal crops, such as paddy and maize, while perennial crops, including coconut, despite their long-term importance, are underrepresented. Hence, it is essential to develop a geo-tagged, mobile-based reporting tool that enables coconut growers to log crop damage, including photographic evidence, date stamps, and the species of wildlife involved (Köpke et al., 2021; Bharathy et al., 2022). Such data would enhance compensation accuracy and help develop spatial heat maps to identify regional hotspots for intervention.

8.2 Strengthen multi-stakeholder response

Human-wildlife conflict around coconut plantations requires a cross-sectoral approach that involves the expertise of the Department of Wildlife Conservation (DWC), the Coconut Cultivation Board (CCB), local Pradeshiya Sabhas, and community groups. Establishing Conflict Response Units at Divisional Secretariat levels to act as first responders during crop raids and to oversee fence maintenance, compensation procedures, and awareness campaigns is vital. Such collaborative platforms also offer opportunities to align wildlife conservation strategies with farmers' interests.

8.3 Promote agroecological buffer designs

Instead of relying solely on electric fencing or chemical deterrents, Sri Lanka should invest in agroecological buffer zones using native, unpalatable plants (e.g., *Gliricidia sepium*, Bougainvillea, Crotalaria) along the edges of coconut plantations. These natural buffers not only deter large herbivores but also help conserve soil, support pollinator habitats, and establish biodiversity corridors. As noted by Abeysinghe (2015), home garden models from the Kandyan region offer scalable insights into integrated agroforestry and buffer-planting systems that can be adapted to dry and intermediate coconut belts.

8.4 Encourage insurance models for perennial props

Traditional agricultural insurance schemes in Sri Lanka largely exclude tree crops due to complex valuation challenges and extended recovery periods. However, there is a growing need for perennial crop insurance mechanisms that account for long-term yield loss, replanting costs, and market disruptions. Amarnath et al. (2023) suggest bundling crop insurance with climate-smart agricultural loans to increase uptake among vulnerable farmers. Pilot programmes could be initiated in coconut-rich areas, such as Kurunegala and Puttalam, with support from agribusinesses or microinsurance cooperatives.

8.5 Integrate farmer-centric early warning systems and wildlife corridor mapping into policy

Integrating real-time wildlife tracking data and corridor maps is crucial for preventing crop raids and minimizing conflicts. Community-based early warning systems, such as text message alerts when elephants are detected nearby, have been successfully trialled in parts of the North Central Province. However, scaling these systems requires formal recognition and investment. Furthermore, incorporating wildlife corridor overlays into coconut land-use plans would ensure that plantation expansion does not occur in high-risk zones. This supports Sri Lanka's climate-smart agriculture strategy (Kadupitiya et al., 2023), which encourages data-driven spatial planning at district and provincial levels.

9. Conclusion

This chapter has explored the multiple effects of human-wildlife conflict (HWC) on coconut (*Cocos nucifera*) farming in Sri Lanka, emphasizing both socio-economic and ecological viewpoints. Using regional case studies and recent national research, key findings reveal that coconut, a crucial part of Sri Lanka's rural economy and agroecological heritage, faces increasing threats from crop damage caused by elephants, toque macaques, giant squirrels, monkeys, porcupines, wild boar, and rodents. These losses are exacerbated by indirect effects, including delays in replanting, damage to infrastructure, disruption of livelihoods, and community disempowerment.

At the economic level, repeated coconut losses in high-conflict zones such as Kurunegala, Monaragala, and Puttalam have caused significant income shocks among smallholders, weakened national export performance, and discouraged investment in long-term replanting. At the social level, the resulting psychological stress, gendered burdens, and breakdown of cooperative systems demonstrate that human-wildlife conflict is not simply a technical issue, but an increasingly significant challenge to rural development. At the ecological level, reactive measures such as over-clearing vegetation and excessive use of chemical deterrents are damaging soil quality, reducing biodiversity, and threatening the sustainability of coconut-based agroforestry systems.

These findings have long-term implications for Sri Lanka's food security and land-use planning. Coconut is not only a cash crop but also a subsistence and cultural staple used in everything from cooking and roofing to cosmetics and carbon manufacturing. Its disruption therefore threatens not just farmers' incomes but also the integrity of agroecosystems and rural economies. Hence, Sri Lanka's coconut sector must now be viewed as both economically strategic and ecologically sensitive.

Moving forward, it is recommended that a comprehensive, island-wide survey be conducted to assess the extent and impacts of wildlife damage on coconut cultivation in Sri Lanka. While localized studies exist, there is currently no national-scale scientific assessment to quantify losses and identify high-risk zones. Such a survey is essential to inform evidence-based management strategies, allocate resources effectively, and develop targeted mitigation policies to safeguard this vital agricultural sector. Further, there is a clear need for a paradigm shift from reactive compensation schemes and fragmented mitigation strategies to a proactive, cohesive, and farmer-centred model of human-wildlife coexistence, specifically tailored to the sustained temporal dynamics of perennial cropping systems. This includes integrating early warning technologies, mapping wildlife corridors, designing agroecological buffers, and promoting inclusive governance that involves farmers, conservationists, and local authorities. Most importantly, national agricultural and wildlife policies must be harmonised to support conflict mitigation while ensuring long-term livelihood security. Without such a shift, the accumulated losses and land-use changes resulting from human-wildlife conflict could threaten Sri Lanka’s long-standing status as a global leader in coconut production and compromise the ecological and cultural resilience of its farming landscapes.

Conflict of Interest

The authors have declared that no competing interests exist

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Chapter 12

Human–Wildlife Conflict and Its Implications for Export Agricultural Crop Production

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Abstract: Human-wildlife conflict (HWC) poses a significant threat to Sri Lanka's export agricultural crops (EACs), including cinnamon, cocoa, coffee, pepper, cardamom, clove, and nutmeg, which are vital to the nation's economy and smallholder farmers' livelihoods. Key species responsible for substantial damage to EACs include several species of monkeys, peacocks (*Pavo cristatus*), wild boars (*Sus scrofa*), Layard's palm squirrel (*Funambulus layardi*), giant squirrels (*Ratufa macroura*), porcupines (*Hystrix indica*), and others, with approximately 40% of annual harvests lost. These losses, estimated at Rs. 17–20 billion annually, exacerbate poverty and food insecurity among farming communities. Anthropogenic factors such as deforestation, land-use changes, and agricultural expansion into wildlife habitats intensify these conflicts. Among EACs, cinnamon faces significant damage from peacocks and barking deer, while cocoa is heavily impacted by squirrels and monkeys. Coffee, pepper, and cardamom suffer damage from monkey and porcupine damage, with nutmeg affected by bats and particularly grey hornbills. Mitigation strategies range from short-term measures like using scarecrows, bio-fencing, and natural repellents to medium-term approaches such as electric fencing and community training, and long-term solutions including habitat restoration, wildlife monitoring, and policy reforms. Despite these efforts, challenges persist due to high costs, animal habituation, and slow policy implementation. This chapter underscores the need for integrated, sustainable approaches combining traditional practices, technological innovations, and robust policy frameworks to balance biodiversity conservation with agricultural productivity. Collaborative efforts, including reforestation, compensation

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schemes, and farmer education, are critical to fostering coexistence and ensuring the resilience of Sri Lanka's export agriculture sector.

Keywords: Crop losses, export agricultural crops, human–wildlife conflict, mitigation, socio-economic perspectives

1. Introduction

Agriculture is the main economic cornerstone of a country. With the highest contribution to employment and a substantial contribution to GDP (8.3% in the year 2024) (DCS, 2024), agriculture has long been a significant component of the Sri Lankan economy. Tea, rubber and coconut are the main agricultural export crops of Sri Lanka while rice is important as the staple diet of the citizens. Apart from these crops, the country has been famous for many other crops since ancient times, for example, spices and beverage crops. These crops bring in considerable amount of export earnings to the country and are collectively called as 'export agricultural crops' (EACs). This group of crops contain mostly perennials, and include spice crops [such as cinnamon (*Cinnamomum verum*), pepper (*Piper nigrum*), cardamom (*Elettaria cardamomum*), clove (*Syzygium aromaticum*) and nutmeg (*Myristica fragrans*)], beverage crops [such as coffee (*Coffea* spp.) and cocoa (*Theobroma cacao*)], essential oil bearing crops [such as citronella -heen pangiri/ maha pangiri (*Cymbopogon nardus* /*C. winterianus*) and lemon grass (*C. citratus* /*C. flexosus*)], masticatory crops [such as betel (*Piper betel*) and arecanut (*Areca catechu*)], and miscellaneous crops [such as garcinia (*Garcinia quaesita/Garcinia zeylanica*), vanilla (*Vanilla planifolia*), ginger (*Zingiber officinale*) and turmeric (*Curcuma longa*)]. The EACs that are primarily cultivated by subsistence smallholder farmers in the wet and intermediate zones of the country, are important components of many agricultural systems such as home gardens and many intercropping systems, and are integral to the nation's economy (DEA, 2025).

Crops are subjected to damage by pests of various kinds, and of these, the damage caused by wild animals poses a significant threat. The kind and extent of agricultural damage caused by wild animals varies greatly around the globe (Fang et al., 2021). Crops in many areas of Sri Lanka are seriously damaged by numerous vertebrate wild animals, causing considerable conflicts between humans and wildlife. A survey carried out by HARTI in 2023 claims that wild animals are estimated to be causing crop damage of Rs. 17 - 20 billion per year (Weerakoon, 2024). Further, the crop damage caused by wild animals in Sri Lanka during the first half of 2022 totaled to around 144,989 metric tons of 28 types of crops. The five types of crops most heavily damaged were identified as coconuts, paddy, vegetables, corn and bananas (Rodrigo, 2023). Six animal species, i.e. elephants (*Elephas maximus maximus*), peafowl (*Pavo cristatus*), wild boar (*Sus scrofa*), monkeys (toque macaques-'*rilawa*'-*Macaca sinica,* gray langur - *Semnopithecus priam* and the endemic purple-faced leaf monkey - *Semnopithecus vetulus*) (Rodrigo, 2023) and giant squirrels (*Ratufa macroura*) have been identified to be causing the greatest damage to crops in Sri Lanka (Ifham, 2022), while toque macaques (*Macaca sinica*) tops the list

(Rodrigo (2023). A study conducted by the Hector Kobbekaduwa Agrarian Research and Training Institute (HARTI), Sri Lanka shows approximately 30-35% of the yearly harvest is lost due to crop destruction by these animals (Amaraweera, 2018), with peacocks being the primary culprits, causing damage from planting through to harvesting. In addition, porcupines (*Hystrix indica*) (Rodrigo, 2023) and squirrels, rats, deer, jungle fowl, bats, grey hornbills, and parrots also have been reported to have been causing significant crop losses (Wickramasinghe, 2022; Wickrama et al., 2021). This damage frequently results in disputes across social groups and has detrimental effects on both people and animals. Anthropogenic drivers such as agricultural encroachment of wildlife habitat through deforestation causing habitat loss, changes in land use, livestock management, expansion of agricultural practices, climate change, resource extraction, infrastructure development and urbanization, and certain government policies that are identified to have weakened the resilience of crops, are responsible for these increased wildlife damages and resultant conflicts (Gross et al., 2021). Such conflicts directly bring about crop losses affecting humans, which spreads poverty and food insecurity amongst people (Emongor et al., 2021).

The government has identified the gravity of the problem, hence identified in their mandate providing solutions to minimize crop damage from wildlife. Different strategies that are economically viable, environmentally sound, and socially accepted need to be employed against vertebrate pests as most of them are protected animals (Jayasinghe et al., 2020). The governemnt emphasized use of modern technological methods, electric fence rehabilitation and maintenance, provision of food and water for animals within reserves, elephant traps, and maintaining tree density as a prime requirement (National Policy Framework of Sri Lanka, 2024). They also have suggested improving natural habitats to provide food and water for all wildlife to minimize their intrusion into villages, studying and managing human-wildlife conflicts, with appropriate techniques and public involvement. The government has also recommended conducting studies on harmful wildlife such as monkeys and wild boar, implementing necessary biological control methods, and engaging young environmental activists in managing human-wildlife conflicts.

HARTI has indicated that food crops face the highest levels of wildlife-related damage, whereas non-food or commercial crops, including cinnamon and other EACs, are comparatively less affected (Weerakoon, 2024). The five types of crops identified to be most heavily damaged are coconuts, paddy, vegetables, corn and bananas (Rodrigo, 2023). Notably, the study by Weerakoon (2024) reported a declining GDP contribution from several crop sectors due to wildlife pressure and highlighted a trend of farmers shifting from food crops to commercial crops such as cinnamon. Although the EACs are also frequently subjected to substantial damage by wild animals, the written records are very scarce, particularly the gravity and extent of the damage. Further, to-date, no comprehensive national study has quantified the economic or agronomic impact of wildlife-induced damage to EACs in Sri Lanka.

Therefore, this chapter was written with the aim of collating available information on crop losses in EACs caused by vertebrate wildlife in Sri Lanka. For ease of reference, the information is summarized on a crop-wise basis.

2. Damage caused by wild animals to different Export Agricultural Crops (EACs)

2.1 Cinnamon (Cinnamomum verum)

Cinnamon is a highly treasured crop, and the peeled, dried, inner bark is economically valuable to be used for culinary and medicinal purposes. It is culturally integrated into Sri Lankan sweets and curries and used in native medicine. Leaves are used to distil essential oil to be used in perfumes and drugs, and roots are used in Ayurvedic medicines. Cinnamon is grown mostly in the coastal areas of Sri Lanka, from Negambo to Matara, although it has also spread to Kalutara, Ratnapura and Kandy (DEA, 2025). Under government assistance, the cinnamon business has expanded significantly by 2022, and from 36,506 hectares of land, Sri Lanka exported 18,300 metric tons of cinnamon goods valued at 71,716 million rupees (DCD, 2024). Despite being a relatively hardy perennial, cinnamon is susceptible not only to insect pests and diseases but also to damage caused by vertebrate wildlife.

The young cinnamon leaves are dark pink/ maroon in colour (Fig 1), which turns light pink, then light green and lastly dark green with maturity (Suriyagoda et al., 2021). The pink/maroon colour in the young leaves are due to high concentrations of anthocyanin pigments, which are photoprotective in nature: The anthocyanins protect the delicate, developing leaf tissue from intense sunlight. These pigments also protect the young leaves against UV damage, and potential herbivore attacks (Gong et al., 2020). However, the coloured, young cinnamon leaves particularly attract wild animals.

Since many vertebrate pests attacking cinnamon are nocturnal, and they tend to move away from humans, their identification is usually difficult. Therefore, the nature of the damage is often used to identify the pest (Jayasinghe et al., 2020). The primary vertebrate pests known to impact cinnamon include, Indian peafowl (Peacock) (*Pavo cristatus*), Barking deer (*Muntiacus muntjak malabaricus*), Sri Lankan axis deer (*Axis axis ceylonensis*), Sri Lankan spotted chevrotain/ mouse deer (*Moschiola meminna*), Bandicoot rat (*Bandicota indica*), Layard's palm squirrel (*Funambulus layardi*), Giant squirrel (*Ratufa macroura*) and Sri Lankan sambar deer (*Rusa unicolor unicolor*). These animals predominantly damage the newly emerging shoots that sprout after the cinnamon harvest, compromising regrowth and yield (DCD, 2024). Jayasinghe et al. (2020) identified peacock, mouse deer, barking deer, squirrels, hares, and stag to be the most common vertebrate pests in cinnamon cultivations that are in close proximity to forest reserves.

Fig 1. The range of colours of young cinnamon leaves - dark pink/ maroon/ reddish coloured to light pink, and light green, in re-growing cinnamon after harvesting, that attracts wild animals (Photo courtesy: A J Mohotti).

The peafowl (peacock) has emerged as a significant and persistent threat to cinnamon. A study by HARTI (2022), revealed that 83% of surveyed residents in the Pitabeddara Divisional Secretariat emphasized negative impacts from the growing peafowl population, and considered them as a major threat to cinnamon. The primary concern identified was the peafowl's tendency to eat the tender shoots on cinnamon bushes arising after the harvest. Cinnamon is managed to grow with a straight stem for a greater harvest. However, due to the feeding of the peacocks on the young shoots, branching occurs in cinnamon stems which decreases its economic value (HARTI, 2022). According to local perceptions, the factors believed to contribute to the rising peafowl population are, absence of natural predators such as jackals and leopards which naturally prey on peafowl, increased food availability due to oil palm cultivation (which supports a higher serpent population), favorable climatic conditions, religious beliefs and legal restrictions that prevent harming peafowl, weak enforcement of wildlife management regulations, and limited public awareness and technical knowledge for crop protection (Wickramasinghe, 2022).

In certain other areas, the barking deer also feeds on the re-growing young shoots of the harvested cinnamon plants (Personnel communications, Mr. P. Gerry, supervisor of a cinnamon plantation, Kandy). In addition, porcupines damage the bark by nibbling, affecting the quality and quantity of the harvest (Fig 2). Electric or low-wire fencing has been found to be effective in blocking access to the plants by small mammals such as porcupines. Ultrasonic sound devices with different frequencies have also shown to repel peacocks from cinnamon cultivations, and a significant reduction of damage to cinnamon has been observed (Jayasinghe et al., 2020). Considering the economic importance of the crop, more research is needed to invent successful methods to deter these wild animals from cinnamon.

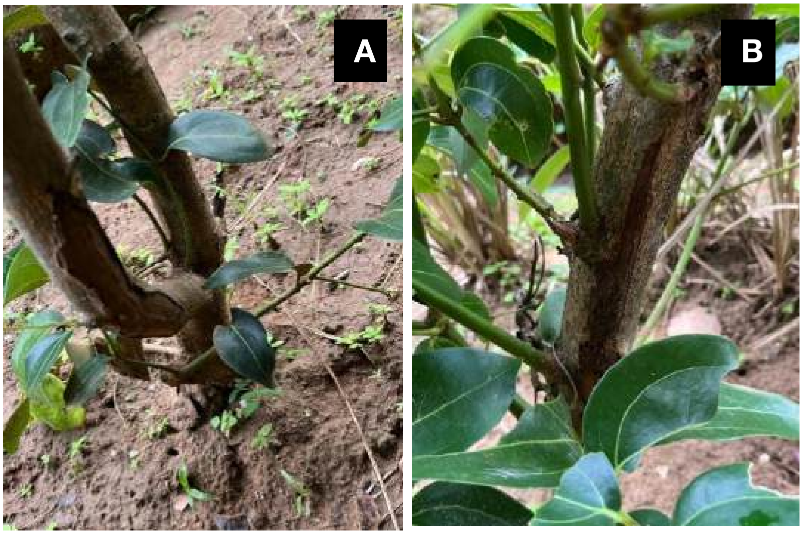

Fig 2. A & B. Damage to cinnamon bark by porcupines (Photo courtesy: A J Mohotti)

2.2 Cocoa (Theobroma cacao)

The economically important part of the cocoa plant is the pod. The beans are removed from the pods, fermented, and dried to be processed into dried beans, which are the main raw material for chocolates. Cocoa beans yield cocoa butter, which is pressed out from the roasted and ground bean, leaving the solid component formed into cocoa powder (DEA, 2025). In Sri Lanka, cocoa is an important component of Kandyan Forest Gardens, partially forming the understory of these gardens. Cocoa is also intercropped with coconut, rubber or banana, which enriches soil fertility by leaf fall (Fig 3a) and provides a humid environment favouring a moist tapping panel in rubber and aids in pollination of cocoa flowers (DEA, 2025).

Fig 3. A. Fall of old cocoa leaf, enriching the soil and B. Damage to cocoa pods caused by squirrels (Photo courtesy: A J Mohotti).

In many areas, Layard's palm squirrels are considered as one of the most important pests in cocoa. They make holes in the pods, and eat up the contents inside, leaving hollow pods (Fig 3b). Monkeys are other most troublesome pests on cocoa, which destroy pods. They nibble and eat up some pods while removing and throwing away most of the fruits, even the young, immature pods and leaves. In certain areas in the Kandy district (e.g. Poojapitiya area), giant squirrels are considered as the most troublesome pests on cocoa. A resident said that the giant squirrels nibble the cocoa pods when they are still young, and they have not seen a mature pod in the trees for years (Personnel communications, Ms Sudharma Dissanayake, resident of Poojapitiya area, Kandy district).

Protecting cocoa from wild animals has become an extremely difficult task in many areas, preventing farmers from cultivating the crop. Covering the pods by a wire mesh is being done by certain farmers, but it can be a costly operation. However, this method keeps away the squirrels and monkeys to some extent (Personnel Communications, Mr Sridharan, Kundasale). In certain countries, chemical repellents such as Anthraquinone, Butanethiol, and Methyl Anthranilate are used to deter wildlife (Hajdu, 2022), but these are expensive and contribute to environmental deterioration and rarely used in Sri Lanka. Community cooperatives in Matale are piloting bio-fencing using such spiny species as agave, with modest results in keeping monkeys out. Such projects require sustainable, affordable deterrents as necessary to ensure the protection of cocoa cultivation. A scarecrow with an ape-like visage/ masks is positioned in fields, a common technique employed by farmers to deter animals especially monkeys that attack crops (Rodrigo, 2023), with some success. However, farmers claim that the monkeys get used to the mask quickly. Air rifles are used by certain other farmers to keep off the monkeys (Kumara et al., 2023). Fire crackers called as 'monkey shots' are also being used with some success to deter the monkeys (Personnel communications, Mr Berty Eriyagama, resident of Peradeniya area, Kandy district).

2.3 Coffee (Coffea spp.)

Coffee is grown primarily for its economically useful seeds to be roasted, ground and consumed in various ways. Two species, i.e. *Coffea arabica* (Arabica coffee) and *C. canephora* (Robusta coffee) are mainly commercially grown in Sri Lanka (Chandrasiri et al., 2022; DEA, 2025). Being a shade-loving plant, coffee is widely grown in homegardens such as Kandyan homegardens and serve as a component in intercropping systems along with crops such as tea, rubber, coconut, banana or spice main crops, and as small plantations. Ecologically, shade-grown coffee creates diversity as birds and insects nest under shade, though this also invites wildlife to stay on (Van Asten et al., 2011; Harelimana et al., 2018).

The well-ripened coffee berries are purple/ red/ orange/ yellow in colour, which attracts wild animals, is a principal threat, particularly in highland regions such as Matale, Kandy and Nuwara Eliya (DEA, 2025). Monkeys damage branches during climbing and hanging in them and they also strip off the ripening berries but don't consume them, causing considerable disruption to yield (Personnel Communications, Mr Mahesh De Silva, Estate Proprietor, Pupuressa, Kandy District).

In countries such as Indonesia, Vietnam and Philippines, the coffee eaten by the Asian Palm Civet (*Paraxorus hermaphroditus*), and passed in its droppings undigested, are collected, cleaned, processed and sold as '*Kopi Luwak'*, which is known to be the most expensive coffee in the world (Miththapala, 2015). Similarly, coffee eaten by other animals such as Thai elephants, Brazilian jacu birds, and Bonobo monkeys too are sold at high prices in some other countries (Wild, 2013). These situations can be considered as examples for instances where the wildlife damage to crops have been used usefully, although these coffees are also being heavily criticized for cruelty to wild animals as these coffees are sometimes being made using animals in captivity (Wild, 2013; Miththapala, 2015).

2.4 Pepper (Piper nigrum)

Pepper is a vine which is usually grown on live supports such as *Gliricidia sepium*, *Grevillea robusta*, coconut, and arecanut trees or trained onto dead supports, such as concrete poles. Pepper's economic importance is in the dry berries, which are an important spice exported to many countries, with the tag of "King of spices". The fruit (a drupe) occurs in a spike, and the ripening of the fruit does not happen evenly across the spike. The ripened fruits are red in colour (DEA, 2025; Wijayasiri et al., 2017).

Pepper is relatively less burdened by wild animal attacks due to the pungency of the fruits. However, farmers are burdened by wild animals such as porcupines which are attracted to the roots of the support trees especially for *Gliricidia*, and while consuming these roots, they damage the pepper vines. Wild boar also interferes with farming by digging up support tree species such as *Gliricidia*, affecting vine performance and reducing harvest quality (Personnel Communications, Ms Karunathilaka, resident of Matale). The monkeys destroy the pepper vines by hanging on them and breaking the branches and spikes.

2.5 Cardamom (Elettaria cardamomum)

Cardamom as known as the "queen of spices" produces economically important product from its pod. The pod with seeds in dried form is used for culinary and medicinal purposes. Cardamom requires shady and humid conditions with well-drained soils; hence, it grows well under forest cover, such as the Knuckles mountain range of Sri Lanka. Since growing cardamom under the forest in those environmentally sensitive areas is now prohibited, it has become quite an expensive spice in Sri Lanka lately (Wijayasiri et al., 2017). This prohibition resulted as Cardamom's shade cultivation in forest borders was found to be derailing biodiversity, attracting wildlife towards it and increasing susceptibility to human-wildlife conflicts, in addition to other issues such as illegal logging. The toque macaque is the primary wild animal affecting the cardamom cultivation (Fig 4). These destroy and consume pods and cut down yields appreciably. Porcupines damage cardamom bushes (Rodrigo, 2023), especially in dry spells as they use the pseudo stems and rhizomes as an alternative water source. Wild boar damage mainly occurs due to their dwelling habit, by disturbing the soil and destroying the bushes to find feed material. To stop such attacks, cultivators typically employ conventional techniques like hooting, us of firecrackers, and even gunfire and traps (Wijayasiri et al., 2017).

Fig 4. Cardamom crop damage by Toque macaques in Knuckles Area (Photo courtesy: H R P B Erabadupitiya, Deputy Director (Research), DEA)

2.6 Clove (Syzygium aromaticum)

The economic value of clove is as unopened flower buds, which are dried and used as a medicine or a culinary spice (DEA, 2025). Cloves also are relatively less affected by wild animals due to the pungency of the buds. The damage by monkeys, which eat buds and break branches, severely reduces yields and export quality of cloves in Kandy and Matale regions of Sri Lanka. Wild boars and porcupines pull out seedlings when they are still young, killing them and affecting production (Personnel Communications, Mr P. Gerry, Field Supervisor, Kandy).

2.6 Arecanut (Areca catechu)

The economic importance of arecanut lies in nuts, which are chewed along with the betel leaves, or used to extract dyes. Monkeys consume and shatter immature nuts, destroying their economic potential. In certain other areas, Layard's palm squirrels toe considerable damage to arecanut (Personnel Communications, Ms Sudharma Dissanayake, resident of Pujapitiya, Kandy).

2.7 Nutmeg (Myristica fragrans)

The seed of nutmeg is the prime economic commodity, either exported as spice or as mace, the seed aril, as highly prized by-product in cuisine. The pericarp is used in making local drinks and jams. Nutmeg is widely grown in homegardens, and about 80% of the nutmeg population in Sri Lanka is concentrated in the Kandy, Kegalle and Matale districts (DEA, 2025). In Matale and Kandy, severe damage by toque macaques substantially reduces yields. The fruits are also eaten by bats during the night. Seedlings are pulled out by wild boars, shortening long-term yields. Grey hornbills damage the nutmeg fruits by splitting the fruit open and consuming the mace (Personnel Communications, Ms Sudharma Dissanayake).

3. Socio-economic perspectives of wild animal damage on EACs mitigation strategies

Crop destruction by wild animals has been consistently identified by many organizations in Sri Lanka as a significant threat to agricultural productivity, adversely impacting the livelihoods of farming communities across various regions of the country. Requests for controlling measures, recurrent reports and appeals from affected stakeholders have led to increased government attention. Therefore, back as early as 2018, HARTI suggested a nationwide study to quantify the damage to crops caused by wildlife.

Figure 5 shows the animals with the largest populations causing crop damage, which came as the result of the national wildlife census conducted on 15th March 2025 by the Ministry of Agriculture, Sri Lanka, to assess the extent and distribution of wildlife-related crop damage in Sri Lanka. Toque macaques and peacocks were the animals identified to be in largest populations, followed by giant squirrels and purple-faced langurs. It is notable that several species implicated in crop damage are classified under protected conservation statuses e.g. both toque monkeys and purple-faced langurs which are endemic species to Sri Lanka (Rodrigo, 2023). Further, same survey highlighted particular hotspots of crop-damaging animal activity in the Kegalle District, notably the Kegalle, Galigamuwa, and Mawanella Divisional Secretariat areas, as well as around Pahathahewaheta, Medadumbara, and Hatharaliyadda in the Kandy District (Jayawardhana, 2025). This also shows that the EACs are particularly vulnerable, as these are also areas of high concentration of EACs.

In a study conducted by Kumara et al. (2023) determined which wild animals in Kandyan Home gardens were the most frequented and destructive, the severity index, incidence index, and risk index were computed. Considering these parameters, they ranked wild boar as the most troublesome wild animal species in Kandyan homegardens, followed by toque monkey, porcupines, giant squirrel, great yellow bat, flying squirrel, barking deer, Sri Lanka grey hornbill and greater bandicoot rat to be the most troublesome ten species in the Kandyan Home gardens. Wild boars (97%) and porcupines (97%) were the most often recorded wild animals followed by toque monkeys (83%). The Indian peafowl was identified to be causing the least danger to crop in the Kandyan Home gardens at present, but it was predicted to become an issue in the future (Kumara et al., 2023). In this study, the greatest risk index was identified with the wild boars (in terms of a risk index of 0.87), followed by toque monkeys (risk index of 0.83), porcupines (risk index of 0.79), and giant squirrels (risk index of 0.55). Aligned with this study, several other studies also have reported toque monkeys and wild boars are seriously harming large-scale commercial horticulture in various regions of the nation in addition to residential gardens (Rudran et al., 2021).

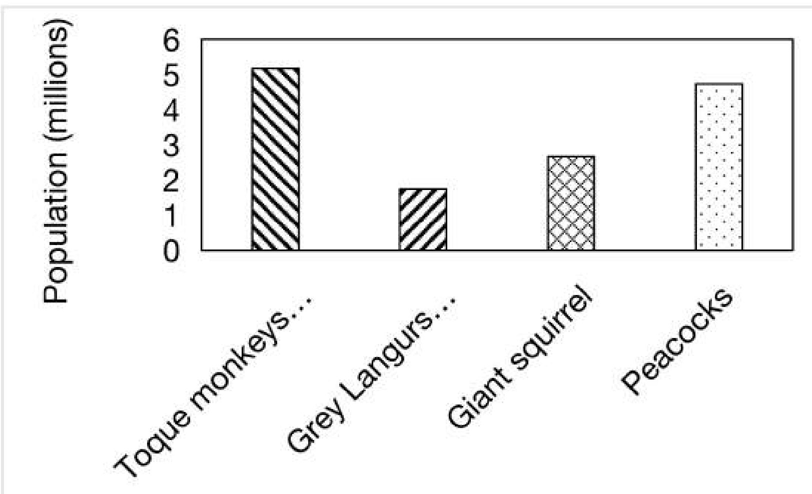

Fig 5. Wildlife population damaging crops in Sri Lanka as of 15th March 2025 (Adapted from Jayawardena, 2025)

In Sri Lanka, various approaches and initiatives have been used to tackle the issue of wildlife causing damage to crops. These include government and policy initiatives, traditional methods, preventive strategies, and new technologies. The goal of these initiatives is to protect both biodiversity and farmers' livelihoods. Drawing on work by organizations such as HARTI, the Ministry of Wildlife Conservation, the Department of Export Agriculture, and adopting successful practices from around the world, strategies that are short-term, medium-term and long-term have to be used.

Short-term strategies are strategies from immediate to a few months that emphasize preventative, non-lethal, quick, and often temporary measures to deter animals and reduce losses with methods to keep wildlife out of the crops. Traditional techniques promoted by the Department of Cinnamon Development, such as covering new plant shoots with harvested branches, and spraying diluted cow dung mixtures or strong-smelling insecticides to effectively deter animals like deer and monkeys (DCD, 2024). Natural repellents like human hair soaked in neem oil to scare porcupines, mixtures of *Canarium zeylanicum* (Common name: *kekuna*) seeds and fish offal, or crushed *Lantana camara* (*Gandapana*/ *Baloliya*) leaves are some low-cost options. Smoke from burning materials like elephant dung or natural emulsions made from garlic and fish can also keep certain animals away. Another study reports that leopard urine deters many wild animals (Perera, 2025). Some farmers employ traditional methods such as firecrackers, scarecrows with certain ape-face-like masks, noise-makers/ sound repellents, scare devices/ bio-acoustic devices with predator calls or distress sounds. Non-lethal tools like scarecrows, sound devices designed for giant squirrels, and animal traps are common, but animals can get used to these; for example, peafowl can become habituated to solar-powered sound scare devices, and they are known not to fear fire crackers; monkeys get adapted to the scarecrows/ masks, so approaches must adapt. Some farmers use dogs as guard animals, but these are ineffective against intelligent and adaptive wildlife such as elephants, which can lay waste to a whole field overnight, or toque macaques, which target specific crops and habitat tall trees (Hajdu, 2022).

Use of physical barriers with or without various plant species as the main crop, or as a bio-fence /buffer zones with unpalatable crops, or mixed planting to deter the wild animals is being used by some farmers. For example, growing chilli peppers, which contain capsaicin, serves both as a deterrent and a way for farmers to make extra income (Hajdu, 2022), but the use of such plants for the purpose is limited in perennial crops such as EACs. Bio-fencing with thorny plants such as palmyra or cacti have reduced crop incursions in some districts, but prohibitively high initial and maintenance costs prevent them from reaching most smallholders (Jayathilaka et al., 2021; Kumara et al., 2023). Modern methods, such as electric fencing powered by solar panels, also can be used against certain animals, but will not be very effective against animals like monkeys. Limited use of high-quality air rifles for crop protection has been suggested, but the Ministry of Agriculture prefers non-lethal methods aligned with conservation policies. Netting or fencing (electric or mesh) around small farms or vulnerable crops is also practiced in the case of crops such as cocoa. Whichever the above method is used, manual vigilance/ human patrolling or watchtowers during peak crop season may be necessary.

Medium-term strategies mainly focus on improving infrastructure, introducing new farming techniques, and working closely with communities. These also include sustainable, policy-based and ecological approaches aimed at coexistence and systemic change. For example, simple physical barriers, or small electric fences funded by subsidy programs, can help keep animals like deer away from crops. Establishing buffer zones with mixed-use forestry/ agriculture to reduce conflicts and provide alternative livelihoods for affected farmers has been suggested in certain situations. In Thailand, beehive fences have been successfully used. They protect crops and bring in extra income from honey sales (Gross et al., 2021). Training programs that teach farmers how to handle human-wildlife conflicts like using crop guards and repellents are essential (Gross et al., 2021).

Long-term strategies focus on bigger systems and new technologies, coupled with research and policy changes. For example, creating crop loss estimates using tech solutions such as drones and remote sensors to track wildlife movements allows better planning and help officials issue early warnings. Long-term ecological studies on animal behavior, crop damage patterns, and habitat use play an important role in planning mitigation actions. Monitoring wildlife populations and controlling their numbers carefully while considering cultural and legal issues helps manage species that raid crops. Restoring natural predators, such as jackals in Sri Lanka, can help control species that damage crops, bringing back natural ecological balance. However, limitations may arise in already urbanized areas, due to unavailability of suitable habitats for them. Tools like measuring how many animals' local communities will accept-which is called 'wildlife acceptance capacity' help inform targeted efforts such as sterilization programs for species like toque macaques, respecting cultural sensitivities in Sri Lanka (Rodrigo, 2023). The official release of the report of the animal census carried out in 2025 also highlights sterilization programmes as a humane method for controlling wildlife numbers (Jayawardhana, 2025). However, unlike in certain countries, Sri Lanka currently lacks policies that allow for partial removal or relocation of wildlife when populations become excessive.

Recently (in December 2024), the Minister of Agriculture, Livestock, Land and Irrigation has issued a statement stating that there will be no legal issues taken against farmers taking any action against wild animals causing crop damages caused within their cultivated lands (Siriwardana and Perera, 2024). However, this statement was subjected to debate and criticism especially by environmentalists that it may encourage farmers to violate established wildlife laws (Mawrata News, 2024). By the previous government too, specifically the Ministry of Agriculture and Plantation Industries, the Sri Lanka Hadabima Authority (SLHA) was authorized with a scheme to provide farmers with air rifles at a 50% discount. According to the scheme, farmers should pay 50% of the cost of an air rifle, with the SLHA covering the remaining 50% of the cost (Times Online, 2023; Ministry of Agriculture, 2023). However, in Sri Lanka, hunting is restricted, which makes some approaches more complicated (Rodrigo, 2023).

In addition, research can support developing crop varieties that are less preferred by wild animals. Further, evaluating and improving local/ indigenous and farmer-made methods can play an important role here, for example planting native fruit trees to keep wildlife in natural habitats and away from farms (Rodrigo, 2023). Advocacy of policy and compensation mechanisms play an important role in managing wildlife conflicts, which necessitates stronger laws and better implementation of compensation schemes for crop damage. Better land-use planning helps prevent conflicts by keeping wildlife habitats connected (Gross et al., 2021), although this may be difficult with already established perennials. Reforestation and habitat restoration and ensuring adequate natural food sources for wildlife in their native habitats to reduce foraging in farms should be considered in such planning. Insurance schemes targeting wildlife damage help spread financial risks, encouraging farmers to keep producing for export markets. Partnerships across different government sectors, along with funding and training programs, are critical to expanding these solutions. Education and awareness programs, training for farmers on wildlife-friendly farming and conflict mitigation can be considered compulsory. However, even with all these efforts, challenges will remain.

4. Conclusion

Human-wildlife conflict is a major risk to Sri Lanka's export crops of agriculture, such as cinnamon, cocoa, coffee, and spices, critical to the economy and livelihood of small farmers. Almost all EACs, for example cinnamon, cocoa, coffee, pepper, cardamom, and cloves, are vulnerable to at least one species of vertebrate pests. Multiple vertebrate species, such as toque macaques, squirrels, giant squirrels, giant squirrels, wild boars, peacocks, porcupines, and others cause an estimated 40% annual crop loss, and add to poverty and food insecurity. Multiple mitigation measures have been attempted, from temporary measures such as scarecrows, bio-fencing, and natural repellents, to medium-term measures such as electric fencing and training of communities, to long-term measures such as habitat restoration, wildlife monitoring, and policy reform. These are limited by prohibitive costs, animal habituation, and incremental policy response. Conservation of coexistence requires reciprocal measures, such as better land planning, reforestation, and compensation to farmers. Ecotourism activities at community levels and technological applications such as drones to monitor wildlife can reduce new conflicts. Multi-stakeholder coordination by government, research, and agriculture communities is essential to balance agriculture productivity and biodiversity conservation for ensuring the resilience of Sri Lanka's export economy while leaving its natural ecosystems intact.

Conflict of interest

The authors declare that they have no competing interests regarding the publication of this article.

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Chapter 13

Impacts and Mitigation of Human–Wildlife Conflict in Urban Landscapes of Sri Lanka

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Abstract: Human-wildlife conflict in Sri Lanka's urban landscapes is an escalating socio-ecological crisis caused by habitat fragmentation, urbanization, and competition for resources. This chapter highlights unmanaged edge environments, blocked movement corridors, and predictable resource hotspots as its key ecological drivers. The synthesis examines repercussions on human livelihoods, physical infrastructure, and agricultural productivity, drawing in empirical studies from rapidly urbanizing regions. Conflicts with insects, birds, and mammals are highlighted hereby, along with their consequences. The negative impacts on wildlife span from individual mortalities to loss of biological diversity, creating the potential for large-scale ecosystem collapse. Economic losses, medical hazards, and emerging tensions between conservation ethics and urban development are discussed as key aspects of concern. In the meantime, gaps in compensation schemes, uneven enforcement of regulations, and limited integration of community knowledge are identified to hinder long-term solutions. Taken together, these findings point to the need for stronger habitat planning, well-managed ecological buffers, improved compensation mechanisms, and community-led mitigation strategies for reducing harm to both people and wildlife and supporting their stable coexistence as Sri Lanka's cities continue to grow.

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1 Introduction

Human populations are expanding globally, and mass migrations into urban areas are happening in search of better opportunities and lifestyle upgrades (Chen et al. 2014). This population expansion demands natural areas to be transformed into built-in environments, hence natural landscapes are changing in size, density, and complexity. This transformative process is known as urbanization (Bradley and Altizer, 2007; Vlahov and Galea, 2002). Such spaces set the stage for new ecological processes and ways that wildlife uses resources.

In an ecological perspective, urbanization transforms natural habitats into resource-altered spaces. The amount and the quality of habitats decrease, promoting habitat degradation and, in some cases, complete habitat loss. Due to the heterogeneity of the habitat degradation rate, some habitats become fragmented (Liu et al., 2016). This results in complex socio-ecological systems where wildlife habitats and human settlements intersect, integrating biological, physical and social components. Humans and wildlife within these systems compete for space and resources, creating conflicts (Basak et al., 2023; Yeshey et al., 2024a). Human-wildlife conflicts involve direct and indirect encounters between humans and wildlife, that lead to negative consequences for one or both sides. Such conflicts typically occur when human activities and objectives adversely affect wildlife, or animal behaviours negatively impact human lives. However, changes of the parts of this system create complex impacts and feedback loops across different components (Liu et al., 2016), and in the present urbanization context, these consequences are generally negative in nature. In Sri Lanka, rapid urbanization has increasingly met biologically rich forest edges and long-used wildlife movement paths, where these dynamics have intensified and given rise to human-wildlife conflict in many regions.

This chapter explores how urban landscapes alter ecological processes and wildlife behaviour, and how these changes translate into impacts on people, livelihoods, and biodiversity. It explores the public attitude towards human-wildlife conflict, followed by an assessment of current mitigation strategies and specific management tools. The chapter concludes with community-based approaches and policy reforms recommended to support long-term coexistence in urban and peri-urban landscapes in Sri Lanka, with minimal human-wildlife conflict.

2 Ecology of Urbanization

2.1 Urban landscape structure and environmental stressors

Urban matrices are habitat mosaics which are structurally and functionally unique from each other, with hardly homogenous components including clusters of buildings with varying densities, tree covers such as urban parks or remnants of forests, and linear structural elements such as roads, railways, and waterways (Soulsbury and White, 2015; Werner, 2011). This structural heterogeneity forms the basic physical template on which urban ecological processes unfold. Urban wildlife ecology is a modern discipline that deals with fauna and flora of cities (Magle et al., 2012).

Land use changes occurring during urbanization pose a range of challenges to inhabiting wildlife, such as noise pollution including vehicle, recreational, manufactural, and constructional noises; light pollution especially including nightlight in streets, vehicles, and buildings; air pollution such as the liberation of smokes, smog, greenhouse gases, toxic gases, and dust; groundwater and surface water pollution; and soil pollution, caused by domestic, commercial, industrial, and agricultural aggregations. Excessive usage of automobiles, improper waste disposal and demolition, continued power generation utilizing non-renewable sources, and the introduction of chemicals including nutrients, pesticides, heavy metals, fertilizers, oils, and other toxicants are among the key causes of urban environmental degradation. In addition to these widespread issues, there are certain point sources of hazards in urbanized environments, such as uncovered power cables which can cause electrocutions, road kills, and collisions. Urbanization can have biological effects as well, including the introduction of alien organisms such as predators, parasites, pathogens, and invasive species. These effects can have serious consequences on the distribution, behaviour, evolution, adaptation, and even survival of local biota. Together, these stressors act as ecological filters that determine which species can persist in urban habitats.

2.2 Species filtering and biotic homogenization

The vast majority of the native animal species with high locomotive capabilities would avoid urbanized landscapes, while those with low dispersal abilities and tolerance levels would perish in the face of the drastic environmental alterations, leading to their extirpation. However, a relatively limited number of species, which are known as urbanophiles, would take over these novel niches, and proliferate in enormous population numbers. Such adaptable species are often exotic cosmopolitan fauna that are opportunistic habitat and dietary generalists, such as crows and pigeons. This dramatic reduction of diverse native fauna and the proliferation of a few urbanophilic species upon urbanization is viewed as biotic homogenization (Chamberlain et al., 2017; Clergeau et al., 2006; Evans et al., 2011; McKinney, 2002; McKinney, 2006; McKinney and Lockwood, 1999; Meffert and Dziock, 2013; Rathnasiri et al., 2024a). This process forms the ecological backdrop against which many urban conflicts emerge.

