EFFICACY AND WELFARE OF AVERSIVE GEOFENCING DEVICES FOR MANAGING THE MOVEMENTS OF ASIAN ELEPHANTS

A Thesis submitted by

Lokuliyanage Surendranie Judith Cabral de Mel
(BSc, MRes)

For the award of

Doctor of Philosophy

2023

ABSTRACT

Aversive geofencing devices (AGDs) or satellite-linked electric shock collars are commercially used on livestock species to restrict them to within a virtual boundary. AGDs can condition animals to associate an audio warning with an impending electric shock which is delivered as they reach a virtual boundary and avoid receiving the shock by modifying their movement. This method has potential to minimise conflicts between humans and Asian elephants (*Elephas maximus*) by conditioning elephants to avoid human habitats. Human-elephant conflict (HEC) poses a great threat to Asian elephant conservation, but most current HEC mitigation approaches have many drawbacks and AGDs have not been previously trialled on this species. Therefore, the aim of this thesis was to explore the potential of AGDs as an HEC mitigation tool by undertaking four empirical studies: assessment of (1) public perceptions of the causes of and solutions to HEC, (2) the ability of AGDs to manage captive elephant movement, (3) the welfare impact of using AGDs on captive elephants, and (4) attitudes towards using AGDs on wild elephants. The analysis of responses from 611 survey respondents revealed that all stakeholder groups (experts, farmers and others who have and have not experienced HEC) agreed on most causes of HEC and the importance of elephant conservation. But farmers who are exposed to HEC disagreed with the experts that people should try to co-exist with elephants. All stakeholder groups agreed on only a few current HEC mitigation tools as being acceptable and effective, emphasizing the need to explore additional methods such as AGDs to effectively mitigate HEC. Pilot experiments with captive Asian elephants using modified dog-training collars showed that elephants modify their movements and display desired behavioural responses to mild electric shocks delivered on the neck. The assessment of behavioural and physiological stress responses of the elephants during the above experiments revealed that AGDs do not cause unnecessary stress to elephants and can be safely used to manage them. The survey on attitudes towards such use of AGDs as a potential HEC mitigation tool revealed that respondents had positive attitudes towards the effectiveness of AGDs to manage elephant movement. Furthermore, if scientific evidence can be provided on the efficacy of AGDs in managing captive elephants, then use of AGDs on wild elephants would be perceived as more acceptable by stakeholders. Based on the outcomes of this study, the continued exploration of AGDs as an HEC mitigation tool should be encouraged. If AGDs can be developed to effectively manage wild elephant movements, it will help save lives of both humans and elephants in the future.

CERTIFICATION OF THESIS

I Lokuliyanage Surendranie Judith Cabral de Mel declare that the PhD Thesis entitled *Efficacy and welfare of aversive geofencing devices for managing the movements of Asian elephants* is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Lokuliyanage Surendranie Judith Cabral de Mel except where otherwise acknowledged, with the majority of the contribution to the papers presented as a Thesis by Publication undertaken by the student. The work is original and has not previously been submitted for any other award, except where acknowledged.

Date: 19th June 2023

Endorsed by:

Professor Tek Maraseni
Principal Supervisor

Dr. Benjamin Lee Allen
Associate Supervisor

Professor Saman Seneweera
Associate Supervisor

Professor Ashoka Dangolla
Associate Supervisor

Professor Devaka Keerthi Weerakoon
Associate Supervisor

Student and supervisors' signatures of endorsement are held at the University.

STATEMENT OF CONTRIBUTION

Paper 1:

Cabral de Mel, S. J., Seneweera, S., de Mel, R. K., Dangolla, A., Weerakoon, D. K., Maraseni, T., Allen, B. L. (2022). Current and future approaches to mitigate conflict between humans and Asian elephants: The potential use of aversive geofencing devices, *Animals*, 12, 2965. https:// doi.org/10.3390/ani12212965.

Student contributed 60% to this paper. Collectively S. Seneweera, R. K. de Mel, A. Dangolla, D. K. Weerakoon, T. Maraseni, B. L. Allen contributed the remainder.

Paper 2:

Cabral de Mel, S. J., Seneweera, S., Dangolla, A., Weerakoon, D. K., King, R., Maraseni, T., & Allen, B. L. (2023). Causes and solutions to conflict between humans and Asian elephants. Submitted to journal.

Student contributed 70% to this paper. Collectively S. Seneweera, A. Dangolla, D. K. Weerakoon, R. King, T. Maraseni, B. L. Allen contributed the remainder.

Paper 3:

Cabral de Mel, S. J., Seneweera, S., de Mel, R. K., Medawala, M., Abeysinghe, N., Dangolla, A., Weerakoon, D. K., Maraseni, T., & Allen, B. L. (2023). Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement. *Applied Animal Behaviour Science*, 258, 105822. https://doi.org/10.1016/j.applanim.2022.105822.

Student contributed 70% to this paper. Collectively S. Seneweera, R. K. de Mel, M. Medawala, N. Abeysinghe, A. Dangolla, D. K. Weerakoon, T. Maraseni, B. L. Allen contributed the remainder.

Paper 4:

Cabral de Mel, S. J., Seneweera, S., de Mel, R. K., Dangolla, A., Weerakoon, D. K., Maraseni, T., & Allen, B. L. (2023). Welfare impacts associated with using aversive geofencing devices on captive Asian elephants. *Applied Animal Behaviour Science,* 265, 105991. https://doi.org/10.1016/j.applanim.2023.105991.

Student contributed 70% to this paper. Collectively S. Seneweera, R. K. de Mel, A. Dangolla, D. K. Weerakoon, T. Maraseni, B. L. Allen contributed the remainder.

Paper 5:

Cabral de Mel, S. J., Seneweera, S., Dangolla, A., Weerakoon, D. K., Maraseni, T., & Allen, B. L. (2023). Attitudes towards the potential use of aversive geofencing devices to manage wild elephant movement. *Animals*, 13, 2657. https://doi.org/10.3390/ani13162657.

Student contributed 70% to this paper. Collectively S. Seneweera, A. Dangolla, D. K. Weerakoon, T. Maraseni, B. L. Allen contributed the remainder.

ACKNOWLEDGEMENTS

First and foremost, I wish to thank my amazing team of supervisors. I sincerely appreciate the support of my principal supervisor Prof. Tek Maraseni for guiding and encouraging me throughout the PhD. I am immensely grateful to Dr. Benjamin Allen, for being such an incredible supervisor, a friend, and a constant source of encouragement. I have no words indeed to express my gratitude to him for granting me this PhD opportunity, guiding and advising me and for always being just a phone call away whenever I needed support or had doubts or questions. I am sincerely thankful to Prof. Saman Seneweera for his guidance, providing financial support for this project through his grant and for facilitating the necessary approvals required for this study. I am incredibly grateful to him for providing me an excellent working space at the National Institute of Fundamental Studies (NIFS), Sri Lanka and also opportunities to develop my organisational and leadership skills while at NIFS. I am sincerely grateful to Prof. Ashoka Dangolla for guiding and supporting me and coordinating with various organisation to obtain necessary approvals. I sincerely appreciate his prompt responses to my requests for support and for regularly checking up on my progress. Last but not least I am ever grateful to Prof. Devaka Weerakoon, my teacher and mentor throughout the journey from my undergraduate degree to my PhD, for always making himself available when I needed his support and helping me to develop a practically workable PhD project.

I sincerely acknowledge the financial support from the University of Southern Queensland through the International Fees Research Scholarship and the National Research Council of Sri Lanka through the Investigator Driven Grant (19-046) awarded to Prof. Saman Seneweera to conduct my PhD study. During this study, waterproof IP67 electric LED Pet Trainer training shock collars (Bestobal, China) were used for the experiments.

I sincerely thank Ms. Renuka Bandaranayake the former Acting Director General and Ms. Dhammika Malsinghe, the former Director General of the Department of National Zoological Gardens, Sri Lanka, the Deputy Directors of the Pinnawala Elephant Orphanage (PEO): Mr. Mihiran Medawala and Mr. Navod Abeysinghe, veterinarians: Dr. Buddhika Bandara, Dr. Roshan Karunarathna, Dr. Malith Liyanage and Dr. Kashmini Sumanasekara, Curators: Mr. Sanjaya Rathnayake, Mr. Asanka Dissanayake and Mr. Sameera Rathnayake, Chief mahout Mr. Sumedha Herath and all the mahouts at PEO, especially Ananda, Sunil Kithsiri, Indika, Milan, Malaka, Susil, Sunil, Nuwan, Keerthi, Thushara, Sumudu, Ranga, Samaranayake, Duminda, Palitha, Upali, Priyantha, Primal, Sanath, Liyanage, Ramesh, Madhura, Alagalla, Sameera, Ajith without whom this work would not have been possible.

I also sincerely appreciate the support provided by Dr. Rachel King of University of Southern Queensland, Prof. I. M. K. Fernando, Dr. Sankha Nanayakkara, Prof. Preethi Udagama of University of Colombo, Dr. Ruchika Fernando of University of Peradeniya, Mr. Chamil Weerasiriwardena of Inov 8 Robotics (Pvt.) Ltd for their support during various stages of my PhD. My special thanks go to Malitha Senanayake of the NIFS, who was hugely involved in my project during its early stages.

I wish to sincerely thank the staff of the NIFS especially Prof. Asiri Kumara, Prof. Lalith Jayasinghe, Dr. Ruvini Liyanage, Prof. Renuka Ratnayake, Prof. M. C. M. Iqbal, Dr. Padmakantha Wanduragala, Prof. Lakshman Dissanayke, Dr. Shalini Rajakaruna, Dr. Kumari Tilakaratne, Mrs. S. Samarakkody, Mr. Anura Herath, Mr. Mahesh Kulathunga, Mr. Sanjeewa Jayaweera, Ms. Shirani Meedeniya, Mr. R. Hapukotuwa, Ms. Jeeva Kasthuri, Ms. Jayasrini Bandara, Ms. Oshadie Senevirathne, Keshan, Janaka, Rusiru, Asanka and Anushika.

I am ever grateful to all those who assisted me during my field and laboratory work and also provided inputs to improve my work in various ways: Noyalin, Hansani, Maleesha, Hasindu, Kolitha, Isuru, Nuwani. Maheshika, Dr. Chandima Kamaral, Upuli, Sewwandi, Isuri, Umair, Mahesh, Sajith, Pramudini, Priyangi, Afka, Thilakshi, Ovini, Sandhya, Tharangika, Manjula, Savani, Kavindya, Kaushalya, Dilhara, Amanda, Harshani, Kulangana, Nirubha, Ishara, Malmi, Yashodha, Menaka, Viraj, Surekha, Sanuri, Buddhika, Rasika Gunaratne, Pubudu Dissanayake, Dr. Pubudu Kumarasinghe, Dr. Rasika Dissanayake and many others. I owe a great deal of gratitude to Ashkar Thasleem, W. Mudiyanse, Sunil Gunathilake, Bhagya, Shashi, Dinesh Gabadage, Yasintha, Parinda, Ajith, Chamath, Dharmashri, Geethika, Rukmi, Dilroy, M. Senevirathne (Senavi), N. Sabesan, T. Senthuran, Pradeep Nishantha, Pavani, Piyumal, Samitha, Dilakshi, Ananda Bandara and Dr. Pravin Wijesinghe for their support in conducting the paper-based survey. I am also indeed thankful to Rukmal Ratnayake, Deepthi Madumali, Sanjaya Weerakkody, Praneeth Ratnayake, Shakila Rathnayake, Isurika Weerasinghe, Ramyani Ratnayake, Nimmi Perera, Inoka Samarkkodi, Suvanthee Gunasekera, Dr. Dishane Hewavithana, Dr. Maheshi Mapalagamage, Dr. Himali Ratnayake and Dr. Gajavathany Kandasamy for supporting me during this PhD journey.