2.3 Habitat fragmentation, encroachment, and edge effect

The fragmentation of natural ecosystems caused by urbanization might result in forest edges in the proximity of human settlements. This can induce edge effect, and these areas can act as conflict hotspots between humans and wildlife. For example, in southern Sri Lanka, 22% of conflict-prone encounters with primates are reported to occur within 1 km from the forest boundary, whereas only 6% at a distance of 5 km (Nekaris et al., 2013), a pattern apparently driven by the reduction in natural resources. Such edge environments intensify interactions between wildlife seeking resources and humans occupying these border zones.

The conflict at habitat edges can become worse in the case of human encroachment into natural ecosystems. Rapid human expansion into forest areas results in a significant shrinkage and degradation of wildlife habitats. For instance, Bharathy et al. (2022) have reported a 13% decline in dense forest cover in Mullaitivu District, Sri Lanka, from 1994 to 2020, displacing wild species into peri-urban areas. Macaques, langurs, and elephants therefore tend to increasingly forage in home gardens and croplands, escalating human-wildlife encounters. Urban sprawl into frequent elephant corridors can be viewed as a specific type of problem associated with encroachment, and contributes to drastically increasing confrontations, with elephants damaging infrastructure while searching for food. These patterns collectively illustrate how spatial changes drive much of the conflict observed in Sri Lanka.

2.4 Case study: Elephants and crop-raiding as a biological and spatial-ecological problem

While habitat fragmentation, edge effect, and encroachment explain much of the rising contact between humans and wildlife, some conflict patterns are also shaped by species-specific biologies and behaviours. These underlying traits help clarify why conflicts with certain animals such as primates, wild boars, and elephants are more prominent in urban and peri-urban areas. Among such species, elephants are a clear example of how spatial change and biological requirements of a species lead to severe conflicts in urban and peri-urban environments.

Apart from habitat , there is an often-overlooked biological reason for the elephants to raid crops. Even though male elephants reach sexual maturity at the age of 12 – 15 years, they ought to attain social maturity, which is reached around 35 years of age, to attract females (cows). Social maturity is usually claimed by physical combat with other males (bulls). Since elephants are ever-growing mammals, the oldest bulls are generally the largest and have advantage in battles. Moreover, cows tend to attract larger bulls. Therefore, to increase body size in a shorter period, young bulls tend to select a diet with high nutritional values. During human evolution, plants producing foods with the highest nutrition content are selected as crops and are cultivated. Hence, agricultural areas are usually rich in food sources with abundant nutrients. This is a biological reason for elephants to invade agricultural areas, and feed on cultivated crops. This is supported by the fact that most elephants that raid crops are reported to be young bulls (Chiyo and Cochrane, 2005).

Crop-raiding behaviour is also shaped by learning. Young bulls are able to quickly identify crops such as paddy, banana, and maize as high-yielding reward foods, and when successful, these bulls tend to revisit the sites. Most of such raids occur during crop-bearing or harvesting periods, and elephants shift their activities to reduce the chance of confronting humans, thus making certain croplands vulnerable to raiding (Anoop et al., 2023).

In addition to nutritional incentives, movement patterns of elephants amplify the conflict risk. Elephant herds follow long-established seasonal routes to migrate into resource-rich areas. However, these are intersected with expanding human settlements or narrowed by infrastructure such as road networks and agricultural lands. This results in bulls taking the shortest available paths along settlement edges and through agricultural lands, creating conflict hotspots with repeated human-elephant encounters, specifically during dawn and dusk (Fernando et al., 2023; Rathnayake et al., 2022).

When it comes to human-elephant conflict, it is hardly investigated if elephants engage in revengeful attacks against humans. In early 2025 in Sri Lanka, a female elephant was seen attacking a train that killed its calf in an accident (Hiru TV News, 2025). This hypothesis is supported by the fact that elephants can distinguish the skeletal remains of other elephants from those of other large land mammals, and tend to react more dramatically, compared to other animals. That is, elephants display a heightened level of interest or 'emotions' towards their dead ones, by spending long periods of time systematically investigating the bones, with special emphasis on the skull and ivory, in contrast to other animals in general that show limited interest towards the carcasses and associated remains of the individuals of their own species (Masson and McCarthy, 1995; McComb et al., 2006). Hence, it is suggested to scientifically study if there is a possibility for elephants to confront individual humans or human settlements/infrastructure as a revengeful act for an anthropogenic destruction experienced or witnessed in the past.

Human-wildlife conflict in urban areas has been a problem since the ancient Egyptian civilization (Dixon, 1989). However, even after thousands of years, still a permanent solution for this problem is hardly available. The main reason for this limited success is the complexity of this problem, and the requirement of case-by-case analyses to devise customized solutions for each complaint received, because each case has unique aspects including the problematic species, their behaviour, human activity, environmental conditions, etc. Mathotaarachchi et al. (2021) describe this as a triparty conflict, rather than a two-way combat between humans and wildlife. According to them, the conflict comprises two human aspects centred around wildlife. One human aspect is the group of people who are facing conflict with animals, and view animals as the cause of the problem. The other human aspect is the people who are appointed to or interested in conserving wildlife, and view humans as the reason for the conflict. Thus, they propose this confrontation to be human-wildlife-human conflict. Hence, it is strongly recommended to consider the well-being of both humans and wildlife when devising mitigation strategies and promoting coexistence while adhering to conservation goals.

3 Impacts of Human-Wildlife Conflict

Understanding human-wildlife conflict requires breaking down the complexity of the issue, encompassing the dynamics between humans and wildlife that coexist (Nyhus, 2016). In a resource perspective, the centralized underlying issue of the urban human-wildlife conflict can be described as the competition for shared resources that are either depleting, altered, or lost (Cumming et al., 2006). This competition leads to financial losses, risks to human lives and livelihoods, and safety concerns for both humans and wildlife, often resulting in wildlife population declines (Kansky et al., 2014; Yeshey et al., 2024a). Overall, such impacts manifest at individual, behavioural, population, and habitat levels in an ecological perspective and at psychological, sociological, economic, and clinical levels in a human perspective, and these are multifaceted. These layered interactions are summarised into a diagram in Fig 1 to further explore the human-wildlife conflict in a global viewpoint, to aid in understanding its scope in Sri Lanka.

3.1 Ecological impacts of urban human-wildlife conflict

i. *Individual-level impacts*

At the individual animal level, negative impacts manifest through a range of direct and indirect factors that result in animal mortalities with intensified urban expansion. One of the most widespread causes of animal mortality is vehicle collision. Species such as deer in the United States (approximately 1.5 million collisions annually, according to Messmer and Messmer (2008)), hedgehogs and foxes in Europe, and endangered animals like Florida Panthers and Koalas in Australia suffer significant population losses in urban road networks (Richard and Alexander, 1998). Furthermore, birds are vulnerable to collisions with aircraft (Dhakal et al., 2025), and glass buildings, worldwide (Lee et al., 2024). Apart from the conspicuous large vertebrates, reptiles, amphibians, and invertebrates suffer mortalities throughout urban transport systems, and are seldom noticed (Andrews and Gibbons, 2005).

Poaching and illegal pet trade are prevalent in most parts of the world. In Africa, it is estimated that 40,000 elephants are illegally killed annually (Wittemyer et al., 2014). In Thailand, urbanization is reported to have dramatically increased illegal pet trade of tortoises and freshwater turtles (Nijman and Shepherd, 2015). Apex predators that cross urban borders are poisoned intentionally and unintentionally, as they often become secondary victims for preying on carcasses of pests (specifically rodents) or other predators. Leopards in India, African Vultures in sub-Saharan Africa, and Urban Red Foxes and Racoons in Europe have been reported to be frequently killed by such poisonings (Athreya et al., 2011)

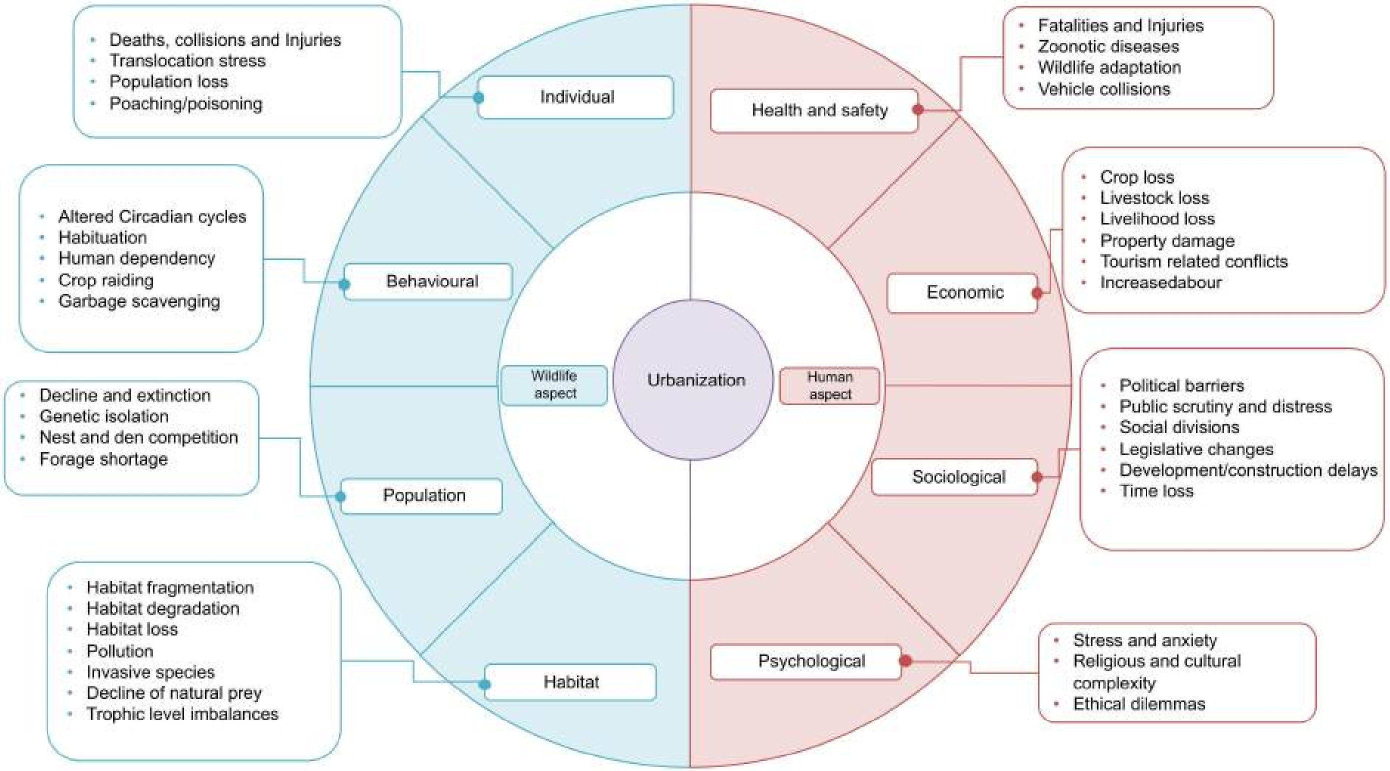

Fig 1. Conceptual diagram illustrating the impacts of human-wildlife conflict, categorized into wildlife-centred (blue) and human-centred (red) aspects. The wildlife-centred aspect is further categorized in an ecological perspective, while the human-centred aspect is further categorized in a socio-economical perspective.

ii. *Behaviour-based impacts*

Urban encroachment alters behavioural adaptations of wildlife, often escalating into human-wildlife conflicts. As natural habitats shrink and fragment, wildlife faces resource shortages, or newfound resources such as agricultural lands, livestock, and landfills. This results in species increasingly exploiting urban landscapes (Bateman and Fleming, 2012; Lowry et al., 2013). Crop raiding, livestock predation, and garbage scavenging become behavioural adaptations of wildlife due to the high-caloric low-effort food opportunities. Herbivores such as elephants raid paddy crops in Asia, wild boars damage maize, sugarcane, and vegetable crops in Europe and Asia, and baboons raid banana and cassava crops causing significant losses to farmers in Africa (Fernando et al., 2005; Humle and Hill, 2016; Massei et al., 2015). In south-east Asia, non-human primates such as macaques and langurs have been reported to raid orchards and vegetable patches (Wallace and Hill, 2012). Additionally, predators such as leopards in India, coyotes in North America, and lions and hyenas in Africa have been documented to prey on livestock, and sometimes, pets (Athreya et al., 2013; Gehrt et al., 2009; Kolowski and Holekamp, 2006). As urban environments expand, landfill areas are expanded as well, and wildlife is presented with easy access to high energy food. For example, behavioural and movement patterns of Black Bears have shifted to become nocturnal foragers, to access garbage bins avoiding humans (Beckmann and Berger, 2003). Some non-human primates, specifically in India and Sri Lanka scavenge, raid crops, invade marketplaces, and damage houses in search of food (Jayarathne et al., 2024; Priston and McLennan, 2013; Rittem et al., 2024).

Moreover, increased artificial lights and noises in urban areas disrupt wildlife circadian rhythms (Gaynor et al., 2018; Newport et al., 2014). Many species including foxes, racoons, bears, and leopards have shifted towards nocturnal behaviour to avoid human interactions and seek newfound resource opportunities with artificial light (Athreya et al., 2013). Additionally, bird species are found to change their song behaviour and dawn call behaviours with the change of noise and artificial lighting, along with their physiologies (Bermúdez-Cuamatzin et al., 2011; Dominoni et al., 2013). Such behavioural changes diminish natural survival skills, alter ecosystem dynamics, and increase the conflict between humans and wildlife.

iii. *Population-level impacts*

Urban expansion creates habitats that are fragmented and resource altered. Such habitats profoundly impact certain wildlife species by compressing populations into smaller and isolated patches, and intensifying competition for resources, even for the species that are spilling over to the urban landscapes. However, the individual success rate could be low due to different skills being required for survival (Dupras et al., 2016; Liu et al., 2016; Rodewald and Gehrt, 2014). As available wildlife habitats shrink, species are forced into smaller patches in proximity, increasing conspecific competition as well as competition with feral and invasive species, especially for foraging, nesting, and denning sites. This kind of crowding scenario disproportionately affects species that are less adapted to changing environments. For example, larger less adapted species such as Koalas in Australia suffer from food shortages and starvation due to deforestation (Lunney et al., 2017), and urban and sub-urban bird communities have faced steep declines in species diversity in highly populated areas (Campbell et al., 2022).

One of the most severe consequences of habitat fragmentation is genetic isolation, especially due to urban structures such as highways that prevent gene flow between sub populations (Habrich et al., 2021; Holderegger and Di Giulio, 2010). For example, Wolverines (*Gulo gulo*) in Canada are facing genetic isolation and demographic fragmentation with the construction of the Trans Canadian Highway. Another study carried out in California reports that commonly found lizard and bird species show a reduction in gene flow, in association with the construction of freeways and surrounding roads (Delaney et al., 2010). Such stressors, combined with other negative ecological processes, can lead to genetic erosion and local extinction of vulnerable wildlife populations.

iv. Habitat-based impacts

Urbanization exerts profound habitat-based pressures on wildlife through habitat loss, degradation, fragmentation, pollution, invasive species, and prey-based decline. Rapid expansion of roads and suburbs, and commercial development can fracture habitats into isolated patches. These patches can be described as ‘islands’ that restrict animal movement, reducing fitness and probability of survival of populations (Liu et al., 2016). For example, apex predators such as Jaguars (*Panthera onca*) in Brazilian forests are being pushed out of their natural habitats to farmlands, due to agricultural expansion (Marchini and Macdonald, 2018). Similarly, in Asia and Africa, elephant habitats are being fragmented, forcing them out of the forests (Shaffer et al., 2019). Alongside these physical barriers, urban environments introduce various pollutants to air, soil, and water such as combustion emissions, solid wastes, and chemical runoffs, often together with noise and light pollution (Müller et al., 2020; Usman et al., 2023). These weaken the health of animals, impair reproductive success, and bring in behavioural changes, especially in fish and amphibian species (Brand et al., 2025; Egea-Serrano et al., 2012). An example is the decline of Gyps Vultures in India due to scavenging on cow carcases laced with anti-inflammatory drugs (Taggart et al., 2007). Such declines of apex predators create functional imbalances in the trophic cascades of natural ecosystems, disrupting predator-prey dynamics (Fischer et al., 2012; Hammerschlag et al., 2022). In urban environments, this can lead to hyper-abundances of prey species such as birds, rodents, and other small mammals. For example, deer populations in some areas of North America are reported to be rising due to the low population sizes of Coyotes (Parsons et al., 2024).

Furthermore, urban spaces can become excellent hotspots for invasive species to establish as the community-level changes create vacant niches, further displacing native fauna in already degrading habitats (Santana Marques et al., 2020). Some of these could be intentionally introduced species such as foxes and rabbits in Australia (Stepkovitch et al., 2019), while some could be accidental introductions such as the Zebra Mussel which has been dispersed throughout North America via ballast water (Ożgo et al., 2020).

3.2 Impacts of urban human-wildlife conflict on humans

i. *Health and safety impacts*

Human-wildlife conflict poses serious threats to public safety and health in rapidly urbanizing environments. Among the most significant and direct consequences of the human-wildlife conflict are the resulting fatalities and injuries (Gulati et al., 2021). For example, between 2001 and 2020, 143 human fatalities were recorded in Myanmar due to human-elephant conflict (Thant et al., 2022). Additionally, in Sri Lanka and India, annual fatalities due to elephant attacks continue to increase, as a result of extensive landscape changes (Gunawansa et al., 2023). In North America, wild carnivore attacks, especially those involving coyotes, cougars, and bears have been documented to be on the rise with rapid urbanization (Bombieri et al., 2018). In urban areas of Cape Town, Baboons have been reported to raid houses, resulting in occasional injuries (van Doorn and O'Riain, 2020).

Beyond the direct physical danger, human-wildlife conflict significantly increases the risk of zoonotic disease transmission. Species such as bats, rodents, and non-human primates are known reservoirs of pathogens responsible for various diseases (Bradley and Altizer, 2007). With the expansion of urban areas and the spill over of wildlife into human-dominated habitats, the risk of contracting zoonotic diseases has increased as well. For example, the Rift Valley Fever virus in Uganda, which is disseminated through a mosquito vector, is found to be transmitted from wild ungulates and livestock to humans (Shoemaker et al., 2019). Another example is the Ebola virus, for which bats are assumed to be the primary reservoir host. Humans receive the virus from infected wildlife through handling, consumption of bush meat, or exposure to bodily fluids of the animals (Hussein, 2023). Furthermore, the global Covid-19 pandemic occurred from 2019 to 2021 is classified as an infectious disease with a probable zoonotic origin, which was able to disrupt day to day human activities globally, and cause thousands of human fatalities (Haider et al., 2020). These indicate the need of sufficient buffer zones between wildlife habitats and human settlements, for the safety of both parties.

ii. Economic impacts

Human-wildlife conflict imposes substantial burdens, particularly for smallholder farmers, pastoralists, peri-urban communities, and local governments (Braczkowski et al., 2023). For example, elephants are responsible for many of the crop damages in Asian and African countries (Montgomery et al., 2022), and predators such as hyenas and loins are accountable for hunting and killing pastoral livestock herds in Africa (Hello et al., 2024; Patterson et al., 2004). In Canada, beavers are reported to cause costly property damages by flooding roads and farmlands, because of beaver dams (Janiszewski and Hermanowska, 2019). In Sri Lanka, within the past decade, monkeys and Giant Squirrels have been reported to bring about excessive damages to orchards and vegetable crops (Jayarathne et al., 2025). Peafowls, which were once considered to be a forest-dwelling bird species, have now become abundant in human-dominated landscapes, causing massive crop losses during the Northeast monsoon season in Sri Lanka (Herath et al., 2021). A recent assessment carried out by Jayarathne et al. (2025) further illustrates that the scale of the burden, specifically monthly income losses among farmers due to macaque raids of fruits and vegetables have almost doubled by 2022 compared to previous years, reaching about 5,000 LKR monthly per person. Outside the fruiting period, coconut damages drive losses between 3,000 and 14,000 LKR per month per farmer. Property damage causes additional household expenses from 850 to 4,000 LKR monthly, while they spend between 1,200 and 3,000 LKR on deterrent measures to keep monkeys away. A recent unpublished study has found that wildlife-related losses account for up to 20% of the national agricultural production, which is approximately 17 – 20 billion LKR per year, in a sector where the contribution to the national GDP is 7 – 8% (Perera, 2025).

The economic pressure is compounded by the increased labour required for guarding the fields and herds (especially at night), adding more strain to already vulnerable livelihoods of these communities, creating significant financial concerns (Baral et al., 2021). Beyond these direct losses, human-wildlife conflict also affects economies that are dependent on tourism. Wildlife attacks in the proximity of ecotourism attractions can deter visitors. For example, shark attacks have become prevalent in many marine sanctuaries, along with certain cases of predatory carnivores such as crocodiles attacking tourists (Barreiros and Haddad, 2019). However, most of these attacks could have been prevented if the recommended ecotourism methods had been practiced, making tourism industry sustainable. Collectively, governments face significant financial burdens managing the human-wildlife conflict, including the costs of fencing, surveillance systems, research, relocation programmes, and compensating affected communities (Ravenelle and Nyhus, 2017). These mitigation expenses, alongside affected agricultural and tourism income, highlight the complex and widespread economic consequences of the escalating human-wildlife conflict.

iii. Social and political impacts

Human-wildlife conflict poses complex socio-political challenges that hinder effective governance, development, and ecological conservation (Braczkowski et al., 2023). Local communities often perceive government interventions as prioritizing wildlife over the welfare of humans, leading to distrust, protests, and even violence against the authorities, especially in conflict-prone areas (Fletcher and Toncheva, 2021; Yeshey et al., 2024a). These tensions escalate when border village populations bear the consequences of wildlife impacts with unequal compensation and mitigation assistance (Braczkowski et al., 2023). In Kenya, lion conservation programs have faced a massive backlash from herders whose livelihoods are at risk (Wairimu, 2013). In another example from Sweeden, debates over wolf culling have reportedly polarized public opinion, and divided policy makers between conservation and human welfare (Eriksson, 2017).

Human-wildlife conflict also can derail infrastructure development projects, and cause delays. Legal ambiguities surrounding land use rights, species protection status, and compensation frameworks further complicate the impediment of developmental activities (Sage et al., 2014). However, it is essential to recognize the importance of conducting thorough Environmental Impact Assessments (EIAs) to carefully evaluate the potential effects on nature, before undertaking any construction project that may impact wildlife habitats or animal populations.

iv. Socio-ethical impacts

Human-wildlife conflict is a culturally, morally, and ethically challenging conservation concern worldwide, as its roots extend beyond physical and economic consequences (Orrick et al., 2024). Such conflicts are known to cause significant chronic stress, sleep disturbances, and increased anxiety among the victimized peoples, especially children and elderly persons (Blackie, 2023).

Ethical dilemmas emerge especially with the decisions considering relocation and culling, as they tend to clash with cultural and religious values (Bhatia et al., 2017; Yeshey et al., 2024b). For example, in India, since Rhesus macaques are revered in the Hindu culture, especially in cities like Delhi and Varanasi, efforts to translocate or cull their populations have met with strong religious oppositions (Anand et al., 2018). Another example is the introduced horses (known as Brumbies by some public entities) in Alpine region of Victoria, Australia. Although these horses are advised to be removed from alpine regions, some communities of the public are against the culling due to emotional and cultural attachments with them (Filley, 2024). These cultural and religious dimensions underscore the necessity of management strategies that are sensitive to local beliefs and practices. Integrating cultural and community values, and traditional knowledge into management practices could be a way forward in mitigating social and ethical clashes in resolving the human-wildlife conflict.

Human-wildlife conflict driven by urbanization presents a complex and accelerating threat to both humans and wildlife. Habitat degradation, fragmentation, and resource scarcity cause changes in animal behaviours and the persistence of wildlife populations. As consequences of this conflict, humans experience increased health and safety risks, and socio-economical and psychological distress. Thus, rapid urbanization calls for collaborative strategies that balance development and ecological sustainability, integrating science with social and traditional knowledge, to ensure lasting human-wildlife coexistence.

4 Consequences for Conservation: Shifting Human Attitudes

A pragmatic problem associated with the human-wildlife conflict is the shift in the attitude of the public regarding conservation, as the conflict intensifies. Religions, especially those in southern and eastern Asia, have played a pivotal role in discouraging animal killing. However, it is reasonable to presume that this attitude will subside under the increasing pressure experienced by humans due to wildlife with overlapping habitats. Certain studies have documented this phenomenon in Asian countries such as India, Nepal, Bhutan, and Indonesia (Lee and Priston, 2005; Parker et al., 2008; Srivastava and Begum, 2005). It is reported that the same communities that were once against harming wildlife such as monkeys, mainly due to religious beliefs, are now increasingly engaged in shooting and poisoning them. In certain Asian countries, it is observed that people are fond of worshiping monkeys in temples, and at the same time, tend to kill them in nearby farms (Lee and Priston, 2005). This attitudinal turnover can even reach a stage where people engage in revengeful killings, such as illegal electrocutions and poison-baiting.

However, it is reported to be less evident in Sri Lanka. Nekaris et al. (2013) indicates that 90% of the people at the focal localities in heavily deforested parts in southern Sri Lanka have never killed trouble-making primate species such as monkeys (Toque Macaque - *Macaca sinica*, and Purple-faced Langur - *Trachypithecus vetulus*), presumably due to the religious realm upon which the country's cultures are based. Many of the prominent religions in Sri Lanka strongly refuse animal killing, and local people seem to still adhere to these values despite the conflict with wildlife. However, this tolerance is delicate, and if timely measures are not implemented to minimize the urban human-wildlife conflict, people may tend to rationalize wildlife culling against the religious framework, which is apparently the only significant preventive force. This is supported by the fact that the Sri Lankans who have admitted having killed troublesome wild primates have indicated that they are even aware of the conservation significance of those species (Nekaris et al., 2013).

A study conducted on the conflict with elephants points out that the positive attitude regarding wildlife conservation suffers a downturn when moving out of the urban areas towards the highly affected rural regions (Bandara and Tisdell, 2003). It is commendable that even the people in the intense conflict zones still bear a positive attitude (understandably to a lesser extent compared to the people in less-affected regions) towards wildlife protection.

Nekaris et al. (2013) have noticed an interesting fact about the attitude of the people who are in conflict with wildlife in an urban setting, regarding forest conservation. Many of the respondents have shown a positive attitude towards preserving forests, despite the wildlife problem. However, it has turned out to be due to their livelihoods, particularly to secure water sources and timber needs, and to a lesser extent, to prevent climate change, however, not to protect animals. This is another testament of the fading attitude of the human community towards wildlife, apparently due to the conflict.

5. Mitigation Strategies

Compared to most parts of the world, Sri Lanka generally shows a less-intense urban human-wildlife conflict (Fig 2). Hence, the most common mitigation strategies used by urban dwellers in the country are limited to constructing brick walls and wooden, steal or biological (live plant-based) fences as physical barriers, clearing vegetation in the proximity of domestic settlements as an ecological barrier, and deployment of guard dogs as an ethological barrier (e.g., Gebo et al., 2022; Thudugala et al., 2025). These preventive measures are ideally suited for controlling medium-sized wildlife species, such as civets, mongooses, monkeys, giant squirrels, etc., which are among the most common causes of urban wildlife conflict on the island.

However, preventive measures vary significantly with the size of the conflict-prone species. For example, to discourage elephants from the urban borders, electric fences are erected by the local government. These fences are composed of three parallel smooth wires, carrying a direct current (DC) at a high voltage of 6,000 V to 9,000 V, however, a low amperage of lesser than 100 mA (Fernando et al., 2025), as a pulse within a 1/3,000 s time, once in a second. This ensures an electric shock which is memorable, however, not fatal for a contacted elephant, imposing a psychological barrier to cross the fence. For maximum efficiency, these electric fences should be maintained properly, with timely revisions to the pulse generator, and without allowing ground vegetation to touch the wires causing leakages of the current to the earth. The latter will significantly reduce the power of the electric pulse, causing a mild and appealing sensation to the contacted elephants, encouraging them to make contact with the fence. A couple of such deliberate contacts made by elephants can smash the fence to the ground.

There are numerous alternatives to the electric fence to deter elephants, such as wooden or stone fences and walls, elephant trenches, and biological barriers such as beds of plants bearing thorns or spikes, though some of them might be impractical in certain areas, and/or financially demanding. A sustainable way to avoid the peri-urban elephant conflict might be the development of a wide strip of land containing unpalatable plantation, between the forest edge and the human settlement. If an economically significant crop species such as rubber is chosen for this, it can become dual-purpose land usage. Another interesting alternative is tested to be positive as an elephant deterrent in Africa (Ndlovu et al., 2016). The combined auditory and olfactory stimuli of active beehives are found to be an effective repellent for elephants. It is reported that elephants tend to avoid sources of sounds of buzzing bees and smell of honey. Since beekeeping is a promotable and a profitable hobby in the peri-urban areas, this can be an attractive strategy to introduce to Sri Lanka. However, comprehensive research is needed to assess the efficacy of this method against the Asian Elephant, and the temporal overlap of its activity peeks with those of the bees.

Rodents such as the Black Rat and the House Mouse are most efficiently controlled with pre-infestation preventive methods, such as 'rodent-proofing', which is leaving as less habitats and entry ways for rodents as possible in the architectural design of the buildings, and sanitation, which includes avoiding leaving leftover food open, proper storage of wastes, and keeping utility areas as dry as possible. Commonly deployed control measures after infestation include non-lethal methods such as sticky pads and live-catch traps, and lethal means such as snap traps, poison baits, and predators. However, using pets such as cats as predators is reported to be relatively ineffective, whereas the presence of owls and snakes (though not common in urban settings) can significantly reduce rodent populations (Koehler and Kern Jr, 2017).

Apart from the mammals, certain birds have been a nuisance in urban areas for a long period of time; however, a relatively limited number of studies have been conducted to figure out strategies to eliminate this problem. Fitzwater (1988) has pointed out various groups of birds that have grown to be a trouble in urban systems. Urban adaptive synanthropic birds such as crows, pigeons, doves, swifts, and to a lesser extent, sparrows have continued to become problematic. Using bins with swinging lids can prevent crows from scattering and dispersing waste. Doves and pigeons can be discouraged from nesting in ceilings and rooftops by sealing the access ways with wire meshes. Swifts can be kept from building mud-nest by making the probable surfaces smooth, in such a way that mud does not stick onto them. A popular effort to discourage sparrows from nesting in undesirable places such as roofs is providing artificial bird nesters and nest boxes in the proximity of the concerned building. However, it is prudent to note that except five species, *viz.* House Crow, Large-billed Crow, White-rumped Munia, Scally-breasted Munia, and Rose-ringed Parakeet, all the other birds in the country are either 'Protected' or 'Strictly Protected' under the Flora and Fauna Protection Ordinance of Sri Lanka, and destructive mitigating measures such as poisoning, shooting, and nest removal should not be carried out without legal clearance.

Mitigating the urban insect problem is a broadly spoken topic, especially due to its entomological importance in disease vector control, and hence, the prevention methods are widely communicated and often well-known. Sanitation (maintaining a clean and healthy environment), source reduction (destroying larval habitats), and exclusion (preventing insects from entering buildings) are the common pre-infestation control strategies, of which the latter includes deploying window screens, air curtains, fans, and doors. Ultra-violet (UV) light traps, slow-release aerosol dispensers, insect-repellent sprays, sticky tubes and ribbons, and occasional fogging can be used to eliminate insects within buildings (Hinkle and Hogsette, 2021). Recently, genetic approaches such as sterile insect techniques (Ranathunge et al., 2022), and *Wolbachia*-based methods (Wijegunawardana et al., 2017) were introduced to Sri Lanka to control pathogenic insects, especially mosquitoes, prevailing in urban areas.

Habitat corridors have been a popular solution among conservationists to mitigate urban wildlife matters around the world for decades. These are strips of land or artificial surfaces that resemble natural habitats, which are supposed to facilitate animal movement and gene flow among fragmented ecosystems separated by roads, railways, artificial canals, downtowns, or other inhospitable lands to wild organisms. Habitat corridors suitable for urban areas include wildlife crossing structures such as underpasses, tunnels, and culverts that permit animal movement under the affected areas, and canopy bridges and overpasses, which are overhead paths for animals to move. Different animals prefer deferent types of corridors (e.g., Clevenger and Waltho, 2005), hence, it is prudent to properly identify the animal(s) or group(s) that are subjected to the conflict and investigate their behaviours to select the most appropriate type of crossing. These are especially effective in mitigating road kills and undesired wildlife encounters in urban areas (Riley et al., 2014). Habitat corridors can be coupled with urban forests restored and properly maintained at the edges of towns. The availability of forest patches in the proximity of a town can presumably limit the wildlife to these patches, and discourage the animals from forage in human settlements, exploiting the fact that natural ecosystems can provide more desirable habitats to most of the wild animals, compared to urbs. However, in Sri Lanka, implementation of habitat corridors is rarely seen in urban areas, in spite of the retention of a considerable number of urban forests in association with many of the main cities in the country, such as the Udawattakele Forest Reserve located at the fringe of the Kandy town, as indicated in Rathnasiri et al. (2024b).

Translocation of problematic animals is practiced in various countries to overcome urban wildlife conflict and is proposed in Sri Lanka as well several times recently. Even though there are success stories (e.g., Imam et al., 2002), translocation should be carried out with solid knowledge and awareness about the probable ecological and genetic consequences. For instance, the mixing of subspecies resulted from improperly planned translocations can jeopardize the genetic diversity among the subspecies, and compromise the ecological adaptations shown by them to local environmental conditions (Dittus, 2012). In the meantime, translocation can be merely the movement of the problem to another area, and it can be ineffective especially when it comes to animals such as monkeys, because even if a troop is removed from a particular locality, troops occupying the neighbouring localities could conveniently take over the vacant niche

(Cabral at al. 2018; Dittus, 2012; Hoffman and O'Rian, 2014; Mendis and Dangolla, 2016). Therefore, if translocation seems to be the most feasible option, it is strongly advised to carry out rigorous research to ensure the suitability of the receptive site, as well as the ecological persistence of the solution at the source site, along with adaptive and genetic wellbeing of the translocated population.

6. Community-based Solutions

Environmental education can be viewed as an effective way to escalate the attention of the community towards wildlife conservation, in spite of the conflict. The expanding free education facilitated by the Sri Lankan government has progressively reached the younger generation of the country, and, with sustainability concepts increasingly being incorporated into developmental activities (Peries, 1998), has caused them to bear a positive attitude towards conservation, and favour environmentally friendly mitigation measures over destructive methods to moderate the human-wildlife conflict. Bandara and Tisdell (2003) have reported an attitudinal pattern complying with this, regarding Asian Elephants in Sri Lanka. According to them, people with higher education levels have more positive attitudes towards wildlife conservation, compared to those with less education. Thudugala et al. (2025) have observed this pattern with relation to mammalian carnivore species in central Sri Lanka. These studies provide insights into the vitality of science-based environmental education to develop supportive thinking among the younger generation, and to drive public attention towards conservation actions. However, there is an overlap between the facts that rural areas exhibit lower levels of education compared to urban areas, and that these same rural areas experience more intense conflicts relative to urbsurban areas. Nevertheless, a success in the ongoing community awareness programmes and information dissemination can be seen as most of the Sri Lankans interviewed by Thudugala et al. (2025) had shown a sufficient understanding of the laws pertaining to wildlife conservation, and the penalties against animal killing, regardless of the level of formal education they have received, or the extent of urbanization of their neighbourhood.

Cabral at al. (2018) proposes the designation of Community Conservation Areas (CCAs) in landscapes where ideal habitats are present to protect conflict-prone wildlife in the long run. These areas should be identified via comprehensive scientific research, and after designation, would be managed by local stakeholders under the guidance of the Department of Wildlife Conservation of Sri Lanka. Community participation to protectin protecting wildlife can be accompanied with ecotourism practices, as a means of elevating public awareness as well as revenue generation. The CCA concept is supposed to be a model to promote both coexistence and conservation of conflict species, simultaneously.

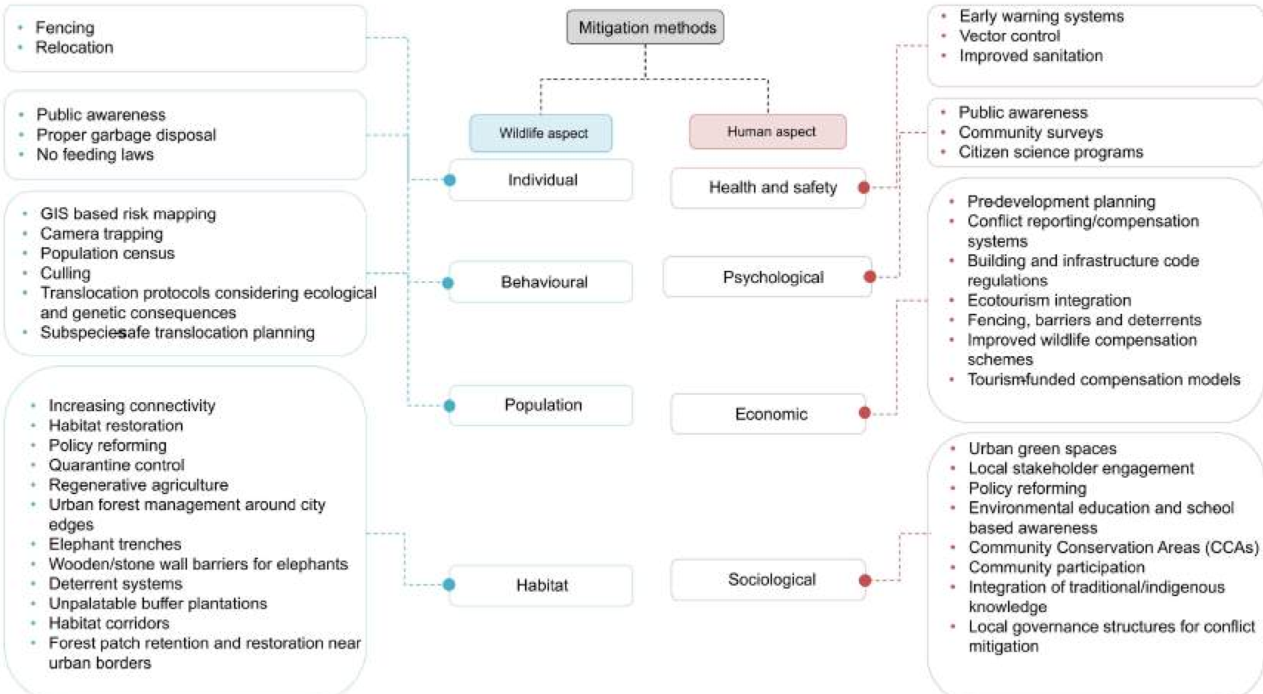

Fig 2. Conceptual diagram illustrating the mitigation methods for human-wildlife conflict, categorized into wildlife-centred (blue) and human-centred (red) aspects. The wildlife-centred aspect is further categorized in an ecological perspective, while the human-centred aspect is further categorized in a socio-economical perspective.

Timely revision of regulations and policy interventions are required for the successful management of the urban human-wildlife conflict. A desirable strategy is government-mediated compensation schemes for economic losses due to wildlife. Suresh et al. (2024) report that Sri Lankan farmers they have interviewed had indicated willingness to accept a reimbursement of USD 295 per an entirely destroyed acre of farmland due to elephant raids. They further suggest that, since the elephant is both an agricultural pest and an ecotourism attraction at the same time, it is recommendable to consider funding such compensation schemes via the revenue generated by the tourism industry. Meanwhile, reimbursement gaps existing in the current compensation schemes should be methodically addressed and fulfilled to ensure the continuous community-level support to manage the urban human-wildlife conflict sustainably.

7. Conclusion

Urban human-wildlife conflict in Sri Lanka represents a rapidly intensifying interface between development and biodiversity, shaped by habitat loss and fragmentation, and the expansion of cities in to frequently used wildlife movement corridors and forest edges. As urban and peri-urban spaces become more structurally complex and resources altered, they filter communities favouring adaptable species. In Sri Lanka, elephants, macaques, peafowls, rodents, and wild boars are some of the prominent conflict-prone species, and while these species occupy newfound niches or bring in conflicts, many native species tend to decline or disappear. As urban environments expand, the ecological changes cascade through individual, population, and landscape levels, affecting behaviour, gene flow, and long-term persistence of species, leading to biodiversity loss.

Human aspects of the conflict with wildlife are not merely inconveniences to people, however, a cluster of stressors that affect health, livelihood, and social interactions. Farmers are experiencing recurring financial losses and property damage, and some estimates point out that wildlife-related losses are now accounting for a substantial share of agricultural output. Direct mortalities and the potential for spreading zoonotic diseases are another concern in densely populated areas associated with wildlife. Such pressures can give rise to social and ethical distresses, erode the tolerance for wildlife and strain the trust between the government institutions and the general public, and create moral dilemmas between wildlife and humans as well as within society.

Despite this complexity, there is a range of mitigation measures already in use or within reach, including physical, behavioural, and ecological options. Physical barriers such as electric fences and alternative deterrents for elephants, and species-specific behavioural responses of rodents, birds, and insects are used as mitigation options, while as ecological measures, establishing better habitat corridors, managing urban forests, and carefully designing ecologically sound translocation protocols that are tailored to local conditions can be highlighted. Community-based approaches are equally important, such as environmental education, designation of community conservation areas, and inclusive conservation decision-making around land use and conflict management. However, the effectiveness of these measures remains constrained due to gaps in compensation schemes, limited long-term monitoring, and lack of spatially explicit data on conflict patterns and costs.

The way forward to reducing the human-wildlife conflict in urban and peri-urban areas in Sri Lanka requires integrated multi scale governance that treats cities as socio-ecological systems rather than purely built environments. This requires embedding wildlife considerations into urban planning, zoning, and infrastructure designing and maintaining, and restoring functional habitat networks within and around cities. Furthermore, introducing and strengthening legal policy frameworks are important, such that compensation, enforcement, and mitigation can be carried out timely and transparently. The chapter calls for interdisciplinary research linking ecological processes with economic, sociological, and health perspectives, integrating local and traditional knowledge, to plan sustainable and wildlife-friendly urban spaces, promoting coexistence instead of conflict.

Conflict of Interest

Authors have declared that no competing interests exist.

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Chapter 14

Human-Wildlife Conflict: Causes and Consequences of Fatalities, Injuries, and Illnesses

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Abstract: This chapter examines the health impacts of human–wildlife conflict (HWC) in Sri Lanka, focusing on six major threats—human–elephant conflict, snakebite envenoming, rabies, leishmaniasis, leptospirosis, and typhus fever—which together cause substantial mortality, injury, disability, and infectious disease burden, particularly in rural communities. Human–elephant conflict alone caused nearly 1,000 deaths between 2013 and 2022 and frequently results in severe trauma and long-term physical and psychological impacts. Snakebites account for over 30,000 hospital admissions annually, with serious systemic and chronic complications worsened by limited antivenom effectiveness and poor first-aid knowledge. Rabies continues to cause around 25 deaths per year despite available prophylaxis, while leptospirosis affects 7,000–10,000 people annually, especially during monsoons, with high fatality due to delayed diagnosis. Leishmaniasis is increasing in rural areas, causing disfigurement and psychosocial stress, and scrub typhus remains underdiagnosed, leading to severe complications. Across all threats, underreporting, weak surveillance, limited diagnostics, and poor integration of health, veterinary, and environmental sectors persist, underscoring the need for a One Health approach to strengthen care, surveillance, prevention, and intersectoral collaboration.

Keywords: Human-wildlife conflict, Zoonoses, Elephant attacks, Snakebite, Rabies, Leptospirosis, Leishmaniasis, Typhus

1. Introduction

Human-wildlife conflict (HWC) has emerged as a critical public health concern, particularly in countries like Sri Lanka where expanding human settlements increasingly intersect with natural habitats. These interactions, often unavoidable, give rise not only to ecological and economic consequences but also to significant health impacts on affected communities. Fatalities, traumatic injuries, and the transmission of infectious diseases are

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common outcomes of such encounters. The complexity of these conflicts is shaped by a combination of environmental changes, population pressures, inadequate waste management, and agricultural practices that bring humans into closer contact with wild and peri-domestic animals.

From a public health perspective, the consequences of human-wildlife conflict are multifaceted. In Sri Lanka, elephant attacks remain one of the most visible and emotionally charged forms of conflict, leading to severe injuries and loss of life, especially in rural farming communities. Snakebite envenoming, while less visible in the media, constitutes a neglected tropical condition with significant morbidity and mortality. Rabies, transmitted primarily through bites of infected animals, poses a continual threat in both urban and rural settings. Beyond direct trauma, zoonotic infections such as leishmaniasis, leptospirosis, and typhus fever underscore the indirect but profound health burden resulting from shared environments between humans and animal reservoirs or vectors.

This chapter examines the causes and consequences of human-wildlife conflict with a focus on six key health threats in Sri Lanka: elephant conflict, snakebite, rabies, leishmaniasis, leptospirosis, and typhus. It explores the epidemiological trends and patterns of related fatalities, injuries, and illnesses, supplemented by quantitative data where available. The chapter further analyses the impacts on human health in terms of clinical presentation and disease burden, discusses the readiness of the healthcare system to manage such cases, and evaluates public awareness and community response to medical care following wildlife-associated incidents. Finally, it considers future directions for the prevention and mitigation of HWC-related health outcomes through a collaborative, One Health framework. By integrating clinical, epidemiological, veterinary, and environmental insights, this chapter aims to provide a comprehensive understanding of human-wildlife conflict as a public health issue and offer evidence-based strategies for reducing its toll on human health.

2. Human Elephant Conflict

2.1 Introduction

Sri Lanka is a country blessed with wildlife, providing a home for 10% of the world's population of Asian elephants (*Elephas maximus*), making it one of the countries with the highest elephant densities. The relationship between elephants and humans extends back centuries in Sri Lankan culture and history. However, due to the rapid growth of the human population and limited land for agricultural and other uses, these two species are often in conflict over resources. This conflict results in injuries and deaths for both parties. The rising trend of deaths has made Sri Lanka one of the worst countries for human-elephant conflict (HEC), recording the highest number of elephant deaths and the second highest number of human deaths annually (Gunawansa 2023). This situation has become a significant public health problem. This chapter elaborates on the HEC in relation to human health.

2.2 Trends and Characteristics of Human Fatalities, Injuries, and Illnesses

Elephant attacks often lead to significant injuries that can result in death or permanent disabilities. As with most human-wildlife conflicts, it is primarily the rural agricultural population, especially in the dry zones of Sri Lanka, affected by HEC. Factors contributing to this conflict include changes in land use, habitat loss due to population growth, crop-raiding behavior of elephants, the presence of problem elephants, and changes in agricultural practices.

Injuries caused by elephant attacks are typically more severe than other animal attacks due to the massive size and force of the elephant. The fatality rates from such attacks remain significantly high. Most attacks occur near human habitats. Elephants are intelligent animals and possess an understanding of the locations of vital organs in the human body, often targeting the head and chest. These attacks lead to multiple traumas, with severe blunt injuries to the head and chest being common (Singh, 2021).

The most reported injury patterns include soft tissue injuries, fractures of extremities, chest injuries, and abdominal trauma (Chitta, 2024). The most common chest injuries among survivors are rib fractures, hemothorax (blood accumulation between lungs and chest wall), pneumothorax (air leaks into space between lungs and chest wall), and surgical emphysema (air accumulate under skin). Survivors present with shortness of breath, pain and tenderness in the chest area, and reduced oxygen saturation. Chest trauma can lead to acute respiratory distress syndrome, necessitating intubation and ventilation (Singh, 2021, Shayhmi, 2021).

Abdominal trauma typically results in injuries to intra-abdominal solid organs such as the liver, spleen, kidneys, and pancreas. Bowel transactions, lacerations of the abdominal aorta, and pelvic fractures have also been reported. Intra-abdominal bleeding can result in hemoperitoneum (blood in abdominal cavity) and shock. Head injuries in these cases can frequently lead to fatalities. Minor injuries, such as avulsion of teeth, maxillofacial trauma, and skull fractures, have been observed among survivors (Shayhmi, 2021).

Polytrauma following an elephant attack often leads to internal bleeding and hemorrhagic shock, which can be fatal. Other leading causes of death in elephant attacks are head injuries, along with chest, abdomen and pelvic trauma, which have been noted in autopsy examinations of victims. Due to the devastating nature of these attacks, many deaths occur at the site of the incident (Bhengra, 2025; de Silva, 2025). Survivors may face long-term complications, including permanent disabilities from limb loss. Additionally, the psychological trauma experienced after an elephant attack is often overlooked (Singh, 2021).

2.3 Quantitative Analysis of Reported Cases

From 2013 to 2022, there were 3,039 reported elephant deaths and 992 human deaths in Sri Lanka due to HEC. Unfortunately, this trend is on the rise. The data published on this matter in the medical field are limited, as this problem is concentrated in a few tropical countries and often neglected. An Indian study indicated that 91.3% of deaths among 23 victims occurred at the incident site, highlighting the devastating nature of elephant attacks. The study also found that 91.3% of victims who died did so due to head injuries and hemorrhagic shock (Bhengra, 2025).

Table 1. Human deaths in Sri Lanka due to HEC- 2013 to 2022

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Human deaths	70	67	63	88	87	96	122	112	142	145
Elephant deaths	206	231	205	279	256	319	407	328	375	433

(Annual report 2022: wildlife and nature protection society Sri Lanka)

A study conducted in Sri Lanka involving 54 cases revealed a fatality rate of 27% among victims brought to hospitals. Among the survivors, 27% experienced long-term complications, and 49% had short-term complications (de Silva, 2025). Notably, the male death rate is significantly higher than that of females (6.3) in HEC. Males are more likely to encounter wild elephants as they are involving in more agricultural activities, crop guarding and being outside of home after dark. The loss of a family's breadwinner leads to an immense socioeconomic burden on the family. Although incidents of HEC are more frequent during cultivation periods, no temporal relationship has been observed between human or elephant deaths and agricultural seasons (Prakash, 2020).

2.4 Public Knowledge and Awareness

While people are aware of the severity of the outcomes related to HEC, their knowledge and practices for preventing these conflicts are inadequate. Ignorance and a lack of respect for animal behavior have resulted in deaths and injuries due to elephant attacks. In some cases, individuals have approached wild elephants to take photographs or feed them, which can provoke attacks. There have been incidents where foreign tourists were also attacked by elephants due to such behavior (Prakash, 2016). Most elephant attacks occur during vulnerable time periods, specifically between 4 AM and 8 AM and 4 PM and 8 PM (de Silva, 2025). Residents living in high-risk areas should avoid these times as much as possible when traveling or travel with increased vigilance during these periods.

2.5 Future Directions and Mitigation Strategies

Preventing HEC is crucial for reducing deaths and injuries caused by elephant attacks. Numerous mitigation strategies have been proposed and implemented to prevent these conflicts. From a healthcare perspective, significant improvements are needed in trauma care systems at hospitals. Studies indicate that the majority of victims of elephant attacks have not received prehospital care, with the average transport time to healthcare facilities exceeding one hour (de Silva, 2025). Improving knowledge of first aid measures and establishing a robust prehospital trauma care structure is essential, alongside enhancing hospital capabilities with adequate skilled personnel and facilities to manage major trauma cases. The Ministry of Health in Sri Lanka has developed an action plan for preventing and managing injuries in 2021. The outcomes of these strategies should be monitored to ensure that the desired results are achieved.

3. Snake bites

3.1 Introduction

Snake bites represent a significant health issue in tropical regions of the world, including South Asia, Southeast Asia, Sub-Saharan Africa, and Latin America. They pose considerable risks of mortality and morbidity, particularly in rural agricultural communities. It is estimated that annually, over 5 million snake bites occur, resulting in approximately 1.8 million cases of envenoming and 94000 deaths worldwide (Kasturiratne, 2008). Sri Lanka has one of the highest incidences of snake bites, with statistics indicating nearly 30000 hospital admissions and around 50 fatalities each year (Annual Health Bulletin, 2023). However, this figure may be underreported, as a significant number of individuals do not seek admission to government hospitals.

Sri Lanka, a country rich in biodiversity, is home to 108 species of snakes found on land and in coastal waters. Most of these species are non-venomous and do not possess venom glands. Among them, only five are considered of highest medical importance due to their clinical outcomes and frequency of bites (Silva, 2023). The clinical features that occur following snake bites can vary based on several factors, including the species of the offending snake and individual characteristics of the victim, such as venom composition, the amount of venom injected, circumstances surrounding the bite, and the victim’s pre-existing health conditions. The consequences of these bites can be both short-term and long-term (Jayawardhana et al, 2018).

3.2 Trends and Characteristics of Human Fatalities, Injuries, and Illnesses

The snakes of highest medical importance include Russell's viper (Daboia russelii), Merrem's hump-nosed pit viper (Hypnale hypnale), the Indian or common krait (Bungarus caeruleus), cobra (Naja naja), and the saw-scaled viper (Echis carinatus) (Silva A 2023). Russell's viper (RV) is responsible for the majority of snakebite fatalities in Sri Lanka. Envenomation by RV leads to local swelling, incoagulable blood, spontaneous bleeding, acute renal injury, and neurological manifestations (Kularatne, 2003).

Fig 1. Medically important venomous snakes of Sri Lanka: **(A)** Russell's viper (*Daboia russelii*), **(B)** Cobra (*Naja naja*), **(C)** Common krait (*Bungarus caeruleus*), **(D)** Saw-scaled viper (*Echisca rinatus*), and **(E)**Merrem's hump-nosed viper (*Hypnale hypnale*).

The hematological effects of an RV bite primarily stem from the activation of clotting factors in the blood. RV venom contains activators of factor V and factor X, which convert these clotting factors to their activated forms. This process activates the clotting cascade and converts prothrombin to thrombin, leading to the consumption of fibrinogen and other clotting factors. This results in multiple factor deficiencies (Isbister, 2015).

The consequences include incoagulable blood and various bleeding manifestations collectively known as venom-induced consumptive coagulopathy (VICC). Fatalities following RV bites typically occur due to these bleeding manifestations, such as internal bleeding that leads to shock, cerebral hemorrhages, cardiac tamponade, gastrointestinal bleeding, and pulmonary hemorrhages. Additionally, RV envenoming can cause acute kidney failure, ischemic events (such as cerebral and peripheral arterial thrombosis), as well as neurological complications and local swelling. Abdominal pain was noted to be an early symptom of RV envenoming (Kularatne, 2003, Palangasinghe, 2018, Senthilkumaran, 2023, Gawarammana, 2009, Kularatne, 2014).

Hump-nosed viper (HNV) envenoming primarily results in localized effects at the site of the bite, including pain, swelling, tissue necrosis, hemorrhagic blisters, bruising, bleeding, and regional lymphadenopathy. The main systemic manifestations in HNV envenoming are VICC and acute kidney injury (AKI) (Wijewantha, 2010, Wijewickrama, 2020). VICC associated with HNV venom is believed to be due to the presence of thrombin-like enzymes that initiate the clotting cascade, leading to the depletion of fibrinogen and other clotting factors (Maduwage, 2014). The exact cause of AKI is not well understood, but several mechanisms have been proposed, including direct venom toxicity to the kidneys, hemodynamic disturbances induced by the venom, intravascular hemolysis, rhabdomyolysis, and thrombotic microangiopathy (Herath, 2012). Death from HNV bites typically results from AKI. Autopsy examinations have revealed thrombosis in micro vessels, cortical and tubular necrosis, and hemorrhages in the lungs and myocardium (Herath, 2012, Rathnayaka, 2021). A small percentage of patients may develop long-term complications, such as chronic kidney disease, chronic ulcers, amputations, fasciotomy-related wounds, and psychological issues (Rathnayaka, 2023).

Of the two species of kraits in Sri Lanka—Sri Lankan krait (*Bungarus ceylonicus*) and common/Indian krait (*Bungarus caeruleus*)—the common krait is regarded as the snake of highest medical importance, based on bite frequency and number of fatalities. Krait venom contains potent neurotoxins, which act both presynaptically and postsynaptically, with the presynaptic neurotoxins being particularly critical in human envenoming. These neurotoxins cause irreversible damage to the presynaptic membrane, resulting in neuromuscular paralysis. This condition can be life-threatening, especially when it affects the respiratory muscles (Silva, 2016). Kraits are nocturnal animals, and most bites occur at night while victims are sleeping on the floor. Clinical features of a krait bite may include abdominal pain and signs of neuromuscular paralysis, such as drooping eyelids, double vision, limb weakness, difficulty swallowing and breathing, and altered mental status. These symptoms can lead to respiratory paralysis, which may result in death. Local symptoms are usually minimal, and bite marks are often not visible. Less common features may include myalgia, paresthesia at the bite site, decreased hearing and vision, and faintness (Kularatne, 2002).

Cobra venom (*Naja naya*) contains neurotoxins similar to those found in kraits. Additionally, it includes cytotoxins that can cause severe local reactions. Patients may exhibit neurological symptoms such as ptosis, ophthalmoplegia, dyspnea, difficulty swallowing, limb weakness, or respiratory paralysis. They can also experience significant local tissue necrosis, hemorrhagic bullae, or swelling. Death may occur due to respiratory paralysis or rapidly spreading extensive tissue necrosis (Kularatne, 2009).

The Saw-Scaled Viper (SSV) primarily inhabits the coastal areas of northern and eastern provinces of Sri Lanka. Its venom mainly contains hemotoxins, which can activate the clotting cascade, leading to VICC. Although SSV is responsible for the highest number of snakebite deaths worldwide, Sri Lankan literature has not reported any fatalities from SSV bites (Warrell, 1977). However, there have been documented cases with the potential for life-threatening outcomes, and it is believed that fatalities may be underreported due to the snake's geographical distribution in the country. Reported complications include bleeding manifestations, intracranial hemorrhages, myocardial infarctions, thrombotic microangiopathy, bradycardia, and renal dysfunction (Kularatne, 2011; Fonseka, 2013; Pirasath, 2021).

In addition to acute complications, multiple long-term issues have been identified. Excessive fatigue is the most commonly observed long-term complication, while others include headaches, vertigo, photophobia, muscle pain and weakness, contractures and amputations, chronic non-healing ulcers, visual impairment, hemiplegia, facial nerve palsy, chronic kidney disease, paraesthesia, hair loss, psychological distress, and various nonspecific symptoms (Jayawardhana et al, 2018; Waiddyanatha, 2022).

3.3 Quantitative Analysis of Reported Cases

Global data indicate that the estimated annual incidence of snake bites may reach between 1,200,000 and 5,500,000 cases. The total number of envenoming ranges from 421,000 to 1,842,000, resulting in approximately 94,000 deaths. Most of these envenoming occur in the South Asian region (Kasturiratne, 2008). In Sri Lanka, statistics show that the total number of hospital admissions due to snake bites in 2022 was 27869, with 65 deaths. In 2023, these numbers changed to 29975 admissions and 48 deaths, according to the health bulletin. However, a nationwide community-based study suggests that the actual figures are much higher, estimating over 80,000 snake bites, 30,000 envenoming, and 400 deaths annually in Sri Lanka.

Hospital data tends to underestimate the disease burden, as not all victims seek hospital treatment (Ediriweera, 2016).

Hump-nosed pit vipers (HNV) are the most common cause of snake bites in Sri Lanka, accounting for 27-77% of all snake bites in the country (de Silva, 1981, Maduwage, 2013). More than 90% of HNV envenoming result in local clinical features, such as pain and swelling (guidelines). In a hospital-based case series of 1,543 patients, systemic manifestations were observed in 67 patients (4.34%). Coagulopathy was the most common feature, occurring in 59 patients (3.8%). This series documented two deaths, resulting in a fatality rate of 0.1% (Wijewantha.H 2010). Another prospective study involving 302 HNV bite patients showed local features in 91% of patients, with 39% developing incoagulable blood. There were five deaths, resulting in a case mortality rate of 1.7% due to renal failure (Ariaratnam, 2008).

Russell's viper (RV) envenoming is responsible for the highest number of deaths from snake envenoming in Sri Lanka, accounting for 30-40% of all snake bites and a mortality rate of 2.6%. RV bites are common in paddy farming, with 41% occurring during agricultural activities. A peak incidence is observed during the paddy harvesting season from March to April (28%). The most common clinical findings include local reactions (92%), followed by hematological manifestations (77%) and neurotoxicity (78%) (Kularatne, 2003).

The Common Krait is primarily found in the dry zones of Sri Lanka, with most bites reported in the North Central Province among farming communities. A study involving 210 krait bite patients found that severe envenoming occurred in 48% of patients, with an overall mortality rate of 7.6%. Out of the 210 patients, 101 experienced respiratory paralysis requiring artificial ventilation. Ptosis was the most common symptom, affecting 70% of these patients. Notably, 65 patients (31%) were unaware of the bite initially, waking up with colicky abdominal pain. Abdominal pain and dyspnea were observed in 68% of all patients, while local features were minimal, noted in only 30% of cases (Kularatne, 2002).

Cobra bites, while less common than viper bites, result in significant mortality and morbidity. A case series involving 25 patients showed that 80% had local reactions, and 36% exhibited neurotoxicity. The case fatality rate was 8%, with four patients requiring assisted ventilation due to respiratory paralysis (Kularatne, 2009). SSV causes the highest number of venomous snake bites in Jaffna peninsula. Although SSV accounts for only 1-2% of snake bites nationwide, it comprises 45.9% of all snake bites in the Jaffna area. Of the confirmed cases, 73% developed local swelling and 92% exhibited bleeding manifestations. Mild renal impairment was noted in one patient (Kularatne, 2011). Another study reported similar findings, with local features in 65% of cases and coagulopathy in 71% (Gnanathasan, 2012).

One-third of patients who suffered snake bites reported long-term complications attributed to their previous incidents. Most of these symptoms are non-specific (25-52%) and cannot be medically explained. Fatigue was reported by 20% of patients, while body aches and pains were experienced by 10%, and photophobia by 3%. Additionally, 2-7% of patients had permanent musculoskeletal problems, and 12-16% reported minor local effects such as recurring pain, numbness, tingling sensations, and swelling at the site of the bite (Waiddyanatha, 2022).

3.4 Frequency of Incidents

The annual number of hospital admissions due to snake bites is estimated to be around 30000. However, since a significant proportion of patients seek indigenous remedies, these numbers may not accurately reflect the true disease burden.

Table 2. Hospital admissions and deaths due to snake bites, 2014-2023 (Ministry of Health, 2022-2023 Annual health bulletin)

Year	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Hospital admissions	37,309	36,631	34,494	31,361	31,847	34,239	30,046	25,043	27,869	29,975
Number of deaths	94	78	55	66	61	50	45	46	65	48
Case fatality rate (%)	0.3	0.2	0.2	0.2	0.2	0.1	0.1	0.2	0.2	0.2

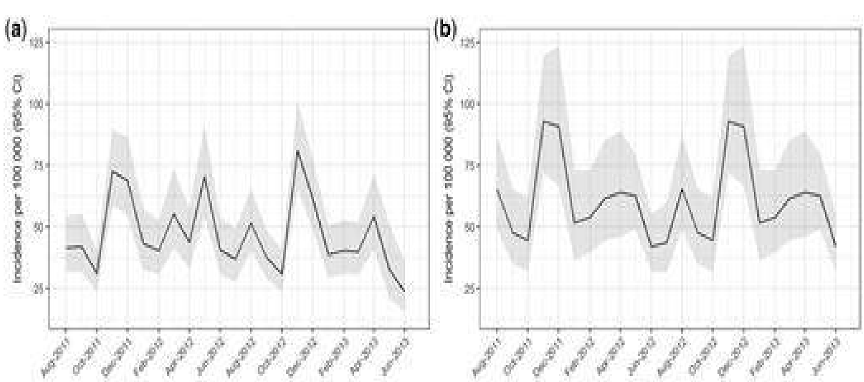

Fig 2. Annual estimated(a) and predicted(b) snake bite incidences (Ediriweera DS 2018).

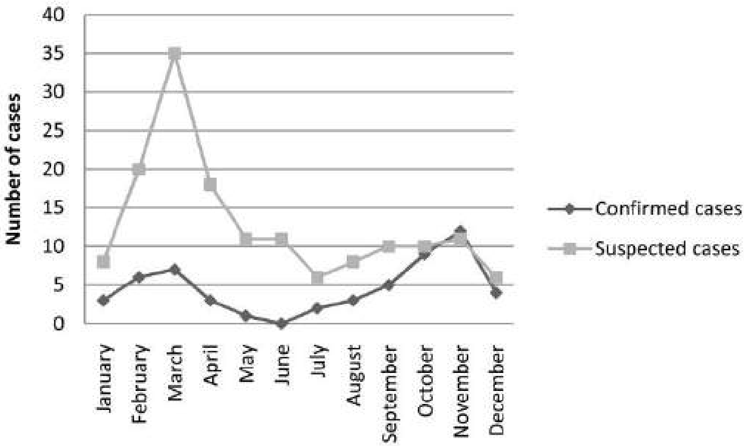

Fig 3. Annual incidences of RV bites (Kularatne, 2014)

It has been noted that there is a temporal pattern in snake bite incidents throughout the year. The highest incidence of snake bites (70.1 per 100,000) occurs from November to December, coinciding with the northeast monsoon season. The second highest peak is noted between March and May, while the lowest incidence is observed from June to July (31.9 per 100,000). There is a notable surge in RV bites between February and April, coinciding with the paddy harvesting season.

3.5 Readiness of the Healthcare Sector

The only available treatment for snake envenoming is antivenom. The antivenom we currently use is produced in India and is made using the venom from Indian snakes, such as the cobra, RV, SSV, and Indian krait. As a result, its use is limited to envenomation from these specific snakes. Studies have shown that Indian polyvalent antivenom can effectively neutralize the venom of these snakes in Sri Lanka (Maduwage, 2016). Although this antivenom is not specifically produced for the Ceylon krait (*Bungarus ceylonicus*) venom, its structural similarity to the Indian krait venom suggests that it may be effective in treating Ceylon krait bites. However, this antivenom is not effective against the HNV species and should not be used for such cases. A significant issue with Indian antivenom is its tendency to cause severe allergic reactions, such as anaphylaxis. Medical professionals need to be aware of this and be prepared to manage anaphylaxis when treating a patient with antivenom. Therefore, it is crucial to select the right patients for treatment. Antivenom is indicated only for patients presenting with systemic symptoms following envenoming or local reactions after cobra bites. A syndromic approach is recommended when managing snakebite cases in hospitals (Ariaratnam, 2009). Hospitals are equipped with all necessary facilities for treating snake bites and managing the aftermath of treatment. The healthcare sector is updated with the latest guidelines issued by the Sri Lanka Medical Association (SLMA).

Nevertheless, some studies indicate that medical staff still have knowledge gaps in snakebite management, and conducting educational intervention programs could enhance their understanding (Darshani, 2021, Shahmy, 2023). The SLMA has also introduced hotlines to assist with management dilemmas concerning snake bites.

3.6 Public Knowledge and Awareness

Despite the high incidence of snakebite-related mortalities and morbidities, general knowledge and awareness among the population remains insufficient. Snake bites are particularly common among agricultural communities in the dry zones of the country. A study in this area showed that many people still believe in incorrect first aid methods, such as applying a tight band above the bitten limb or sucking out venom. Additionally, a significant proportion of people practice harmful remedies, like excising the bitten area. They are also unaware that substances like aspirin and alcohol should not be administered to a snakebite patient. A considerable number still believe that identification of the snake is essential for treatment. Moreover, many people seek traditional treatments as their first option for snake bites (Silva, 2014, Ediriweera, 2017).

Even when knowledge is present, individuals may lack the attitude necessary to prevent snake bites. For instance, farmers understand that wearing fully covered footwear, such as boots, can prevent snake bites, but they seldom practice this advice. However, it is worth noting that they tend to seek hospital treatment more promptly after a snake bite compared to their counterparts in other South Asian countries (Silva, 2020).

Numerous awareness programs have been conducted by various organizations across the country to improve public knowledge. These initiatives have led to some improvements in understanding and health-seeking behaviors within the general population. Nonetheless, without comprehensive public awareness regarding snakes and snake bites, reducing the incidence of snake bites and the associated disease burden in Sri Lanka will be a challenging task.

3.7. Future Directions and Mitigation Strategies

Preventing snake bites is far more important than treating them. Strategies suggested by the Epidemiology Unit of the Ministry of Health for snake bite prevention include wearing shoes or boots and ankle-length garments, avoiding tall grass and dense undergrowth, and utilizing a flashlight to avoid stepping on snakes. Carrying a stick to beat the grass and undergrowth while walking in snake-prone areas, treading heavily to warn snakes of one's approach, avoiding reaching into anthills, tree cavities, and thick undergrowth, regularly disposing of trash to keep surroundings clean, and preventing the attraction of snakes through proper waste management are also recommended. It is advisable to avoid storing paddy inside homes as it attracts rodents and to hang rolled-up mats from the ceiling. Only knowledgeable individuals should handle or keep snakes, and dead snakes should be handled with great caution, as they can still bite reflexively even after being killed (Ministry of Health 2018)

As antivenom is used only when a patient develops systemic symptoms, treatment can sometimes be delayed as clinical symptoms may take time to manifest. However, research is being conducted on detecting key components of snake venom in a patient's blood using enzyme immunoassays (Maduwage, 2014). If this method can be implemented in clinical practice in the future, it will greatly enhance snakebite management. Additionally, the need for a safer and more effective antivenom is critical. Research is being conducted to develop antivenom for Sri Lankan snakes, which will represent a significant advancement in snakebite management when it becomes available for clinical use. (Villalta et al, 2016).

4. Rabies

4.1. Introduction

Rabies remains a significant zoonotic disease in Sri Lanka, predominantly transmitted to humans through bites or scratches from rabid animals. The primary interface between humans and wildlife in both urban and rural settings involve domestic and stray dogs, which are responsible for the majority of human rabies cases. Although wild animals such as bats, mongooses, and jackals serve as reservoirs of the virus, dog-mediated transmission continues to be the principal driver of human infections.
Exposure to rabies carries serious health consequences, including:

- Injuries: Bites and scratches can cause local tissue damage and increase the risk of secondary infections.
- Illness: Infection with the rabies virus results in acute, fatal encephalitis.
- Fatalities: Once clinical symptoms develop, rabies is almost universally fatal without timely administration of post-exposure prophylaxis (PEP).

4.2 Trends and Characteristics of Human Fatalities, Injuries, and Illnesses Caused by Wildlife

Annually, approximately 25 human deaths from rabies are reported in Sri Lanka, despite the widespread availability of PEP. Young males represent a disproportionately affected group, often due to occupational exposure or behavioral factors. The majority of animal bite incidents, numbering around 250,000 each year, are attributed to dog bites, with nearly 100,000 individuals receiving PEP. Incidence peaks in rural and peri-urban areas where stray dog populations are higher and where awareness or access to medical care may be limited.

4.3. Quantitative Analysis of Reported Cases

In 2023, rabies surveillance data from major diagnostic laboratories, including the Medical Research Institute (MRI), Teaching Hospital

Karapitiya, and the Veterinary Faculty at Peradeniya, indicated that 37% of animal heads tested were positive for rabies virus. Dogs accounted for nearly 80% of confirmed rabid animals, followed by cats (16%), with other wildlife species constituting a minor proportion. Approximately 100,000 dog bite victims annually seek PEP; however, incomplete vaccination courses remain a significant factor in fatal outcomes. The number of postmortem-confirmed human rabies cases remains relatively stable, highlighting persistent transmission risks.

4.4. Impacts on Human Health: Types, Nature, and Severity

Physical trauma from animal bites ranges from minor wounds to severe injuries requiring medical intervention. Rabies virus infection leads to progressive neurological deterioration, characterized by hydrophobia, paralysis, and coma, culminating in death usually within 7 to 10 days of symptom onset. Beyond the physical toll, psychological impacts include fear, stigma, and distress experienced by affected individuals, families, and communities. Economic burdens arise from healthcare costs related to PEP, loss of productivity, and allocation of resources for rabies control programs.

4.5. Frequency of Incidents

Animal bite incidents occur frequently throughout Sri Lanka, with variations influenced by season and geography. The frequency of dog bites closely correlates with dog population density and patterns of human-animal interaction. Rabies outbreaks in animal populations occur sporadically, necessitating prompt public health responses to prevent human infections.

4.6. Readiness of the Healthcare Sector to Manage Cases

Sri Lanka boasts a well-established rabies surveillance and notification system, which mandates immediate reporting of suspected cases. Government programs ensure free provision of anti-rabies vaccines (ARV) and rabies immunoglobulin (RIG) in hospitals and clinics. Healthcare workers receive training in wound management, PEP administration, and rabies case recognition. Despite these strengths, challenges persist, including inconsistent completion of PEP, delays in care-seeking behavior, and limited advanced diagnostic capacity at peripheral health facilities. Palliative care services are available for symptomatic patients; however, prognosis remains poor once clinical symptoms appear.

4.7 Public Knowledge and Awareness of Medical Care After Wild Animal-Related Injuries

Public awareness regarding rabies and the necessity for prompt medical care after animal bites has improved but remains incomplete in certain rural and marginalized populations. Misconceptions about traditional remedies and delayed healthcare seeking continue to contribute to preventable fatalities.
Ongoing public education campaigns stress responsible dog ownership, bite prevention strategies, early wound washing, and timely PEP administration.

Schools, community centers, and health outreach programs serve as critical platforms for disseminating this information.

4.8 Future Directions and Mitigation Strategies

Achieving the national goal of zero dog-mediated human rabies deaths by 2030 requires sustained multi-sectoral interventions:

- Mass Dog Vaccination: Continued campaigns targeting at least 70% vaccination coverage, utilizing mobile and fixed clinic outreach to maintain year-round coverage.
- Dog Population Control: Strategic sterilization programs focusing on high-density stray dog populations to reduce reproduction.
- Improved Waste Management: Proper garbage disposal to reduce stray dog attraction and proliferation.
- Enhanced Surveillance and Rapid Response: Strengthening laboratory diagnostic capabilities and rapid field investigations of suspected cases.
- Community Engagement: Intensified education on bite prevention, responsible pet ownership, and adherence to PEP regimens.
- Health System Strengthening: Ensuring universal and timely access to PEP and ongoing training for healthcare workers.
- Legislative and Policy Support: Enforcement of dog control laws, mandatory bite reporting, and support for animal control initiatives.
- Intersectoral Collaboration: Coordinated efforts among health, veterinary, and local government sectors adopting a One Health approach to rabies elimination.

Integrating these strategies within the human-wildlife conflict framework is essential to reduce rabies transmission and safeguard public health in Sri Lanka.

5. Leptospirosis

5.1 Introduction

Leptospirosis is a globally significant zoonotic bacterial disease caused by pathogenic species of the genus Leptospira. The disease is primarily maintained in nature through wildlife reservoirs, most notably rodents such as rats and bandicoots, as well as domestic animals including livestock and canines. Humans are incidental or accidental hosts, acquiring infections mainly through environmental exposure to water or soil contaminated with the urine of infected animals. This chapter explores leptospirosis within the framework of human-wildlife conflict, emphasizing its epidemiology, health impacts, and strategies for prevention and control, with a particular focus on Sri Lanka.

5.2 Trends and Characteristics of Human Fatalities, Injuries, and Illnesses Caused by Wildlife (Leptospirosis Reservoirs)

Leptospirosis remains an endemic and clinically significant disease in Sri Lanka, with an estimated annual caseload ranging from 7,000 to 10,000 reported cases. Data from 2022 recorded approximately 7,000 notifications alongside 123 confirmed deaths, resulting in a case fatality rate (CFR) of 1.7%. The disease predominates in rural regions characterized by intensive agricultural activity and heavy rainfall—environments where human interaction with wildlife reservoirs or contaminated surroundings is frequent. Leptospirosis exemplifies a zoonosis arising from the interface between humans, wildlife, and the environment. Rodent species, serving as primary reservoirs, shed Leptospira bacteria in their urine, contaminating water bodies and soil. Human infections commonly occur through breaches in the skin or mucous membranes during contact with such contaminated media.

5.3 Quantitative Analysis of Reported Cases

In 2022, epidemiological surveillance revealed approximately 7,000 leptospirosis cases nationally. The highest burden was reported in the Rathnapura district, accounting for 16.5% of cases, followed by Kegalle at 10.2% and Galle at 9.1%. Males constituted the majority of cases, representing 83%, while females accounted for 16%. Adults aged 30 to 60 years were most affected, with peak incidence seen in the 40 to 49-year age group. Mortality related to leptospirosis was notable, with 123 deaths reported and an overall CFR of 1.7%. Seasonal analysis showed bimodal peaks coinciding with the monsoon periods, where environmental exposure to contaminated floodwaters and displacement of reservoir animals increased transmission risk.

5.4 Impacts on Human Health: Types, Nature, and Severity

Leptospirosis presents a broad clinical spectrum ranging from mild to severe disease. Mild illness typically manifests as nonspecific flu-like symptoms, including fever, chills, headache, and muscle tenderness, often resembling other febrile illnesses. However, the infection can progress to severe multi-organ involvement such as jaundice, acute renal failure, pulmonary hemorrhage, myocarditis, and other life-threatening complications. While the national average CFR remains approximately 1.7%, fatality rates can reach as high as 30% in severe cases, primarily due to organ failure and hemorrhagic complications. Most infections arise through occupational or environmental exposures, especially when abraded skin or mucous membranes come into contact with contaminated water or soil.

5.5 Frequency of Incidents

Leptospirosis in Sri Lanka exhibits a distinct bimodal seasonal distribution. A smaller peak occurs from March to May, followed by a larger peak from October to December. These periods correspond with the monsoonal floods that increase human exposure to contaminated environments and cause displacement of reservoir animals, such as rodents, into human habitations and agricultural fields. This ecological disturbance heightens transmission risk and drives seasonal surges in leptospirosis cases.

5.6 Readiness of the Healthcare Sector to Manage Cases

Managing leptospirosis presents several challenges for the healthcare sector. Clinical diagnosis is often complicated by the nonspecific nature of symptoms and overlaps with other endemic febrile illnesses such as dengue fever. Laboratory confirmation via the Microscopic Agglutination Test (MAT) or Polymerase Chain Reaction (PCR) is critical for diagnosis but is frequently limited by availability and accessibility in many healthcare settings. Empirical antibiotic treatment must therefore be initiated promptly based on clinical suspicion without awaiting confirmatory tests. Supportive care, including fluid management and renal dialysis for cases with renal impairment, is vital for patient survival. Although healthcare infrastructure is generally sufficient for treatment, continuous professional training is essential to improve early recognition and management, especially during peak outbreak periods. Additionally, the surveillance system needs strengthening as incomplete data collection hampers accurate epidemiological assessment and timely response.

5.7 Public Knowledge and Awareness of Medical Care

Public awareness regarding leptospirosis prevention and medical care remains inadequate, particularly among high-risk groups such as farmers, agricultural laborers, and individuals involved in flood cleanup operations. There is widespread underutilization and inconsistent adherence to chemoprophylaxis regimens, such as doxycycline. Community knowledge regarding avoidance of contaminated water and effective rodent control measures is limited. Furthermore, dissemination of timely and accurate information following flooding events is often insufficient, limiting the ability of at-risk populations to take protective actions. Enhancing awareness through targeted education campaigns is therefore essential to promote early health-seeking behaviors and reduce the overall disease burden.

5.8 Future Directions and Mitigation Strategies

Mitigating the health impacts of leptospirosis linked to human-wildlife conflict requires a multifaceted approach. Surveillance systems must be improved to ensure completeness and accuracy of case notifications and investigation data, allowing better characterization of disease burden and epidemiological patterns. Targeted health education programs should be developed and implemented to increase awareness among at-risk populations, emphasizing preventive behaviors, early symptom recognition, and the importance of prophylaxis. Rodent control and environmental management efforts must be strengthened at the community level to reduce reservoir populations near human habitations and agricultural zones.

Promoting occupational safety by encouraging the use of personal protective equipment, such as boots, gloves, and waterproof dressings, is critical for those engaged in farming, sanitation, and flood management activities. Ongoing healthcare system strengthening, including regular training for healthcare providers, is vital to maintain a high index of suspicion during leptospirosis-prone seasons, ensure timely empirical treatment, and improve reporting mechanisms. Lastly, community engagement through mobilization of local stakeholders in flood preparedness initiatives and public health education can help reduce exposure risks and facilitate early detection of cases.

6. Leishmaniasis

6.1 Introduction

Leishmaniasis is a vector-borne disease caused by protozoan parasites of the genus Leishmania. Transmission occurs through the bite of infected female sandflies (Phlebotomus species in the Old World). In Sri Lanka, the predominant form is Cutaneous Leishmaniasis (CL), caused by *Leishmania donovani*, which uniquely manifests as cutaneous rather than visceral disease. The illness primarily presents skin lesions that result in morbidity and social stigma. Visceral Leishmaniasis (VL), or Kala-azar, a severe systemic form, has also been reported but remains rare. Mucocutaneous Leishmaniasis (MCL), a destructive form affecting mucosal tissues, is uncommon in Sri Lanka.
The consequences of leishmaniasis include:

- Injuries: Skin ulcers and lesions, mainly from CL, cause disfigurement, secondary infections, and scarring.
- Illness: VL causes severe systemic symptoms including fever, hepatosplenomegaly, anemia, and can be fatal if untreated.
- Fatalities: Untreated visceral leishmaniasis carries a fatality rate exceeding 95%, whereas cutaneous forms rarely result in death but contribute significantly to morbidity.

6.2 Trends and Characteristics of Human Fatalities, Injuries, and Illnesses Caused by Wildlife

The first indigenous case of CL in Sri Lanka was reported in 1992. Since then, cases have increased markedly, particularly in districts such as Hambantota, Polonnaruwa, and Anuradhapura. Over 90% of cases are cutaneous leishmaniasis, predominantly occurring in rural and jungle fringe areas with abundant sandfly habitats. Visceral leishmaniasis cases remain sporadic but pose severe health risks. CL lesions commonly appear on exposed skin areas, forming long-lasting ulcers that may heal spontaneously or persist for extended periods. Human fatalities are rare, except in cases of VL which, though infrequent, are severe. Clusters of cases indicate anthroponotic transmission cycles, suggesting humans act as the main reservoirs in Sri Lanka.

6.3 Quantitative Analysis of Reported Cases

In 2011, 358 cases were reported in Anuradhapura, 156 in Polonnaruwa, and additional cases in Hambantota. National surveillance data reveal a rising trend of CL over the past three decades, correlating with increased exposure to sandfly vectors. Due to the rarity of VL, comprehensive national data are lacking; however, isolated cases have been documented since 2006, mainly in Anuradhapura. Incidence varies geographically, influenced by environmental and socioeconomic factors affecting vector presence and transmission dynamics.

6.4 Impacts on Human Health: Types, Nature, and Severity

- Cutaneous Leishmaniasis (CL): Characterized by polymorphic skin lesions that start as papules and progress to ulcers with raised edges. These lesions are often painless but can cause significant disfigurement. Healing may take weeks to years.
- Visceral Leishmaniasis (VL): Causes systemic illness with prolonged fever, weight loss, anemia, hepatosplenomegaly, lymphadenopathy, and immunosuppression. The disease is fatal if untreated.
- *Mucocutaneous leishmaniasis* (MCL): Rare in Sri Lanka, but in other endemic regions leads to destructive lesions of mucosal tissues.

Morbidity includes psychological distress, social stigma, and economic burden related to prolonged illness and treatment. Secondary bacterial infections often complicate CL skin ulcers. Severity depends on parasite species, host immune status, and treatment access.

6.5 Frequency of Incidents

Sandflies are most active at dusk and night, with exposure common in endemic rural areas featuring dense vegetation and inadequate housing. Hundreds of CL cases are reported regionally each year, with sporadic VL cases. Outbreaks may follow environmental changes, deforestation, or population movements that increase sandfly habitats. Frequent sandfly bites, especially among outdoor workers, farmers, and those sleeping outdoors, sustain transmission cycles.

6.6 Readiness of the Healthcare Sector to Manage Cases

Diagnosis relies primarily on clinical evaluation supported by microscopy of lesion smears and culture at specialized dermatology clinics. Sri Lanka's healthcare system offers free diagnosis and treatment, including cryotherapy, antimonial drugs, and amphotericin B for severe cases. Diagnostic capacity and awareness are stronger in endemic districts but limited in peripheral areas. Treatment protocols are tailored to disease form, parasite species, and patient characteristics, requiring specialist consultation. VL demands timely diagnosis and treatment to prevent mortality; however, awareness and diagnostic capacity for VL remain limited. Vector control and patient education form part of public health programs but require further strengthening.

6.7 Public Knowledge and Awareness of Medical Care

Community awareness of leishmaniasis and sandfly bite prevention is improving but remains insufficient, especially in rural areas. Delays in seeking medical care due to lack of knowledge or access increase the risk of disease progression and complications. Public education campaigns emphasize protective clothing, insect repellents, use of bed nets, and environmental sanitation to reduce sandfly exposure. Local health workers play a crucial role in raising awareness about early symptom recognition and the importance of prompt treatment. Misconceptions regarding traditional remedies persist, necessitating ongoing health education efforts.

6.8 Future Directions and Mitigation Strategies

- Vector Control: Integrated vector management including insecticide spraying, environmental management to eliminate sandfly breeding sites, and community-wide vector suppression campaigns.
- Reservoir Control: Research is needed to clarify potential animal reservoirs in Sri Lanka to guide targeted control measures.
- Personal Protection: Promotion of insecticide-treated bed nets, protective clothing, and repellents, especially for high-risk populations.
- Surveillance: Strengthening surveillance systems for early case detection, outbreak response, and improved data management.
- Health System Strengthening: Expanding diagnostic and treatment capacity at peripheral health centers and training healthcare workers in leishmaniasis management.
- Public Awareness: Enhanced community engagement to increase knowledge of transmission, prevention, and the critical importance of timely treatment.
- Research: Continued studies on parasite strains, sandfly ecology, and socio-environmental factors to inform tailored interventions.
- Policy Support: Government commitment to sustained funding and intersectoral collaboration between health, environment, and veterinary sectors under One Health principles.

7. Typhus

7.1 Introduction

Typhus fever encompasses a group of vector-borne zoonotic infections caused by Rickettsia and *Orientia* species, transmitted to humans through the bites of infected arthropod vectors such as fleas, lice, and chiggers. These vectors often parasitize wild rodents and other small mammals, creating a critical link between wildlife reservoirs and human populations. Human-wildlife interactions—particularly in settings marked by rapid urbanization, deforestation, environmental degradation, and poor sanitation—have intensified the risk of typhus transmission. Among these infections, scrub typhus, also known as bush typhus, is of particular concern in Sri Lanka. Caused by *Orientia tsutsugamushi*, it is transmitted via the bite of infected larval trombiculid mites, especially *Leptotrom bidiumakamushi* and L. deliense, which acquire the pathogen from wild rodents. Humans typically become infected through contact with mite-infested vegetation during outdoor activities such as farming, military exercises, or recreational exposure to natural habitats. Scrub typhus therefore represents a growing public health challenge in Sri Lanka at the intersection of human activity and wildlife ecology. This chapter explores the role of human-wildlife conflict in the emergence and spread of typhus, with a focus on its causes, epidemiological trends, health consequences, and directions for prevention and control.

7.2. Trends and Characteristics of Human Fatalities, Injuries, and Illnesses

Unlike direct injuries caused by wildlife encounters, typhus represents a subtler but equally significant consequence of human-wildlife interaction. It arises from indirect contact, where ectoparasites—such as fleas, lice, and chiggers—transmit zoonotic pathogens from wildlife or peri-domestic animals to humans. Common reservoirs include rodents (rats, mice, squirrels), opossums, and other small mammals, which thrive in both rural and urban environments. Factors such as deforestation, human encroachment into natural habitats, and inadequate urban waste management contribute to increased proximity between people and these reservoir hosts, fostering conditions for typhus outbreaks.