This would not have been possible without the unwavering support and love of my family. My deepest appreciation goes to my loving husband Ruvinda, for being my best friend, constant support, advisor, lab mate, field assistant, editor, troubleshooter and for bearing with me and keeping me sane, to my wonderful parents Melanie and Sunil and my sister Ruvendranie for their love, understanding, being my inspiration and never letting me give up on my passion, and to my brother-in-law Maithri, nieces Liana and Anika and my parents-in-law Niranjalie and Rienzie for their understanding and encouragement. I am eternally grateful to them for standing by me every step of the way.

I also sincerely thank the respondents who dedicated their time to participate in the questionnaire survey. Finally, I owe a great debt to the amazing elephants at PEO. Without their cooperation this project would have just been a dream.

TABLE OF CONTENTS

LIST OF TABLES

All tables in this thesis appear in the thesis chapters of published/submitted papers, hence are not included here.

LIST OF FIGURES

All figures in this thesis appear in the thesis chapters of published/submitted papers, hence are not included here.

ABBREVIATIONS

AGD	- Aversive geofencing device
CITES	- Convention on the International Trade in Endangered Species
FCM	- Faecal cortisol metabolite
GLMM	- Generalised linear mixed-effects model
GPS	- Global Positioning System
HEC	- Human-elephant conflict
HWC	- Human-wildlife conflict
IUCN	- International Union for Conservation of Nature
NGO	- Non-governmental organisation
NIFS	- National Institute of Fundamental Studies
PCI_2	- Potential for Conflict $Index_2$
SDB	- Self-directed behaviour

CHAPTER 1: INTRODUCTION

Managing negative interactions between humans and wild animals, often termed human-wildlife conflict (HWC) (Madden, 2004), is one of the biggest challenges faced by conservation biologists. Addressing this issue requires the integration of multiple disciplines such as biology, agriculture, social sciences, economics and technology, and the production of related research has risen exponentially in the recent past (König et al., 2020; Marchini et al., 2019). HWC mitigation is especially challenging when dealing with charismatic and symbolic species such as black bears *Ursus americanus* (Johnson and Sciascia, 2013), wolves *Canis lupus* (Marino et al., 2016), pumas *Puma concolor* and jaguars *Panthera onca* (Engel et al., 2017). The Asian elephant *Elephas maximus* (Linnaeus 1758) is another such species and is the focus of this thesis.

Asian elephants have great cultural and conservation importance and are involved in HWC across their entire distribution (Williams et al., 2020). Negative interactions between humans and elephants have increased despite efforts to mitigate them (Chen et al., 2013; Prakash et al., 2020b; Zhang and Wang, 2003). This thesis focusses on human-elephant conflict (HEC) mitigation in Asia (Chapters 2 and 3) and explores satellite-linked electric shock collars or aversive geofencing devices (AGDs), a novel virtual fencing technology used on livestock species (Goliński et al., 2023), as a potential HEC mitigation tool (Chapters 4, 5 and 6). This chapter (Chapter 1) provides relevant background information on Asian elephants, including a brief overview of their biology and threats for their conservation, and also introduces the objectives, scope and organisation of the thesis.

1.1. Biology of Asian elephants

The Asian elephant belongs to the Class Mammalia and Order Proboscidea comprising of one extant Family, Elephantidae. The Elephantidae family includes only two living genera: *Loxodonta* with two species, the African savanna elephant *Loxodonta africana* and the African forest elephant *Loxodonta cyclotis*; and *Elephas* with one species, the Asian elephant *Elephas maximus*. Three subspecies of Asian elephants are currently recognised by the International Union for Conservation of Nature (IUCN): the Indian elephant *E. m. indicus* on the Asian mainland; the Sumatran elephant *E. m. sumatranus* on the Indonesian island of Sumatra; and the Sri Lankan elephant *E. m. maximus* in Sri Lanka (Williams et al., 2020). Asian elephants in Borneo are identified as genetically and morphologically distinct from the other subspecies and therefore may be considered as a fourth subspecies *E. m. borneensis* in the future (Fernando et al., 2003; Sharma et al., 2018). Asian elephant (hereafter elephant) distribution once extended from the Euphrates and Tigris Rivers in west Asia to the Yangtze-Kiang River in China (Olivier, 1978), but they presently range in only 13 countries: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam (Fernando and Pastorini, 2011). Population estimates of elephants in range countries vary from 104–132 individuals in Vietnam to 29,964 in India (Menon and Tiwari, 2019). The global population of this species is estimated to be about 48,323–51,680 individuals, of which ~75% is found in India and Sri Lanka (Menon and Tiwari, 2019).

Elephants are social animals, living in basic social units of matriarchal groups of 5–20 individuals, comprising closely related adult females and their offspring, led by the oldest female (Sukumar, 2006). Both males and females attain sexual maturity around 10–14 years of age, and males disperse from their natal herds as they reach adulthood, thereby avoiding inbreeding, and mostly live alone or in small temporary groups with weak bonds (Sukumar, 1989). Female elephants reproduce every four to five years with a gestation period of 20-21 months (Sukumar, 2006). Male elephants come to musth (a physiological and behavioural phenomenon where the testosterone levels in blood is generally increased, temporal glands secrete a pungent fluid, with the animal showing high level of aggression towards other animals) once a year, during which males have better chances for mating with females (Sukumar, 2006; Vidya and Sukumar, 2005).

Elephants are mega-herbivores. They browse and graze, spending about 12–18 hours consuming ~150 kg of food a day (Sukumar, 2003; Vancuylenberg, 1977). They are also forest engineers, modifying their habitat as they move and forage. Radio telemetry studies have shown that home ranges of this species vary from as small as ~50 km^2 to as large as ~800 km^2, and that they may travel long distances, with variations dependent on resource availability, reproductive status, etc. (Alfred et al., 2012; Baskaran et al., 1993; Fernando et al., 2008b). Elephants are highly intelligent animals with superior cognitive skills and having strong awareness of their social and physical environment (Bates et al., 2008; Byrne et al., 2009; Hart et al., 2008). Scientists have provided evidence of elephants' ability to learn, cooperate, solve problems and innovate through experiments with both captive and wild elephants (Barrett and Benson-Amram, 2021; Dale and Plotnik, 2017; Irie-Sugimoto et al., 2008; Jacobson et al., 2023, 2022; Plotnik et al., 2011, 2010). Elephants' behavioural flexibility and their ability to innovate have also made them able to adapt, survive and overcome challenges in changing anthropogenic environments (Barrett et al., 2019; Plotnik and Jacobson, 2022).

1.2. People, culture, and Asian elephants

Elephants have played an important role in Asian cultural heritage since ancient times. The elephant is considered a sacred being and plays an important role in Hinduism and Buddhism, two of the main religions in the Asian region (Gogoi, 2018; Köpke et al., 2021; Sukumar, 2003). Elephants and elephant motifs have been used in India and Sri Lanka to symbolise pride and status (Sukumar, 2003; Wisumperuma, 2004). The earliest elephant motifs probably date back to the prehistoric Stone Age (Wisumperuma, 2004) and the earliest evidence of captive elephants is found in the Bronze Age (~3000 B.C.) during the Indus valley civilisation (Sukumar, 2003). Ancient kings maintained thousands of elephants as work animals and warriors; they also traded and gifted them between countries (Csuti, 2006; Fernando and Pastorini, 2011; Locke, 2013; McGaughey, 1960; Olivier, 1978; Riddle and Christopher, 2011; Sukumar, 2003). At present, captive elephants are commonly kept in temples and used in ceremonial and religious rituals; they are also used in the logging and tourism industries (Riddle and Christopher, 2011). There is a captive elephant population of ~15,000 in range countries (Menon and Tiwari, 2019) and another ~1,000 maintained in zoos in non-range countries (Sukumar, 2006). The largest regional populations of captive elephants are in India, Myanmar and Thailand (Asian Elephant Specialist Group, 2017). Demand for working animals has decreased with the introduction of mechanisation as well as bans on logging in many countries within the range states (Fernando and Pastorini, 2011; Lainé, 2018; Riddle and Christopher, 2011). Captive elephant populations play an essential role in creating awareness and conservation of the species (Riddle et al., 2003). Attitudes towards elephants among people may vary significantly based on religious and cultural backgrounds and also depending on whether negative or positive interactions occur between humans and wild elephants (Bandara and Tisdell, 2004; Gogoi, 2018). The greater focus on development to improve human lives today are increasingly threatening the survival of elephants.

1.3. Threats for conservation of Asian elephants

The Asian elephant is listed as Endangered by the IUCN Red List of Threatened species (Williams et al., 2020) and in Appendix 1 of Convention on the International Trade in Endangered Species (CITES) prohibiting or regulating international trade of elephants or elephant parts. The Sumatran subspecies is further listed as Critically Endangered due to the small and fragmented nature of its remaining forests being unable to sustain a viable population (Gopala et al., 2011). Despite legislation imposed internationally and within range countries for the protection of elephants, serious threats to their conservation continue.

1.3.1. Habitat loss and fragmentation

Many of the elephant range countries are developing nations with dense human populations (The World Bank, 2022) focussed on largescale development projects, converting elephant habitats to permanent human settlements, commercial areas and agricultural lands (Fernando et al., 2015; Othman et al., 2019; Padalia et al., 2019; Wadey et al., 2018). The resulting loss and fragmentation of elephant habitats lead to disruption of landscape connectivity and obstruction to traditional travel and migration routes, isolating elephant populations and reducing access to essential needs such as water sources (Fernando, 2015; Shaffer et al., 2019; Sukumar, 2006). The range of elephants has been significantly reduced over the past few decades (de Silva et al., 2023; Luo et al., 2022; Sukumar, 2003), with the worst case probably being experienced in Sumatra and Borneo (Gopala et al., 2011; Luo et al., 2022). Only 51% of the range of elephants remain unfragmented, while only ~8% is protected (Leimgruber et al., 2003). Some elephant populations are very small or declining at a high rate in some range countries (Fernando and Pastorini, 2011; Menon and Tiwari, 2019), and the local overabundance of elephants in some other areas could be due to crowding in the remaining habitats (Banks et al., 2007; Riddle et al., 2010).