Historically, large-scale outbreaks of typhus have been closely linked with societal disruptions such as war, displacement, and poverty. Epidemic typhus, caused by Rickettsia prowazekii, has been responsible for significant mortality during times of armed conflict and natural disasters, particularly in crowded and unhygienic settings. In contrast, scrub typhus, caused by *Orientia tsutsugamushi*, remains endemic in many parts of the Asia-Pacific region, particularly in forested and agricultural areas where individuals are exposed through occupations such as farming, logging, or military service.

Clinically, scrub typhus manifests as an acute febrile illness with symptoms including fever, headache, rash, lymphadenopathy, and a characteristic eschar at the site of the chigger bite. The incubation period typically ranges from 6 to 20 days. If left untreated, the disease can progress to severe complications such as pneumonitis, hepatic dysfunction, multi-organ failure, encephalitis, and death. Neurological symptoms and respiratory distress in severe cases underscore the potentially fatal nature of this infection. These patterns reflect how human-wildlife conflict, though often considered in the context of traumatic injuries, also significantly contributes to morbidity and mortality through zoonotic illnesses like typhus.

7.3. Quantitative Analysis of Reported Cases

Despite its clinical significance, typhus remains underreported in many endemic regions due to nonspecific symptoms, misdiagnosis, and limited access to diagnostic facilities. However, epidemiological data exists highlight the considerable public health burden posed by the disease. Scrub typhus accounts for an estimated one million cases annually worldwide, with a high concentration in the rural areas of the Asia-Pacific region, particularly within the so-called "tsutsugamushi triangle" encompassing countries such as India, Sri Lanka, Nepal, and those in Southeast Asia. Murine typhus, caused by Rickettsia typhi, is sporadically reported in urban settings across the globe and is now re-emerging in parts of the United States, Mexico, and Sri Lanka. Epidemic typhus, caused by Rickettsia prowazekii, has become rare in recent decades but remains a threat under crisis conditions such as war, displacement, and natural disasters.

Globally, several significant outbreaks have underscored the ongoing risk posed by scrub typhus. In Nepal, between 2015 and 2017, 1,239 cases were reported, with a decline in the case fatality rate from 5.7% in 2015 to 1.1% in 2017, attributed to improved detection and timely treatment. In 2022, Australia experienced an outbreak among military personnel exposed to mite habitats during field exercises. These patterns emphasize the disease’s persistence across diverse ecological and geographic settings, shaped by environmental conditions and human activity at the human-wildlife interface. In Sri Lanka, scrub typhus has been endemic for decades, with cases primarily reported from the central and southern provinces. These clusters are frequently associated with exposure to forested environments and rodent-infested habitats. Surveillance data from 2006 to 2024 show that over 1,000 cases have been recorded annually, with a notable peak of 1,788 cases in 2016. A temporary decline occurred in 2021, with 1,120 cases reported, but numbers rose again to 1,371 by 2024. Murine typhus, though less prevalent, occasionally emerges in urban areas with poor sanitation and high rodent populations.

7.4. Impacts on Human Health: Types, Nature, and Severity

Typhus fever presents a wide clinical spectrum, from mild self-limiting febrile illness to life-threatening complications. The nature and severity of the disease depend on the causative agent—*Orientia tsutsugamushi* in scrub typhus, Rickettsia prowazekii in epidemic typhus, and Rickettsia typhi in murine typhus—as well as host factors such as age, immune status, and access to timely medical care.

All forms of typhus typically begin with nonspecific symptoms including high fever, headache, muscle aches, and rash. However, distinguishing features and complications vary. Scrub typhus may present with lymphadenopathy and, in some cases, a pathognomonic eschar—a painless, necrotic skin lesion at the site of the mite bite—which serves as an important diagnostic clue. Yet, the eschar is not universally present, and in endemic regions, scrub typhus is frequently misdiagnosed as dengue or leptospirosis, resulting in delays in appropriate therapy and poor clinical outcomes. Epidemic typhus is generally more severe, with potential for neurological symptoms such as confusion and stupor. Without treatment, it carries a high mortality rate, historically reaching up to 40%. Murine typhus is usually milder, but it can still lead to complications, particularly in elderly or immunocompromised patients.

Scrub typhus illustrates the range of clinical manifestations most clearly. In its mild form, it causes fever, chills, headache, and malaise. Moderate disease may include rash, eschar, and swollen lymph nodes. Severe cases can progress to pneumonia, liver inflammation, central nervous system involvement (such as encephalitis), renal failure, and death. These complications reflect the systemic vasculitis induced by the pathogen and highlight the importance of early diagnosis and treatment with appropriate antibiotics such as doxycycline or azithromycin. Overall, typhus fever poses a significant health risk, particularly in resource-limited settings where diagnostic uncertainty and treatment delays are common. The burden is further amplified in areas experiencing increased human-wildlife contact, underscoring the disease's relevance in the context of environmental and ecological change.

7.5. Frequency of Incidents

Typhus fever in Sri Lanka demonstrates persistent endemicity with notable seasonal and geographic patterns. The disease typically peaks during the cooler months from December to February, while the lowest incidence is observed from May to July. These fluctuations suggest a strong influence of climatic conditions on the ecology of vectors and reservoir hosts, which in turn affects human exposure and disease transmission.

National surveillance data from 2006 to 2024 show more than 1,000 typhus cases reported annually, with significant year-to-year variation. From 2006 to 2010, incidence remained relatively stable, ranging between 1,079 and 1,226 cases annually. A gradual increase was noted from 2011 onwards, culminating in the highest number of reported cases—1,788—in 2016. This peak was followed by a period of fluctuating but sustained transmission, with case numbers ranging between 1,446 and 1,611 until 2020. A notable decline occurred in 2021, reaching a low of 1,120 cases, possibly influenced by pandemic-related disruptions in healthcare access or reporting. However, the upward trend resumed in subsequent years, with 1,482 cases in 2023 and a slight decrease to 1,371 in 2024. These trends reflect periodic outbreaks and suggest that while overall endemicity persists, the intensity of transmission varies over time.

Geographic analysis further underscores regional differences in disease burden. Jaffna consistently reported the highest number of cases over the 2022–2024 period, with 742 in 2022, peaking at 782 in 2023, and slightly declining to 645 in 2024. This sustained high burden indicates ongoing transmission dynamics possibly linked to environmental conditions and rodent populations. Galle witnessed a sharp increase in reported cases, from 49 in 2022 to 132 in 2024, marking a concerning rise in transmission in the southern region. Similarly, Puttlam experienced a notable increase—from 10 cases in both 2022 and 2023 to 44 in 2024—suggesting emerging risk in the northwestern zone.

Urban areas previously considered low-risk, are also showing signs of vulnerability. Colombo, which reported minimal cases in prior years, recorded a rise to 10 cases in 2024. This indicates the potential for urban transmission, likely influenced by poor waste management and increasing rodent infestations. The frequency of typhus infections is intricately linked to environmental, socio-economic, and climatic factors. Deforestation, unmanaged urban growth, rodent proliferation, and human intrusion into wildlife habitats all create ecological conditions conducive to disease outbreaks. These patterns emphasize the need for strengthened surveillance, targeted public health interventions, and integrated vector and rodent control strategies to manage the recurrent burden of typhus in Sri Lanka.

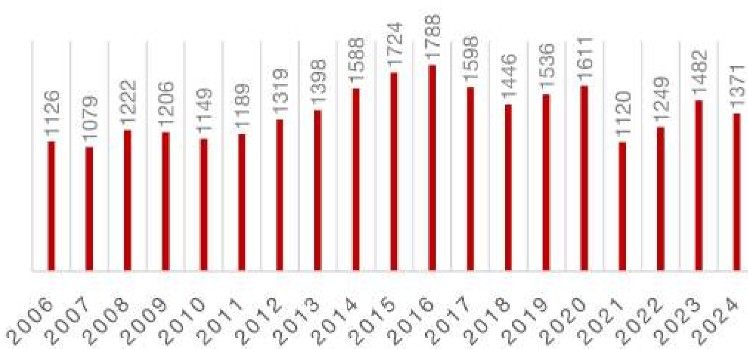

Fig 4. Typhus cases in Sri Lanka from 2006 to 2024. Source: Epidemiology Unit.

7.6. Readiness of the Healthcare Sector

The healthcare sector's readiness to address typhus fever—particularly scrub typhus—remains uneven, with significant gaps in diagnostic capacity, clinical recognition, and surveillance infrastructure. Diagnosis often depends on a high index of clinical suspicion, supported by basic laboratory findings such as thrombocytopenia, elevated liver transaminases, and changes in lymphocyte counts. However, these indicators are nonspecific and overlap with other febrile illnesses, making definitive diagnosis challenging in resource-limited settings.

Definitive diagnostics include serological tests (IgM/IgG antibody detection), molecular assays such as polymerase chain reaction (PCR), and imaging studies when complications are suspected. Yet, access to these tools—particularly PCR and immunofluorescence assays—is limited in peripheral and rural healthcare facilities where scrub typhus is most prevalent. This often leads to underdiagnosis or misdiagnosis, especially in regions where dengue, leptospirosis, and other endemic febrile illnesses are common.

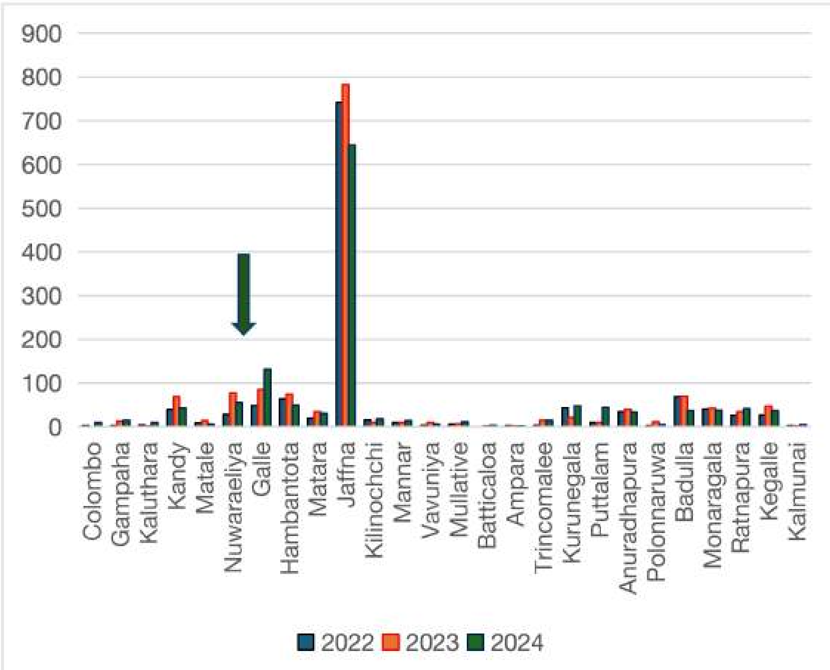

Fig 5. Typhus Cases in Sri Lanka by District for the Years 2022, 2023, and 2024- Source: Epidemiology Unit.

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Early treatment with doxycycline is both effective and widely available, and timely initiation can significantly reduce morbidity and prevent fatal outcomes. This constitutes a major strength of the current response capacity. Moreover, in some countries, typhus has been incorporated into differential diagnosis protocols for acute febrile illness, improving case recognition and management.

Nonetheless, weaknesses persist. Limited clinical awareness among frontline healthcare workers continues to result in delayed or inappropriate treatment. In many endemic regions, typhus is still under-recognized in routine clinical practice, leading to missed opportunities for early intervention. In addition, weak surveillance systems hamper early detection of outbreaks and limit the effectiveness of public health response strategies. To improve healthcare readiness, investment is urgently needed in capacity-building initiatives—including laboratory strengthening, clinical training on zoonotic fevers, and integration of typhus into national disease surveillance systems. Improved diagnostic access at the primary care level, combined with public health education and cross-sectoral coordination, will be essential to enhance early detection, appropriate treatment, and outbreak control in typhus-endemic regions.

7.7. Public Knowledge and Awareness

Public knowledge and awareness of typhus—particularly scrub typhus—remain markedly limited in many endemic areas, especially rural and underserved communities. Unlike visible injuries or dramatic encounters with wildlife, typhus arises from indirect contact with infected ectoparasites such as fleas and mites, making the link between exposure and illness less intuitive. This invisibility contributes to delays in care-seeking and underrecognition of disease risk.

Key gaps in awareness include a poor understanding of high-risk environments, such as scrublands, overgrown vegetation, or rodent-infested surroundings. Individuals engaging in farming, forestry, or other outdoor activities often do so without adequate personal protection, such as insect repellents or protective clothing. Furthermore, many people do not associate rodent presence, mite bites, or poor waste management with the risk of illness. In rural settings, fevers are frequently self-managed with home remedies or delayed visits to healthcare facilities, especially when early symptoms of typhus mimic other more familiar illnesses. Hygiene and vector control practices—such as rodent control, safe garbage disposal, and flea management in domestic animals—are inconsistently implemented in high-risk environments.

Compounding the issue, health education campaigns and public health messaging in many countries prioritize diseases with higher visibility or recent outbreaks, such as dengue, malaria, or rabies. As a result, rickettsial infections like typhus remain underrepresented in community-level health promotion activities. To bridge this awareness gap, targeted health education interventions are needed. These should include information on typhus transmission routes, preventive behaviors, early symptom recognition, and the importance of timely medical attention. Community engagement, especially through local health workers, schools, and media, is vital to empower at-risk populations and reduce disease burden through behavior change and improved environmental management.

7.8. Future Directions and Mitigation Strategies

Addressing the growing public health burden of typhus—particularly scrub typhus—within the context of human-wildlife conflict requires a comprehensive, multi-sectoral approach grounded in both prevention and early intervention. Given the zoonotic and vector-borne nature of typhus, control efforts must simultaneously target vectors, reservoirs, human behavior, and healthcare system readiness.

Public health education remains a cornerstone of effective disease mitigation. Raising awareness among at-risk populations about the habitats of mites and fleas, personal protective measures, and early symptom recognition can facilitate timely care-seeking and reduce transmission. Special emphasis should be placed on educating communities engaged in high-risk occupations such as farming, military training, and forestry work.

Vector control and habitat management are essential in reducing human exposure. Strategies include environmental cleanup to eliminate vector breeding grounds, rodent control in both urban and rural settings, and the application of insecticides where appropriate. The control of ectoparasites in domestic animals and livestock can further minimize spillover to humans. Chemoprophylaxis using doxycycline has shown promise in high-risk groups, particularly during periods of intense exposure, such as military operations in endemic areas. However, its use must be guided by risk-benefit assessments and adherence to antibiotic stewardship principles.

Surveillance and diagnostics must be enhanced to accurately track disease trends and ensure subtype-specific reporting (e.g., distinguishing scrub typhus from murine or epidemic typhus). Improved laboratory infrastructure and data sharing across regions can support early outbreak detection and targeted responses.

A One Health approach—integrating human, animal, and environmental health—is critical in tackling the disease at its source. Intersectoral collaboration involving public health, veterinary services, environmental agencies, and local communities can foster coordinated actions to reduce the interface between humans and infected wildlife. This includes rodent surveillance, ecological studies of mite populations, and monitoring environmental changes that may influence vector dynamics.

Research and policy development must support these efforts. Key areas include longitudinal studies on host-vector-pathogen interactions, modeling the impact of climate change on vector proliferation, and integrating typhus control into broader zoonotic disease management frameworks.

In conclusion, effective mitigation of typhus fever in the context of human-wildlife conflict demands sustained investments in education, surveillance, environmental health, and cross-sectoral partnerships. Through such integrated strategies, the global and local burden of typhus can be reduced, protecting vulnerable populations and enhancing public health resilience.

Conflict of Interest

The authors have declared that no competing interests exist.

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Chapter 16

Contribution of Modern Technologies in Mitigating Human–Wildlife Conflict in Sri Lanka

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Abstract: Human wildlife conflict (HWC) poses significant challenges in Sri Lanka, threatening biodiversity conservation, rural livelihoods, and sustainable development. Traditional mitigation measures have offered limited, often temporary relief, as they are labor-intensive, costly, and difficult to sustain. Against this backdrop, modern technologies present innovative opportunities to transform conflict management from reactive to proactive approaches. This chapter examines the integration of advanced tools, including GPS (Global Positioning System) tracking, drones, wireless sensor networks, artificial intelligence (AI), geospatial systems, and mobile-based platforms, into Sri Lanka's HWC mitigation strategies. These technologies enhance monitoring, early warning, predictive analytics, and community engagement, while also enabling data-driven decision-making for land-use planning and conservation management. Case studies highlight successful applications and the value of combining technological innovations with local participation. At the same time, the chapter critically addresses barriers to adoption, including high costs, infrastructure limitations, digital literacy gaps, and community mistrust. It argues that technology cannot serve as a stand-alone solution but must be integrated with traditional ecological knowledge, participatory governance, and locally appropriate practices. Looking ahead, greater emphasis on cross-sector collaboration, capacity building, and supportive policy frameworks is essential to scale up effective interventions. By embedding modern technologies within inclusive, community-centered approaches, Sri Lanka can move toward a more sustainable coexistence model that protects both human well-being and wildlife conservation.

Keywords: Artificial intelligence, community-based conservation, human–wildlife conflict, modern technologies

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1. Introduction

Human-wildlife conflict (HWC) represents a long-standing challenge that integrates ecological conservation, rural livelihoods, and sustainable development. In Sri Lanka, as in many biodiverse regions worldwide, the pressures of land-use change, habitat fragmentation, and human population growth have intensified interactions between people and wildlife, often with negative consequences for both (Gunawansa et al. 2023; Köpke et al. 2023). While HWC is not a new phenomenon, its frequency and severity have grown in recent decades. Incidents such as crop damage by elephants, attacks on livestock by leopards, and property destruction by monkeys have become increasingly common. These conflicts result in significant economic losses, psychological distress, and, in some cases, human and animal fatalities. They contribute to the weakening of conservation strategies, as hostility and intolerance toward wildlife continue to increase.

Traditionally, mitigation of HWC in Sri Lanka has relied heavily on physical and community-based measures ranging from fencing and scare tactics to crop guarding and translocation. While these approaches have had varying degrees of success, they often lack precision, are labor-intensive, and may not be sustainable in the long term (Athulathmudali et al. 2024; Horgan et al. 2019; Köpke et al. 2023). In recent years, however, a new paradigm has begun to emerge: one that integrates modern technologies into the broader framework of conflict mitigation. From satellite tracking of elephants to AI-powered prediction models and drone-based surveillance systems, technological tools offer the potential to revolutionize how we detect, understand, and respond to HWC.

This chapter explores the role of such technologies in supporting sustainable and science-based conflict management. It examines the types of technologies being employed both locally and globally, their applications across different stages of conflict, and the opportunities and challenges they present within the Sri Lankan context. The objective is not to propose technology as a universal solution, but rather to assess how it can enhance traditional methods and contribute to a more proactive, data-driven, and ethical approach to human-wildlife coexistence.

2. The Role of Modern Technologies in HWC: A Conceptual Overview

As HWC intensifies in biodiversity-rich regions such as Sri Lanka, the shortcomings of conventional approaches have become increasingly apparent. These methods provide temporary relief but rarely address the complex ecological, social, and spatial dynamics of conflict. In response, modern technologies have emerged as adaptive, data-driven solutions that enable proactive conflict management while fostering coexistence between humans and wildlife.

This section provides a conceptual overview (Fig. 1) of how modern technologies function within HWC mitigation frameworks, outlining four interrelated domains of contribution. They are monitoring and surveillance, early warning and predictive analytics, geospatial planning and decision support, and communication and community engagement.

2.1 Surveillance and monitoring

GPS collars, drones, wireless sensor networks (WSNs), and camera traps are increasingly employed to observe wildlife movements with high precision and minimal disturbance. Such tools allow continuous data collection, facilitating the mapping of migration corridors, identification of high-risk zones, and recognition of behavior patterns linked to conflict. These insights support early interventions, enabling wildlife managers to anticipate rather than merely react to incidents.

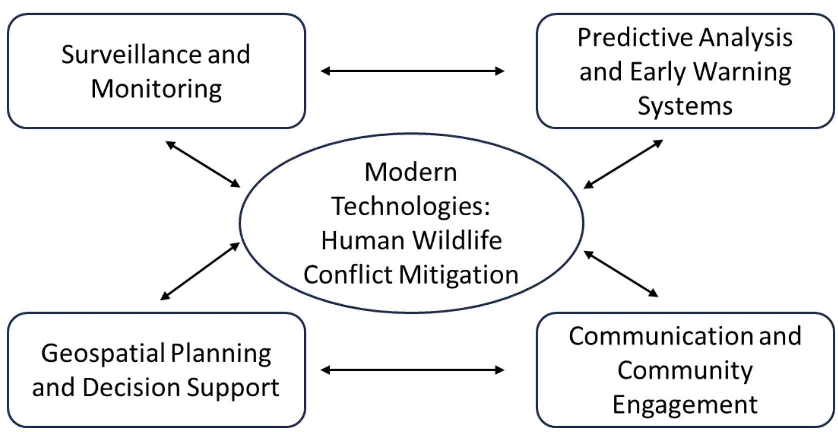

Fig. 1. Conceptual overview of how modern technologies function within HWC mitigation frameworks

2.2 Predictive analytics and early warning systems

Artificial intelligence (AI), machine learning (ML), and big data analytics now underpin real-time risk modeling. By integrating variables such as rainfall, crop cycles, and historical conflict data, these systems forecast likely conflict events. When linked with mobile apps or SMS-based alerts, predictive platforms provide farmers with timely warnings, improving preparedness and reducing losses.

2.3 Geospatial technologies for spatial planning

GIS, satellite imagery, and remote sensing enable the integration of ecological, environmental, and social data layers into comprehensive conflict maps. These tools are vital for designing wildlife corridors, identifying suitable buffer zones, and planning land-use strategies that reduce conflict at its root. In Sri Lanka, remote sensing data combined with AI could be applied to locate elephant corridors and high-risk farmland, allowing for targeted interventions and smarter resource allocation.

2.4 Communication and community engagement

Technology also strengthens participatory management by empowering communities to act as both beneficiaries and contributors. Mobile reporting apps, citizen science platforms, and village-based alert systems allow residents to document wildlife sightings, receive warnings, and co-manage interventions. These initiatives improve the granularity of conflict data while fostering trust and shared responsibility between communities, conservation authorities, and researchers. While these domains highlight the transformative role of technology, challenges remain. Issues of affordability, infrastructure, digital literacy, and community acceptance limit widespread adoption. Moreover, technological tools must be integrated with traditional ecological knowledge and socio-cultural practices to avoid unsustainable, top-down approaches. Modern technologies offer a conceptual framework for moving from reactive to proactive HWC management. Their effectiveness lies in enhancing monitoring and prediction, supporting data-informed decision-making, and embedding participatory processes. The following sections explore how these tools are applied, emphasizing both their promise and their practical constraints.

3. Applications of Modern Technologies in HWC Mitigation

The global ecosystems rely greatly on wildlife, which is in turn increasingly vulnerable to the negative effects of human activities such as deforestation, poaching, illegal wildlife trade, the introduction of invasive species, and the spread of pests and diseases. In addition, human-induced environmental and climate changes also impact wildlife by altering its habitats and increasing the extinction rate of numerous species (Varghese et al. 2022). These pressures have brought different species of wildlife into closer contact with human settlements, resulting in increased human-wildlife conflicts, mostly due to human infrastructure and development. Therefore, addressing the root causes of these conflicts while ensuring the coexistence of human and wildlife has become a critical global priority. Among the emerging approaches, the use of modern technologies offers a promising, non-invasive, and adaptive solution to mitigate such conflicts effectively.

The pace of digitalization has changed with the addition of other technologies like the Internet of Things (IoT), machine learning, artificial intelligence (AI), augmented reality, and big data analytics across various sectors. However, as Mwonzora and Mwonzora (2024) point out, these technologies have not been widely utilized toward resolving HWC issues. Despite the growing array of technological tools, there is still no universal solution for HWC mitigation. The coexistence strategies, as written by Blackwell et al. (2016), still require a deep understanding of animal behavior. On the other hand, modern advancements in wireless sensor networks (WSNs) and computer vision (CV) have yielded promising outcomes in preventing the entry of wildlife species into agricultural areas. Motion sensor nodes and camera modules can now capture real-time notifications of animal intrusions, which facilitate timely human responses. Species-specific response strategies and CV algorithms further enhance these systems by enabling automatic identification of intruding species, supporting species-specific response strategies (Doss et al. 2024).

All these emerging technologies have improved early warning capabilities, monitoring systems, and community participation technology, which are fundamental to the coexistence of human and wildlife. In Sri Lanka, the adoption of remote sensing, AI-assisted analytics, and mobile-based platforms has notably influenced the management of human-elephant conflict (HEC), enabling proactive surveillance and faster response. Therefore, subsequent sections explain possible technologies further, along with case studies focused on providing practical solutions to unaddressed problems.

3.1 Wildlife monitoring and movement tracking

Tracking wildlife is crucial for understanding the spatial and temporal patterns of HWC, particularly in regions where elephant-related incidents are frequent. Advances in tracking technologies have transformed wildlife monitoring by greatly increasing accuracy, precision, and real-time telemetry. Satellite-based GPS collars have significantly enhanced tracking to monitor the migration routes of elephants, identify conflict hotspots, and evaluate the functionality of wildlife corridors (Kei et al. 2025). Real-time location tracking further allows issuing timely warnings when elephants approach human settlements (Gamage and Wijesundara, 2014). Moreover, the usage of drones fitted with high-resolution cameras and convolutional neural networks (CNNs) and such, enables the identification of elephants with an accuracy of 98.59% (Rana et al. 2024), which reduces ground survey requirements and aids in remote data collection or inaccessible areas. The integration of IoT technologies with GPS collars and environmental sensors enables the continuous collection of data on the movement and habitat conditions of wildlife. These systems can send alerts via Global System for Mobile Communications (GSM) networks, significantly improving community safety and response efficacy (Reddy et al. 2023; Ronoh et al. 2022). Contrary to traditional approaches, these integrated systems provide a more dynamic and comprehensive understanding of the mobilization of animal species. More advanced tracking approaches via detection of seismic-induced vibrations and infrared sensors have improved the intrusion detection capability in the agricultural settings that elephants often raid (Wijesekera et al. 2021).

Meanwhile, satellite imagery and geographic information systems (GIS) support the long-term wildlife corridor mapping as well as land-use planning. Although the imagery of high resolute can be limited due to the cloud cover and a lot of processing power, the long-term MODIS dataset (measurements from NASA's Moderate Resolution Imaging Spectroradiometer) provides nearly cloud-free imagery suitable for trend analysis (Gbagir et al. 2022). Aversive Geofencing Devices (AGDs) are another new emerging technology based on satellite-linked collars that give audio warnings and electric shocks when the animal crosses pre-defined virtual fence boundaries. The strategy is to make the elephants more reluctant to approach human habitation.

3.2 Early warning and alert systems for human–wildlife conflict mitigation

Technological advancements have significantly enhanced early warning systems in mitigating HWC. Devices such as motion sensors, geofencing, and mobile alerts, all set within one community-based alerting system, now play a crucial role in reducing the number of interactions between humans and wildlife. Wildlife management and security can be achieved using Passive Infrared (PIR) sensors, which detect heat signatures and combine them with GPS trackers and camera modules (Ronoh et al. 2022). Modern setups often include accelerometers, gyroscopes, and magnetometers as inertial sensors to monitor animal orientation and behavior, similar to Inertial Measurement Units (IMUs) used in robotics (Lahoz-Monfort and Magrath, 2021). Geofencing uses geographic coordinates to create virtual fences, and stakeholders are notified when wildlife crosses the zones or boundaries. GNSS-based geofencing systems, with added advantages of WAAS in North America, provide high spatial accuracy and could be adapted for conservation purposes in Sri Lanka (Amarasekara et al. 2014; Cohen et al. 2023). For real-time communication, mobile technologies and dedicated applications like SMS alerts are very useful. Information can reach the farmers, villagers, and conservation personnel without delay, with the assistance of these devices. The Tusker Alert system is one of the examples that enhance rapid response by disseminating elephant movement updates to both authorities and local communities (Rathnayaka et al. 2020). In addition to those, Mobile Applications such as "WildEye" and "Report-a-Tusker" enable community-based reporting of wildlife sightings and conflict incidents. Through this public sourcing of information, these platforms improve transparency, data integration, and public involvement, which are critical to co-management. By integrating with community notification networks, wildlife alert messages can be disseminated to residents, village leaders, and emergency services. This approach is more decentralized and enables better coordination in response to wildlife alerts, which increases public safety (Ronoh et al. 2022; Waidyanatha et al. 2008).

3.3 Conflict deterrents and barriers

Community feedback indicates that automated lighting and electric fencing are useful in preventing elephants from entering villages and farms. Moreover, advanced systems like *Elemantra* utilize deep learning to detect triggers in real-time and activate light and sound systems, which further reduces intrusion (Bandara and Bandara, 2023). Wijesekera et al. (2021) also found that these systems reduced nighttime elephant incursions into human spaces. Sound-based technologies (Acoustic Deterrents) to disrupt animal movement create an artificial boundary that obfuscates animal movement. Success stories have been reported in other countries. Use of sound-based technologies in Finland to protect fisheries from seal predation, indicating broader applicability (Elvitigala et al. 2015; Veneranta and Westerbom, 2024). Smart systems like *WildGuard* integrate deep learning along with IoT to identify and classify animals and subsequently activate tailored deterrent mechanisms. Their differentiation between harmful and neutral species enables them to avoid excess damage (Begum et al. 2024). Virtual fences, including lasers, can assist in mitigating and humanely preventing elephants from encroaching into settlements, therefore showcasing scalable and effective mitigation systems (Anastácio et al. 2018; Firdhous, 2020). Geofencing technology like *LionAlert* helps communities receive alerts about the proximity of predators, proactively preventing livestock losses (Grinko et al. 2023). These systems could similarly be applied to the elephant corridors and prevent predators from coming to livestock in rural areas in Sri Lanka, as these systems help reduce unexpected encounters and conflicts.

4.2 Data management and predictive analytics

AI and machine learning (ML) now serve as key tools in forecasting wildlife behavior and conflict incidents. During high-risk periods such as the harvest season, GPS data is analyzed to predict elephant movements and issue timely warnings, particularly during intrusions (Amarasekara et al. 2014; Fernando et al. 2023). Mobile reporting tools and citizen science platforms work together and contribute significantly to data collection. Farmers can submit real-time sightings, enhancing databases used for training predictive models. Systems such as Tusker Alert combine AI with community-reported data to issue timely alerts and mitigate conflicts (Rathnayaka et al. 2020). These goals are further complemented by wireless sensor networks, which automate behavioral monitoring and intrusion detection. This cyclical system of real-time feedback increases the precision and flexibility of the AI systems (Amarasekara et al. 2014). Even with the potential these tools provide, the trustworthiness and accuracy of the data remain an important focus. Inadequate or biased datasets can impede predictive accuracy, just like in other critical fields such as healthcare or finance. Thus, in AI-powered conservation, data is a vital yet overlooked resource.

While these technologies provide considerable benefits, at the same time, they pose social and ethical issues, particularly in developing countries (Shrestha and Lapeyre, 2018), highlighting the risk of local and Indigenous peoples being left behind due to the digital gap. Research conducted in Nepal's Terai-Arc Landscape is an example of how peripheral and militarized conservation approaches, often made possible by digital monitoring, systematically marginalize local actors. As such, strategies to foster socio-ecological integration that combine traditional ecological knowledge (TEK) with new tools are essential for advancing sustainable conservation efforts (Boafo et al. 2016; Berkes, 2005). Another issue with technological developments such as AI image recognition, multi-sensor detection systems, and Shutdown On Demand (SOD) technology is their energy requirements. While these devices were originally developed for wind energy projects to reduce bird strikes, they are now being considered for broader wildlife protection applications (Cohen et al. 2023). This emphasizes the need for the technology framework to correspond with the community-centric policy approaches that these communities require.

4. Case Studies or Pilot Projects from Sri Lanka or the Region

Human wildlife conflict (HWC) remains one of the most pressing conservation and livelihood issues in Sri Lanka, particularly affecting rural communities adjacent to forested or wildlife habitats. In recent years, the integration of modern technologies into HWC mitigation strategies has ranged from electric fencing and sensor-based alert systems to real-time mobile applications. However, given the ecological, socio-economic, and institutional factors, these technologies do not prove effective within all contexts. A number of pilot studies and initiatives undertaken by the Department of Wildlife Conservation (DWC), academic institutions, NGOs such as the SPEARS Foundation, and community-based initiatives have had both successes and failures, which depict valuable lessons that can guide in providing further progress.

As is the case elsewhere, electric fencing remains the single most common technological intervention used to manage human elephant conflict (HEC) in Sri Lanka. It was shown that in projects undertaken in *Kandaketiya, Kalagama*, Mahaweli System G, and *Lunugamvehera*, provided these fences were properly maintained, these fences significantly reduce crop-raiding by elephants. Community-based maintenance mechanisms, where local people are involved in fence upkeep and monitoring, have proven more effective than government-maintained systems (Gunaratne and Premarathne, 2005). However, fencing alone is not the answer. A study conducted around *Udawalawe* National Park revealed that elephants frequently bypass or damage fences at vulnerable points like gates or during power outages (Ranjeewa et al. 2025). This is consistent with experiences elsewhere: in Kenya, for example, intrepid elephant herds have been documented learning to circumvent fences by breaking into non-electrified sections, showcasing learned adaptive behavior (Kioko et al. 2008). These studies emphasize the need for continual improvement and strong technical support; otherwise, fencing systems are bound to fail.

Moreover, other studies have sought to reduce the risks of electrocution of monkeys or other climbing animals to the level of the electric post. In Polonnaruwa, this small infrastructural change dramatically reduced langur and macaque deaths, illustrating how even the most cost-effective technological solutions can be lifesaving if properly thought out (Dittus, 2020). The Tusker Alert System is foremost in innovative pilot projects, which is a wireless sensor network that detects motion and infrared elephant movement, sending alerts in real-time through SMS and mobile applications. Field evaluations indicated that the system achieved an over 92% detection rate, enabling villagers to prepare and possibly avert conflict (Rathnayaka et al. 2020). Also, *Gaja-Mithuru* Monitoring System is another innovation that uses IoT-based seismic and GPS technologies to monitor the movements of elephants for issues of early warning, proving how data-driven devices can assist in changing from reactive to proactive management (Fernando et al. 2020).

In addition to these, some of the possible technologies that are used internationally, where conditions are the same as in Sri Lanka, could be applied. One is that Camera traps and automated voice alert systems installed in India's Valparai Plateau help set up early warning systems to reduce human-elephant encounters by 50% at night (Nishant et al. 2019). Botswana geo-fencing enabled satellite collaring of elephants to alert communities when elephants approached farmland (Dampage et al. 2021). These are all advanced technologies and outline the need for successful model adaptation for Sri Lankan efforts. In Sri Lanka, the focus regarding HWC is primarily centered on elephants; however, toque macaques and grey langurs are also a growing concern for rural and peri-urban regions. Farmers in areas such as Monaragala and Polonnaruwa report crop damages amounting to LKR 14,000-30,000 every month, particularly during off-peak harvest seasons (Jayarathne et al. 2025). Aggressive macaques pose a threat to urban populations as well, resulting in damage to both property and personal safety.

In Sri Lanka, the conflict mitigation technology targeted towards monkeys is almost non-existent. However, the groundwork is there from spearhead efforts by the SPEARS Foundation and the DWC (Rudran et al. 2020). These include the creation of Community Conservation Areas (CCAs), as well as the more participatory creation of region-specific monkey management plans (Cabral et al. 2018). Recommendations suggest a combination of behavior modification techniques, TNR (Trap-Neuter-Return), and the removal of the individuals to adjacent buffer zones; sadly, these options are fraught with ethical and ecological difficulties. Promisingly, international experiences offer scalable models. For instance, in Japan, face recognition AI and deep learning have been employed for identifying and monitoring specific monkeys responsible for raiding farms, which permits targeted deterrence (Sang-ngenchai et al. 2024). In agricultural regions of India, monkey monitoring drones, alongside other automated noise-emitting devices, have been tested with reasonable, although modest, repeatable successes (Kays et al. 2019). Technologies like these, with careful consideration, could be tested in Sri Lanka's conflict zones with the possibility of providing enduring solutions, unlike manual guarding or lethal control.

Monitoring wildlife is yet another area where the public can actively participate. More recently, a website along with a mobile application to report wildlife-vehicle collisions was launched in Sri Lanka (Rastogi et al. 2024). The system performs both functions with regard to educating the public and accumulating data that informs wildlife crossing hotspots, which guides the design of underpasses or warning signals. These efforts correspond to international practices where Canadian and Australian road management make use of GPS-collared cadaver data about roadkill, which improves highway infrastructure planning and wildlife corridors (Olson et al. 2014). The past experiences of Sri Lanka showcase how technology is not a standalone solution for HWC. The primary determining factors appear to be social integration, community ownership, and organizational backing. For instance, electric fences that villagers help maintain are maintained much better than those managed exclusively by government departments (Gunaratne and Premarathne, 2005). In a similar manner, alert systems dependent on communication frameworks, local confidence, and rapid response teams are the only ones that work. Moreover, technological failure often results from one-size-fits-all approaches. A good example is the uneven effectiveness of elephant fences in dry and wet zones. Future strategies must prioritize site-specific focus of customization, ecosystem-based approaches, and social acceptability. Importantly, the growing challenge of monkey-related conflict is currently under-addressed yet demands immediate attention, which constitutes perhaps the greatest problem area needing immediate attention. It is suggested that a national plan that includes community-based conflict resolution strategies, as well as non-lethal deterrents, be set up as a matter of urgency. The Central and North Central Province pilot zones could act as demonstration areas, drawing on domestic initiatives and international best practices.

5. Challenges and Limitations

5.1 High cost, maintenance, and technical skill requirements

The application of advanced technologies in human wildlife conflict mitigation, like GPS collars, drones, automated lighting, electronic fences, and AI-driven data analytics require significant financial investment. These technologies require high capital for purchasing, installation, and integration into existing systems. For example, GPS satellite radio collars (around $ 5,000-8,000 per collar) and drones are not having an affordable price, and their deployment across large or remote areas can multiply costs further (Fernando et al. 2008; Osei and Bakker, 2008). Additionally, ongoing expenses such as software licenses, data storage, and regular upgrades are a financial burden. In Sri Lanka, where government agencies and local communities often operate with limited budgets, these high costs can severely limit the scale and sustainability of technological interventions.

Modern HWC mitigation technologies are mostly solutions that require regular maintenance to ensure continuous effectiveness. As an example, electronic fences and automated lighting systems have to be inspected regularly and repaired to prevent malfunctions to ensure their continuous operation. Drones and sensor-based monitoring systems need periodic calibration, battery replacements, and software updates. In rural or remote areas that are common HWC in Sri Lanka, access to spare parts, technical support, and consistent electricity supply is challenging. Without proper monitoring, maintenance, and updating, these systems can fail while reducing their effectiveness. (Fernando et al. 2008; Gunaratne and Premarathne, 2005; Osei and Bakker, 2008).

The successful application and operation of advanced HWC mitigation technologies depend heavily on the availability of specialized technical skills. Installing, configuring, operating, and analyzing technical advancements require expertise that is often not readily available among local communities or even within some government agencies. Training local individuals is possible, but it requires additional investment in capacity-building programs and ongoing support. In many cases, reliance on external experts or consultants is necessary, which further increases costs and may not be sustainable in the long term. Furthermore, the lack of technical skills can lead to improper use of equipment, misinterpretation of data, or failure to respond effectively to alerts, reducing the overall impact of these technologies (Fernando et al. 2008; Gunaratne and Premarathne, 2005).

5.2 Connectivity and infrastructure issues in rural areas

Most HWC mitigation technologies, such as early warning systems, real-time wildlife tracking, and mobile-based alert platforms, fundamentally work with cellular or internet connectivity. However, in Sri Lanka, rural areas and regions near forests often have limited or no network coverage, leading to communication failures that affect rapid information exchange. (Rathnayaka et al., 2020). For example, when elephants reach village areas, the failure to send real-time alerts due to poor network coverage can lead to missed opportunities for timely community response and increased risk of crop damage or human injury.

In addition to digital barriers, physical infrastructure challenges also affect the scenario. Many HWCs are happening in remote areas with poor road networks, unreliable electricity, and limited access to transport. These barriers make it difficult to establish and maintain equipment like electric fences, camera traps, and monitoring stations, particularly during the monsoon season. The lack of reliable infrastructure can increase the cost and complexity of applications such technologies by reducing the consistency and reliability of their performance. Operational delays in repairs can affect to increase of community vulnerability to wildlife attacks. (Athulathmudali et al., 2024; Köpke et al., 2023).

5.3 Resistance or lack of trust among local communities

Efforts that have been taken to address HWC through the introduction of modern technologies have often been met with resistance from rural communities. This mostly happens with the social and cultural context of village life in the country, where traditional methods like collective night watches and the use of firecrackers have been used by generations to ward off wildlife. When technological solutions are introduced by external organizations or government agencies without actively involving local stakeholders, these interventions are often seen as disconnected from everyday experiences or as threats to community independence (Fernando et al. 2008). The use of surveillance-based tools like camera traps and GPS collars can raise concerns about privacy and the potential for data misuse. In Sri Lanka, where issues related to land ownership and resource use are often sensitive, communities may fear that data collected for wildlife management could be used for purposes such as law enforcement or land acquisition, which can increase trust issues. These concerns are increased by the lack of transparency regarding how information is collected, stored, and used, particularly when local residents are not adequately guided or informed throughout the process.

5.4 Coordination between stakeholders

Effective coordination among stakeholders such as government bodies, non-governmental organizations (NGOs), local communities, and conservation groups is essential for mitigating HWC. However, this coordination has limitations within the country, with fragmented institutional roles and weak collaboration. Deficiency of a centralized data collection system also makes it difficult to track wildlife incidents or evaluate the success of interventions (Edirisooriya and Bandara, 2022; Handunnetti, 2019). Another major limitation is the insufficient involvement of local communities in planning and managing HWC solutions. Many conflict mitigation efforts are introduced without consulting residents, which can lead to mistrust or a lack of cooperation. In some cases, communities do not fully understand the technology or do not receive proper training, resulting in poor maintenance and eventual failure of these efforts. Involving communities from the beginning can improve their ownership and the long-term success of conflict mitigation strategies (World Bank, 2021).

In addition, challenges such as limited financial resources, lack of technical training, and weak policy enforcement restrict the effectiveness of stakeholder coordination. Short-term projects often fail to establish consistent relationships or sustainable systems. And there is no national framework specifically addressing HWC across different species and ecosystems. This policy gap leads to inconsistent practices and isolated actions among stakeholders. Addressing these issues requires stronger leadership, integrated planning, and policies that promote inclusive collaboration (Madhubhashini et al. 2024).

6. Future Opportunities and Recommendations

6.1 Integration of AI, remote sensing for tracking and data security

Addressing the increasing threat of HWC in Sri Lanka requires the use of advanced technologies like Artificial Intelligence (AI) and remote sensing. These tools can play an important role in monitoring wildlife movements, detecting environmental changes, and predicting conflict hotspots. For example, remote sensing and GIS techniques have been successfully used to map human-elephant conflict hotspots and land use changes, allowing for targeted intervention in high-risk areas (Gunawansa et al. 2024; Rathnayake et al. 2022). When connected with AI models, such data can support early warning systems that alert authorities and communities about potential wildlife attacks based on real-time environmental and behavioral patterns. AI has the potential to enhance early warning systems by analyzing complex environmental and behavioral data. AI-powered platforms such as Elemantra, which combines sensors, cameras, and automated alerts, have been developed to provide real-time detection of wildlife presence and send notifications to communities and wildlife officers. These systems also integrate predictive models that use machine learning algorithms to forecast the likelihood of animal movement into human settlements, allowing for pre-preparation (Bandara and Bandara, 2023). The integration of these technologies can reduce the need for reactive responses and instead promote strategic data-driven decision-making in conservation management. When these technologies become more commonly used, it is important to ensure data security and ethical management. The collection and use of sensitive location information, especially in rural areas, must be carried out carefully to prevent privacy and misuse (Parliament of Sri Lanka, 2022). Strong data protection measures like encryption, access controls, and secure data storage are essential to maintain trust and safeguard both human and wildlife interests.