1.3.2. Hunting and capture for domestication

Legal and illegal live capture and illicit trade of elephants to supplement the captive elephant populations are recorded in several nations, contributing to the continued decline of elephant numbers in the wild (Baskaran et al., 2011; Hankinson et al., 2020; Jayantha, 2011; Nijman, 2014; Prakash et al., 2020a). This could affect the conservation of wild elephants, especially in countries such as Myanmar, where large captive populations cannot be sustainably maintained by wild captures in the long term (Caughley, 1995; Leimgruber et al., 2008; Songer et al., 2016). Corruption within government authorities has also been noted as a serious issue that poses difficulties in controlling illegal capture and trade of wild elephants (Milman, 2013; Prakash et al., 2020a). Hunting elephants for ivory, meat, hair, tail, bones and skin also poses a significant threat to elephants (Khounboline, 2007; Nijman and Shepherd, 2014; Perera, 2009; Sampson et al., 2018; Santiapillai et al., 1999; Shepherd and Nijman, 2008). Selective hunting or capture of 'tuskers' (tusked males) could be reflected by the high proportion of tusk-less males in wild populations (Sukumar, 1989). Only male Asian elephants have tusks (Evans, 1910) and in the past the proportion of tuskers in a population was typically >90% (Kurt et al., 1995). Now, the proportion of tuskers is very low, particularly in north-eastern India, Myanmar and Sri Lanka (Fernando, 2000; Kurt et al., 1995; Sukumar, 2003). The selective poaching of tuskers has also led to skewed sex ratios in Southern India and such population changes may result in inbreeding due to low genetic diversity (Ramakrishnan et al., 1998; Sukumar, 2003). A rise in demand for other elephant body parts now results in the poaching of elephants irrespective of their gender or presence of tusks (Elephant Family, 2018; Sampson et al., 2018).

1.3.3. Human-elephant conflict (HEC)

HEC is a consequence of unplanned or poorly planned development amongst elephant habitats, to accommodate the needs of the rising human population, with no consideration for elephants' behavioural ecology (Fernando et al., 2008a; Fernando and Pastorini, 2011; Nelson et al., 2003; Perera, 2009; Sukumar, 2006). Large proportions of elephants inhabit fragmented and human-modified landscapes, and negative interactions between humans and elephants are somewhat unavoidable (Fernando et al., 2021; Liu et al., 2017; Madhusudan et al., 2015; Othman et al., 2019; Padalia et al., 2019). Many elephant and human lives are lost annually as a consequence of HEC (Acharya et al., 2016; Ganesh, 2019; Prakash et al., 2020b), and people also experience large scale crop and property damage (Nair and Jayson, 2021; Saif et al., 2020). Most current HEC mitigation approaches have many drawbacks and have been ineffective in sustainably resolving HEC (Cabral de Mel et al., 2022; Shaffer et al., 2019). This situation also compels people to retaliate against elephants to protect their lives and livelihoods (LaDue et al., 2021; Qomariah et al., 2018). Elephants' motives for venturing into agricultural fields and other human-dominated landscapes may be because selectively bred cultivated crops are more palatable and attractive, regardless of the availability of other food (Sukumar, 1989). It may also be because these areas overlap with traditional dispersal pathways or lie between fragmented, important habitats that fulfill their nutritional and reproductive needs (Mumby and Plotnik, 2018). Thus, conservation biologists need to explore more effective methods to resolve HEC by taking into consideration the elephants' needs and perspectives. More details on HEC and its mitigation are discussed in Chapters 2 and 3 of this thesis.

1.4. Aversive geofencing devices (AGDs) as a potential HEC mitigation tool

HEC is a very complicated and severe issue in most parts of the elephant range. Despite the many efforts by governments, researchers and conservation organisations, HEC has escalated, and elephant conservation has become extremely challenging. Most current HEC mitigation tools lack the flexibility to accommodate the needs of elephants and have been unsuccessful in providing long-lasting solutions for HEC (Mumby and Plotnik, 2018; Shaffer et al., 2019). Finding innovative HEC mitigation tools that can overcome the weaknesses of existing methods remain a key research and management priority. AGDs, or animal-borne satellite-linked electric shock collars have been suggested as a potential tool to prevent conflicts with problem elephants (Fernando, 2011) and may address many of the drawbacks of existing methods (See Chapter 2; Cabral de Mel et al., 2022). AGDs are commercially used on livestock species as a grazing management tool to restrict animal movement within virtual boundaries (Goliński et al., 2023). AGDs can automatically deliver an audio warning followed by an electric shock when an animal reaches a virtual boundary. AGDs have been successful in conditioning cattle *Bos taurus* and sheep *Ovis aries* to avoid the electric shock by associating it with the prior audio warning and thereby preventing animals from crossing virtual fences (Boyd et al., 2022; Campbell et al., 2018; Marini et al., 2018). There is potential for AGDs to successfully condition intelligent wild animals like elephants in a similar way and prevent them from entering human-dominated areas and direct them towards alternative habitats or travel routes, thereby reducing the chances of HEC incidents. For these reasons, AGDs are a tool worthy of exploring for managing elephant movements.

1.5. Objectives and methodological overview

The overall aim of this study was to explore the potential of AGDs as an effective and acceptable tool to mitigate HEC. Firstly, it was important to identify and understand the weaknesses of existing HEC mitigation methods to ensure that those issues were addressed and overcome by AGDs to the best extent possible. It was also important to review previous work done with AGDs to determine how and what needs to be done to develop this idea in a plausible way, for elephants. AGDs have never been tried on such a large wild animal before. Therefore, it was necessary to develop some basic understanding of the efficacy and welfare impacts of using AGDs in managing elephant movement by conducting preliminary research or pilot studies in controlled settings. For this, preliminary experiments needed to be conducted in a managed environment with captive elephants so that the elephants' behavioural and physiological responses to AGDs could be closely monitored (Lee and Campbell, 2021). Considering the perceptions of stakeholders is also very important when planning and implementing HEC mitigation programmes (Reed, 2008). So, it was also required to know how different stakeholders perceived the causes and solutions to HEC and the potential use of AGDs on wild elephants. Knowledge on the effectiveness and welfare impact of using AGDs on elephants and stakeholder opinions on HEC and AGDs will help to understand the potential of AGDs to mitigate HEC and to identify and prioritise areas for further research. Thus, the overall aim of this study was achieved via five specific objectives as follows:

1. Review the literature to identify drawbacks of current HEC mitigation approaches and the potential use of AGDs to mitigate HEC (Chapter 2).

A comprehensive review of literature was required to synthesise an understanding of the reasons for current HEC mitigation approaches to have failed in resolving HEC. Similar reviews have been performed in the past under various themes of HEC mitigation (Denninger Snyder and Rentsch, 2020; Goswami and Vasudev, 2017; Montgomery et al., 2022; Mumby and Plotnik, 2018; Shaffer et al., 2019). However, our review aimed to identify and discuss key problems in current HEC mitigation tools and to recognise characteristics of an ideal HEC mitigation tool to explore the possibility of how AGDs may achieve them. By reviewing the studies conducted on other species using AGDs, this review also provides an overview of how AGD development for elephants may progress and identify future areas for research in this regard.

2. Assess stakeholders' perception towards causes and solutions to HEC (Chapter 3).

When planning HEC mitigation programmes, stakeholder support and involvement is critical. Often, the lack of consensus between different stakeholders, particularly the experts and people affected by HWC, creates obstacles for successful introduction and implementation of conservation and management strategies (Kendal and Ford, 2018; Redpath et al., 2013). Therefore, in Chapter 3 we assessed how opinions of different stakeholder groups towards the causes of HEC, the importance, conservation and co-existence with Asian elephants, and the acceptability and effectiveness of potential HEC mitigation tools varied. This chapter identifies many important areas that stakeholders agree and disagree and areas that need special attention to improve the conservation and management of elephants. This chapter also shows how critical it is to explore additional methods to mitigate HEC. Although the focus of this chapter is not directly related to AGDs, the results of this survey are critical to successfully planning HEC mitigation programmes that implement AGDs in the future.

3. Evaluate the potential of managing captive elephant movement using AGDs (Chapter 4).

How elephants would respond to an electric shock from AGDs is unknown. Through preliminary or pilot experiments with captive Asian elephants in Sri Lanka this chapter evaluates the optimum strength of the electric shock required and the ideal location on the neck of the elephant for the shock to be delivered so that elephants would show the desired behavioural responses. This study also demonstrates the ability to condition elephants to avoid receiving an electric shock with an audio warning and prevent them reaching a food reward.

4. Evaluate animal welfare impacts associated with electric shocks from an AGD (Chapter 5).

If AGDs are to be implemented on wild elephants, such a tool must ensure that the animal's welfare is not unduly impacted when using them. Previous studies conducted to assess welfare impact of electric shock on dogs and livestock species have demonstrated negligible chronic effects of using them on the welfare of study animals (Campbell et al., 2019b, 2017; Kearton et al., 2020, 2019; Schalke et al., 2007; Steiss et al., 2007). Similar evidence will be important to gain the support of stakeholders to adopt AGDs as an HEC mitigation tool. Therefore, this chapter evaluates the behavioural and physiological stress responses shown by the captive elephants that participated in the experiments described in Chapter 4, on experiment days compared to pre-experiment days (baseline levels).

5. Assess attitudes towards using AGDs as a potential HEC mitigation tool (Chapter 6)

Successful adoption of a novel wildlife management approach depends on stakeholders perceiving it as a favourable and an effective approach (Denninger Snyder and Rentsch, 2020; Noga et al., 2015). Managing animals using electric shock collars has always been criticised (Blackwell et al., 2012; Masson et al., 2018b, 2018a), so this study gathered opinions of different stakeholder groups on the acceptability and effectiveness of AGDs to mitigate HEC. This chapter also discusses reasons for unacceptability and potential challenges for implementing AGDs based on respondents' feedback. This chapter helps identify areas that should be given attention when developing AGDs and to gain social acceptability so that AGDs can be successfully adopted as an effective HEC mitigation tool in the future.

CHAPTER 2: LITERATURE REVIEW – PAPER 1 – CURRENT AND FUTURE APPROACHES TO MITIGATE CONFLICT BETWEEN HUMANS AND ASIAN ELEPHANTS: THE POTENTIAL USE OF AVERSIVE GEOFENCING DEVICES

2.1. Introduction

This chapter is a review article published in *Animals* journal titled "Current and future approaches to mitigate conflict between humans and Asian elephants: The potential use of aversive geofencing devices". This review paper provides an overview of HEC in Asia and briefly discusses the functions and drawbacks of current HEC mitigation approaches, highlighting the need for additional innovative and more effective approaches to be investigated. It then introduces AGDs as a potential tool to mitigate HEC. By reviewing findings on AGDs from studies conducted with livestock species and other wild animals this chapter identifies potential challenges that could be faced when developing and implementing AGDs for elephants. It then shows how AGDs are intended to be used on wild elephants to avoid human-modified landscapes and reduce incidence of HEC. Finally, it provides recommendations on how to progress with the development of AGDs as a potential HEC mitigation tool, highlighting the research areas undertaken in the experimental chapters of this thesis, thereby setting the foundation for the rest of the thesis.

animals MDPI

Review

Current and Future Approaches to Mitigate Conflict between Humans and Asian Elephants: The Potential Use of Aversive Geofencing Devices

Surendranie Judith Cabral de Mel [1,2,*], Saman Seneweera [2,3], Ruvinda Kasun de Mel [4], Ashoka Dangolla [5], Devaka Keerthi Weerakoon [6], Tek Maraseni [1,7] and Benjamin Lee Allen [1,8]

1 Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia
2 National Institute of Fundamental Studies, Kandy 20000, Sri Lanka
3 Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, VIC 3010, Australia
4 Centre for Behavioural and Physiological Ecology, Zoology, University of New England, Armidale, NSW 2351, Australia
5 Department of Veterinary Clinical Sciences, University of Peradeniya, Peradeniya 20400, Sri Lanka
6 Department of Zoology and Environmental Sciences, University of Colombo, Colombo 00300, Sri Lanka
7 Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
8 Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth 6034, South Africa
* Correspondence: surendranie.cabral@gmail.com

check for updates

Citation: Cabral de Mel, S.J.; Seneweera, S.; de Mel, R.K.; Dangolla, A.; Weerakoon, D.K.; Maraseni, T.; Allen, B.L. Current and Future Approaches to Mitigate Conflict between Humans and Asian Elephants: The Potential Use of Aversive Geofencing Devices. *Animals* **2022**, *12*, 2965. https://doi.org/10.3390/ani12212965