6.2 Capacity building for local agencies and communities

Strengthening the capacity of local wildlife authorities and rural communities is a critical component in ensuring the successful application of modern technologies to mitigate HWC. Field officers of the Department of Wildlife Conservation, along with local government agents and community members, do not have adequate technical knowledge and resources to effectively use advanced tools. Training programs focusing on the operation, maintenance, and interpretation of data from these systems are essential to bridge this gap. As an example, in regions like the North Western and Uva Provinces, where human elephant conflict (HEC) is particularly high, equipping officers with skills for handling GPS data on elephant movement could significantly improve early warning and response mechanisms (Fernando et al. 2008).

Introducing user-friendly digital platforms such as the Spatial Monitoring and Reporting Tool (SMART) to wildlife offices in conflict-prone areas could improve patrol coverage and threat detection (Critchlow et al. 2017). While SMART has not yet been widely implemented across Sri Lanka, there could be potential advantages in enhancing data-driven management if integrated into the training curricula of field staff. Additionally, empowering communities through participatory approaches such as citizen reporting apps or community-based elephant monitoring programs can enhance base-level engagement. In areas like Hambantota and Monaragala, local communities have valuable traditional ecological knowledge that can complement technological interventions. Encouraging their active participation would build trust in wildlife conservation initiatives and contribute to the long-term sustainability of conflict mitigation strategies (Nyhus, 2016).

Furthermore, Sri Lanka would benefit from enhanced collaboration between the DWC, universities, NGOs such as the Centre for Conservation and Research (CCR), and private technology providers. Such collaborations can facilitate knowledge exchange and ensure that locally appropriate technologies are developed and tested. Allocating dedicated funding for continuous training, establishing district-level technical support centers, and integrating modern HWC mitigation technologies into national conservation and disaster preparedness plans would be more effective.

6.3 Need for cross-sector collaboration: conservationists, engineers, policymakers

With the collaboration among conservationists, engineers, and policymakers, each group brings a unique set of expertise with comprehensive and sustainable solutions. Conservationists have critical knowledge about wildlife behavior, habitat use, and ecological dynamics. Engineers contribute by designing and developing context-specific technological interventions that can enhance the effectiveness of advanced mitigation approaches. However, without the involvement of policymakers, these innovations cannot be implemented. They are responsible for creating legal frameworks, allocating budgets, and facilitating institutional partnerships to support the scaling up of pilot projects and promote data-driven decision-making (Bandara and Tisdell, 2003).

Efforts to reduce HWC within the country often face challenges because of poor coordination between government departments, research institutions, and local authorities. This lack of connection leads to duplicated efforts, delays in project approvals, and poor long-term results. Creating formal systems for cross-sector communication can strengthen collaboration, clarify roles and responsibilities, and ensure that solutions are not only technically feasible but also environmentally sustainable and socially acceptable. For example, partnerships between the Department of Wildlife Conservation, the Ministry of Agriculture, state universities, and local councils can help identify region-specific priorities and integrate them into national conservation strategies (Gunawansa et al. 2023).

6.4 Policy and funding frameworks to support technology adoption

Although Sri Lanka has made progress by developing a national policy on HEC, the long-term success of this policy will depend on how well it encourages innovation and the use of modern technologies. The policy highlights the need to support scientific research that combines traditional knowledge with community, environmentally sustainable, and modern technologies tailored to specific species and locations (Dela et al. 2018). One important opportunity is to create a dedicated funding system to support the particular research, especially in advanced technologies. The policy also highlights the importance of community-based research to understand the social and environmental factors behind HWC, such as land-use changes and animal movement patterns, to support flexible and informed management strategies (Dela et al. 2018). In addition, the regular monitoring and reassessment of conflict mitigation tools are recommended to ensure they remain effective under changing environmental and social conditions (Barua et al. 2013).

To make success on these efforts, the Sri Lankan government could set up a coordination mechanism involving multiple ministries under the Ministry of Environment, along with a national innovation fund dedicated to HWC solutions. Including these strategies in broader land use policies and environmental impact assessment processes would help to identify the most effective technologies. International collaboration, involvement of the private sector, and support for innovation at the community level can further help the adoption of these technologies. When guided by national policy and supported by coordinated funding, these actions can help uplift the approach to HWC mitigation from an effective, technology-driven model that protects both biodiversity and rural communities (Nyhus, 2016).

7. Conclusion

Since both human actions and climate change are causing more problems between people and wild animals in Sri Lanka, creative and fast solutions are needed to support long-term coexistence. Even though technologies such as IoT, AI, and big data analytics have promising results in HWC control, their maximum potential remains unreached. So far, the use of these technologies has made major progress in monitoring and tracking animals, early warning, and preventing conflicts, mainly to manage the HEC in Sri Lanka. GPS collars, drones, wireless sensor networks, programs that use AI, and mobile applications help to monitor situations in real time, respond faster, and use the results of those observations for decision-making purposes. The use of electric fencing together with local communities in Sri Lanka, as well as the 'Tusker Alert' and 'Gaja-Mithuru' Monitoring systems, proves the benefits of mixing modern technology and local participation.

Even with these positive changes in technology, people find it hard to accept renewable technologies because of the high price, upkeep requirements, and the lack of trained professionals. Poor access to the internet and basic services in rural areas, while facing community distrust because of little involvement, also causes big difficulties. In addition, there is not enough coordination among authorities, which stops HWC mitigation from being effective. Next, a plan should be put in place using both AI and remote sensing to improve tracking and security of data, while focusing on increasing the abilities of local agencies and residents. Teamwork among people working in conservation, engineering, and policymaking areas is required to create sustainable, environmentally appropriate solutions, which are also supported by strong and plentiful resources for these sectors. The success of HWC management in Sri Lanka depends on the use of cutting-edge technology together with the involvement of local communities, their ownership, and the continuous help from organizations.

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Conflict of Interest

The authors have declared that no competing interests exist.

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Chapter 16

Climate Change and Emerging Human–Wildlife Conflicts in South Asia and Sri Lanka: Challenges, Implications and Pathways for Climate-Resilient Coexistence

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Abstract: Human–wildlife conflict (HWC) is increasingly recognized as one of the most complex socio-ecological challenges of the Anthropocene, with climate change emerging as a critical risk multiplier that intensifies interactions between people and wildlife. Across South Asia, rising temperatures, altered precipitation regimes, increasing climatic variability, and more frequent extreme weather events are reshaping ecosystem processes, wildlife behaviour, habitat suitability, and resource availability, thereby exacerbating conflict within densely populated and climate-sensitive landscapes. Despite growing recognition of these interactions, climate change has rarely been incorporated explicitly into HWC research, policy, or management frameworks.

This chapter synthesizes current knowledge on the climate–HWC nexus, with particular emphasis on South Asia and Sri Lanka, a global biodiversity hotspot where high human population density, fragmented habitats, and climate vulnerability converge. It examines the ecological mechanisms linking climate change with wildlife movement and behavioural adaptation, evaluates the socio-economic consequences for food security, rural livelihoods, biodiversity conservation, ecosystem resilience, and One Health, and analyses emerging conflicts involving elephants, primates, peafowl, wild boar, and other adaptable wildlife species. The chapter further explores how

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climate change interacts with land-use transformation, governance, and human vulnerability to create increasingly complex and dynamic conflict systems.

Moving beyond conventional conflict mitigation, the chapter proposes an integrated framework for climate-resilient coexistence that combines landscape-scale conservation, ecosystem restoration, climate-smart agriculture, adaptive governance, technological innovation, community participation, and One Health approaches. It also highlights the importance of incorporating Sri Lanka's long-standing cultural compassion towards wildlife into future coexistence strategies while strengthening wildlife health management and disease surveillance. Finally, priority research and policy directions are identified to support evidence-based adaptation, biodiversity conservation, and sustainable development in an increasingly uncertain climate.

Keywords: Biodiversity conservation, Climate change, Climate-resilient coexistence, Human–wildlife conflict, One Health

1. Introduction

1.1 Human–wildlife conflict in the anthropocene

Human–wildlife conflict (HWC) has become one of the most pressing environmental and development challenges of the twenty-first century. Defined broadly as interactions between humans and wildlife that result in adverse impacts on people, wildlife, or both, HWC encompasses a diverse range of outcomes including crop damage, livestock depredation, property destruction, threats to human life and safety, transmission Both zoonotic and diseases within a given species: e.g: reservoirs for dengue, chikungunya, and retaliatory killing of wildlife (Nyhus, 2016; Pooley et al., 2021). Monkeys, as evolutionarily close relatives of humans among the non-human primates, possess advanced cognitive abilities, behavioural flexibility, and strong social learning capacities that enable them to rapidly adapt to changes in their environment. These traits allow them to quickly habituate to human activities and to learn, individually and socially, how to overcome commonly used deterrent measures such as guarding, chasing, fencing, noise-making devices, and other crop-protection strategies (Dittus et al., 2019; Jayarathne et al., 2024). Although interactions between people and wildlife have existed throughout human history, the scale, frequency, and complexity of these conflicts have increased substantially during the Anthropocene, an era characterized by unprecedented human influence on ecological systems (Steffen et al., 2015).

Rapid human population growth, speculated expansion in animal populations, agricultural intensification, urban expansion, infrastructure development, and increasing demand for natural resources have transformed landscapes across much of the globe (Foley et al., 2011; IPBES, 2019). These processes have reduced and fragmented wildlife habitats while simultaneously increasing spatial overlap between wildlife populations and human settlements (Haddad et al., 2015). As a result, many wildlife species increasingly depend on human-modified environments (e.g. trees outside forests) for food, water, and movement, thereby creating conditions that favour conflict (Gross et al., 2021). Simultaneously, rural communities remain heavily dependent on natural resources and climate-sensitive agricultural systems, increasing their exposure to wildlife-related losses and environmental risks (FAO, 2023).

Historically, research and management efforts have largely focused on direct drivers of conflict such as habitat loss, land-use change, and demographic pressures (Nyhus, 2016). However, growing evidence indicates that climate change is emerging as an additional and increasingly influential driver that interacts with existing stressors to reshape human–wildlife relationships (Pecl et al., 2017; IPCC, 2023). Understanding this interaction is essential for developing effective conservation for animals in conflicts and and development of human-related strategies under future environmental conditions.

1.2 Climate change as a risk multiplier of human–wildlife conflict

Climate change is increasingly recognized as one of the most significant threats to biodiversity, ecosystem functioning, and human well-being during the twenty-first century (IPCC, 2023; IPBES, 2024). According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), climate change affects ecological and social systems simultaneously through rising temperatures, altered precipitation regimes, increasing climatic variability, and more frequent extreme weather events (IPCC, 2023). These changes influence ecosystem productivity, hydrological processes, habitat quality & species distributions for both plants and animaks, and the availability of critical resources (Pörtner et al., 2022).

Unlike traditional drivers of HWC, climate change operates across broad spatial and temporal scales and affects both wildlife populations and human communities concurrently (Pecl et al., 2017; Lenoir and Svenning, 2015). Wildlife species respond to environmental change through behavioural adaptation, altered movement patterns, shifts in habitat use, and redistribution across landscapes (Pecl et al., 2017). Human communities, particularly those dependent on agriculture and natural resources, experience declining livelihood security, increasing exposure to climatic extremes, and heightened resource competition (IPCC, 2023). The convergence of these ecological and social responses creates new pathways through which HWC emerges and intensifies (Abrahms et al., 2023).

Consequently, climate change is increasingly viewed as a threat modifier rather than an isolated driver of conflict. It interacts with habitat fragmentation, natural food source depletion, agricultural expansion, demographic change, and governance challenges to amplify existing vulnerabilities and create novel conflict dynamics (IPBES, 2024). This perspective highlights the need to understand HWC within broader socio-ecological contexts rather than as a purely wildlife-management issue (Pooley et al., 2021).

1.3 South Asia and Sri Lanka as climate-sensitive socio-ecological systems

South Asia represents one of the world's most important regions for understanding climate-sensitive HWC. The region supports nearly one-quarter of the global population and encompasses globally significant biodiversity hotspots, including the Himalayas, Indo-Burma, and Western Ghats–Sri Lanka landscapes (Myers et al., 2000) highlighting the close coexistence of dense human populations and exceptional biological diversity. Thus, human populations, agricultural systems, and wildlife frequently coexist within highly fragmented and resource-constrained environments, creating conditions particularly conducive to conflict.

Climate change is expected to affect South Asia disproportionately (IPCC, 2023). Rising temperatures, changing monsoon dynamics, prolonged droughts, glacier retreat, floods, and increasing frequency of extreme weather events are already influencing ecological processes throughout the region (Shrestha et al., 2021). These changes affect a wide range of wildlife, including elephants, large carnivores, primates, birds, and agricultural pest species. During periods of environmental stress and resource scarcity, many of these species are increasingly compelled to exploit human-modified landscapes in search of food, water, and shelter, thereby intensifying HWC.

Sri Lanka provides a particularly valuable case study within this regional context. Despite its relatively small geographic extent, the country possesses exceptional biodiversity and endemism while supporting one of the highest human population densities in South Asia (Ministry of Environment, 2021). A substantial proportion of wildlife populations occur outside protected areas, sharing landscapes with agriculture, irrigation systems, transportation networks, and rural settlements (Fernando et al., 2019; Rathnayake et al., 2022). Consequently, interactions between wildlife and people are unavoidable, widespread and often intense.

The Human-Elephant Conflict (HEC) remains the most prominent and costly form of HWC in Sri Lanka, resulting in significant human casualties, elephant mortality, crop losses, property damages economic hardships (and several social issues especially for women (Fernando et al., 2019; Köpke et al., 2024). Simultaneously, emerging conflicts involving toque macaques, peafowl, wild boar, porcupines, and other adaptable species are becoming increasingly important. These trends make Sri Lanka an ideal model system for understanding how climate change interacts with ecological, social, and institutional factors to influence conflict dynamics. Erecting electric fences when there was no proper knowledge on elephant corridors, now only we know we have done the wrong thing in wrong placeExperience has demonstrated that erecting electric fences without adequate knowledge of elephant ranging behaviour and movement corridors often results in fences being placed in ecologically inappropriate locations. Contemporary research therefore advocates landscape-level planning based on elephant movement ecology and corridor mapping, rather than relying solely on barrier-based interventions (Samaranayake et al., 2023).

Traditional Kandyan forest homegardens in Sri Lanka, characterized by their multi-strata structure and year-round production of fruits, spices, and other edible plant resources, provide continuous food and shelter for wildlife. Consequently, these homegardens attract a range of animal species, including toque macaques (*Macaca sinica*), purple-faced langurs (*Semnopithecus vetulus*), etc., and numerous bird species, thereby increasing opportunities for HWCs and conflict in the Kandy region (Pushpakumara et al., 2012).

1.4 Objectives and structure of the chapter

This chapter examines the growing influence of climate change on HWC in South Asia, with particular emphasis on Sri Lanka. The chapter develops with an integrated socio-ecological perspective that recognizes conflict as the outcome of dynamic interactions among climate drivers, ecological processes, wildlife responses, human vulnerability, governance systems, and development trajectories.

Specifically, the chapter aims to: (i) examine the ecological mechanisms through which climate change influences human–wildlife interactions; (ii) analyse regional and national patterns of climate-sensitive conflict; (iii) evaluate implications for food security, livelihoods, biodiversity conservation, and sustainable development; (iv) assess adaptation and coexistence strategies capable of reducing future conflict risks; and (v) identify emerging research and policy priorities. Through this synthesis, the chapter seeks to provide a comprehensive framework for understanding and managing HWC under increasingly uncertain climatic conditions while contributing to broader discussions on climate resilience, biodiversity conservation, and sustainable development while assuring food security.

2. Conceptual Framework for Climate-Sensitive Human–Wildlife Conflict

2.1 Human–wildlife conflict as a coupled socio-ecological system

HWC is increasingly recognized as a complex socio-ecological phenomenon Traditional approaches frequently viewed conflict as a wildlife-management issue resulting from direct encounters between humans and animals. Contemporary research, however, demonstrates that conflict emerges from dynamic interactions among ecological, social, economic, institutional, and political factors operating across multiple spatial and temporal scales (Ostrom, 2009; Nyhus, 2016; Pooley et al., 2021).

The socio-ecological systems (SES) framework provides a valuable conceptual lens for understanding these interactions. The SESs comprise interconnected ecological and social subsystems linked through feedback mechanisms, adaptive responses, and reciprocal dependencies. Wildlife populations, ecosystems, natural resources, agricultural landscapes, rural communities, institutions, and policy systems are viewed as components of an integrated and adaptive system. Changes occurring within one component inevitably influence the behaviour and functioning of others, often generating cascading consequences and emergent outcomes.

Climate change introduces an additional layer of complexity because it simultaneously affects both ecological and social subsystems. Consequently, climate-sensitive HWC cannot be understood solely through ecological drivers such as habitat loss or wildlife abundance. Rather, HWC emerges through interactions among climate variability, ecosystem responses, wildlife adaptation, human vulnerability, institutional capacity, and crop-animal development trajectories.

2.2 Climate change as a threat multiplier

Climate change is increasingly recognized as a major driver of ecological transformation and human vulnerability during the twenty-first century (IPCC, 2023). Rising temperatures, altered precipitation patterns, increasing climatic variability, and more frequent extreme weather events affect ecological systems, wildlife and human societies simultaneously. Climate change therefore amplifies existing drivers of conflict including habitat fragmentation, agricultural (crops and animals) expansion, demographic pressures, and governance challenges.

Recent IPBES assessments further emphasize that biodiversity loss, food insecurity, water scarcity, health risks, and climate change are interconnected components of a broader socio-ecological nexus that cannot be addressed independently (IPBES, 2024). Within HWC systems, wildlife populations experience changing habitat suitability, altered resource availability, and increasing environmental stress, while human communities face declining food security and livelihood security,y and increasing exposure to climatic hazards. The convergence of these responses creates conditions that favour increased competition for resources, greater spatial overlap, and escalating HWC.

2.3 Ecological pathways linking climate change and conflict

Several ecological mechanisms explain how climate change influences HWC. Resource scarcity represents one of the most important pathways. Changes in rainfall patterns, drought frequency, and hydrological regimes modifying water availability and vegetation productivity within natural habitats. Wildlife populations often respond to resource scarcity by expanding their movements and exploiting alternative food and water sources, many of which occur within agricultural landscapes and human settlements, leading to heightened incidences of crop raiding and livestock predation.

Climate change also affects ecosystem quality and productivity, species interactions, and trophic dynamics. Altered flowering, fruiting, and vegetation growth cycles influence food availability for herbivores, frugivores, and omnivores, while cascading effects propagate through food webs. Generalist species capable of exploiting diverse resources frequently adapt more successfully than species with narrow ecological niches and increasingly utilize anthropogenic food sources. Behavioural plasticity, species redistribution, and altered habitat use therefore emerge as key pathways through which climate change reshapes conflict dynamics across landscapes.

2.4 Vulnerability, resilience and adaptive capacity

Vulnerability and resilience are central concepts for understanding climate-sensitive HWC. Vulnerability refers to the degree to which ecological or social systems are susceptible to harm from environmental disturbances, whereas resilience describes their capacity to absorb change, adapt, and/or maintain essential functions under stress (Folke et al., 2016; IPCC, 2023).

Wildlife populations become vulnerable when habitat quality declines, ecological connectivity is disrupted, or critical resources become increasingly scarce. Similarly, human communities become vulnerable when livelihoods depend heavily on climate-sensitive sectors such as agriculture, forestry, fisheries, and water resources. Conflict frequently emerges where vulnerable wildlife populations and vulnerable human communities compete for increasingly limited resources.

Climate change intensifies vulnerability on both sides of the conflict equation. For example, prolonged droughts simultaneously reduce forage availability for wildlife and agricultural productivity for farmers. Under such circumstances, competition for food, water, and space increases substantially, creating conditions conducive to conflict escalation. Consequently, climate-sensitive HWC represents a manifestation of coupled vulnerabilities within socio-ecological systems rather than isolated ecological or social challenges.

Resilience-based approaches seek to strengthen the capacity of both ecological and social systems to cope with environmental change. Ecological resilience can be enhanced through habitat restoration, ecological connectivity, biodiversity conservation, and ecosystem-based adaptation. Social resilience can be strengthened through livelihood diversification, climate-smart agriculture, adaptive governance, social protection mechanisms, and participatory planning processes (IPBES, 2024).

2.5 Governance, feedbacks and conflict dynamics

Conflict outcomes are influenced not only by ecological processes but also by governance systems, institutions, policies, and social perceptions. Human responses to wildlife interactions influence ecological conditions, and the resulting changes in turn, affect human behaviour, creating feedback loops that shape future dynamics of HWC (Ostrom, 2009).

Repeated crop damage and livestock predation, for example, may alter land-use decisions, attitudes toward conservation, and support for wildlife protection and often lead to retaliatory killing of wildlife. Conversely, conservation interventions may modify wildlife behaviour, habitat use, and the movement patterns of most of the animals. These reciprocal interactions highlight the importance of adaptive governance systems capable of responding to changing ecological and social conditions. Adaptive governance emphasizes flexibility, stakeholder participation, collaboration, learning, and responsiveness to uncertainty (Folke et al., 2016). Such approaches are particularly important under climate change because future environmental conditions and conflict dynamics remain inherently unpredictable. Effective governance systems facilitate information exchange, support collective action, strengthen institutional learning, and improve the capacity of communities and conservation agencies to respond to emerging challenges.

2.6 An Integrated framework for climate-resilient coexistence

The climate-sensitive HWC emerges through interactions among climate drivers, ecological responses, wildlife adaptation, human vulnerability, and governance systems. These interactions operate through multiple pathways and feedback mechanisms that vary across spatial and temporal scales.

An integrated conceptual framework therefore views climate change as an external driver influencing ecological processes, wildlife behaviour, resource availability, and human well-being. Wildlife populations and human communities respond through varying adaptation strategies. Feedbacks among these responses ultimately determine conflict outcomes and coexistence trajectories.

This framework reinforces the need to move beyond species-focused interventions toward integrated approaches that simultaneously address biodiversity conservation, climate adaptation, food security, and sustainable development. Climate-resilient coexistence should therefore, be understood not as the elimination of conflict, but as the capacity of socio-ecological systems to manage interactions between people and wildlife while maintaining ecological integrity, human well-being, and adaptive capacity under changing environmental conditions.The overall conceptual framework is illustrated in Figure 1.

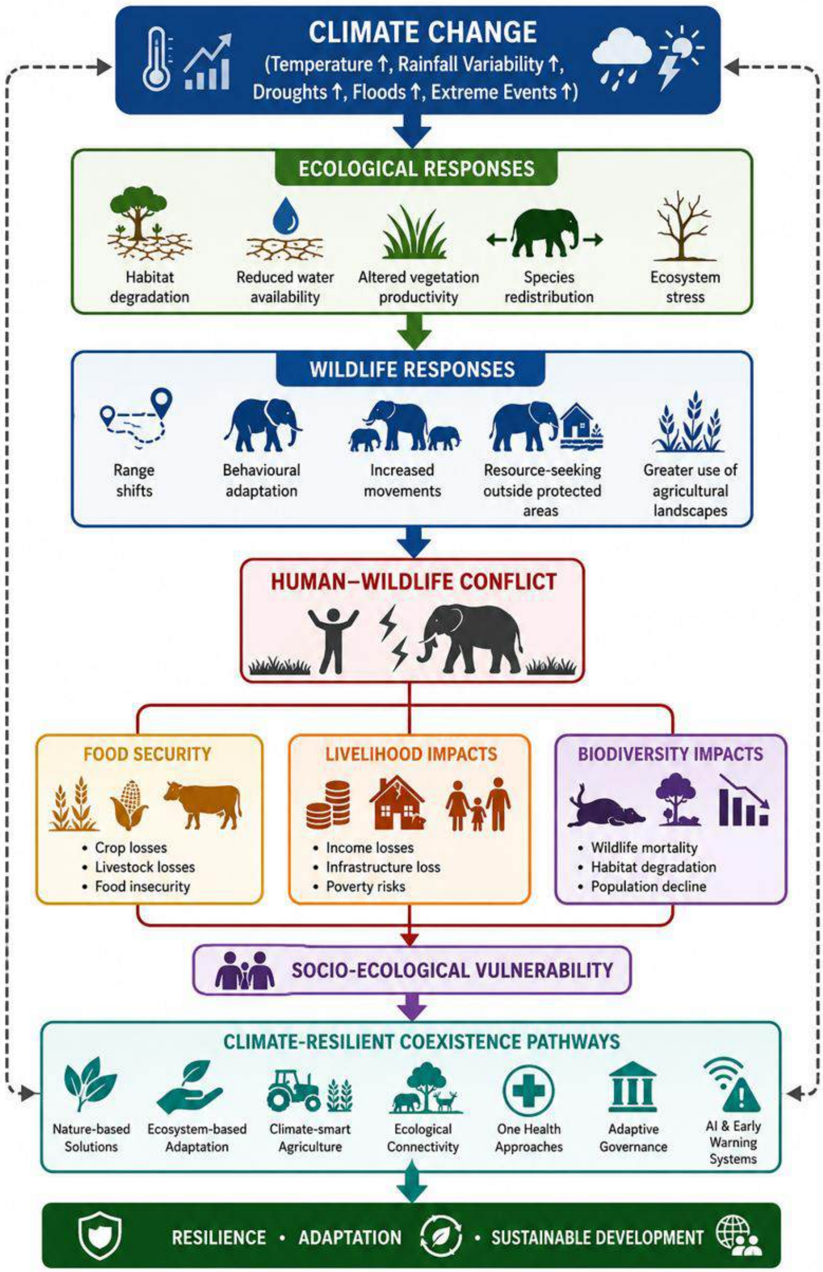

Fig 1. Conceptual framework illustrating the pathways through which climate change influences human–wildlife conflict and the feedback mechanisms affecting climate-resilient coexistence (Figure generated through AI assistance)

3. Climate Change and Human–Wildlife Conflict in South Asia

3.1 South Asia as a global hotspot of climate-sensitive human–wildlife conflict

South Asia represents one of the world's most complex socio-ecological landscapes, characterized by exceptionally high human population densities, globally significant biodiversity, climate-sensitive economies, and rapidly changing land-use systems. This coexistence of dense human populations and rich biodiversity creates conditions that favour frequent interactions between people and wildlife. The vulnerability of South Asia to climate change further amplifies these interactions. The Intergovernmental Panel on Climate Change identifies South Asia as one of the most climate-sensitive regions globally, facing increasing temperatures, altered monsoon patterns, glacier retreat, sea-level rise, prolonged droughts, and more frequent extreme weather events (IPCC, 2023). These climatic changes are altering ecosystem productivity, hydrological processes, habitat suitability, and species distributions, thereby influencing wildlife behaviour and spatial dynamics. At the same time, millions of rural households remain heavily dependent on agriculture, forestry, fisheries, and ecosystem services for their livelihoods, creating overlapping vulnerabilities within coupled socio-ecological systems (Pörtner et al., 2022).

Climate change therefore intensifies existing drivers of HWC, including habitat fragmentation, agricultural expansion, infrastructure development, and socio-economic inequalities (IPBES, 2024). HWC in South Asia has consequently become not only a conservation challenge but also a significant issue for food security, climate adaptation, rural development, and sustainable development. Table 1 presents the climate change drivers, ecological responses, conflict outcomes, and adaptation options available for people relevant to climate-sensitive HWC in South Asia and Sri Lanka.

3.2 Climate change, ecological transformation and conflict pathways

The influence of climate change on HWC operates through interconnected ecological pathways. Rising temperatures and changing precipitation regimes influence vegetation productivity, water availability, species interactions, and ecosystem functioning. These changes affect wildlife populations directly through altered habitat suitability ~~and~~ resource availability and indirectly through modifications of ecological communities and trophic interactions (Pecl et al., 2017; Lenoir and Svenning, 2015). Resource scarcity represents one of the most important mechanisms linking climate change and HWC. Droughts, changing rainfall patterns, and declining water availability reduce food and water resources within natural habitats which, in turn, result wildlife populations to expand their movements into agricultural landscapes, reservoirs, irrigation systems, and human settlements where resources remain relatively abundant (Abrahms et

Table 1. Synthesis of major climate change drivers, ecological responses, conflict outcomes, and adaptation options relevant to climate-sensitive human–wildlife conflict in South Asia and Sri Lanka.

Climate Driver	**Ecological Response**	**Wildlife Response**	**Conflict Outcome**	**Adaptation Options**
Rising temperature	Reduced habitat suitability	Range shifts	New conflict hotspots	Climate-informed land-use planning
Prolonged drought	Water scarcity	Increased movement into agricultural areas	Crop raiding and resource competition	Water-source restoration, climate refugia
Rainfall variability	Reduced vegetation productivity	Expanded foraging ranges	Increased crop damage	Ecosystem restoration, habitat enrichment
Extreme weather events	Habitat disturbance	Temporary displacement	Human–wildlife encounters increase	Early warning systems, emergency response planning
Habitat fragmentation	Reduced connectivity	Restricted movement corridors	Increased conflict intensity	Wildlife corridors and ecological networks
Agricultural expansion	Resource concentration in farms	Attraction to crops	Chronic crop losses	Climate-smart agriculture and buffer crops
Urbanization	Habitat encroachment	Adaptation to anthropogenic resources	Urban wildlife conflicts	Integrated urban biodiversity planning
Climate-induced livelihood stress	Reduced adaptive capacity	Increased competition for resources	Socio-economic vulnerability	Livelihood diversification and social protection

el., 2023). Climate-induced habitat degradation and fragmentation further intensify these dynamics. Species attempting to track suitable environmental conditions increasingly encounter landscapes fragmented by agriculture, improved infrastructure, and urbanization. Restricted ecological connectivity limits adaptive movements of animals in HWC, and increases reliance on human-dominated landscapes as movement corridors and resource refuges. The interaction between climate change and habitat fragmentation is therefore emerging as a major driver of future conflict throughout South Asia (Haddad et al., 2015; IPBES, 2024).

3.3 Human–elephant conflict under climate change

Human–elephant conflict (HEC) remains the most widespread and economically significant form of human–wildlife conflict (HWC) across the 13 South and Southeast Asian countries that constitute the current range of the Asian elephant (*Elephas maximus*), causing substantial losses of human lives, livelihoods, crops, property, and elephants while posing one of the greatest threats to the long-term conservation of the species (Shaffer et al., 2019; Fernando & Pastorini, 2023).

The Asian elephants require extensive home ranges, e.g. In Sri Lanka, typical home ranges range from approximately 50 to 150 km², while adult males may expand their ranges considerably during the musth period in search of receptive females (Fernando et al., 2008), and substantial quantities of food and water, making them particularly sensitive even to minor environmental change. Across India, Sri Lanka, Nepal, Bangladesh, and Bhutan, elephant habitats increasingly overlap with agricultural landscapes and human settlements, creating persistent conflict situations (Fernando et al., 2012; Goswami et al., 2014).

Climate variability strongly influences elephant ecology. Prolonged droughts, declining forage availability, and reduced access to water frequently trigger long-distance movements, particularly along elephant corridoors, beyond protected areas. Agricultural landscapes often provide attractive alternatives because irrigated crops, reservoirs, canals, and managed vegetation remain productive during dry periods. Consequently, elephants increasingly utilize croplands and settlement areas during periods of environmental stress, leading to crop losses, property damage, human casualties, and elephant mortality (Köpke et al., 2024).

Recent studies indicate that climate change may further intensify HEC by increasing drought frequency, altering vegetation productivity, and modifying habitat suitability throughout elephant ranges (Abrahms et al., 2023). Simultaneously, agricultural expansion and infrastructure development continue to reduce opportunities for natural movement, thereby increasing HWC intensity and reducing coexistence opportunities.

3.4 Carnivore–human conflict in a changing climate

Large carnivores are also increasingly affected by climate-driven ecological change. Tigers (*Panthera tigris*), leopards (*Panthera pardus*), snow leopards (*Panthera uncia*), wolves (*Canis lupus*), and bears occupy ecosystems undergoing rapid environmental transformation (Johnson et al., 2023; Carter & Di Minin, 2024; Mitchell et al., 2024). Climate change influences prey abundance, vegetation structure, habitat connectivity, and disease dynamics, thereby affecting predator behaviour and distribution patterns (Ripple et al., 2023).

In Himalayan ecosystems, warming temperatures are shifting vegetation zones and altering prey distributions. Carnivores frequently respond by expanding their ranges or increasing dependence on livestock, leading to elevated HWC with pastoral communities. Such HWCs often result in retaliatory killings that threaten already vulnerable animal populations and undermine their conservation efforts (Aryal et al., 2022).

3.5 Primate conflicts and climate-induced resource dynamics

Primate-related conflicts have become increasingly important throughout South Asia. Species such as rhesus macaques (*Macaca mulatta*), bonnet macaques (*Macaca radiata*), Hanuman langurs (*Semnopithecus* spp.), and Sri Lanka's endemic toque macaque (*Macaca sinica*) increasingly exploit agricultural and urban environments (Sha et al., 2022), being intelligent adaptable primates.

Climate-induced changes in fruiting cycles, vegetation productivity, and habitat quality may reduce natural food availability and increase reliance on cultivated crops and anthropogenic food sources. As omnivores, many monkey species also exploit insects, bird eggs, and other small animals that are abundant in human-modified landscapes, making residential and agricultural areas reliable foraging habitats. Their remarkable behavioural flexibility, cognitive ability, and social learning enable them to rapidly adapt to human-dominated environments and overcome conventional deterrent measures, thereby intensifying human–monkey conflict (Estrada et al., 2017; Jayarathne et al., 2024; Ellwanger et al., 2026).

3.6 Emerging conflict species and novel ecological interactions

Emerging conflicts involving wild boar (*Sus scrofa*), peafowl (*Pavo cristatus*), porcupines (*Hystrix indica*), rodents, parrots, and other potential species are becoming increasingly important throughout South Asia. Many of these animal species possess broad dietary niches, high reproductive rates, and considerable ecological flexibility, characteristics that often confer advantages under environmental change and disturbance (Pecl et al., 2017). Climate change may therefore favour ecological generalists while increasing pressure on specialist species, potentially altering the composition of future conflict-causing wildlife communities.

3.7 Socio-economic consequences of climate-sensitive human–wildlife conflict

The impacts of HWC extend far beyond wildlife conservation and directly affect food security, livelihoods, public health, and social well-being. Agriculture remains the primary source of food and income for much of South Asia's rural population, making crop losses and livestock depredation particularly significant. Climate change compounds impacts on all of them by reducing agricultural productivity, increasing environmental uncertainty, and limiting adaptive capacity (FAO, 2023; IPCC, 2023).

Smallholder farmers, women, indigenous communities, and marginalized households are often disproportionately affected because they possess fewer financial and institutional resources limiting their capacities to absorb losses and recover from shocks. Consequently, climate-sensitive HWC contributes to poverty, food insecurity, social inequities, and reduced resilience within vulnerable communities (IPBES, 2024). Recent research increasingly highlights the cumulative nature of impact of climate change on these important methods of livelihood. Rural communities often experience concurrent losses arising from climatic variability and loss and damage to wildlife, creating reinforcing cycles of vulnerability that hinder sustainable development outcomes. These interconnected challenges underscore the need to address HWC within broader frameworks of predicted climate adaptation, rural development, and poverty alleviation.

3.8 Towards climate-resilient coexistence in South Asia

The growing influence of climate change on HWC necessitates a transition from reactive conflict management towards proactive coexistence strategies. Although interventions such as fencing, repellents, translocation, and compensation can reduce conflict under specific circumstances, they often fail to address the underlying ecological and socio-economic drivers of HWC. As climate change further alters habitat quality, resource availability, and species distributions, these stand-alone measures are likely to become less effective unless integrated within adaptive, landscape-scale management strategies (Carter and Linnell, 2016).

Climate-resilient coexistence requires integrated approaches that simultaneously address biodiversity conservation, climate adaptation, livelihood resilience, and sustainable development. Key priorities include maintaining ecological connectivity, restoring degraded ecosystems, promoting climate-smart agriculture, strengthening community participation, improving early warning systems, and enhancing adaptive governance. Nature-based Solutions (NbS) and Ecosystem-based Adaptation (EbA) approaches offer particular promise because they generate co-benefits for biodiversity conservation, climate resilience, and human well-being (IPBES, 2024; Seddon et al., 2021). Ultimately, successful coexistence will depend upon recognizing HWC as a manifestation of broader socio-ecological change rather than simply a wildlife-management problem. Climate-informed and interdisciplinary approaches will therefore be essential for sustaining both biodiversity and human well-being in an increasingly uncertain environmental future.

4. Sri Lanka as a Climate-Sensitive Human–Wildlife Conflict Hotspot

4.1 Sri Lanka as a model socio-ecological system

Sri Lanka provides one of the most compelling examples globally of the complex interactions among climate change, biodiversity conservation, agricultural development, and HWC. Despite occupying less than 0.03% of the Earth's terrestrial surface, the island harbours exceptionally high levels of biodiversity and endemism and forms part of the globally recognized Western Ghats–Sri Lanka Biodiversity Hotspot (Myers et al., 2000; Ministry of Environment, 2021). Simultaneously, Sri Lanka supports one of the highest human population densities in Asia, with much of its biodiversity occurring outside formally protected areas.

Unlike many wildlife-rich countries where protected areas contain substantial proportions of wildlife populations, a large proportion of Sri Lanka's elephants, primates, peafowl, wild boar, and other wildlife species inhabit multi-use landscapes shared with agriculture, irrigation infrastructure, settlements, transportation corridors, and industrial development (Fernando et al., 2019). Consequently, interactions between wildlife and people are widespread and often unavoidable.

Sri Lanka, recognized as one of the countries highly vulnerable to climate change, faces an additional layer of complexity in its existing socio-ecological systems. Observed increases in temperature, growing rainfall variability, prolonged droughts, extreme rainfall events, and shifting seasonal patterns are altering ecosystem productivity, hydrological processes, and wildlife resource availability across the island (Eriyagama et al., 2010; IPCC, 2023). These changes increasingly influence wildlife behaviour, distribution, and movement patterns, thereby intensifying conflict risks in many parts of the country.

4.2 Human–elephant conflict: the dominant conflict system

Consistent with the broader South Asian context, HEC is the most severe and economically significant form of HWC in Sri Lanka and is widely regarded as one of the nation's foremost conservation challenges. The Sri Lankan elephant (*Elephas maximus maximus*), an endemic subspecies of the Asian elephant, functions as a keystone species that shapes ecosystem structure and biodiversity through seed dispersal, vegetation modification, nutrient cycling, and habitat engineering (Campos-Arceiz and Blake, 2011).

Historically, elephants occupied most ecological zones of the island and moved seasonally in response to rainfall, water availability, and forage resources. However, more than a century of land-use transformation associated with plantation agriculture, irrigation development, settlement expansion, road construction, and urban growth has substantially reduced and fragmented elephant habitats (Fernando et al., 2012). As a result, elephant populations increasingly depend upon landscapes shared with farming communities.

Recent analyses indicate that Sri Lanka experiences among the highest rates of HEC globally, with annual human and elephant mortality continuing to increase despite decades of management interventions (Fernando et al., 2019; Köpke et al., 2024). Crop damage, property destruction, injuries, and fatalities impose significant social and economic burdens on rural communities, while retaliatory killing, electrocution, poisoning, train collisions, and explosive bait devices contribute substantially to elephant mortality. As per conservative assessment of the authors, about 400 elephants and about 100 humans annually loose lives due to HEC.

Recent evidence confirms the continuing escalation and spatial complexity of HEC in Sri Lanka. Rathnayake et al. (2022) reported that between 1991 and 2018, recorded human deaths, elephant deaths, human injuries, and property-damage reports associated with HEC increased substantially, indicating that conflict has intensified alongside land-cover change and expanding human use of elephant landscapes. More recent assessments further show that elephant mortality has remained exceptionally high, with 2023 and 2024 records indicating continuing pressure on both elephants and rural communities (Department of Wildlife Conservation, 2024; Köpke et al., 2024). These trends demonstrate that HEC in Sri Lanka is not simply a species-management issue but a landscape-level socio-ecological problem driven by habitat fragmentation, land-use transformation, climatic variability, and inadequate integration of wildlife needs into development planning.

4.3 Climate change and elephant ecology

Climate variability increasingly influences elephant ecology and conflict dynamics. Elephants require large quantities of water and forage to meet their metabolic demands and are therefore highly sensitive to changes in environmental conditions. Droughts reduce forage quality and quantity, lower water levels in natural wetlands and reservoirs, and increase nutritional stress within elephant populations (Abrahms et al., 2023).

During prolonged dry periods, elephants frequently expand their movements beyond protected areas in search of food and water. Agricultural systems often become attractive because irrigation infrastructure, village tanks, paddy fields, and perennial crops provide reliable resources even when surrounding natural habitats are degraded. Consequently, many HEC incidents increase during drought periods, particularly within the Dry Zone where climatic variability is greatest (Fernando et al., 2012; Rathnayake et al., 2022).

Climate projections suggest that increasing temperatures and greater rainfall variability will continue to alter habitat suitability and resource distribution within elephant ranges throughout the twenty-first century (IPCC, 2023). These changes are expected to increase the importance of landscape connectivity and climate-resilient habitat management for elephant conservation.

4.4 Emerging human–wildlife conflicts beyond elephants

Although human–elephant conflict (HEC) remains the most visible and economically significant form of human–wildlife conflict (HWC) in Sri Lanka, increasing evidence suggests that the country is experiencing a broader transition towards a multi-species conflict system involving a diverse range of wildlife taxa. Similar trends have been reported globally, where adaptable wildlife species increasingly exploit anthropogenic resources in fragmented landscapes, resulting in the emergence of more complex conflict systems that extend beyond traditional flagship species (Gross et al., 2021; Pooley et al., 2021; IPBES, 2024).

Among the 13 principal HWC species in Sri Lanka (Table 2) are the endemic toque macaque (*Macaca sinica*), Indian peafowl (*Pavo cristatus*), wild boar (*Sus scrofa*), porcupines (*Hystrix indica*), giant squirrels (*Ratufa macroura*), civets, monitor lizards, fruit bats, parrots, and several rodent species. Many of these animals possess ecological characteristics that favour persistence under rapidly changing environmental conditions, including broad dietary niches, behavioural flexibility, high reproductive rates, rapid learning capacity, and tolerance to human disturbance (Pecl et al., 2017; Nahallage et al., 2023).

Importantly, these species increasingly occupy landscapes outside formally protected areas. Home gardens, agroforestry systems, roadside vegetation, irrigation reservations, plantation landscapes, riparian buffers, urban green spaces, and religious premises collectively function as supplementary habitats, feeding grounds, and movement corridors. Such habitats provide year-round food and water resources that facilitate wildlife persistence within human-dominated environments. Consequently, conflicts are no longer confined to agricultural frontiers but are increasingly observed in peri-urban and urban settings, creating new management challenges and governance requirements (Gross et al., 2021; IPBES, 2024). The growing prominence of multiple conflict-causing species suggests that future HWC management in Sri Lanka must move beyond species-specific approaches and adopt integrated, landscape-scale strategies capable of addressing the ecological complexity and spatial heterogeneity of emerging conflict systems.

Table 2. The 13 principal HWC species in Sri Lanka.