Academic Editors: Dimitrios Bakaloudis and Bruce Alexander Schulte

Received: 24 September 2022
Accepted: 25 October 2022
Published: 28 October 2022

Simple Summary: Conflict between humans and Asian elephants is a major conservation issue. Here we discuss common tools used to manage human-elephant conflict (HEC) in Asia and the potential of animal-borne satellite-linked shock collars or Aversive Geofencing Devices (AGDs) for managing problem elephants. Most current HEC mitigation tools lack the ability to be modified to accommodate needs of elephants and therefore are sometimes unsuccessful. AGDs currently used to manage livestock movement can be adapted to mitigate HEC to overcome this problem. AGDs can constantly monitor animal movements and be programmed to deliver sound warnings followed by electric shock whenever animals attempt to move across virtual boundaries demarcated by managers. Elephants fitted with AGDs are expected to learn to avoid the electric shock by associating it with the warning sound and move away from specified areas. Based on the potential shown by studies conducted using AGDs on other wild species, we suggest that experiments should be conducted with captive elephants to determine the efficacy and welfare impact of AGDs on elephants. Further, assessing public opinion on using AGDs on elephants will also be important. If elephants can learn to avoid virtual boundaries set by AGDs, it could help to significantly reduce HEC incidents.

Abstract: Asian elephants are a principal cause of human-wildlife conflict. This results in the death/injury of elephants and humans and large-scale crop and property damage. Most current human-elephant conflict (HEC) mitigation tools lack the flexibility to accommodate the ecological needs of elephants and are ineffective at reducing HEC in the long-term. Here we review common HEC mitigation tools used in Asia and the potential of Aversive Geofencing Devices (AGDs) to manage problem elephants. AGDs can be configured to monitor animal movements in real-time and deliver auditory warnings followed by electric stimuli whenever animals attempt to move across user-specified virtual boundaries. Thus, AGDs are expected to condition elephants to avoid receiving shocks and keep them away from virtually fenced areas, while providing alternative routes that can be modified if required. Studies conducted using AGDs with other species provide an overview of their potential in conditioning wild animals. We recommend that the efficacy and welfare impact of AGDs be evaluated using captive elephants along with public perception of using AGDs on elephants as a means of addressing the inherent deficiencies of common HEC mitigation tools. If elephants could be successfully conditioned to avoid virtual fences, then AGDs could resolve many HEC incidents throughout Asia.

Keywords: aversive conditioning; *Elephas maximus*; human-wildlife conflict; virtual fencing; wildlife management

1. Introduction

Asian elephants *Elephas maximus* (Linnaeus 1758) once inhabited areas between the Euphrates and Tigris Rivers in west Asia to the Yangtze-Kiang River in China [1], but now inhabit a much smaller range within 13 countries: Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam [2]. The total global population is estimated to be about 48,323 to 51,680 individuals, of which almost 75% of the population is found in India and Sri Lanka [3]. There is also a captive Asian elephant population of approximately 14,930 to 15,130 in range countries [3] and another ~1000 maintained in zoos outside range countries [4]. Asian elephants (hereafter elephants) are worshiped as a god in Hinduism and have an important role in Buddhism, two of the main religions in the region [5–7]. Ancient kings maintained thousands of elephants as work animals and warriors; they also traded and gifted them between countries [1,6,8–10]. In contemporary societies, captive elephants are commonly kept in temples and are used in ceremonial and religious rituals; they are also used in the logging and tourism industries [11–13]. Thus, elephants have played an important role in Asian cultural heritage since ancient times.

Despite the elephant conservation legislation imposed, various anthropogenic activities have continued to threaten the survival of elephants. Legal and illegal capture and illicit trade of elephants to supplement captive populations occur in several nations, which contributes to the decline of elephant numbers in the wild [14–16]. Hunting elephants for ivory, meat, hair, tail, bones and skin further poses a major threat [17–19]. Thus, elephants are listed in Appendix 1 of the Convention on the International Trade in Endangered Species (CITES), prohibiting international trade of elephants and elephant parts. Elephants are also listed as Endangered on the International Union for Conservation of Nature (IUCN) Red List of Threatened species [20] given elephant distribution has fragmented and declined considerably over the past few decades [21–25]. Many Asian countries with extant elephant populations also have high human population densities and developing economies [26]. These countries focus on large-scale and rapid industrial development and expansion projects which inevitably convert areas of wilderness to permanent human settlements, commercial zones and agricultural lands [27–31]. The resulting fragmented and heterogenous landscapes thus increases the frequency of interactions between humans and elephants [32,33], which is the root cause of human-elephant conflict (HEC).

Many elephant and human lives are lost as a consequence of HEC with highest numbers recorded in India and Sri Lanka, where an average of 124 elephants and 571 humans in India [34] and 263 elephants and 81 humans in Sri Lanka [35] are killed annually. HEC related elephant deaths result from gunshot injuries, poisoning, electrocution from illegal electric fences, accidents such as falling into agricultural wells or abandoned gem pits, and collision with trains [29,36,37]. Exposure to human disturbances increases stress levels of elephants which effects their reproductive success [38]. Many infant elephants are orphaned as a result of HEC as well [29]. Injury and death of humans often occur during chance encounters, particularly at night when humans confront and seek to deter crop-raiding elephants and those that damage houses to feed on stored grains [39,40], when people step out at dawn for toileting [41], enter forests to extract resources [42], or due to irresponsible behaviour [35]. Crop raiding is the main source of conflict between humans and elephants [6,43] as elephants raid many different cultivated crops such as rice, corn, millet, maize, sugar cane, vegetables, fruits and even coconut palms [40,44–47]. Affected people experience substantial economic losses and governments spend large sums of money in compensation payments for elephant impacts [48–50]. Apart from loss of lives, crops and property, there are also social and psychological effects which are often not accounted for when assessing HEC impacts [51,52]. Thus, mitigating HEC remains a key challenge for many of the elephant range countries.