Functional Category	No.	Common name	Scientific name	Principal conflict
Large mammals	1	Sri Lankan elephant	*Elephas maximus maximus*	Crop raiding, property damage, human fatalities
	2	Wild boar	*Sus scrofa*	Severe crop damage and soil disturbance
Primates	3	Toque macaque	*Macaca sinica*	Crop damage, food theft, property damage, zoonotic concerns
	4	Purple-faced langur	*Semnopithecus vetulus*	Crop and fruit damage (especially home gardens)
Birds	5	Indian peafowl	*Pavo cristatus*	Damage to paddy, maize, vegetables and horticultural crops
	6	Parrots (mainly parakeets)	*Psittacula* spp.	Grain and fruit crop damage
	7	Munias ("*Vee kurulla*")	*Lonchura* spp.	Rice and cereal crop damage
Small mammals	8	Indian crested porcupine	*Hystrix indica*	Root and tuber crop damage
	9	Giant squirrel	*Ratufa macroura*	Damage to fruits and plantation crops
	10	Civets (Palm civets)	*Paradoxurus* spp.	Fruit crop losses and poultry predation
	11	Rodents (rats and mice)	Family *Muridae*	Crop losses during cultivation and storage
Reptiles	12	Water monitor lizard	*Varanus salvator*	Poultry and fish predation
Flying mammals	13	Fruit bats (Flying foxes)	*Pteropus* spp.	Fruit crop damage; disease concerns

4.4 Toque macaques as a climate-adaptive generalist species

The endemic toque macaque represents one of the most striking examples of wildlife adaptation to rapidly changing socio-ecological environments in Sri Lanka. Historically associated with forest ecosystems, toque macaques now occupy a wide range of habitats, including agricultural landscapes, villages, temples, tourism destinations, urban centres, and residential settlements. Their success is largely attributable to exceptional behavioural plasticity, dietary flexibility, social learning capacity, and cognitive abilities that enable them to exploit diverse anthropogenic resources (Nahallage et al., 2023; Sha et al., 2022).

Climate change may further reinforce these adaptive tendencies. Changes in rainfall patterns, temperature regimes, vegetation productivity, fruiting phenology, and forest composition can influence the availability and distribution of natural food resources. Simultaneously, increasing climatic variability may alter predator–prey relationships and ecological interactions that historically contributed to regulating macaque populations. Under such conditions, cultivated crops, household food resources, urban waste streams, and tourism-associated feeding opportunities become increasingly attractive alternatives (Pecl et al., 2017; Abrahms et al., 2023).

Recent studies indicate that human–macaque conflict is becoming an increasingly important socio-economic issue in Sri Lanka. Jayarathne et al. (2025) demonstrated that macaque-related crop damage, property destruction, and food losses impose substantial economic costs on households and commercial farming enterprises, particularly in agricultural regions where macaque populations have expanded. In many locations, macaques have become highly habituated to human presence and capable of circumventing conventional deterrent measures through behavioural innovation and social transmission of learned behaviours.

The close evolutionary relationship between primates and humans also introduces important public-health considerations. Increased interactions between macaques and humans create opportunities for pathogen exchange, disease transmission, and other One Health concerns that may become increasingly significant under future climate scenarios (WHO, 2023; IPBES, 2024). Consequently, management strategies for macaques must extend beyond traditional conservation approaches and incorporate behavioural ecology, population management, public education, disease surveillance, and community engagement.

4.5 Peafowl, wild boar and other emerging conflict species

Peafowl and wild boar have emerged as major contributors to agricultural losses across many regions of Sri Lanka, illustrating how environmental change, habitat modification, and climate variability can reshape wildlife communities and conflict dynamics. Both species have demonstrated remarkable adaptability to human-modified landscapes and increasingly exploit agricultural systems as reliable sources of food and water.

Peafowl populations are now widespread throughout many agricultural landscapes. Their increasing abundance has been associated with habitat alteration, expansion of irrigation systems, improved access to water resources, reduced predation pressure, and increased availability of cultivated food resources (Dissanayake et al., 2021). Consequently, peafowl are increasingly implicated in damage to paddy, maize, pulses, vegetables, and horticultural crops, particularly during sensitive growth stages.

Wild boar represent one of the most destructive agricultural pests in Sri Lanka. Their omnivorous feeding behaviour, high reproductive capacity, adaptability to diverse habitats, and ability to exploit anthropogenic food sources contribute significantly to their success in disturbed environments. In addition to direct crop consumption, rooting activities damage soil structure, irrigation systems, bunds, and farm infrastructure. Climate-induced disturbances may further favour wild boar populations because ecological generalists often benefit disproportionately from changing environmental conditions and landscape disturbances (Pecl et al., 2017; Abrahms et al., 2023).

Emerging evidence indicates that giant squirrels, porcupines, fruit bats, parrots, munias (*Vee kurulla*) civets (*urulewa*), monitor lizards, and several rodent species are also contributing to increasing agricultural and livelihood losses throughout the country. Collectively, these species demonstrate that the future HWC landscape of Sri Lanka is likely to become more diverse, geographically widespread, and ecologically complex than the elephant-dominated systems that have historically dominated conservation discourse.

Population dynamics represent an important but often overlooked component of these emerging conflicts. Changes in habitat quality, food availability, predator abundance, reproductive success, and climatic conditions may allow some wildlife populations to increase beyond local ecological carrying capacities. Future management strategies will therefore require greater emphasis on population ecology, demographic monitoring, reproductive biology, and socially acceptable approaches to population regulation where scientifically justified (Massei and Cowan, 2014; IUCN SSC, 2023)

4.6 Emerging conflict hotspots under future climate scenarios

Climate projections consistently indicate increasing temperatures, greater rainfall variability, more frequent droughts, intensified extreme weather events, and increasing climatic uncertainty across Sri Lanka during the twenty-first century (IPCC, 2023). These changes are expected to influence ecosystem productivity, water availability, habitat suitability, wildlife distributions, and ecological interactions throughout the island.

Future conflict hotspots are likely to emerge where climate vulnerability, habitat fragmentation, intensive agricultural production, and expanding human settlements intersect. Dry-zone irrigation settlements, agricultural colonization areas, peri-urban growth corridors, and landscapes surrounding protected areas are expected to experience particularly elevated conflict risks. During periods of environmental stress, wildlife species seeking food, water, thermal refugia, and movement corridors may increasingly utilize agricultural lands, reservoirs, irrigation infrastructure, and urban environments.

Climate change may also alter wildlife movement patterns, migration behaviour, pathogen dynamics, and species interactions, creating novel ecological relationships and increasing the likelihood of conflict emergence in previously unaffected landscapes (Abrahms et al., 2023; WOAH, 2024). Species possessing behavioural flexibility, broad dietary preferences, rapid reproductive rates, and tolerance of human disturbance are likely to benefit most from these changing conditions. Consequently, ecological generalists may become increasingly dominant components of future conflict systems.

Recent advances in remote sensing, geographic information systems, artificial intelligence, species-distribution modelling, climate-risk assessments, and predictive ecological analytics provide important opportunities for anticipating future conflict hotspots before they emerge. Such proactive approaches can support climate-informed land-use planning, habitat restoration, ecological corridor protection, and targeted adaptation interventions aimed at reducing future conflict risks while supporting biodiversity conservation and sustainable development.

4.7 Towards climate-resilient and compassion-based human–wildlife coexistence in Sri Lanka

The growing influence of climate change necessitates a transition from reactive conflict management towards proactive coexistence strategies capable of strengthening resilience within both ecological and social systems. Historically, management interventions have focused primarily on mitigating individual conflict events through fencing, deterrents, translocation programmes, compensation mechanisms, and physical barriers. Although such approaches may provide localized benefits, they often fail to address the underlying ecological, climatic, demographic, and socio-economic drivers that generate conflict (Fernando et al., 2020; Pooley et al., 2021).

Climate-resilient coexistence requires integrated approaches that simultaneously strengthen biodiversity conservation, climate adaptation, food security, ecosystem restoration, livelihood resilience, and adaptive governance. Maintaining ecological connectivity, restoring degraded habitats, protecting climate refugia, promoting climate-smart agriculture, strengthening community participation, and improving institutional coordination should therefore become central components of future conflict-management strategies (IPBES, 2024; Seddon et al., 2021).

An important and often overlooked dimension of coexistence in Sri Lanka is the deep cultural compassion that many communities maintain towards wildlife. Even among individuals directly affected by crop losses, property damage, or other forms of conflict, there remains considerable reluctance to support lethal control of wildlife species. This societal characteristic reflects long-standing cultural, ethical, and religious traditions that shape human–wildlife relationships throughout the country. Such attitudes provide a valuable social foundation for conservation and offer opportunities to develop a uniquely Sri Lankan model of coexistence based on stewardship, tolerance, and shared responsibility.

However, increasing proximity between humans and wildlife also creates opportunities for disease transmission, pathogen spillover, reverse zoonoses, and other One Health challenges. Climate change may further influence these risks by altering wildlife distributions, host–pathogen interactions, vector ecology, and opportunities for cross-species transmission (WHO, 2023; IPBES, 2024; WOAH, 2024). Consequently, future coexistence frameworks must integrate biodiversity conservation, wildlife health, public health, disease surveillance, and ecosystem management within a unified One Health approach.

Ultimately, climate-resilient and compassion-based coexistence should not seek to eliminate interactions between people and wildlife. Rather, it should aim to manage these interactions in ways that maintain ecological integrity, safeguard human well-being, strengthen adaptive capacity, reduce conflict risks, and promote sustainable coexistence under increasingly uncertain environmental conditions.

5. Implications of Climate-Sensitive Human–Wildlife Conflict for Food Security, Rural Livelihoods and Biodiversity Conservation

5.1 Human–wildlife conflict at the climate–biodiversity–development nexus

Climate-sensitive HWC sits at the intersection of three of the most pressing challenges of the twenty-first century: climate change, biodiversity loss, and sustainable development. Recent global assessments emphasize that climate change, food security, ecosystem degradation, water security, and human well-being are deeply interconnected and must be addressed through integrated policy frameworks rather than sectoral approaches (IPCC, 2023;

IPBES, 2024). HWC represents a manifestation of these interconnections because it simultaneously affects ecological integrity, agricultural production, rural livelihoods, and conservation outcomes. Climate change amplifies these interactions by increasing ecological stress within wildlife habitats while reducing the adaptive capacity of communities dependent upon climate-sensitive resources. Consequently, HWC increasingly emerges as a socio-ecological challenge with implications extending far beyond wildlife management.

5.2 Food security under climate-sensitive human–wildlife conflict

Food security remains one of the most important dimensions-through which HWC affects human well-being. Crop raiding by elephants, primates, wild boar, peafowl, porcupines, and other wildlife species, and livestock predation by wild predators reduces food availability by damaging agricultural production systems. Such losses are particularly substantial for smallholder farmers who depend heavily on seasonal harvests for household consumption and income generation.

Climate change compounds these impacts by simultaneously reducing agricultural productivity through droughts, floods, heat stress, changing pest dynamics, and increasing climatic uncertainty (IPCC, 2023). Communities therefore often experience cumulative losses arising from both climatic extremes and wildlife damage. Such interactions can significantly increase household food insecurity and reduce resilience to future environmental shocks.

Recent studies increasingly suggest that climate-sensitive HWC should be viewed as an emerging food-systems challenge because it influences agricultural production, food distribution, economic access to food, and long-term livelihood sustainability simultaneously (IPBES, 2024).

5.3 Rural livelihoods, poverty and vulnerability

Agriculture remains the principal source of livelihood for hundreds of millions of people across South Asia. Wildlife-related losses therefore have implications extending far beyond immediate damage to agricultural produces. Households incur costs associated with guarding fields, repairing damaged infrastructure, replacing livestock, constructing barriers, and implementing deterrent and repellant measures. These direct and indirect costs can substantially reduce household income and increase economic vulnerability (Barua et al., 2013).

Climate change further amplifies livelihood risks by increasing environmental uncertainty and reducing agricultural reliability. Droughts, changing rainfall patterns, declining water availability, and extreme weather events reduce crop yields while simultaneously increasing wildlife incursions into productive landscapes. Such interactions create reinforcing cycles of vulnerability that may trap households in chronic poverty and reduce opportunities for livelihood diversification.

Smallholder farmers, landless labourers, indigenous communities, and marginalized groups are often disproportionately affected because they possess meagre financial resources and therefore, limited adaptive capacity. Consequently, climate-sensitive HWC increasingly represents both a conservation issue and a rural development challenge requiring integrated responses that address structural drivers of vulnerability.

5.4 Gender and social dimensions

The impacts of HWC are not distributed evenly within communities. Gender, age, socio-economic status, land ownership, and access to resources influence both exposure and adaptive capacity. Women frequently play central roles in food production, water collection, household nutrition, and natural resource management and therefore experience unique consequences associated with wildlife-related losses (FAO, 2023).

Climate change can further exacerbate these inequalities because women often possess less access to financial capital, technology, land ownership, and decision-making processes. Similarly, children, elderly persons, and socially marginalized groups frequently experience heightened vulnerability in conflict-prone landscapes. These social dimensions highlight the importance of inclusive and gender-responsive adaptation strategies.

5.5 Biodiversity conservation consequences

While HWC imposes substantial costs on people, it also presents major challenges for biodiversity conservation. Conflict-related mortality remains a significant threat to numerous wildlife species throughout South Asia. Retaliatory killings, poisoning, electrocution, snaring, shooting, and transport-related collisions contribute substantially to wildlife mortality and may compromise long-term population viability (Ripple et al., 2023).

Large mammals such as elephants, leopards, bears, and other long-lived species are particularly vulnerable because relatively small increases in mortality can have significant population-level consequences. Climate change further intensifies conservation risks by increasing environmental stress within wildlife habitats and reducing ecosystem resilience.

5.6 Ecosystem functions, ecosystem services and ecological resilience

Many wildlife species involved in conflict perform essential ecological functions that support ecosystem integrity and resilience. Elephants act as ecosystem keystones through seed dispersal, vegetation modification, nutrient cycling, and habitat creation (Campos-Arceiz and Blake, 2011). Primates contribute to seed dispersal and forest regeneration, while birds, bats, and insects support pollination and biological pest control. In addition, wildlife plays a fundamental role in maintaining the structure and functioning of food chains and food webs, thereby contributing to ecosystem stability and resilience. Different groups of wildlife occupy various trophic levels and regulate the flow of energy and nutrients within ecosystems (Lacher and Davidson, 2019).

Conflict-driven declines in wildlife populations may therefore produce cascading ecological consequences extending far beyond individual species. Loss of ecological functions can alter ecosystem processes, weaken ecosystem resilience, reduce biodiversity, and compromise the delivery of ecosystem services upon which human societies depend (IPBES, 2024).

5.7 Protected areas, connectivity and climate adaptation

Protected areas remain the foundation of biodiversity conservation throughout South Asia. However, climate change increasingly challenges their effectiveness because species distributions, habitat suitability, and ecological processes are becoming more dynamic (Pörtner et al., 2022).

Many wildlife populations require access to resources beyond protected-area boundaries, particularly under conditions of increasing climatic variability. Consequently, climate adaptation and biodiversity conservation increasingly depend upon maintaining ecological connectivity across broader landscapes (Haddad et al., 2015).

Wildlife corridors, ecological networks, climate refugia, and landscape-scale conservation initiatives can facilitate species movements while reducing conflict risks. Such approaches provide important opportunities for simultaneously supporting climate adaptation, biodiversity conservation, and sustainable development.

5.8 Human–wildlife conflict and sustainable development

Climate-sensitive HWC directly influences multiple Sustainable Development Goals (SDGs), including No Poverty (SDG 1), Zero Hunger (SDG 2), Gender Equality (SDG 5), Climate Action (SDG 13), and Life on Land (SDG 15). The multidimensional nature of conflict highlights the need to move beyond narrow wildlife-management perspectives and adopt integrated development approaches that address ecological, social, and economic dimensions simultaneously (UN, 2024).

6. Adaptation Pathways for Climate-Resilient Coexistence

6.1 From conflict management to climate-resilient coexistence

Conventional approaches to HWC management have historically focused on reducing immediate damages through interventions such as fencing and physical barriers, translocation, deterrents, compensation schemes. While these measures may reduce short-term impacts, they often fail to address the underlying ecological, social, and climatic drivers that generate conflict (Nyhus, 2016; Pooley et al., 2021).

Climate change is altering resource availability, wildlife distributions, ecosystem productivity, and human vulnerability simultaneously, creating increasingly dynamic conflict systems that cannot be addressed through static management interventions alone. Consequently, there is growing recognition that future strategies must shift from reactive conflict mitigation towards proactive coexistence approaches that enhance the resilience and adaptive capacity of both ecological and social systems.

6.2 Nature-based solutions and ecosystem-based adaptation

Nature-Based Solutions (NbS) have emerged as one of the most promising approaches for simultaneously addressing biodiversity conservation, climate adaptation, and sustainable development challenges (IUCN, 2020). Within HWC systems, NbS can reduce conflict risks by restoring ecosystem functions, enhancing habitat quality, increasing resource availability within wildlife habitats, and improving ecological connectivity.

Habitat restoration, watershed rehabilitation, reforestation, assisted natural regeneration, and corridor establishment can reduce the need for wildlife to depend on agricultural landscapes and human settlements for critical resources. Ecosystem-Based Adaptation (EbA) further strengthens resilience by utilizing biodiversity and ecosystem services to support adaptation to climate change (UNEP, 2022).

6.3 Climate-informed landscape planning and ecological connectivity

Landscape fragmentation remains one of the most important underlying drivers of HWC throughout South Asia. Climate change further intensifies fragmentation effects because species increasingly require access to larger and more connected landscapes to track suitable environmental conditions (Haddad et al., 2015).

Climate-informed landscape planning integrates biodiversity conservation, climate adaptation, agricultural production, and infrastructure development within broader socio-ecological systems. Ecological corridors, climate refugia, buffer zones, stepping-stone habitats, and multifunctional landscapes can facilitate wildlife movement while reducing conflict risks.

6.4 Climate-smart agriculture and livelihood resilience

Climate-smart agriculture (CSA) has emerged as a widely recognized framework for enhancing agricultural productivity, strengthening resilience, and reducing environmental impacts under changing climatic conditions (FAO, 2023). Within conflict-prone landscapes, CSA can contribute to coexistence by promoting crop diversification, drought-tolerant varieties, agroforestry systems, efficient irrigation technologies, and climate-resilient farming systems.

Alternative livelihood opportunities such as ecotourism, payments for ecosystem services, sustainable forest enterprises, and climate-resilient value chains can further reduce dependence on conflict-sensitive agricultural activities while enhancing community resilience.

6.5 Technological innovations and early warning systems

Technological innovation is increasingly transforming HWC management. Advances in satellite remote sensing, geographic information systems (GIS), artificial intelligence (AI), machine learning, GPS telemetry, camera-trap networks, unmanned aerial vehicles (UAVs), and mobile communication technologies provide unprecedented opportunities for monitoring wildlife movements and predicting conflict risks (Wall et al., 2023). Technology related biological measures in cumbersome wildlife population control provides another side of control (Massei and Cowan, 2014)

AI-assisted early warning systems can analyse environmental variables, wildlife movement data, climatic conditions, and historical conflict patterns to forecast potential conflict events. Such systems enable proactive interventions, allowing communities and wildlife managers to respond before conflicts occur. In elephant landscapes, GPS collars and real-time monitoring systems have already demonstrated considerable potential for reducing conflict risks by providing advance warnings of elephant movements. Similar technologies are increasingly being applied to carnivores, primates, and other conflict-prone species.

6.6 One health and integrated risk management

The One Health framework provides an increasingly important lens through which climate-sensitive human–wildlife conflict (HWC) can be understood and managed. One Health recognizes the interconnectedness of human health, animal health, and ecosystem health, emphasizing that environmental change, biodiversity loss, land-use transformation, and climate variability influence all three domains simultaneously (WHO, 2023). As climate change alters wildlife distributions, movement patterns, resource use, and interactions with human-dominated landscapes, the frequency and intensity of contact among wildlife, livestock, companion animals, and people are expected to increase.

Such interactions create opportunities not only for conflict but also for the emergence, transmission, and persistence of infectious diseases. Climate-induced shifts in temperature, precipitation regimes, and extreme weather events can influence pathogen survival, vector ecology, host susceptibility, and disease transmission pathways. Consequently, both zoonotic diseases transmitted from animals to humans and reverse zoonoses transmitted from humans to wildlife may become increasingly important within shared landscapes. The growing movement of wildlife into agricultural areas, peri-urban settlements, and urban environments further amplifies these risks.

In Sri Lanka and many parts of South Asia, communities often maintain close cultural and emotional relationships with wildlife, resulting in frequent direct and indirect interactions. While such attitudes contribute positively to coexistence, they may also increase exposure to disease transmission pathways if not supported by appropriate health and biosecurity measures. Future coexistence strategies should therefore integrate wildlife health surveillance, disease-risk assessment, veterinary interventions, ecosystem monitoring, and public-health preparedness within a unified One Health framework.

Integrating One Health principles into climate adaptation and biodiversity conservation planning can generate multiple co-benefits, including improved ecosystem resilience, reduced disease risks, strengthened wildlife conservation outcomes, enhanced food security, and greater societal resilience to future environmental change. Consequently, One Health should be considered a central pillar of climate-resilient coexistence strategies throughout South Asia.

6.7 Adaptive governance and community-based coexistence

Governance remains one of the most critical determinants of coexistence outcomes. Traditional command-and-control approaches often struggle to respond effectively to complex and rapidly changing socio-ecological conditions. Climate change introduces additional uncertainty, requiring governance systems capable of learning, adaptation, and collaboration (Folke et al., 2016).

Adaptive governance emphasizes flexibility, stakeholder participation, cross-sectoral coordination, knowledge sharing, and iterative learning. Community participation is particularly important because local communities often bear the greatest costs associated with wildlife conservation and possess valuable ecological knowledge that can improve management effectiveness (Pooley et al., 2021).

Compensation schemes, benefit-sharing mechanisms, participatory monitoring, community stewardship programmes, and collaborative landscape management can strengthen trust and improve long-term conservation outcomes.

6.8 Transformative adaptation for future coexistence

Incremental adaptation alone may be insufficient to address the scale of future climate and biodiversity challenges. Increasingly, global assessments advocate transformative adaptation that addresses underlying drivers of vulnerability and fundamentally reconfigures relationships among people, wildlife, and ecosystems (IPCC, 2023; IPBES, 2024).

Transformative adaptation may involve rethinking land-use systems, redesigning agricultural landscapes, restoring ecological connectivity, reforming governance structures, strengthening environmental education, and integrating biodiversity considerations into broader development planning. Such approaches recognize that long-term coexistence depends upon systemic changes that enhance resilience across entire socio-ecological systems.

7. Future Research Agenda for Climate-Sensitive Human–Wildlife Conflict

7.1 Emerging challenges in a rapidly changing world

HWC is entering a period of unprecedented complexity as climate change, biodiversity loss, land-use transformation, urbanization, and socio-economic change increasingly interact across multiple scales. Although significant advances have been made in understanding conflict dynamics, much of the existing knowledge remains fragmented across disciplines, geographic regions, and taxonomic groups.

Future research must therefore move beyond species-specific investigations and adopt integrated approaches capable of addressing the complex interactions among climate, ecosystems, wildlife, and human societies (IPCC, 2023; IPBES, 2024).

7.2 Understanding climate–conflict mechanisms and ecological responses

Future research should prioritize understanding how climate-induced changes in habitat quality, vegetation productivity, water availability, phenology, species interactions, and ecological connectivity influence wildlife populations, movement patterns and resource use.

Long-term ecological monitoring is essential for quantifying wildlife responses to environmental change, enabling the early detection of behavioural changes in individuals and subsequent demographic and distributional changes in populations that may increase the risk of human–wildlife conflict (Parmesan, 2006; Pecl et al., 2017; IPBES, 2023).

7.3 Climate scenario modelling and conflict forecasting

One of the most important research priorities is the development of predictive frameworks capable of forecasting future HWC under alternative climate scenarios. The application of Shared Socioeconomic Pathways (SSPs), species-distribution models, habitat suitability analyses, land-use change scenarios, and socio-economic indicators offers considerable potential for identifying future conflict hotspots and climate refugia (IPCC, 2023). Such approaches would provide valuable information for conservation planning, infrastructure development, agricultural policy, and climate adaptation strategies.

7.4 Harnessing emerging technologies for monitoring and decision support

Rapid technological advances are creating unprecedented opportunities for studying and managing HWC. Satellite remote sensing, AI, UAVs, GPS telemetry, camera traps, environmental DNA (eDNA), and automated acoustic monitoring systems are transforming ecological research and wildlife management (Wall et al., 2023). Future research should focus on integrating these technologies into comprehensive monitoring and early warning systems capable of supporting real-time decision-making.

7.5 Future research agenda

Future research should move beyond traditional assessments of wildlife abundance and conflict occurrence to investigate the mechanisms through which climate change influences wildlife population dynamics, behavioural adaptation, disease ecology, and socio-ecological resilience. Particular emphasis should be placed on long-term population monitoring of conflict-prone species, including elephants, macaques, peafowl, wild boar, giant squirrels, and other adaptable wildlife. Understanding demographic trends, reproductive ecology, carrying capacities, and threshold population levels will be essential for anticipating future conflict risks under changing environmental conditions.

The rapid emergence of wildlife-associated diseases highlights another critical research priority. Future studies should investigate how climate change influences pathogen evolution, host–pathogen interactions, vector distributions, wildlife health, and disease transmission among wildlife, livestock, companion animals, and humans. Integrating disease ecology within HWC research offers opportunities to operationalize One Health approaches and strengthen preparedness for emerging health risks.

Technological innovations are expected to play a transformative role in future conflict management. Advances in remote sensing, artificial intelligence, environmental DNA, camera-trap networks, GPS telemetry, drones, and citizen-science platforms offer unprecedented opportunities for monitoring wildlife populations and forecasting conflict events. Future research should focus on integrating these technologies into predictive decision-support systems capable of identifying emerging conflict hotspots and supporting proactive interventions.

Governance research should further examine adaptive and participatory approaches capable of responding to increasingly dynamic socio-ecological systems. Comparative studies evaluating compensation schemes, community stewardship programmes, incentive mechanisms, benefit-sharing arrangements, and policy instruments will be important for identifying socially acceptable and ecologically effective coexistence strategies. Special attention should be given to the role of local ecological knowledge, social perceptions, and cultural values in shaping coexistence outcomes.

Ultimately, future research should embrace interdisciplinary integration among climate science, ecology, conservation biology, public health, agricultural sciences, economics, behavioural sciences, and governance studies. Such integration will be essential for developing climate-resilient, socially inclusive, and scientifically robust coexistence frameworks capable of addressing the growing complexity of human–wildlife interactions in the Anthropocene.

8. Conclusions: towards climate-resilient human–wildlife coexistence

HWC is increasingly emerging as one of the most complex socio-ecological challenges of the Anthropocene, shaped by the convergence of biodiversity loss, climate change, land-use transformation, and human development pressures. The evidence synthesized throughout this chapter demonstrates that climate change functions as a powerful risk multiplier that amplifies existing vulnerabilities and creates new pathways for interaction between people and wildlife (IPCC, 2023; Pörtner et al., 2022).

The chapter has demonstrated that climate-sensitive HWC is best understood as a coupled socio-ecological phenomenon rather than a purely ecological or wildlife-management issue. Interactions among climate drivers, ecological processes, wildlife responses, human vulnerability, governance systems, and development trajectories create dynamic feedbacks that shape conflict outcomes across spatial and temporal scales (Ostrom, 2009; Folke et al., 2016).

South Asia provides a particularly important context for understanding these emerging dynamics. The region exemplifies the challenges associated with balancing biodiversity conservation, agricultural production, rural livelihoods, and economic development within rapidly changing environments. Sri Lanka, in particular, represents a globally significant case study where exceptional biodiversity, dense human populations, extensive wildlife use of multifunctional landscapes, and increasing climate vulnerability converge to create conditions under which HWC is likely to intensify.

The chapter further demonstrates that the consequences of climate-sensitive HWC extend beyond wildlife conservation and directly affect food security, rural livelihoods, ecosystem resilience, and sustainable development. Crop losses, livestock depredation, infrastructure damage, human injuries, and wildlife mortality create significant economic and social burdens, particularly for vulnerable rural communities. Simultaneously, conflict-related mortality threatens wildlife populations and may compromise ecosystem functions and services that support long-term ecological stability.

One of the most important conclusions arising from this synthesis is that conventional conflict-management approaches alone will be insufficient under future climate conditions. Climate-resilient coexistence requires integrated strategies that combine biodiversity conservation, climate adaptation, livelihood resilience, adaptive governance, technological innovation, and ecosystem restoration. Ultimately, climate-resilient coexistence should not be viewed as the elimination of conflict but rather as the capacity of socio-ecological systems to manage interactions between people and wildlife while maintaining ecological integrity, human well-being, and adaptive capacity. Achieving this goal will require transformative changes in how societies perceive, govern, and interact with nature.

An important but often overlooked dimension of HWC in Sri Lanka is the socio-cultural context within which it occurs. Despite increasing economic losses and safety risks associated with human–elephant and human–monkey conflicts, public attitudes are generally characterized by strong cultural, religious, and ethical values that promote compassion towards wildlife and favour coexistence over lethal control. However, the country's stringent wildlife protection legislation may discourage or limit public intervention to provide emergency assistance to injured or diseased wild animals without the involvement of the responsible authorities. This interaction between conservation ethics, legal constraints, and wildlife management has received limited scientific attention but may have important implications for animal welfare, disease surveillance, and the management of zoonotic diseases under increasing HWC. Future research should therefore integrate ecological, epidemiological, and social dimensions of HWC by incorporating robust estimates of wildlife population sizes, conflict intensity, disease prevalence, and pathogen transmission dynamics. Given the continuing evolution and host adaptation of infectious agents, a One Health framework that explicitly considers bidirectional pathogen transmission between humans, domestic animals, and wildlife is increasingly essential, particularly under climate change and expanding human–wildlife interfaces.

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Conflict of interest

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Chapter 17

A Roadmap for the Future - for an Effective Management of Human − Elephant Conflict in Sri Lanka

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Abstract: The Department of Wildlife Conservation (DWC), under the 1937 Fauna & Flora Protection Ordinance, manages Sri Lanka's network of wildlife Protected Areas (PAs) and protects wildlife outside these areas. Endangered wild elephants are found mainly in the dry zone lowlands and several provinces across the country. While many elephants live within DWC- and Forest Department-managed reserves, a significant number reside outside protected areas, increasing Human-Elephant Conflict (HEC). Comprehensive policies and actions are needed to, **a.** Create a unified portfolio of protected areas by combining all wild elephant habitats managed by DWC and FD under joint management, **b.** Identify and legally include all wild elephant habitats outside current protected areas to expand and connect the network scientifically, **c.** Manage and reduce Human-Elephant Conflict (HEC) while promoting coexistence through compensation, livelihood support, gender-inclusive measures, education, and awareness for affected communities, **d.** Ensure protected elephant habitats remain free from human interference and protect human settlements using practical measures like village and mobile electric fences to prevent HEC.

Comprehensive conservation and Human-Elephant Conflict (HEC) mitigation efforts benefit both wild elephants and local human communities by protecting wildlife and their shared habitats. While the Department of Wildlife Conservation (DWC) plays a major role in elephant conservation, some other agencies lack understanding and support, and DWC's institutional capacity needs strengthening to better manage current challenges. In this chapter, it is expected to evaluate the strategies and other efforts implemented by DWC and other relevant agencies for the management of HEC, in order to identify the way forward for a better achievement in conservation of wild elephants in Sri Lanka.

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1. Introduction

Sri Lanka, a tropical island with a favorable climate and mountainous central region, supports diverse biological resources year-round. It is recognized as one of the world's 36 Biodiversity Hotspots, indicating rich but highly threatened biodiversity. Historically, Sri Lankan kings protected forests and wildlife through regulations. Modern conservation efforts began in 1891 with the Forest Department's laws and were strengthened by the Fauna & Flora Protection Ordinance (FFPO) of 1937. Since 1938, a network of Wildlife Protected Areas (PAs) has been established and expanded, covering various habitats across the island, including marine zones. The Department of Wildlife Conservation (DWC), founded in 1949, manages these protected areas and wildlife protection under the FFPO. Sri Lanka is one of the world's 36 Biodiversity Hotspots, hosting rich but highly threatened species. The Department of Wildlife Conservation (DWC) enforces the Fauna & Flora Protection Ordinance (FFPO) to safeguard wildlife, particularly wild elephants. DWC's strategies to reduce Human-Elephant Conflict (HEC) include managing Protected Areas, legal protection outside reserves, HEC mitigation, veterinary care, and relocating problematic elephants.

More than 50 countries worldwide are home to the world's wild elephant, mainly in Africa and with just 13 in Asia (Perera, 2009; Wijesekera et al., 2021; World Wildlife Fund, 2022). There are estimates of 51,000 to 66,000 elephants in Asia, but only 35,000 to 50,000 live in their natural habitats (Nakandala et al., 2014). Asian elephants (*Elephas maximus)* are listed in the International Union for Conservation of Nature (IUCN) red data book as endangered species (IUCN, 2020). Sri Lanka is home to 10% of Asian elephants living in their natural habitat, accounting for around 2% of the global range of Asian elephants (Fernando et al., 2011; Perera, 2009). Asian elephants are classified into three sub-species: the Indian (*Elephas maximus indicus*), the Sumatran (*Elephas maximus sumatranus*), and the Sri Lankan (*Elephas maximus maximus)* (Animalia, 2022; Fleischer et al., 2001; Sukumar, 2006).

Currently, elephants live in five South Asian countries, and Sri Lanka holds the second-largest wild elephant population in South Asia alongside Bangladesh, Bhutan, India, and Nepal (Fernando and Pastorini, 2011). In Bangladesh, Bhutan, and Nepal, there are less than 500 wild elephants in the whole country (Fernando and Pastorini, 2011; Sukumar, 2006). According to the most recent estimate in 2017, mainland India has the largest population of Asian elephants, with 29,964 (Koshy, 2021; Montez, 2021). Sri Lanka has about 5,787 elephants, including 1,107 calves and 122 tuskers (World Wildlife Fund, 2019), according to the elephant census conducted in 2011. The Sri Lankan elephant, classified as Endangered due to habitat loss and HEC, had an estimated wild population of 5,787 in 2011, representing about 10%.

Dayaratne P.W.C (2025) states that the human elephant conflict has been reported in 19 districts and 131 Divisional Secretariats across Sri Lanka. In 2024, 386 elephants and 154 people died due to the Human–Elephant Conflict (HEC). This is a serious and growing crisis. More than 70% of estimated 5,500 to 6,000 wild elephant population in the country live outside the Protected Areas (PAs), covering 62% of Sri Lanka's land area. This overlap with human settlements fuels the ongoing conflict. Conservationists warn the problem is escalating, calling for a new, effective solution to mitigate the HEC. A main key factor often overlooked in mitigating HEC is the protection of traditional forest corridors used by elephants. Many such corridors have been encroached upon and blocked for either legal or illegal agricultural activities. During the 1980s, the Accelerated Mahaweli Development Program established large agricultural systems (H, B, and C) without preserving clear elephant habits and corridors elevating the HEC to a dangerous paradigm. Only the upper catchment areas of the reservoirs developed under this Project.

Gunawansa et al. (2023) states that the Human-elephant conflict (HEC) is a severe conservation, socio-economic and environmental issue of forests and ecosystems in elephant inhabiting countries, including Sri Lanka. Due to the rapid growth of human and elephant populations, both struggle to share limited land resources. The major causes and contexts of HEC in Sri Lanka include land use change, habitat loss due to human population growth, crop raiding behavior, problem elephants, and changes in agriculture practices. Since 2019, 125 people and 370 elephants have killed annually on average due to the conflict. Also, Sri Lanka has recorded the highest annual elephant deaths and second-highest human deaths due to HEC. The human death rate has increased by approximately 42% over previous three decades.

2. The Constitutional Obligation of Sri Lanka to Conserve Environment

Sri Lanka's constitutional commitment to environmental conservation is established mainly through two key provisions in the 1978 Constitution: Article 27(14) and Article 28(f). These articles make it the State's responsibility to "protect, preserve and improve the environment for the benefit of the community" and impose a fundamental duty on every individual to "protect nature and conserve its riches." These provisions act as guiding principles for State policy and individual duties, highlighting the importance of sustainable environmental management for present and future generations. Additionally, these constitutional mandates support Sri Lanka's legal and institutional environmental frameworks, including Environmental Impact Assessments (EIA) and public participation, strengthening efforts to safeguard natural resources and biodiversity. Overall, the constitution forms the basis for nationwide environmental protection, encompassing initiatives like elephant conservation, resolving human-elephant conflict (HEC), and promoting human-elephant coexistence (HECoEx).

3. Use Flagship Species for Conservation of Wildlife in Sri Lanka

Using flagship species for biodiversity conservation is an effective approach because these species act as symbols that attract public attention and raise awareness and funds for broader conservation efforts. Their popularity can influence policymakers and engage diverse audiences to support habitat and ecosystem protection. Many flagship species also serve as umbrella species, benefiting other species sharing their habitat. Research shows that well-selected flagship species can secure high biodiversity representation while efficiently directing conservation resources, demonstrating that this approach supports cost-effective biodiversity protection. Hence, it can help to direct resources efficiently. Thus, flagship species play a valuable role in mobilizing support and resources for conserving a wide range of biodiversity beyond just the species themselves.

A flagship species approach uses charismatic or well-known species to raise public awareness, stimulate engagement, and generate funding for conservation. This can increase local and broader interest in biodiversity and ecotourism. Flagship species conservation may indirectly protect broader habitats by focusing on species that require large or specific habitat types, providing umbrella effects for co-occurring species. Focusing exclusively on flagship species can skew conservation priorities and may not prevent extinction of the flagship itself or other species in the ecosystem. Also, selection needs to be strategic, combining appeal, endangerment, and ecological importance to maximize both fundraising and biodiversity benefits. Sri Lanka uses flagship species like the Asian Elephant, Sloth Bear, Leopard, and others to focus conservation efforts and raise public awareness. These charismatic and ecologically important animals serve as symbols that attract support and act as an entry point for broader biodiversity conservation and sustainable ecosystem management. Their unique traits and ecological roles make them key to driving effective wildlife conservation initiatives in the country. Flagship species aid conservation by attracting public, political, and financial support. These species also largely support to raise community awareness, improving policies, strengthening conservation and law enforcement.

4. The Extent of Land Use Changes and due to Development Project the Aggravated HEC in Sri Lanka

The Mahaweli Development Project in Sri Lanka is the largest integrated rural development program in the country, focused on the Mahaweli river basin. According to the latest data up to 2022, the project has opened about 106,735 hectares of irrigable land, along with constructing an extensive irrigation canal network of 9,484 km. Hence, the Mahaweli Development Project in Sri Lanka caused profound land use changes, mainly converting shrublands and less cultivated dry zone areas into extensive agricultural lands with irrigation infrastructure.

This expansion encroached on elephant habitats, leading to a reduction in available wild habitat and fragmentation of forest corridors crucial for elephant movement. The land-use changes taken place not only due to Mahaweli development program, but also due to other development projects have resulted in loss of natural habitat, fragmentation of elephant home ranges forcing wild elephants to depend more on agricultural land etc. The accelerated crop cultivation and year-round farming sustained by the Mahaweli and other development schemes further spread the conflict spatially and temporally. Efforts such as elephant drives and electric fencing to mitigate human elephant conflict together with cultivating agricultural crops in vast land extents where once the wild elephants roamed freely has often affected the natural behavior of wild elephant while increasing the stress and aggressiveness of these animals. Therefore, altered habitat availability of the wild elephant significantly affected their behavioral patterns influencing crop raiding, property damage, injuring and killing of people. This issue should be understood by all stakeholders and collectively endeavored rationally to resolve it as soon as possible ensuring human elephant co-existence. However, the human elephant conflict remains a severe challenge, threatening both elephant conservation and local human livelihoods. This conflict has manifested in higher mortality rates of both humans and wild elephants and continues to be a critical conservation and social challenge.

Across Asian elephant range, elephant management has been based on confining elephants to protected areas hence the Human–elephant conflict occurs entirely outside protected areas and has continued to escalate over the past few decades, necessitating a rethink of management approaches (Fernando and Pastorini, 2011).

It is essential that the home range of wild elephants should be able to meet their daily needs of water, food and natural cover. If those basic needs are not available in the home range adequately, it is inevitable that the elephants will move out of their home ranges and encroach the human habitations and crop fields. Degradation of the natural elephant habitats due to various human activities has created an HEC which has been intensified during the last few decades, as indicated in Figure 1.

5. Mitigation Measures Reduce Conflicts After Habitat Loss

The Department of Wildlife Conservation (DWC) enforces the Fauna & Flora Protection Ordinance to protect wildlife, especially wild elephants, using strategies like managing Protected Areas, providing legal protection to wildlife beyond reserves / protected areas, mitigating human elephant conflicts, providing veterinary care for wild animals, conducting community outreach, education and awareness programs and relocating problematic elephants. Sri Lanka's wild elephant population was about 5,787 in 2011, making it the second largest in South Asia and classified as Endangered due to habitat loss and human-elephant conflict (HEC).

P.W C. Dayaratne (2025) in Sunday Times, 31.08.2025, reports that as of 2024 DWC records, HEC is widespread across 19 districts and 131 Divisional Secretariats in the country and caused 386 elephant and 154 human deaths. Over 70% of wild elephants live outside Protected Areas, overlapping with human settlements that intensify the loss of wild elephant habitats and increasing the HEC. He also states that, more than 70% of the country's elephant population of estimated 5,500 to 6,000, live outside the Protected Areas (PAs) covering 62% of Sri Lanka's land area and this overlapping of wild elephant roaming areas with human settlements fuels the ongoing HEC.

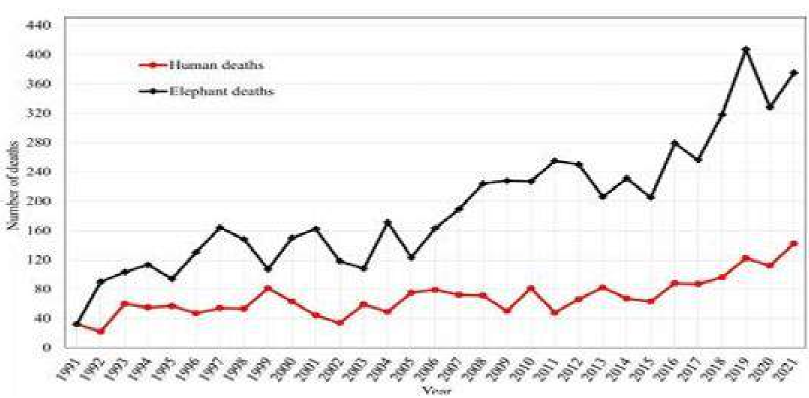

Fig 1. Human and Elephant deaths in Sri Lanka from 1991 to 2021 (Gunawansa et al., 2023)

6. The Importance of Wildlife Habitat Mapping for Effective HEC Mitigation

Conservationists highlight that, now it is high time to bring new solutions, emphasize the importance of so far overlooked important wild elephant habitats, their migratory patterns and routs in order to protect the traditional elephant habitats to reduce HEC. It is also very important to obtain the support of all stakeholders to make integrated land use plans to mitigate HEC.

Mapping the underlying causes of HEC is very important to mitigate HEC fostering HECoEx. These maps can effectively be used to identify the hot spots of HEC, areas to be protected for wildlife / wild elephants, Elephant migratory routes and patterns, the most suitable ecological corridors that link the protected areas, where the human encroachments taking place, what areas to be fenced inclusion of suitable areas in one unit (disregarding the administrative boundaries) and how the conflict mitigation strategies and actions be planted on the ground. These identified areas should be science-based, ecologically functional and socially accepted to link habitat patches to facilitate unhindered successful wildlife movement.

These identified areas should be mapped for successful management and monitoring by using modern techniques and technology.

Hence, GIS techniques can be used extensively for these purposes with the use of following essential GIS layers such as habitat patches (polygons of key habitat areas to be connected), land cover / land use, topography, roads and infrastructure, hydrology, protected areas, human, animal movement data, soil type and geomorphology, land ownership and administrative boundaries to identify, design and map the candidate ecological corridors to create suitable connectivity between important forest patches. The GIS tools such as cost-distance analysis, least-cost pat, corridor modeling etc. can be used to identify optimal routes that minimize movement resistance and human activities, while maximizing habitat connectivity. Integrating ecological, topographic and anthropogenic variables will ensure the corridors are ecologically functional, socially feasible and promote wildlife connectivity while reducing Human Elephant Conflict. Inter-agency coordination among data custodians is very important to execute these mapping exercises effectively.

7. Economic Cost of Human Elephant Conflict in Sri Lanka

The economic cost of human-elephant conflict (HEC) in Sri Lanka is significant and multifaceted. Rural farmers face substantial crop losses, sometimes amounting to hundreds of dollars in a single night, which can effectively wipe out a family's annual income. This leads to economic vulnerability and pushes marginalized communities closer to poverty. Additionally, the conflict results in human fatalities and injuries, property damage, and social disruptions.

The economic cost of human-elephant conflict (HEC) in Sri Lanka is substantial and multifaceted. The conflict primarily impacts rural farmers who form the backbone of Sri Lanka’s agricultural economy. Elephants often destroy crops worth hundreds of dollars in a single night, which can effectively wipe out a family's annual income, pushing households closer to poverty. The financial losses extend beyond just the crop destruction to include lost opportunities, disrupted education, social displacement, and costs for mitigation measures like electric fences and security personnel. Poorer communities (including men, women, girls / boys and children) face higher vulnerability due to inability to afford the costs of protective measures.

The broader economic impact encompasses not only direct losses but also long-term instability in affected regions. Furthermore, the psychological toll on local communities due to stress and trauma from ongoing conflicts adds to the social costs, influencing economic productivity and community well-being. Thus, the economic cost of human-elephant conflict in Sri Lanka includes direct agricultural damages, government mitigation expenses, lost tourism revenue, social and psychological effects on communities, and long-term regional economic instability.

Thiviyatharshini D. reports in the Sunday Times on 09 March 2025 that the Sri Lankan government has allocated a large sum of funds amounting to Rs. 640 million, for mitigation efforts, including compensation for victims, habitat improvement, and better wildlife management infrastructure. These direct costs are compounded by broader socio-economic impacts like lost opportunities and disrupted education, affecting the fabric of rural life. Sri Lanka's high density of wild elephants and ongoing habitat loss due to agricultural expansion and infrastructure development exacerbated this conflict, making it an urgent national issue with profound economic and social consequences.

8. The Economic Value of Conserving the Wild Elephants Against the Economic Loss due to HEC in Sri Lanka

The economic value of wild elephants in Sri Lanka goes beyond direct tourism revenue to include the willingness of urban populations to pay for their conservation, which surpasses the costs of human-elephant conflict damages. Urban residents are willing to pay Rs. 506.7 million monthly (Rs. 2,713.3 million annually), much higher than the Rs. 1,121.42 million annual damage caused by elephants to crops and property. This suggests a strong economic case for elephant conservation (Bandara and Tisdale, 2002). The Daily FT October 2024 states that tourism linked to wild elephants, with an estimated wild elephant population of 6,000, have the potential of generating over Rs. 23.4 billion ($128 million) annually. It further indicates that, according to an economic valuation done by Dr. Srilal Miththapala, the value of a single wild elephant to tourism is estimated at about $21,400 (around Rs. 4 million) and furthermore, the great elephant gatherings in Minneriya and Kaudulla National Parks are valued at approximately Rs. 1.2 billion. These valuations clearly highlight the significant economic benefits elephants bring to Sri Lanka’s tourism industry.

HEC continues to be a significant issue involving social, economic, and environmental challenges such as crop raiding, property damage, human and elephant injuries and deaths, habitat loss, and weak policies. In 2022, the government paid USD 946,553.34 in compensation for 160 human deaths, 192 injuries, and 2,741 property damage cases caused by elephants. This financial burden highlights the urgent need for effective strategies and policies to reduce HEC and promote sustainable coexistence.

When considering the economic losses against the potential gains of wild elephants in the country, it gives a strong, economically justified message to the policy makers and managers of the wildlife, tourism, agriculture, social welfare and economic sectors to pay a greater attention for wildlife and wild elephant conservation. Also, sustainable financing through ecotourism and alternative livelihoods is crucial for the long-term success of protected areas. Effective use through rational of appropriate Market Based Instruments (MBIs) such as payment for Ecosystem Services (PESs) etc. also can be strongly suggested. However, all these management tools require ongoing monitoring, evaluation, and adaptive strategies to address challenges from population growth, climate change, and biodiversity loss. This ensures proper and effective wildlife management and also Sri Lanka's compliance with regional and international environmental agreements.

9. Women, Girls and Children on HEC and HECoEx, Education

The gender perspective on human-elephant conflict (HEC) and coexistence in Sri Lanka reveals distinct roles and experiences shaped by socially constructed gender norms in affected communities. In rural villages, men and women respond differently to HEC. Women's views and coping strategies are largely influenced by their responsibilities in food security and livelihoods, facing indirect impacts such as crop loss and limited resource access. Girls and children often recognize wild elephants through cultural significance, charisma, and coexistence challenges, supporting conservation efforts focused on safety, education, awareness, and sharing landscapes respectfully. Understanding gender roles is crucial for addressing HEC effectively, as men primarily face higher risks of physical attacks, while women endure multiple direct and indirect impacts, including social, economic, and psychological burdens. Gender-inclusive approaches are essential for sustainable coexistence, as women's vulnerabilities extend beyond physical threats to broader social and emotional challenges. This perspective advocates conflict management that actively includes women's voices and addresses their unique needs, challenging traditional conservation models that overlook gendered social dynamics and promoting coexistence strategies attentive to the safety and well-being of all community members.

10. Why Should We Concern about Human Elephant Conflict in Sri Lanka

Human-elephant conflict (HEC) arises where humans and elephants coexist and has intensified due to changes in agriculture and land use. The construction of Mattala airport cleared around 2,000 hectares of forest, fragmenting elephant habitats and disrupting their movement corridors (Fernando et al., 2005; Anuradha et al., 2019; PEAD, 2015; Bandara, 2020). Likewise, mega development projects such as Mahaweli Development project and other agricultural and human settlement projects also cleared vast extents of lands which are known to be prime wild elephant ranging lands aggravating the HEC.

Human activities, especially infrastructure projects like the Mahaweli Development Project, have led to population growth and major land-cover changes in Sri Lanka's elephant habitats. Settlements near water sources have driven agricultural expansion, reduced elephant populations and fragmenting their (elephant) habitats. As elephant habitats shrink, conflicts with humans have intensified, causing crop damage and loss of life, making farmers often incompatible neighbors to elephants in these areas (Fernando et al., 2015; Paranage, 2019; Liu et al., 2017).

Sri Lanka's wild elephant population has increased to 7,000 from 5,787 in 2011 and at the same time, the rural population has also grown rapidly since 1960 altering the land use pattern in the country, expanding agricultural lands and human settlements into conservation areas. Traditional farming allowed better coexistence with elephants, but modern agriculture using high-yielding crop varieties (such as paddy and maize which attract more elephant to the farmlands) and agronomic practices / methods have lessened this harmony (Perera and Tateishi, 2012; The World Bank Group, 2022). Sri Lanka's forest cover decreased from 24.8% in 1992 to 21.0% in 2019, leading to habitat fragmentation and resource scarcity. This has pushed wildlife, especially wild elephants closer to human settlement, increasing conflicts like crop raiding, property damage, and human deaths. Habitat fragmentation and droughts force elephants into agricultural areas and new zones, heightening human-elephant conflicts and threatening elephant survival (Ranagalage et al., 2020; Köpke et al., 2021; Shaffer et al., 2019). This result in ever increasing HEC in the country and the policy makers and every citizen of the country shall take a serious note of this man-made national disaster and work together to mitigate the HEC fostering HECoEx.

The association between man and elephant in Sri Lanka is ancient. Elephants being the largest terrestrial herbivores, require relatively large areas and divers environments to forage. With the increase in human population density and changes in the land-use patterns caused continuous reduction in elephant habitats. Failure to recognize the significance of the human-elephant conflict can result in a negative attitude to elephants and apathy or indifference to conservation initiatives. Although it is unlikely that the human-elephant conflict can be eliminated altogether, yet every effort must be taken to reduce it to tolerable levels (Santiapillai et al., 2010).

Human-elephant conflict (HEC) occurs wherever humans and elephants coexist, but it has been intensified recently due to irrational land allocation for human-beings for various purposes which restrict wild elephants from those lands. Rapid human population growth, especially in rural areas, has increased land demands, leading to expanded agriculture and settlements near protected forests. Traditional farming promoted coexistence with elephants, but modern agricultural expansion and infrastructure projects like the Mahaweli Development Project have reduced elephant ranges and habitat connectivity. As habitats shrink, elephants increasingly encounter humans, causing frequent conflicts including crop raiding and loss of life. This makes peaceful coexistence difficult in Sri Lanka's agricultural elephant ranges (Fernando et al., 2005-2021; Anuradha et al., 2019; Paranage, 2019; Liu et al., 2017).

11. The Status of the HEC in Sri Lanka

Human-elephant conflict (HEC) is widespread in Sri Lanka, with about 59.9% of elephants confined to the lowland dry zone and 69.4% of their range overlapping human settlements, a situation expected to worsen. HEC causes injuries, deaths, crop damage, and property loss for both humans and elephants. Sri Lanka has the highest annual elephant deaths and second-highest human deaths due to HEC globally, with most fatalities occurring during crop raiding. Elephants are increasingly confined to shrinking habitats surrounded by crops. Conflict intensity varies seasonally, with the dry and post-rainy seasons seeing more damage as elephants move in search of water, often targeting paddy fields near water bodies and forests (Fernando et al., 2021; Prakash et al., 2020; Campos-Arceiz et al., 2009).

Since 1991 in Sri Lanka, elephant deaths have consistently outnumbered human deaths from human-elephant conflict (HEC), with a sharp rise recently (figure 1). Human fatalities have increased by about 42% over the past 30 years, reaching 142 in 2021. Over the last three decades, there have been 2,111 human and 5,954 elephant casualties due to HEC. Human deaths are concentrated in wildlife regions like Anuradhapura and Polonnaruwa, mostly involving males, as most incidents happen at night. Property damage from elephants has also risen, exceeding 1,000 cases annually since 2011, peaking at 2,195 in 2020. The government enforces laws protecting elephants, penalizing killings with fines and imprisonment. Victims of elephant-related deaths receive compensation of LKR 1,000,000, with additional support for disabilities and injuries, as well as compensation for property damage up to LKR 200,000 (Gardner, 2008; Wikramanayake, 2022; DWC).

Human Elephant Conflict in Sri Lanka poses significant conservation, socio-economic, and environmental challenges due to rapid growth in human and elephant populations competing for land. Key causes include land use changes, habitat loss, crop raiding, problematic elephant behavior, and agricultural shifts. Since 2019, an average of 125 people and 370 elephants die annually from HEC, with Sri Lanka having the highest elephant deaths / killing and second-highest human mortality rates from HEC although the endangered Sri Lankan elephant is legally protected, and management strategies exist up to now. Despite these issues, comprehensive, standardized frameworks to address HEC effectively is lacking and the updated data on forest cover, wild elephant migration patterns, HEC hotspots etc. is insufficient leading into difficulties to understand habitat changes in full.

12. Whether to Drive Elephants to Protected Areas or Not? Think Many Times Before Acting

In his write-up of the NASSL guest lecture, Prof. Dewaka Weerakoon comes up with an eye-opening case study for which the policy makers and wildlife managers should draw their careful attention on, the result of wild elephant drives that have been undertaken by the authorities and the aftermath and fate of the driven wild elephant populations. A person well converse with the subject, states that "The first such drive took place in 1961, aiming to move 14 elephants from Deduru Oya to Wilpattu National Park, but it was labeled a "dismal failure" by Dr. R L Spittel. Since then, many drives have been carried out to push wild elephants into nearby protected zones. These drives can last from months to years and demand substantial manpower to cordon the cleared area and prevent elephants from returning. The last major drive occurred in 2005-2006 for the Walawe left bank development project, relocating over 225 elephants from Mattala to Lunugamvehera National Park. However, post-drive monitoring revealed more than 400 elephants, including many conflict-prone bull elephants—remained in the Mattala area after escaping the cordon and continued to cause problems. Even more concerning was the fate of the herds relocated to Lunugamvehera: due to limited food resources, many females and calves starved over time. This pattern has been observed in several drives conducted by the DWC recently. Additionally, elephants often become habituated to being driven and become more aggressive afterward, increasing conflict instead of reducing it. Moreover, the least conflict-prone herds suffer or die despite large public expenses. Consequently, elephant drives have proven ineffective as a strategy to manage and reduce human-elephant conflict.

13. Biodiversity Conservation and Protected Area Management

Biodiversity conservation in Sri Lanka combines in situ methods, such as protected areas and national parks, with ex situ approaches like zoos and gene banks to protect ecosystems and endemic species. The government supports these efforts through a Biodiversity Conservation Action Plan (BCAP) focused on preventing habitat loss and illegal activities. Ecotourism is promoted as a sustainable way to generate income and support conservation, coupled with education, policies, and collaborations to address challenges like overexploitation. Coordination among government agencies and provincial bodies ensures effective natural resource management, while innovative strategies like Payments for Ecosystem Services are emerging to enhance sustainability. Despite these efforts, the conflict results in significant losses—386 elephants and 154 people died in 2024 due to HEC.

Prof. Dewaka Weerakoon at his NASSL guest lecture states that to mitigate the escalating human elephant conflict, nearly 13% of the land area of Sri Lanka has been declared as Protected Areas (PAs) under the management of DWC, where the central focus has been conservation of wild elephants. Most of these areas before being declared as PAs, were managed by farmers mainly under a slash and burn regime. Thus, chena farming in Sri Lanka has created elephant habitats for thousands of years as a byproduct of the farming practice contributing to a high density of elephants. Mature forests have a lower carrying capacity for elephants (ca. 0.2 elephants/ km2) while disturbed habitats that are created mostly by slash and-burn or shifting cultivation the carrying capacity can be as high as 3 elephants/km2. However, when an area is declared as a protected area, farmers no longer have access to these lands. Therefore, the slash and burn cycle that existed in these lands will now be replaced by another cycle called ecological succession, which will over time convert secondary forests into mature forests. Studies done on carrying capacity of different landscapes for elephants have clearly demonstrated that a secondary forest can support 15 times more elephants than a mature forest of similar extent. Therefore, the carrying capacity of the protected areas that have been set aside for elephant conservation has declined over time, due to removal of the key process that created elephant habitat in these landscapes, slash and burn agriculture. Hence, it is no surprise that elephants must come outside the protected areas to find food, especially during the dry season. These elephants invariably come into conflict with humans, especially bull elephants or bull groups that are responsible for more than 80% of the conflicts reported".

Protected areas (PAs) in Sri Lanka play a vital but limited role in resolving human-elephant conflict (HEC). About 13% of the country's land is designated as WLPAs, managed primarily by the Department of Wildlife Conservation (DWC). These areas serve as refuges to conserve elephants and their habitats, providing space for breeding and reducing direct human-elephant encounters within the boundaries. However, since around 70% of Sri Lanka's elephants live outside protected areas where human settlements and agriculture predominate, the PAs alone cannot fully resolve HEC. Protected areas help by preserving critical elephant habitats and forest corridors needed for elephant movement between these areas, which reduces habitat fragmentation, a major driver of conflict. In addition to conservation, PAs act as focal points for conflict management strategies including **a.** Installation and maintenance of electric fences around PA boundaries to prevent elephants from entering human-dominated areas. **b.** Habitat enrichment and water source development within PAs to discourage elephants from venturing out for resources. **c.** Scientific monitoring and mapping of elephant populations and movements from PAs to identify conflict hotspots. **d.** Support for community-based mitigation efforts in buffer zones adjoining PAs. **e.** Education and awareness campaigns conducted in PA regions to foster coexistence.

Yet, existing protected areas, managed elephant ranges and corridors, face challenges such as inadequate enforcement, poor electric fence maintenance and illegal encroachments which allow elephants to raid crops and village areas. Consequently, while PAs form a critical backbone, linking these PAs with areas outside PAs is essentially needed worked out through a broader integrated landscape-level approach with community participation for a meaningful HEC mitigation. Holistic HEC mitigation strategies fostering HECoEx should involve integrated land use planning, scientific habitat management, establishing physical barriers, early warning systems and empowerment of communities living in HEC areas that border with protected areas. Key measures include electric fencing (village and mobile), cultivating buffer crops which are unpalatable to wild elephants, and promoting alternative livelihoods like eco-tourism, handicrafts, and small-scale farming including micro livestock raring.

Elephants are being squeezed into smaller areas of their remaining natural habitat, surrounded by crops that elephants like to eat (Palita and Purohit, 2008). Presently, almost all the crop varieties that the farmers grove are edible to wild animals, especially by wild elephants and hence, farmers experience risk losing their entire livelihood in one night due to crop raiding (Bandara and Tisdell, 2002). Small-scale agriculture is the main economic activity in rural Sri Lanka. Banana, coconut, sugarcane, and seasonal crops are cultivated during the rainy season, including paddy, maize, pumpkin, green chili, bitter gourd, and watermelon (Campos-Arceiz et al., 2009; Ranaweerage, 2012). Rice, banana, coconut, cassava, corn, papaya, and sugarcane are wild elephants' most preferred crops while they avoid lime, orange, sesame, and cashew (Santiapillai et al., 2010; Webber et al., 2011). It has also been observed that elephants tend to consume more nutritious crops like sugarcane, rice, and the tops of pineapples and additionally, bananas are a preferred food for elephants due to their high nutritional value and ease of digestion (Haven, 2019). Interestingly, it appears that elephants are not fond of the smell of citrus trees (Rathnayake, 2020).

It is known that elephants raid crops throughout the year, but their activities are intensified during certain months (Bandara and Tisdell, 2002). Elephants raid paddy fields in January when the grain matures and continue until harvesting is completed (Ranaweerage, 2012; Santiapillai et al., 2010). They damage bananas during every stage of the crop's life (Santiapillai et al., 2010). Mango trees are attacked during their fruiting seasons, from May to June and November to December (Bandara and Tisdell, 2002). Elephants also attack perennial crops, such as jackfruit and coconut, when other crops are unavailable along their usual raiding routes (Bandara and Tisdell, 2002; Campos-Arceiz et al., 2009).

14. Establishment of Scientifically Determined and Managed Wild Elephant Roaming Habitats

Rapid human population growth and land conversion have intensified Human-Elephant Conflict (HEC) in Sri Lanka. Despite mitigation efforts like translocation, use of deterrents, electric fencing and other mitigatory measures proven ineffective. Hence, urgent need has arisen to find sustainable solutions. Sustainable strategies should be focused on conserving wild elephants by creating scientifically determined and managed broader elephant habitats linking the in current wild elephant ranges and protected areas through participatory approaches, especially engaging the affected communities. This would also be very important in achieving biodiversity conservation, ecosystem balance, and climate resilience. Effective habitat management requires strong governance, community participation, and stakeholder involvement to ensure sustainable use, benefit sharing, and habitat connectivity, promoting successful human-elephant coexistence.

Gunawansa et al, 2023, suggest suitability of applying satellite data fusion with GIS modeling to identify risk zones of HEC in Sri Lanka. Satellite remote sensing has the capability to classify land cover types with high accuracy, and this fact has proven by thousands of researches throughout the world (Xie et al., 2008). GIS could be applied to integrate land cover data with other spatial data layers such as elephant movement records, HEC recorded spots, seasonal variations on vegetation, spatial distribution of human activities, and climatic data. Different land cover classification methods including random forest classifier and support vector machine will be used to classify land cover types to produce the most accurate land cover maps (Qin and Liu, 2022) to obtain high accuracy in forest boundaries. GPS data can be used to observe, identify, and record the routes and movements of elephants and integrate field observations with GIS database and through the GIS data analysis, it will be possible to reveal elephant movement routes, corridors, and entry points into human settlements or crop fields. The resulting HEC zone and elephant hot spots were then visualized on a map using GIS software. This system will inspire researchers to find new ways to protect people and elephants (Gunawansa et al., 2023).

The relationship between elephant habitats and land cover changes, particularly vegetation, is unclear due to limited updated data on Sri Lanka's forest cover. Therefore, developing a hotspot risk map for HEC is essential for conflict reduction. A standardized framework is urgently needed to monitor, identify, and predict HEC risk zones (Gunawansa et al., 2023). Although many people talk high on elephant corridors, many of the corridors remain ineffective since these corridors were planned with limited scientific data on elephant behavior and ecology, leading to flawed and unsustainable management. Prof. Dewake Weerakoon in his speech at NASSL states that "so-far, only the Nilgala (linking Maduru Oya Gal Oya National Parks) and Kuda Oya (linking Udawalawa and Lunugamwehera National Parks) corridors have become successful yet, among number of other proposed corridors. Therefore, establishment of ecological corridors should be done with sound scientific background, knowledge and an understanding the facts that the ecosystems are dynamic and it undergoes the natural succession which has the possibility of turning the targeted areas into secondary forest followed up by turning into mature forest which are not suitable for wild elephants".

Long-term HEC mitigation requires strategies based on up-to-date research and advanced ecological knowledge. What is important is to form sizable / large enough contiguous elephant habitats and carry out the habitat improvement activities to improve the carrying capacities of those contiguous habitats. This approach supports global best practices by using corridors as vital links for endangered species, promoting ecosystem health and resilience. It aligns with national biodiversity plans emphasizing habitat preservation, restoration, invasive species control, and conflict mitigation. A key challenge is the lack of specifically mapped priority elephant habitats for flagship species like wild elephants. Creating a comprehensive elephant habitat including protected area and areas outside the protected areas is very necessary. Incorporating new data from advanced technologies is crucial for designing effective wild elephant habitats / corridors that reduce habitat fragmentation and HEC. Therefore, effective and lasting HEC mitigation strategies and measures must be developed based on the latest research, information, and advanced ecological and biological understanding of elephants and affected communities. Therefore, it has to be kept in mind that you cannot just set aside corridors and let it be on their own, hence they should be maintained continuously and managed scientifically to drive them towards success.

15. Practice Ecosystem-Based Management (EBM)

Authorities of The Department of wildlife Conservation (DWC) in their communications have indicated that, the issue of Human-elephant conflict (HEC) in Sri Lanka affects 19 out of 25 districts and poses serious environmental, social, political, and economic challenges. To address this issue, Sri Lanka needs holistic, integrated approaches that consider ecological, social, and economic interactions within ecosystems. Hence, practicing EBM is strongly suggested since it has significant positive impacts with effective applications on managing wildlife populations and maintaining ecosystem health. Some key applications are understanding population trends to create targeted conservation strategies, managing habitats to conserve biodiversity and enhance resilience, and balancing human activities like agriculture and urban development with wildlife conservation goals. Hence, policymakers and wildlife managers are encouraged to adopt Ecosystem-Based Management (EBM), which focuses on ecosystem health, resilience, and complex interactions. EBM helps develop effective conservation strategies, manage habitats for biodiversity, and balance human activities with wildlife conservation enabling policy makers and wildlife managers to identify areas of high conservation value and develop strategies to protect and restore habitat connectivity.

16. Implementing a New Policy and a Strategic Action Plan

The “Proposal to mitigate the Human-elephant conflict in Sri Lanka” prepared and published by the Center for Environment Justice (CEJ) in April 2024 (hereafter referred as Proposal-2024) highlights HEC as a significant and complex issue threatening the conservation of the Asian elephant and the wellbeing of rural communities. It identifies causes such as habitat loss from development, forest clearing, population growth, and poor wildlife management, compounded by contradictory policies like land grabbing and ineffective compensation systems. The current conservation strategies, including confining elephants to designated areas, elephant drives have proven unsuccessful. In response, CEJ conducted wide range of stakeholder (including rural communities) consultations and reviewed the National Action Plan (NAP) prepared by the presidential committee for HEC mitigation in Sri Lanka in 2020 (hereafter referred as NAP-2020) chaired by Dr. Prithiviraj Fernando which recommends short-, medium-, and long-term actions, including electric fences, conflict reduction activities, compensation, insurance, road safety, and public awareness.

The CEJ’s Proposal 2024 builds on the National Action Plan (NAP-2020) to address human-elephant conflict by incorporating community input, expert advice, and official guidance. Both plans promote collaborative and adaptive strategies focused on preserving elephant habitats and corridors, maintaining effective electric fences, and encouraging sustainable agriculture to reduce conflicts. They emphasize Ecosystem Based Management and land use considerations to support long-term human-elephant coexistence. Over the past decade, the Sri Lankan government has highlighted the need for a sustainable solution to human-elephant conflict (HEC) and has made efforts to create a comprehensive mitigation program. However, many believe it is inefficient to develop new policies from scratch. Hence, the government is strongly requested to pay sufficient attention to the well-developed NAP-2020 and CEJ Proposal-2024 involving significant time, funds, expert and community inputs, rather than going to prepare a new policy, strategy and an action plan.

17. Priority Policy Directives Proposed for Long-term HEC Solutions in Sri Lanka

Bringing up appropriate policy changes timely to the existing Policy is extremely necessary to strengthen the actions enable to reduce habitat fragmentation and financially incentivize the communities and landowners to maintain forest cover, protect biodiversity, expand protected areas network, in order to implement effective conservation measures. The key policy gaps in Sri Lanka's long-term HEC mitigation include a lack of serious commitment and weak implementation. Absence of adequate integrated land use planning, insufficient focus on community-based strategies, weak inter agency coordination, poor monitoring and weak data and information availability, lack of research and development, limited human, financial and physical resources, and limited technical resources should be highly considered to formulate new practical policy interventions.

It is suggested to pay more attention to the following policy directives to derive new policy interventions, strategies and actions to address HEC: **a.** Shifting from a purely human-centric approach to one that integrates elephant biology, behavior, and habitat needs in land-use and development planning. **b.** Ending the ineffective policy of confining elephants strictly to Department of Wildlife Conservation (DWC) protected areas by fencing their boundaries, which often lie inside forests and fragments elephant ranges. **c.** Implementing electric fences on ecological boundaries, separating developed human areas from elephant habitats rather than strictly fencing protected area borders. These fences should be community-based and seasonal—used to protect crops temporarily during vulnerable periods and removed afterward to allow elephants access to crop residue. **d.** Encouraging community participation in fence maintenance and involving farmer organizations directly in seasonal agricultural fencing to reduce crop raiding. **e.** Incorporating conflict mitigation as an integral part of project planning processes, including environmental impact assessments, to avoid exacerbating elephant conflict zones through development. **f.** Promoting co-existence and community awareness through education and creating incentives like community-based elephant tourism to turn elephants from economic liabilities into assets. **g.** Advocating landscape-level strategic frameworks that consider elephant ranges extending beyond protected areas, ensuring development projects are located appropriately or mitigated with proper HEC measures. **h.** Supporting rigorous scientific data collection and research to guide decisions and adapt policies to ground realities.

It is important that the new policies represent strategic, science-based, and community-supported approach designed to reduce conflict while sustaining both human livelihoods and elephant conservation in Sri Lanka. These policy directives are suggested aiming to maintain ecosystem connectivity, protect elephants, and support local communities economically while fostering sustainable human-elephant coexistence.

18. Priority Legal Reforms Proposed for Long-term HEC Solutions in Sri Lanka

The legal reforms proposed to solve human-elephant conflict (HEC) in Sri Lanka mainly build upon the existing National Action Plan (NAP). Therefore, new legal reforms are proposed to be brought in to strengthen wildlife protection laws in order to support implementing appropriate conservation strategies effectively. Some of the proposed salient key legal reforms include: **a.** Establishment of stringent standards for private electric fences to prevent harm to elephants and ensuring construction and maintenance of electric fences around villages and farms with community involvement or government responsibility where needed, **b.** Preserving and legally protecting elephant habitats and corridors to reduce habitat loss and fragmentation, **c.** Developing an integrated wild elephant conservation plan and national land-use policy that balances human development with wildlife conservation, **d.** Introducing comprehensive compensation and insurance schemes for human deaths, injuries, and property or crop damage caused by elephants to support affected communities, **e.** Implementing road safety laws with measures such as clearing road verges and installing lighting and signaling with suitable pass throughs (passages across motor and rail roads) to prevent elephant-vehicle collisions, **f.** Create a dedicated elephant protection force reinforced with highly equipped veterinary facilities (with both human, financial and physical resources) and strengthen its enforcement under updated wildlife protection statutes, **g.** Conduct regular elephant population censuses, migratory patterns and distribution surveys, backed by legal mandates together with modern technical and technological support to better informed conflict mitigation efforts, **h.** Promoting sustainable intensive modern agriculture on existing lands to reduce the need for excess land or additional forest clearing leading to elephant habitat encroachment. **i.** Establish ecological corridors in order to strengthen and improve the connectivity between protected areas essential for species movement, genetic exchange, and ecosystem resilience, **j.** Periodical review of legal provisions and bringing up necessary legal reforms to the wildlife conservation sector in order to strengthen entire wildlife sector.

These reforms call for updating Sri Lanka's Fauna and Flora Protection Ordinance by integrating modern conservation principles, community participation, scientific research, and multi-sectoral coordination to effectively address the complex human-elephant conflict and enhance coexistence.

19. Awareness and Education on HEC and HECoEx

School programs must be prepared to educate and aware children about elephant coexistence through age-appropriate curricula covering elephant biology, ecology, behavior, and habitat protection. These programs should use interactive activities like arts, crafts, poetry, and role-playing to foster empathy and personal connections to wildlife. Awareness programs should target diverse groups, including students (primary, secondary and tertiary levels), stakeholders, and politicians, teaching human-elephant conflict mitigation and emphasizing empathy, ethical values, environmental care, social cohesion importance of co-existence, and safety. Programs should be conducted to promote long-term peaceful coexistence between humans and elephants on knowledge-sharing, creative expression and real-world exposure school programs aim to cultivate youth leadership in conservation can be used very effectively. These programs should aim to build foundational social, emotional, and environmental skills to encourage critical thinking, moral judgment, and social responsibility. It is essential to carry out programs to cultivate youth leadership to support long-term peaceful coexistence between humans and elephants by combining knowledge-sharing, creative expression, and real-world experiences.

20. Conclusions

Sri Lanka has spent a large sum of funds on various human elephant conflict (HEC) mitigation measures, but all have fallen short because of irrational planning. It is necessary to consider both socio-economic facts of humans and biological, economic cultural value of wild elephants to come up with successful strategic plans for HEC Mitigation through participatory integrated planning.

Ecosystem-based management (EBM) is essential in resolving HEC in Sri Lanka by meeting the ecological needs of humans and elephants within shared landscapes. Since EBM integrates socio-economic development enhancing conservation, building community resilience and supporting peaceful HECoEx, empowering communities as active partners in conservation. This helps aligning HEC mitigation efforts with national and global conservation goals, while reducing HEC in Sri Lanka. Nevertheless, participatory land use planning (PLUP) is essential to balance the spatial needs of both people and elephants through collaborative decision-making. It helps prevent human settlement and agricultural encroachment into elephant habitats, reducing conflict by limiting landscape fragmentation, and enhancing the effectiveness of HECoEx. Thus, the ecosystem or habitat-based approaches are more comprehensive and offer more holistic and sustainable biodiversity conservation. For such exercise, mapping of human-elephant conflict risk zones enabling them to draw early warning systems and helps communities to be prepared.

Elephants, being a ‘flagship species’ play a crucial role in their natural habitats in keeping the balance and protecting the overall health of the forest ecosystem while paving the way for the protection of many other species as well. The flagship species approach can strengthen community-based conservation by linking people emotionally and economically to a species. This is further supported as wild elephants derive a large portion of the tourism economy. The wild elephants have become one of the country’s biggest tourist attractions, as evidenced by the upward trajectory in visitor numbers to wildlife parks

Community participation and economic incentives could promote coexistence and minimize losses. Compensation and insurance schemes help offset economic damage, encouraging tolerance over retaliation. Supporting alternative livelihoods and elephant-unfriendly farming reduces dependence on vulnerable crops. Additionally, elephant-focused ecotourism generates revenue, incentivizing habitat protection and reducing hostility. Overall, these instruments balance economic benefits with conservation goals to foster sustainable human-elephant coexistence and community empowerment in Sri Lanka. More emphasis should be given to promote creative Payment for Ecosystem Services (PES) measures should be further explored and implemented.

Strong coordination among government, communities, private sector, NGOs, CBOs, INGOs and conservation bodies, supported by comprehensive legal frameworks and scientific research should always be encouraged to ensure effective HEC management. These strategies focus on coexistence, minimizing crops, property damage and loss of lives along with integrating habitat management, infrastructure, community engagement, policy, and science. The way forward in resolving human-elephant conflict in Sri Lanka lies in a balanced, compassionate, scientifically informed strategy that emphasizes habitat preservation, community participation, sustainable land use, and long-term planning and continuous monitoring and evaluation. Combined, the above approaches can mitigate HEC, protect both human communities and wild elephants, and promote HECoEx.

21. Recommendations for the way forward - for a HEC free Sri Lana towards a healthy HECoEx

Recommendation – 1

Prepare and implementing integrated HEC mitigation strategies and activities fostering HECoEx through a holistic planning process

Recommendation – 2

Establish and manage a contiguous landscape especially for wild elephant populations in their current context by amalgamating lands belongs to both Departments of Wildlife Conservation and Forests as well as the areas outside the protected areas (to the maximum extent possible) in order to mitigate HEC fostering HECoEx : **a.** Develop hotspot risk maps in order to identify HEC risk areas accurately using Utilizing satellite data fusion combined with GIS Techniques and technologies. **b.** Create a rational portfolio of Protected areas with appropriately designed corridors that constitute a broader / wider ecological network, ensuring connectivity between wildlife habitats facilitating unhindered species movement while reducing human wild animal conflicts. **c.** Promote and effectively use sustainable financing through ecotourism and other alternative livelihoods by introducing rational and appropriate Market Based Instruments (MBIs) such as payment for Ecosystem Services (PESs) etc.

Recommendation – 3

a. Scientifically identify, demarcate, map, declare, provide legal protection, comprehensively / continuously manage and monitor the critical wild elephant habitat patches that need connectivity and connection beyond administrative boundaries by way of ecological boundaries / corridors, understanding the movement and migration patterns of wild elephants in order to mitigate human-wildlife conflict and habitat fragmentation.

b. Identify all the critical rail and road passages that runs through the traditional wild elephant migratory routes where wild elephants used to cross to reach their natural habitats and construct secure passthroughs by way of scientifically planned / determined overpasses or tunnels / underpasses.

Recommendation – 4

Practice Ecosystem-Based Management (EBM) that recognizes the intricate relationships within ecosystems and manages them in a sustainable, scientific and adaptive manner.

Recommendation – 5

Department of Wildlife Conservation and the responsible Ministry should convene the authors of the existing NAP-2020 and the CEJ Proposal 2024 and make arrangements to formulate a combined new HEC Policy and Strategic Action Plan (short, medium, and long-term) by reviewing and updating the current NAP-2020 and the CEJ Proposal 2024, ensuring sufficient funding for its implementation in order to mitigate HEC fostering HECoEx effectively.

Recommendation – 6

Bring up suitable policy changes and new policies where it is necessary to create a holistic approach to reduce habitat fragmentation by protecting, restoring, and sustainably managing Sri Lanka's ecosystems to maintain its connectivity and biodiversity.

Recommendation – 7

a. Develop or update management plans for the protected areas focusing on ecological corridors and connectivity. **b.** Establish dedicated funds or trusts to finance protected area management, supporting restoration, monitoring, and community programs in order to enhance HEC mitigation fostering Human-Elephant Coexistence (HECoEx). **c.** Strengthen law enforcement against illegal encroachments and habitat destruction to preserve the integrity of ecological corridor network. **d.** Eliminate encroachers as much as possible from the current wild elephant migratory routes / ecological corridors / wild elephant habitats. **e.** Take immediate actions to build capacity of the DWC at all levels such as human physical resources and provide adequate funds for its field operations. **f.** build state-of-the-art facilities of the rapid response and rescue and veterinary divisions. **g.** improve the communication and mobility (vehicular) facilities of DWC. **h.** Make all due DWC employee promotion as soon as possible. **Establish** a comprehensive database on human-wildlife conflict with a special attention on human-elephant conflict.

Recommendation – 8

The Department of Wildlife Conservation (DWC) should gather existing economic valuation studies on wildlife management and conduct further economic studies with the support of experts and academia to conduct further research to provide data to justify state financial allocations and enable informed decision-making in wildlife conservation.

Recommendation – 9

a. Empower women to actively participate in wildlife resource conservation decision making process while addressing the unique risks that women face in Human-Elephant Conflict (HEC). **b.** Develop gender-sensitive policies that integrate the diverse needs and roles of all genders to promote holistic, sustainable HEC mitigation strategies and actions fostering human-elephant coexistence.

Recommendation – 10

Carry out programs through creative methodologies and activities to teach school children, university students, stakeholder institutions, politicians and public about human elephant conflict mitigation and how to bring about human elephant coexistence through structured, age-appropriate education contents that covers elephant biology, ecology, and the significance of elephants in ecosystems.

Recommendation – 11

a. Re-visit the existing electric fencing system and re-adjust them to suit them the current context / situation through a holistic approach including the people affected by HEC.

b. Establish a platform for the local level electric fence developers and support them to develop and improve their e-fences adhering to approved / accepted set of specification and quality control norms (to assure quality control, safety etc) and support and coordinate them to access necessary technical and financial resources.

c. Pay special attention to providing sufficient funds and technical knowhow to the vulnerable communities to establish more community based electric fences that built along village and farmland boundaries to surround those entities to prevent wild elephant invasions.

d. Encourage communities to plant Palmyra and lime trees (in suitable and appropriate locations) along the electric fences in zig-zag pattern (with appropriate spacing).

e. Remove all the irrational establishments of electric fences that restrict the natural habitats of wild elephants (eg. Electric fences which had been constructed separating DWC lands and FD lands etc.) and re-establish the e-fences to create a maximum possible land extent for the wild elephants and other wild animals.

Recommendation – 12

a. Identify all critical natural habitats and migratory routes of wild elephants and put them under scientific management with appropriate legal protection as soon as possible and prevent them from human encroachments.
b. Stop all kinds of permission granting for the areas used by wild elephants and put them under the FFPO of the DWC jurisdiction.

Conflict of Interest

The authors have declared that no competing interests exist.

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Case Study 1

Human-Wildlife Conflict in Kandyan Homegardens in Sri Lanka: A Situational Analysis

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Abstract: The wild animal damage in the Kandyan homegardens (KHs) system has increased at an alarming rate over the last two decades. The harmful impact of wild animal damage on homegarden crops cannot be overstated. The objective of this study was to assess the status of human-wildlife conflict within the KHs and address the existing gaps in comprehensive scientific research on this topic. A questionnaire survey was conducted in 60 homegardens in Kandy district over the four months period and the quadrat method was used to quantitatively assess the severity of the wild animal damage in six selected homegardens over the period of two months. The risk index and severity index were used to assess the risk and the severity of the wild animal damage. The study further focused to assess the effectiveness of existing control methods and gathered ethnobiological knowledge that could aid in reducing damage caused by wild animals. Data were analysed using the chi-square test and descriptive statistics. The study highlighted the urgent need to address wild animal damage as a major problem in the KHs system. The highest risk index was observed for wild boars (0.870), followed by monkeys (0.833), porcupines (0.790), and giant squirrels (0.550). This damage not only results in yield losses and physical damage but also poses a great threat to financial stability of rural and peri-urban communities. This damage not only results in yield losses and physical damage but also poses a great threat to financial stability of rural and peri-urban communities. While the peacock attack currently does not pose a significant threat within the KHs system, it remains a significant concern in specific regions of the country. The current methods used to control human-wild animal conflict in the KHs were found to be inadequate, emphasizing the need for an immediate and well-defined strategic plan to address the issue while considering the conservation of the wild animal population within the urban landscape.

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Keywords: Kandyan homegarden, Risk index, Severity index, Wild animal damage

1. Introduction

Competition between people and wildlife for resources and space has increased to unprecedented proportions, especially as natural landscapes of the world have transformed into cultural landscapes (Leta et al., 2016). Biodiversity conservation goals can only be best achieved when there are firm support and cooperation from locals, especially in emerging economies where poor communities often bear most of the cost of human–wildlife conflict (Khattak et al., 2022). Forest animals such as elephants (*Elephas maximus*), wild boar (*Sus scrofa*) and some deer species migrate into the nearby agricultural fields in search of food and cause huge damage to the crops not only by eating but also by trampling. In certain areas of India, crop damage can reach up to 100%, with an average range of 50-60% (Goel and Sharma, 2021). The problem of animal induced damage is a burning issue and has a direct bearing on the socio-economic conditions of the people in general, and in the farming community in particular (Thakur et al., 2022).

Sri Lanka is a predominately agricultural country and the unique climate and soil characteristics along with elevational gradient have resulted in rich agrobiodiversity and a vast array of agricultural ecosystems (Gunatilleke et al., 2008, Horgan and Kudavidanage, 2020; Marambe et al., 2012). It has been identified that wild animal damage to cultivated crops in the agricultural ecosystem is one of the major issues in the agricultural sector over the last few decades (Rudran et al., 2020, 2021; Wijethilaka et al., 2021). Regardless of the cropping systems, crop types, and cultivation extent, they cause significant damage to most crops and the physical properties of farmlands, leading to numerous socio-economic problems. While comprehensive scientific articles on the subject are limited, a few surveys conducted over the past two decades have provided insight into crop damage caused by wild animals (Rudran et al., 2021; Wijethilaka et al., 2021). The Ministry of Agriculture has estimated that the wild animal damage to crops in Sri Lanka amounts to 54 billion rupees annually (Daily News, 2022). A survey conducted by the research team at Sri Lanka’s Hector Kobbekaduwa Agricultural and Training Institute found that the country loses an estimated 107 million coconuts annually due to toque monkeys and squirrels in coconut plantations (Colombo Page, 2022).

Kandyan Homegardens (KHs) are traditional agroforestry systems that exist to support rural livelihoods in Kandy District, Sri Lanka and these agro-ecosystems have been sustained over generations of socio-ecological change and are recognized today for their biodiversity conservation and ecosystem services (deHaan et al., 2020; Jayakody and Basu, 2022). KHs illustrate how mixed-crop, household-based agriculture can be advantageously positioned in modern development due to their resilience and adaptability (Landreth and Saito, 2014). Several perennial food crops, fruits, vegetables, roots, tubers, medicinal plants, spices, and wood crops are all part of this multi-story, traditional, complex, and risk-averse production system (Pushpakumara et al., 2012).

Though few studies have reported the severity of wild animal damage for homegarden crops in KHs (Dissanayake and Dilini, 2020), detailed information is not available on the nature and severity of their damage. Wild animals, including toque monkeys (*Macaca sinica*), wild boar (*Sus scrofa*), porcupine (*Hystrix indica*), and giant squirrel (*Ratufa macroura*), pose a significant threat to the KHs, damaging crops throughout the year. They damage all kinds of crops, and their damage is not restricted to a specific season of the year. To improve the household food security and nutritional diversity, both government and other organizations have initiated programs to promote homegardening in Sri Lanka over the last two decades. The community claims that many of these programs have proven ineffective due to damage caused by wild animals. Wild animals are causing significant frustration for residents in certain areas as they continue to damage and destroy crops, leading to considerable economic losses. Despite attempting various methods to minimize damage, these efforts have not been as efficient or effective as hoped. The main drivers of the adaptation and the sustainability of homegardens are the local farmers who manage them daily (deHaan et al., 2020). Thus, it is important to look at these locally driven control methods used by the local community. Ethnobiological knowledge is an important source of information at the forefront of research interests, particularly in relation to the importance of biocultural diversity in sustaining the earth's ecosystems (Turner et al., 2022). Therefore, it is important to comprehend this dynamic relationship between wild animals and the communities affected by wild animal damage. It is also essential to understand the measures they have implemented to address the issue with the resources available to them.

Some of the recorded wild animals in KHs are listed as threatened species (MOE, 2012). Although the toque monkey is endemic to Sri Lanka, the community claims their population has increased rapidly over the last two decades, causing significant damage to homegarden crops. Despite their biological value, the community kills them due to the severe damage to crops caused by some wild animals. Ekanayake et al. (2003) also highlighted that wild toque monkeys are subject to a wide array of physical and biological challenges unique to natural populations. Bandara and Tisdell (2003) noted marked differences in attitudes toward elephant conservation: most urban respondents favored elephant conservation, while rural respondents expressed a mix of positive and negative attitudes. Thus, it is important to strategically handle this issue while considering the perspectives of different stakeholders in the community. Moreover, most of the reported wild animals are native and listed in the National Red List (MOE, 2012), making their management a significant challenge in alignment with wildlife conservation strategies.

Even though responsible institutions have been working on this issue for a significant period, they have yet to develop an effective method to successfully address and resolve the problem. However, it is essential to first gain a comprehensive understanding of the nature, severity, and frequency of the damage, as well as the effectiveness of current control methods and socioeconomic factors before developing a strategic plan to minimize wild animal damage in the KHs system. Even though a review by Pushpakumara et al. (2012) on KHs did not identify this issue as a significant concern in the past, most recent media reports specifically highlight that it is becoming increasingly problematic. Therefore, the present study aims to analyze the status of human-wildlife conflicts in the KHs system to develop more effective and efficient control measures.

2. Materials and methods

2.1 Site selection

A preliminary field assessment was conducted to identify suitable areas and homegardens for a detailed investigation. Initially, we conducted several field visits to identify severely affected areas within the Kandy District and held detailed discussions with the community. The community had experience and insights into the severity of the damage caused by wild animals. After discussions with garden owners, 90 home gardens were initially selected. Of these, 60 homegardens were randomly selected for the questionnaire survey (Fig 1), and among those, 6 homegardens were purposefully selected for a detailed study. In this study, homegardens with an area of less than two acres with a considerable extent of vegetation were considered. When the land extends beyond 2 acres, it deviates from the concept of home gardening, so we specifically selected homegardens that range from 0.5 to 2.0 acres. Each selected homegarden had vegetation on at least half of its total land extent. These homegardens predominantly feature perennial crops, with spices being the dominant category, while fruits and vegetables are the secondary focus. The plant species within the homegardens are arranged in three distinct layers, showcasing a diverse range of annual and perennial crops, many of which hold economic potential. The owners of these homegardens maintain them as a subsistence farming model to meet the household’s food requirements. However, a portion of the produce also contributes to their income.

2.2 Questionnaire survey

Owners of 60 randomly selected homegrdens were interviewed. A pre-test was performed before data collection to determine the applicability and suitability of the study area and to understand the willingness of respondents to participate in the survey and validate the questionnaire. The consent of respondents was obtained after explaining the background and objectives of the study before conducting interviews.

The questionnaire includes both open and close-ended questions and information on the nature of the damage, severity of the damage, frequency of the damage, mostly damaged crops, crop damage percentage, currently used methods, the effectiveness of currently used methods, involvement of responsible institutes, and ethnobiological knowledge. Crop damage percentage was estimated on a household basis, and respondents were asked to self-estimate the overall yield losses due to wild animal damage. Later the damage percentage was estimated based on the current yield and the expected yield in the absence of wild animal damage. Effectiveness of each control method was recorded as a percentage value based on the response of each respondent and finally, an average value was calculated from all responses for each control method. The usage percentage was calculated considering the proportion of each method's use and the total number of respondents.

2.3 Field data collection using quadrat method

Based on field survey results, six homegardens were selected to establish experimental plots for continuous monitoring and evaluation. This data was also used to validate the information obtained from a questionnaire survey. Six experimental plots (15 m x 15 m) were established in six selected homegardens. Each experimental plot was demarcated by fixing four wooden poles at its corners. Each experimental site was visited once every two weeks for monitoring and data collection. Information on the types of crops damaged by wild animals, severity of crop damage, nature of the damage (feeding, dropping, digging and scratch marks), number of visits of each species, indirect signs of wild animal visits, date and time of visit and effectiveness of control measures were collected. Information was collected from direct interviews with the householders.

2.4 Data analysis

Data were analyzed using SAS statistical software. Categorical data were analyzed using the chi-square test (α=0.05) and descriptive statistics were used to explain nature and severity of crop damage and effectiveness of different control methods. The severity index and Incidence index were calculated as follows. Thereby the Risk Index was calculated following Smith et al. (2000) and Webber and Hill (2014) as follows.

2.4.1 Severity index

The Severity Index measures the intensity and impact of damage caused by wild animals to home garden crops.

$$S_j = 1 + \frac{(r-1)}{(n-1)}$$

S_j= Severity index
r = Rank based on severity by the interviewee
n= Total number of wild animal species

The Severity Index is given a score from 1 (severe) to 2 (not severe).

2.4.2 Incidence index

The Incidence Index quantifies the frequency of these damage incidents. In this study, we calculated the Incidence Index by considering the ratio of the number of reported incidents for each wild animal species to the total number of respondents.

$$I_j = \frac{t}{T}$$

I_j = Incidence index
t = Number of responses
T = Total response

The Incidence Index is from 0 (not mentioned) to 1 (mentioned by all).

2.4.3 Risk index

The Risk Index integrates both the Severity and Incidence Indices to assess the overall risk posed by the wild animals.

$$Rj = \frac{I_j}{Sj}$$

R_j = Risk index
I_j = Incidence index
S_j= Severity index

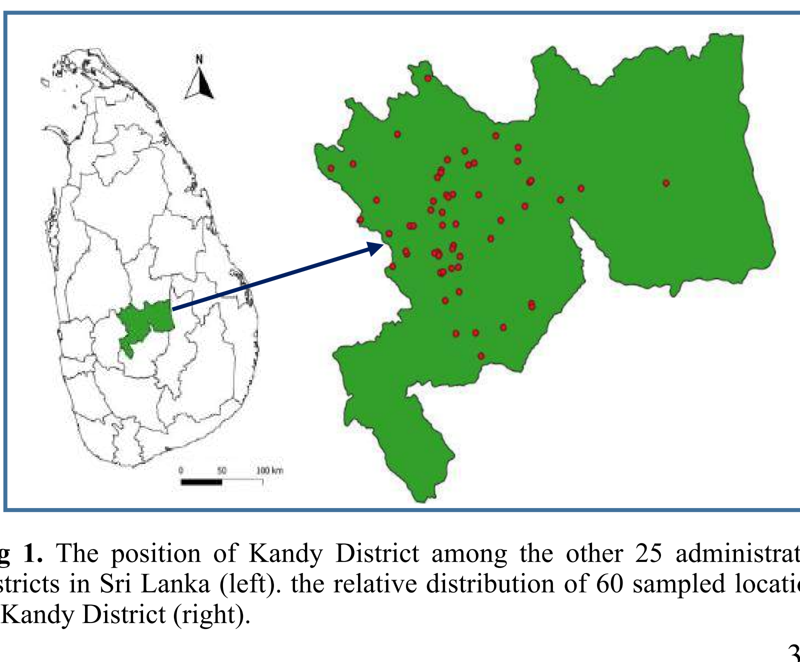

Fig 1. The position of Kandy District among the other 25 administrative districts in Sri Lanka (left). the relative distribution of 60 sampled locations in Kandy District (right).

3. Results

3.1 Risk assessment

The severity index, incidence index, and risk index were calculated to identify the most visited and destructive wild animals in KHs. Table 1 shows the most destructive wild animals in KHs along with their conservation status, as per the National Red List (MOE, 2012). Wild boar (97%) and porcupine (97%) are the most reported wild animal species (Incident Index) followed by the toque monkey (83%) in the KHs. Indian peafowl have the highest Severity Index (2.00), but the lowest risk of crop damage. This is because when the severity index increased, the severity of the damage decreased. Though Indian peafowl damage is not significant in KHs, it might be the beginning of a severe problem in the future. The highest risk index was observed for wild boar (0.87), followed by toque monkey (0.83), porcupine (0.79), and giant squirrel (0.55). Numerous reports suggest that, besides homegardens, toque monkey and wild boar are causing significant damage to large-scale commercial cultivation areas in other parts of the country as well (Rudran et al., 2021). Though yield and economic losses have not been quantitatively estimated, informal information reveals that the yield loss is over 30% due to toque monkey damage.

Since the KHs are rich in species diversity (Pushpakumara et al., 2016), it provides a diverse range of foods for wild animals throughout the year. Moreover, the high density of perennial trees (e.g. fruits, spices, timber, etc.) provides favorable habitats and resting places for them. During the field surveys, we observed that most of the torque monkey's and wild boar's corridors are running through the well-managed species-rich homegardens in the study area. KHs resemble forest ecosystems due to their high species density, which includes multiple canopy layers and a diverse range of woody perennials (Gunawardena and Fernando, 2022). Thereby KHs provide hiding places for some wild animals during the daytime, particularly barking deer, greater bandicoot rats, and porcupine. Within this background, controlling wild animal damage in KHs is a big challenge. However, more scientific investigations and community surveys are required to develop a comprehensive and long-term strategic plan to protect KHs from wild animal damage.

Table 1. Ranking of most destructive wild animals in KHs based on risk index and their conservation status

Wild animal	Conservation status	Severity index (S_j)	Incidence index (I_j)	Risk index (R_j)	Rank
Sus scrofa (Wild boar)	Least concern	1.11	0.97	0.87	1
Macaca sinica (Toque monkey)	Least concern	1.00	0.83	0.83	2
Hystrix indica (Porcupine)	Least concern	1.22	0.97	0.79	3
Ratufa macroura (Giant squirrel)	Near threatened	1.33	0.73	0.55	4
Pteropus giganteus (Indian flying fox)	Least concern	1.67	0.63	0.38	5
Petaurista philippensis (Flying squirrel)	Endangered	1.56	0.52	0.33	6
Muntiacus malabaricus (Barking deer)	Near threatened	1.44	0.37	0.25	7
Ocyceros gingalensis (Sri Lanka grey hornbill)	Least concern	1.78	0.40	0.23	8
Bandicota indica (Greater bandicoot rat)	Least concern	1.89	0.35	0.19	9
Pavo cristatus (Indian peafowl)	Least concern	2.00	0.23	0.12	10

Note: Conservation statuses are based on the National Red List (MOE, 2012)

3.2 Type and severity of crop damage

Figure 2 shows the most damaged food trees in the assessed area. Annona (*Annona muricata* L.), Avocado (*Persea Americana* Mill.), Rambutan (*Nephelium lappaceum* L), Guava (*Psidium guajava* L.), and Durian (*Durio zibethinus* L.) take more than 70% yield losses due to wild animal damage. Though most wild animals feed on fruits, toque monkeys eat immature leaves and flower buds of some plants. The wild boar, greater bandicoot rat, and porcupine mostly damage root and tuber crops, particularly manioc and yams. It is interesting to observe that monkeys are not only damaging food crops but also ornamental species. They pluck flowers, give them a sniff, and then crush them before discarding them. Despite a yield loss of 65%, coconut (*Cocos nucifera* L.) is the most frequently reported crop damaged by wild animals. Out of the 60 homegardens assessed, over 45 homegardens reported coconut as the crop which is most vulnerable to wild animal damage. The coconut is one of the main species found in almost all homegardens in the studied area and is one of the three main export crops and is also highly important for the food and nutritional security of Sri Lankan families: being as essential component of Sri Lankan's cousin. It is particularly susceptible to damage by the toque monkey, giant squirrel, and flying squirrel. The young shoots are also damaged by wild boar and porcupine.

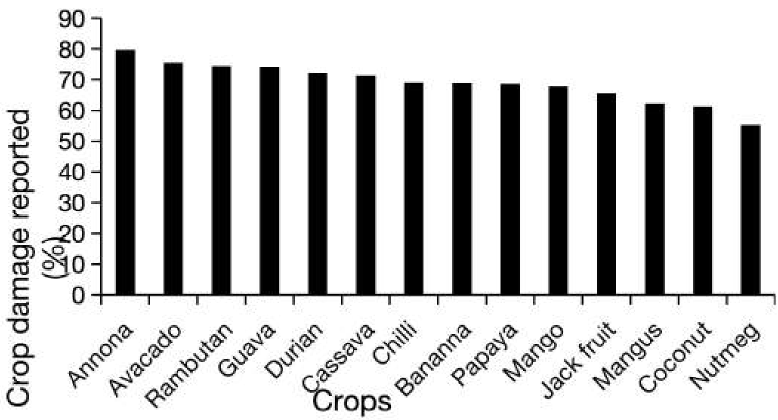

Fig 2: Reported crop damage % in KHs.

Compared to other plant categories, fruit crops are the most vulnerable crop group to wild animal damage. The KHs are rich in fruit crop species, and they provide food and habitat for wildlife throughout the year. The Toque monkeys, bats, giant squirrels, and flying squirrels are largely fed on fruit crops. Of them, toque monkeys are the most destructive species. However, according to our observations, we found that toque monkeys do not damage crops like Citrus spp., some *Solanum* species, Ginger and Turmeric, due to their special characteristics. But such crops may be damaged by wild boar, porcupine, and greater bandicoot rats. However, when selecting crop species for KHs, such crops can integrate with other species. Additionally, it is important to investigate whether these crops can serve as effective barrier crops against toque monkeys.

3.3 Application of different control methods and their effectiveness

Despite numerous methods are used to control wild animal damage, there is currently no single, permanent solution that is consistently effective in minimizing crop damage. However, as mentioned by respondents, integration of several methods would be the most effective approach to control wild animal damage in KHs. A list of currently applied methods along with their effectiveness and usage is given in Table 2.

Table 2: Different control methods used with usage percentage and effectiveness

Control methods	Effectiveness according to household experience %	Usage %
Solar powered electric fence	90	7
Wire net	73	12
Cover with barrel halves	66	12
Hanging sarees	65	5
Shooting air rifle	60	13
Using fish net	60	3
Covering of seedlings	60	3
Nickel wire	60	2
Cover with white polythene strips	50	8
Use of dogs	50	3
Cover using nylon threads	48	3
Use of face mask	46	15
Use of (*Gliricidia sepium* (Jacq.) Steud.) fence	45	17
Removing garbage from homegarden	40	3
Use of scarecrow	40	2
Hanging electric bulbs on tree	34	8
Use of *Takaya**	33	17
Use of fire crackers	30	33
Growing thorny grass/ crops at the boundaries	30	3
Use of Catapult	29	28
Spread hair cut waste around crops	25	3
Use of bamboo fence	20	2

**Takaya* is a locally developed simple tool which is making sounds and hanging on a tree.

The effectiveness of these control methods was assessed according to household experiences. The survey showed that the use of firecrackers is the most frequently used method, but its effectiveness is relatively low (30%).

This control method is mostly used for controlling toque monkeys. However, currently, there is no effective and successful method for controlling them. Recently, some people have resorted to using air rifles and face masks as a means of controlling them. However, monkeys get adapted very quickly to any new method used against them and therefore it becomes ineffective.

Though the solar powered fence system is the most effective method (90%), its usage is quite low (7%) due to the high installation cost. Respondents reported this method is especially effective for controlling wild boar and porcupine. But due to the high installation cost of solar powered fence, people use other alternative methods, such as hanging sarees, and covering the field with white polyethylene or nickel to control the wild boar damage, because such methods show more than 50% effectiveness. In addition, some traditional control methods such as covering the cultivated land using nylon threads, spreading hair cut waste around crops, removing garbage foods from a homegarden, and installation of *G. sepium* or bamboo fences are used, but they were found to be less effective.

Within the Kandy District, porcupine damage is more frequent than that of other wild animals in some areas. Since there are no accepted and effective methods, people protect their cultivation by covering barrel halves, placing a cover around seedlings, and using *G. sepium* fences. But none of these methods are successful and effective to minimize the visits of porcupines. One of the reasons for the failure of the *G. sepium* fence is that porcupines eat *G. sepium* roots and damage the root system. While it is evident that giant squirrels cause significant damage to fruit trees, controlling their population remains a challenge. Developing effective measures to curb their behavior and the resulting damage is particularly challenging due to the unique characteristics of these creatures.

In the study area, a method for damage prevention measures of flying squirrels and bats involves hanging light bulbs on trees. For instance, during the fruiting season of Durian, when flying squirrel attacks are prevalent, people will hang light bulbs on the trees to deter them. The survey reported damage by Sri Lanka grey hornbill for some crops which is uncommon but might be the beginning of a severe problem in the future. The hornbill causes more damage to the nutmeg tree which is one of the most economically important crops in KHs. Currently, there is no record of any method used by the people to control the hornbill. Out of the 60 households surveyed, only nine reported wild animal damage to their crops to the relevant authorities. Only three homegardens had received subsidies to prevent their crops from wild animal damage. Interviewees claimed that the government prioritizes addressing human-elephant conflict while not giving serious consideration to damage caused by other wild animals. The vast majority believe that controlling a growing population of wild animals, particularly, toque monkeys and wild boars by killing is the only successful method to protect their cultivation. However, it is not a realistic and viable solution due to not only their biological significance, but also cultural taboos, religious barriers as well as the resistance of animal welfare movements because most of the methods used (e.g. poisoning, shooting, electrocution, etc.) against them are injurious and lethal.

Since wild boar, toque monkeys, porcupines, and barking deer are the most destructive animals in KHs, people use various methods to control them. To find the effectiveness of the control measures against them, six experimental plots were established in selected homegardens and observations were made at regular intervals. It was considered in this study whether there is a relationship between the control methods and the number of visits of wild animals or crop damage percentage. In other words, whether or not a control method is in place affects the number of visits and the percentage of crop damage. Here animals or crops are not specified in relation to each control method. According to the results, the use of control methods has significantly minimized the number of visits of three animals other than wild boars ($P<0.05$) (Fig. 3). Even when wild animal control methods are employed, such as fencing or other physical barriers, they are not always effective in preventing wild boar attacks. Wild boars pose a significant challenge to effective control due to their strength and size, which allows them to break physical barriers. Additionally, these animals may be subject to attacks by domesticated animals and humans. Another difficulty in controlling wild boar is their nocturnal habits, which makes it challenging to implement effective control methods during the night.

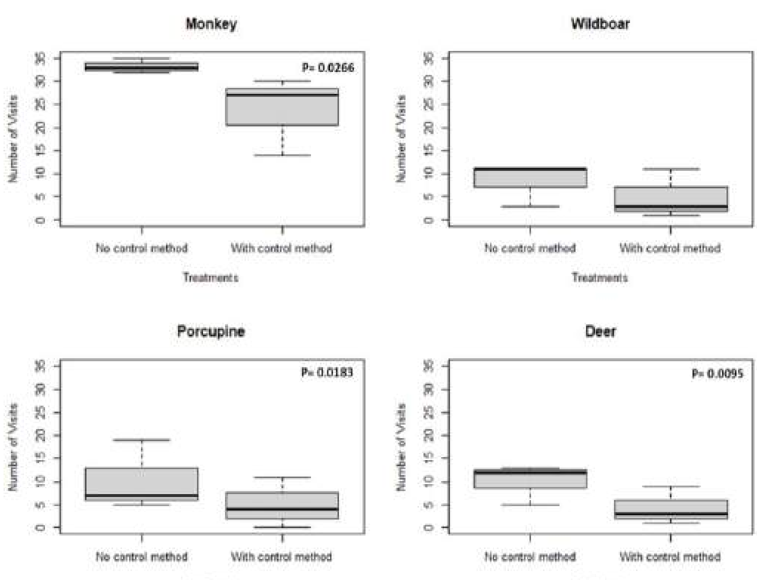

Fig 3: Effectiveness of use of control methods for four selected wild animal species.

Following the same way, the effectiveness of control methods used to protect four highly damaged crops was tested. Results revealed that except for cassava, the use of control methods has significantly minimized the crop damage (P<0.05) (Fig. 4). Being a root crop, cassava is highly attractive to both wild boars and porcupines. Toque monkeys eat both tubers and immature leaves whereas barking deer prefer to have their immature leaves at the initial growing stage. Since the crop is attracted by four major and most destructive animals, the use of currently practiced control methods is less effective in homegarden cultivation of cassava. However, our experiment concludes that the practice of the commonly used control methods is less effective for controlling wild boar damage in homegarden crops and none of the methods works for protecting cassava from wild animal damage. Although these findings offer valuable insights, it's important to note that they are specific to the site under study. Thus, it's necessary to consider that control measures should be tailored to the unique characteristics of each location and not generalized to other homegardens in different parts of the county.

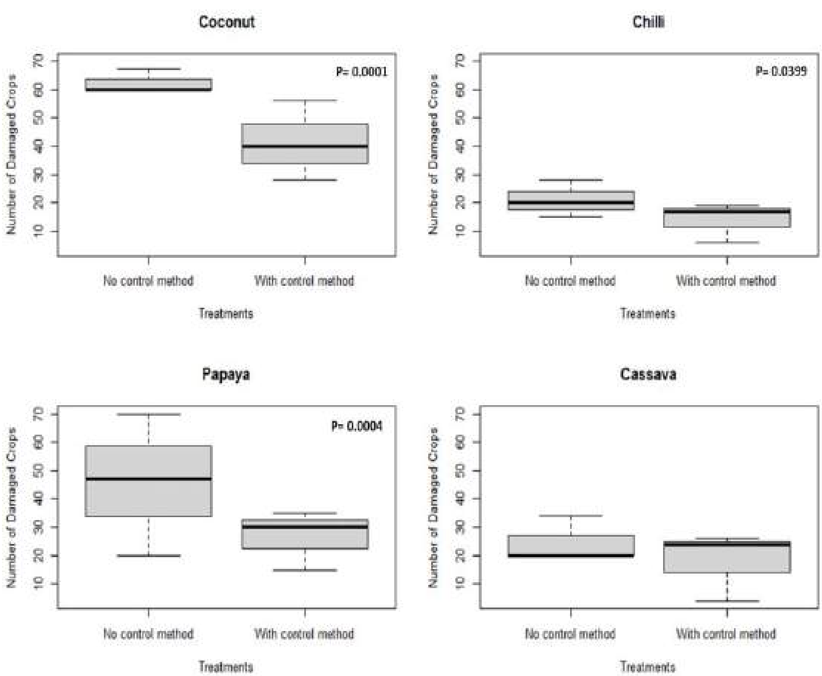

Fig 4: Effectiveness of control methods for four selected crops

3.4 Use of ethnobiological knowledge

Though people used newly introduced and traditional control methods, none of those methods are found to be an effective solution for controlling wild animal damage completely. However, some people used their own methods, developed through their experiences or handed down from their elders, to address this particular issue. Such ethnobiological knowledge will help to understand the ground truth of this perennial problem as well as contribute to setting the appropriate control measures against damage caused by wild animals. Therefore, it is important to collect, document and utilize their traditional knowledge related to wild animal damage aiming for developing more effective and efficient methods. Because integration of traditional methods and modern scientific knowledge will be an effective tool to control wild animal damage in KHs system. During our community survey, we aimed to collect and document traditional ethnobiological knowledge related to human-wild animal conflicts in KHs, which was gained through experiences and knowledge handed down from previous generations. It includes their observations of the population dynamics of wild animals in and around their area, the methods they practiced managing the conflict, and their perspectives for mitigating this issue in the future.

According to the respondents, wild animal damage has gradually increased over the last 5-10 years in KHs system. The survey reported that the toque monkey's damage to crops and their numbers have increased more rapidly than other wild animals. The respondents have an idea on both the most vulnerable crops to toque monkey damage and the most resistant crops. Drawing from their personal experiences, they are giving high priority on cultivating some crops in order to protect them from damage caused by toque monkeys. They have knowledge of the animal repellent characteristics of certain crop species. For example, *Curcuma longa* L. and *Zingiber officinale* Roscoe are highly valued due to their pungent smell. Additionally, *Solanum insanum* L. and *Solanum torvum* Sw. have pointed and sharp thorns and pubescent leaves that deter toque monkeys. As respondents mentioned, even though *Syzygium samarangense* (Blume) Merr. & L.M.Perry is full of fruits, monkeys do not damage them, perhaps due to the dark red and shiny color of the fruits. Mostly, Citrus species are not attacked by toque monkeys due to their pointed thorns and unique citrus smell of the fruits and leaves. Furthermore, among vegetables, *Capsicum annuum* L. and *Raphanus raphanistrum* subsp. *sativus* (L.) Domin are highly valued due to minimal damage, attributed to their high pungency and unique smell, respectively. It is important to consider such knowledge from traditional communities when formulating plans for managing human-wildlife conflict in home garden systems.

According to several respondents, there was a time when wild boar damage was not a significant issue in the Kandy District. This was likely because piglets were a primary food source for wild fox, which helped to control the boar population. Furthermore, they believe that with the loss of fox habitats and the increased use of agrochemicals, the fox population in the area has declined and concentrated in only a few remaining forested areas. This has allowed the wild boar population to grow unchecked, leading to more frequent incidents of damage. Moreover, people believe that with the introduction of various agrochemicals, wild foxes were locally extinct due to the eating of crabs and frogs in polluted paddy fields and marshy lands. They find that wild boar and porcupine cause most damage to homegarden crops during the rainy season. Some of the cultural and religious norms associated with the traditional community (e.g. *kem* systems) have also been used to control wild animal damage. For example, *Pirith* written papers hang on trees to protect crops from animals. *Pirith* is verses and scriptures chanted by Lord Buddha to bless and safeguard people from disasters, crisis situations, invisible forces, etc. Moreover, the survey reported that some people spread *Pirith pan* (chanted water by *Pirith*) in and around their homegarden to chase away wild animals from cultivated crops.

As respondents mentioned, they have observed that the number of visits is high during the flowering season of *Kitul* trees (*Caryota urens* L.) and there is a substantial yield reduction during their visits. However, it is important to understand the scientific background behind their observations, experience as well as traditional methods they used. Most of the respondents informed that wild animals moved from nearby forests to homegardens after clearing some forested areas and replanting pine trees in and around the Kandy District. Furthermore, they believe that toque monkeys are purposively introduced animals into the Kandy District during the period of 1990-2000. However, the survey results highlighted the importance of knowledge of the traditional community and methods used by them based on their experiences and knowledge handed over from their elders. Because such ethnobiological knowledge will be a good source of information to develop effective and efficient methods to overcome this problem.

4. Discussion

The KHs system is considered one of the most sustainable agricultural systems which significantly contributes to present-day food and nutritional security (Dissanayake, 2020; Jayakody and Basu, 2022). This unique agroforestry system has been extensively studied for its contribution to uplifting household economy, providing environmental services, and enhancing the social well-being of the community (Pushpakumara et al., 2021). Hence, government and non-government organizations have introduced several programs to further enhance the production and productivity of KHs while aiming for developing a sustainable food production unit. Respondents claimed, however, that neither projects were effective nor successful due to high incidents of wild animal damage. In addition, some respondents noted that they have had to temporarily cease growing crops and managing homegardens due to the dangers posed by wild animals, specifically wild boars and toque monkeys. They also further expressed their displeasure towards the organizations responsible for not giving adequate attention to address this problem. These facts clearly reflect the depth and weight of the human-wildlife conflicts associated hoemegarden system.

The human- wild animal conflict in homegardens is not a newly emergent crisis, but it has intensified over the last two decades. It also has global importance due to the escalating severity of these issues worldwide (Derebe et al., 2022; Mukherjee, 2016; Oommen, 2021). The present survey also evidenced that the increasing wild animal population and their impact on homegarden crops are the major impediments to crop cultivation in KHs. Therefore, it is important to understand the driving triggers which contribute to the increase in the population growth of wild animals associated with homegardens and their impact on the production and productivity of homegardnes crops. It is also important to recognize appearing of new macro pests, such as hornbills and Indian peafowl. However, it requires a national-level discussion with all stakeholders to find a solid and permanent solution for addressing this perennial problem. There has been considerable research on human-elephant conflict and ample information is available on various aspects of it (Anuradha et al., 2019; Gunawansa et al., 2023a, 2023b; Prakash et al., 2020; Rathnayake et al., 2022). The human-monkey (both toque monkey and purple faced langur (*Semnopithecus vetulus*)) conflict has also been studied to some extent (Cabral et al., 2018; Dittus et al., 2019; Dittus, 2012; Rudran et al., 2021), but adequate attention has not been given to other wild animal damage to homegarden systems. However, this knowledge gap has become a serious concern, as the involvement of monkeys in damaging crops and physical properties across the country has escalated to a critical level. The information on wild animal damage in KHs is scarce due to inadequate scientific investigation into this matter. It implies that without having baseline information, it is not possible to develop effective and efficient strategic plans to control wild animal populations and their impact on homegarden crops. Apart from biological research, conducting community surveys and extracting ethnobiological knowledge are equally important to find more viable solutions.

The active involvement of the government and private sector plays a crucial role in handling this problem. For example, the government and non-government organizations have significantly contributed to finding the viable solution for minimizing human-elephant conflict. As we realized that despite the crucial role that KHs systems play in providing sustainable agriculture and ensuring local food security and environmental stability, the issue of wild animal damage to these systems has not received adequate attention. This lack of attention is concerning, as it puts the livelihoods of farmers and the balance of local ecosystems at risk. Government involvement is critical to handle this issue, because sometimes policy changes are needed. For example, though the giant squirrel is a one of the most destructive animals in some areas of the country, the use of control measures is problematic, because the giant squirrel is the national animal of Sri Lanka. Moreover, though some animals are macro pests and cause severe damage for cultivation, they have been declared as threatened and protected animals (Table 1). Additionally, out of the 10 most damaging animals identified in the present study, two species, the Sri Lanka grey hornbill and the toque monkey, are endemic to Sri Lanka. Despite their significance in biological diversity and being endemic or protected animals, the threats by them for cultivated crops is more significant nowadays. Since they pose significance threats to the national and household economy and food security (Colombo Page, 2022; Daily News, 2022), we consider it important to discuss the possibility of delisting them from various conservation lists and acts. The recent decision by the government to remove certain wild animals from protected lists is an important step towards mitigating this problem. However, it indicates the necessity of particularly focusing on countries' wildlife conservation policies and consulting with conservationists and researchers involved in wildlife ecology and conservation while preparing management guidelines.

Apart from the increasing population of some wild animals, respondents categorically mentioned that due to the decrease in forest cover and loss of other wildlife habitats, the damage has intensified at an alarming rate, perhaps due to the migration of animals to the human landscape. This implies the importance of conservation of existing natural habitats and reestablishing suitable habitats for them. Since data and research evidence are not available on the population dynamics of wild animals in KHs, conducting a comprehensive study on the population dynamics of wild animals associated with human habitats is a prime need. It is worth to note that Wijethilaka et al. (2021) has also reported that damage to crops and property was higher in the dry season compared to the wet season, because the wet season triggers flushing and fruiting of food sources in the forest, so the monkeys are able to get enough natural food at this time of year within the forest. But in the dry season, food sources are scarce inside the forest. According to them, this might be the reason for intensified foraging in the adjacent homegardens, resulting in high crops and property damages. It is further highlighted that importance of preserving wildlife habitats and minimizing damage to their habitats. It is also important to conduct a comprehensive environmental impact assessment before introducing new agricultural and industrial projects, and human settlements.

Traditional knowledge plays a key role in finding solutions for human-wildlife conflict (Joshi, 2017). The present study also reports that traditional communities have a substantial knowledge base, gained from their environment through experience and knowledge handed down from their elders. This knowledge has been studied in some Asian and African countries, revealing the potential of integrating such knowledge with modern practices (Hussain et al., 2022; Mwamidi et al., 2012; Ocholla et al., 2013). Some traditional practices are based on the beliefs and religious aspects of the traditional community. Without conducting detailed and comprehensive studies, it is difficult to measure their effectiveness and efficiency. Additionally, measuring the efficiency or effectiveness of religious practices is a highly sensitive topic. Yeshey et al. (2023) is also emphasized that understanding peoples' values and beliefs relating to wildlife is important in regions where human wildlife conflict is prevalent. We observed these practices during the survey and noted their continuity over generations. Exploring and documenting such ethnobiological knowledge related to human-wildlife conflict might be useful for proposing a holistic approach to handling this issue.

Due to the predominantly Buddhist population in and around the Kandy District, there is reluctance to implement many of the measures used to control wild animal populations. Furthermore, certain cultural, social, and religious barriers may limit the implementation of certain control measures, particularly those aimed at managing animal populations. In addition, it is crucial to address the concerns of various stakeholders, including government institutions and non-governmental organizations that advocate for animal rights and welfare. Public awareness programs also play a key role in mitigating wild animal damage for KHs. However, in conclusion, rather than focusing on single control methods, a more holistic approach with combination of several mechanisms is required to find a viable solution for this issue.

5. Conclusions

The issue of wild animal damage to homegarden crops is not a newly emerged problem, but it has recently intensified manifold, due to increase in population size at an unprecedented rate. These animals not only damage crops but also pose a threat to physical properties, domestic animals, and humans. Unfortunately, none of the currently applied measures have been effective in controlling them. Additionally, there is no agreement between responsible government institutes and environmental groups advocating animal rights and biodiversity conservation. The growing desperation of people who are victims of wild animal damage has a severe impact on the country's agricultural sector, food security and national income. Therefore, it is essential to take immediate action to address this issue by engaging in discussions with all stakeholders, while changing existing policies and legislation aiming to come up with an amicable solution for this perennial problem. We believe that the facts and opinions discussed here will help to enhance our understanding of the weight of the problem and provide a direction for future research focus.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

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Case Study 2

Sri Lankan Jackals (*Canis aureus naria*) as Ecological Controllers of Rodent Pests in Paddy Dominated Agricultural Landscapes of Sri Lanka

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Abstract: Rodent infestations pose a significant challenge to paddy cultivation in Sri Lanka, causing substantial crop losses and increasing the risk of zoonotic diseases such as leptospirosis. Conventional control methods relying on chemical rodenticides may lead to environmental contamination and secondary poisoning of non-target species, underscoring the need for sustainable, ecosystem-based pest management strategies. This study documents the predatory role of the Sri Lankan jackal, *Canis aureus naria*, within paddy-dominated agricultural landscapes. A total of 18 independent rodent predation events were recorded across four provinces (Western, North Western, North Central, and Southern). Observations revealed active excavation of rodent burrows along paddy bunds, successful capture of rats and mice from underground tunnels, and in-field prey consumption. The highest frequency of predation events was documented in the Western (44.4%) and North Central (33.3%) Provinces, indicating regional variation in hunting activity. These findings provide direct field-based evidence that jackals function as effective natural predators of rodent pests in agro-ecosystems. By regulating populations of rodent species, jackals may contribute to reduced crop damage and potentially lower the transmission risk of rodent-borne diseases. The study highlights the ecological and agricultural importance of conserving jackals as part of

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Salgado, A., Kodithuwakku, S., Ranawana, K.B., and Weerasekera, D.S. (2026). Sri Lankan Jackals (*Canis aureus naria*) as Ecological Controllers of Rodent Pests in Paddy Dominated Agricultural Landscapes of Sri Lanka. In: Ranil, R.H.G., Kopiyawattage, K.P.P., Weerasekera, D.S. & Chamara, R.M.S.R. (eds.). *Human−wildlife conflict of Sri Lanka*. Postgraduate Institute of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka. pp. 393–399.

integrated, wildlife-friendly pest management strategies in Sri Lanka's paddy landscapes.

Keywords: Ecological pest control, Jackals, Leptospirosis, Paddy fields, Rodents, Western Province

Introduction

Paddy cultivation is a cornerstone of agriculture in Sri Lanka, sustaining rural livelihoods and contributing significantly to national food security (Suppiah, 1985). However, paddy ecosystems are highly susceptible to rodent infestations, particularly by various species of rats (*Rattus* spp.) and mice (*Mus* spp.) and also, by bandicoot rats (Lesser Bandicoot-Rat *Bandicota bengalensis* and Greater Bandicoot-Rat *Bandicota indica*) (Sarathchandra et al., 2022). These rodents cause extensive crop losses by feeding on germinating seedlings, developing tillers, and mature grains. In addition, their burrowing activities weaken bund structures, leading to water leakage and reduced irrigation efficiency. Beyond economic impacts, rodents serve as reservoirs for zoonotic pathogens, including *Leptospira* spp., the causative agents of leptospirosis (rat fever), which poses a serious occupational health risk to farmers working in flooded fields (Agampodi et al., 2015).

Rodent control in paddy systems traditionally depends on chemical rodenticides and trapping methods (Me et al., 2021). Although these approaches may reduce rodent populations in the short term, they can result in environmental contamination, secondary poisoning of non-target wildlife, and the disruption of ecological balance within agroecosystems (Santiapillai and Read, 2010). The increasing need for sustainable agriculture has therefore highlighted the importance of ecosystem-based pest management strategies that promote natural predation as a regulatory mechanism.

The Sri Lankan jackal (*Canis aureus naria*) is a widely distributed mesopredator occurring across diverse habitats in Sri Lanka, including scrublands, wetlands, agricultural mosaics, and peri-urban landscapes (Salgado et al., 2026). Its opportunistic and flexible diet enables it to exploit small mammals, reptiles, invertebrates, and anthropogenic food sources (Fabbri, 2021). In paddy landscapes, jackals are frequently observed along field bunds, irrigation canals, and fallow patches—microhabitats that also support high densities of rats and mice. Despite their common presence in these agricultural environments, detailed documentation of jackals actively preying on rodent pests in paddy ecosystems remains limited (Jayaweera et al., 2024).

As mesopredators, jackals may provide an important ecological service by suppressing rodent populations (Salgado et al., 2026). Natural predation can reduce pest abundance, limit crop damage, and potentially lower the transmission risk of rodent-borne diseases such as leptospirosis. Recognizing and quantifying this ecological function is crucial for integrating wildlife conservation with sustainable agricultural practices.

In this study, we document 18 field observations of Sri Lankan jackals preying on rats and mice in paddy landscapes across Sri Lanka. We aim to highlight their potential role in ecological rodent control, reduction of crop damage, and mitigation of rat-borne disease risks within agricultural ecosystems.

Materials and Methods

Observations were conducted in paddy fields of Sri Lanka during October 2025. To ensure equal sampling effort, 20 observations were carried out at each study site. All observations were conducted during the dawn period, between 6:00 am and 11:30 am.

Adult Sri Lankan jackals were observed using binoculars (Swarovski EL 8.5 × 42) and a spotting scope (Swarovski ATX 95, 30–70× zoom), and photographs were taken using an iPhone 12 Pro attached to the scope, using PhoneSkope adapters at both ends.

A total of 18 hunting events were recorded. For each event, we noted the type of rodent captured (rats or mice), hunting behaviour, capture success, and any interactions with other jackals. Observations were documented in field notebooks for subsequent analysis.

Results

A total of 18 independent rodent predation events by the Sri Lankan jackal (*Canis aureus naria*) were recorded from paddy-dominated agricultural landscapes across four provinces of Sri Lanka. Observations were made in Western, Northwestern, North Central, and Southern Provinces, encompassing both actively cultivated and recently harvested paddy fields.

During these events, jackals were observed actively excavating rodent burrows along paddy bunds, capturing rodents from underground tunnel systems, and consuming the prey directly within the field environment. Handling behavior, including prey manipulation and consumption, was consistently recorded, providing direct evidence of their role as natural predators of rodents in agricultural landscapes.

The spatial distribution of predation events exhibited clear regional variation (Figure 1). The highest number of observations occurred in the Western Province (n = 8; 44.4%), followed by the North Central Province (n = 6; 33.3%). Fewer predation events were documented in the North Western Province (n = 2; 11.1%) and Southern Province (n = 2; 11.1%). The higher frequency of rodent-hunting activity in the Western and North Central Provinces suggests these regions may provide more favorable conditions for jackal foraging in paddy ecosystems. Nonetheless, the occurrence of predation events across all four provinces indicates that jackals contribute to rodent population regulation throughout diverse agro-ecological zones of Sri

Lanka, highlighting their potential role in both ecological pest control and the mitigation of rodent-borne diseases such as rat fever.

Plate 01. Observed rodent predation behavior of the Sri Lankan jackal. The jackals actively excavated rodent burrows along paddy bunds (A), captured rodents from underground tunnels and consumed the prey within the field (B).

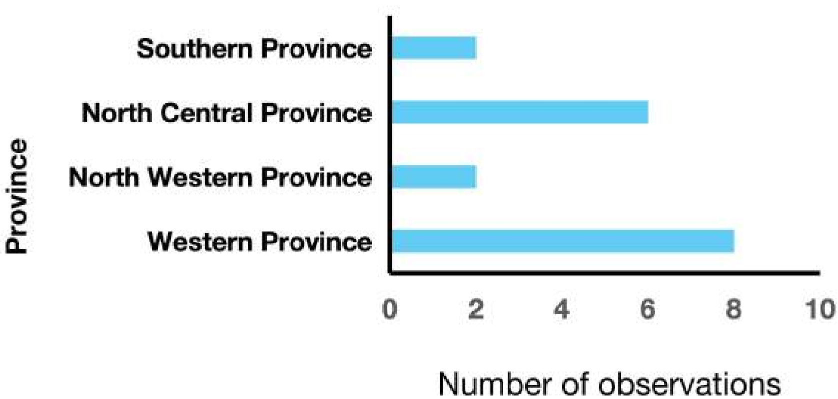

Figure 1. Distribution of recorded rodent predation events by the Sri Lankan jackal (*Canis aureus naria*) across four provinces in Sri Lanka (n = 18). A higher frequency of observations was recorded in the Western and North Central Provinces compared to the North Western and Southern Provinces.

Discussion

The present study provides direct field-based evidence of rodent predation by the Sri Lankan jackal across multiple paddy-dominated agricultural landscapes in Sri Lanka. A total of 18 independent predation events were documented, demonstrating that jackals actively hunt and consume rodents in both cultivated and recently harvested paddy fields. Observations of excavation of rodent burrows, extraction of prey from underground tunnels, and handling behavior underscore the role of jackals as effective natural predators of rodents in these agro-ecosystems (Salgado et al., 2026).

The spatial distribution of predation events revealed regional variation, with the Western (n = 8; 44.4%) and North Central (n = 6; 33.3%) Provinces exhibiting higher frequencies of observed hunting activity compared to the North Western and Southern Provinces (n = 2 each; 11.1%). This pattern may reflect differences in habitat structure, prey availability, agricultural intensity, or landscape connectivity that influence Jackal foraging efficiency. For example, densely cultivated paddy landscapes with intact bunds and limited human disturbance may provide optimal conditions for burrow excavation and rodent detection, thereby facilitating predation (Pushpakumara et al., 2023).

These findings align with previous research indicating that mesopredators, including jackals, play a critical role in regulating small mammal populations within agricultural and human-modified landscapes (Salgado et al., 2026). By targeting rodents, jackals can contribute to ecosystem-based pest management, potentially reducing crop damage and economic losses caused by pest species such as *Rattus rattus* and *Bandicota bengalensis*. In addition to agricultural benefits, natural predation by jackals may help mitigate the spread of rodent-borne zoonoses, including leptospirosis (rat fever), which is a significant public health concern in Sri Lanka (Agampodi et al., 2015).

The consistent observation of active hunting behavior, prey handling, and in-field consumption suggests that jackals employ specialized foraging strategies that optimize rodent capture (Salgado et al., 2026). These behaviors indicate a high degree of behavioral plasticity and adaptability, allowing jackals to exploit rodent prey efficiently across varying agro-ecological zones (Agampodi et al., 2015). Importantly, the occurrence of predation events across all four provinces demonstrates that jackals provide a widespread ecological service rather than a localized effect, highlighting their importance in integrated pest management strategies.

Future research should focus on quantifying the impact of jackal predation on rodent population dynamics, including the frequency of successful hunts, prey selection, and seasonal variation in hunting activity. Integrating such studies with landscape-level assessments of rodent abundance and crop damage will provide a more comprehensive understanding of the ecological and economic benefits of jackals in paddy-dominated agro-ecosystems. Overall, the present findings underscore the potential of *Canis aureus naria* as a natural, sustainable control agent of rodent pests, contributing simultaneously to agricultural productivity and public health protection.

Conclusion

The Sri Lankan jackal (*Canis aureus naria*) actively preys on rodents in paddy fields across multiple provinces of Sri Lanka, providing natural pest control. Observed behaviors, including burrow excavation, prey capture, and consumption, demonstrate their role in reducing rodent populations. This predation not only helps limit crop damage but may also reduce the risk of rodent-borne diseases, highlighting the ecological and agricultural importance of conserving jackals in farmland landscapes.

Conflict of Interest

The authors have declared that no competing interests exist.

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