Various tools and strategies are used to mitigate HEC and keep damage-causing elephants away from crops and other human-dominated areas [39,53]. The occurrence and frequency of HEC has increased despite mitigation efforts by governments and conservation organisations [35,54,55] due to various weaknesses in the HEC mitigation methods presently used. Current methods are mainly focussed on managing the symptoms of the conflict, but successful mitigation of HEC requires a greater focus on the root causes [56]. Elephants occupy large home ranges and travel long distances, depending on resource availability and reproductive status [32,57,58]. For example, elephants have larger home ranges in fragmented landscapes compared to non-fragmented habitats as elephants travel more in search of food and water due to their limited availability [32]. Further, during the musth period, male elephants cover much wider ranges in search of mates compared to the non-musth period [57]. Therefore, maintaining habitat connectivity is vital for HEC mitigation and elephant conservation [59]. For this, understanding and accommodating human and elephant behaviour to prevent HEC from occurring is extremely important [60]. Developing innovative tools and strategies that can reliably keep problem-causing elephants away from humans and crops, are dynamic and flexible enough to be modified according to elephant and human needs, and pose minimum welfare impacts to elephants are sorely needed.

Satellite-linked electric shock collars or Aversive Geofencing Devices (AGDs) can automatically deliver a warning sound followed by an electric shock as an animal reaches a virtual boundary, and have been successfully used in managing livestock movement [61–63]. The earliest reference of using AGDs on a wild species is for coyotes *Canis latrans*, in 1976 where three out of the four shock-collared animals learnt to avoid black domestic rabbits and prey on white rabbits after 3–5 shocks [64]. AGDs appear to have the potential as an HEC mitigation tool where wildlife authorities could fit them on identified "problem" elephants [65], and create and modify virtual fences based on human and elephants' needs. If virtual fences can be created appropriately for high HEC areas and problem elephants can successfully learn to avoid them, then AGDs may become a very powerful HEC mitigation tool.

Here we briefly review the use of common approaches to manage conflict between humans and elephants across Asia, highlighting their function and drawbacks. We then discuss the potential use of AGDs as a means to address these drawbacks and sustainably mitigate HEC. We further describe important research needs that require addressing to advance the use of AGDs on elephants. Our aim is to highlight the similarities and differences between AGDs and other HEC mitigation tools and outline a pathway forward for the trial and development of AGDs on elephants.

2. HEC Mitigation Tools

A wide array of tools are used in Asia to mitigate HEC and several reviews have been published in the recent past on various aspects of HEC mitigation [56,59,60,66,67]. These have highlighted some progress, but have also highlighted a series of weaknesses in current approaches, which we discuss under five categories: (1) exclusion (2) removal of problem elephants, (3) early warning systems, (4) human centric methods and (5) habitat management, summarised in Table 1.

Table 1. Summary of common human-elephant conflict (HEC) mitigation tools.

HEC Mitigation Tool	Function	Drawbacks and Non-Targeted Effects
1. Exclusion		
Physical fences		
i. Electric fences [68,69] ii. Non-electric fences e.g., trenches, rock walls and ditches [45,70,71]	• Constructed to delineate a defined geographical area where managers can separate animals from people • Can be effective where proper monitoring and sufficient funding for fence maintenance is available [72] • In contrast to attempts at restricting elephants to small and permanently fenced areas, placing permanent electric fences around villages and temporary electric fences around agricultural lands, managed by local communities have been proven more effective [73,74]	• Expensive to build and their location cannot be easily moved once constructed [75,76] • Restrict access to critical food or habitat resources, disrupt movement and dispersal, and lead to isolation and fragmentation of populations for both elephants and non-target species [77–79] • Problem may be solved locally but can be moved to another place [80] • Elephants also learn to break electric fences [68,75] • Trenches can be filled due to erosion and elephants kicking-in the sides [18,81]
Bio fences		
iii. Live fences- planting thorny plants like *Agave*, cacti, cane/rattan etc. [39,82]	• Creating buffer zones using thorny plants that inflict mild pain and lacerations if ignored, surrounding commercial crop plants and home gardens to keep elephants away	• Applicable only in very small scale [39] • Require regular monitoring and maintenance [82] • Thick-skinned elephants can push aside thorny shrubs or move through gaps created during planting [39,75]
iv. Planting non-preferred crops e.g., chilli, citrus, bitter gourd, okra, tea, coffee, aromatic medicinal plants etc. [18,82–85]	• Planting non-preferred crops as a buffer zone or substituting attractive commercial crops with less attractive crops to keep elephants away • May also provide an additional income to farmers	• Some non-preferred plants (e.g., chilli and oranges) are known to be consumed by elephants at times [75] • May not have a good market value and even if not consumed, damage may be caused by trampling them [39]
v. Beehive fences [71,86,87]	• Beehive boxes fixed with ropes to fences are intended to repel elephants from crop fields as they fear the sting of the honeybee • Bees' honey may also provide an additional income to farmers	• Using Asian honeybees *Apis cerana indica* may be ineffective for Asian elephants because Asian honeybees are not very aggressive or because they are active during daytime while elephants raid crops during the night [86] • Bees may move away from boxes due to disturbance from humans, ants, or other animals [71]

Table 1. *Cont.*

HEC Mitigation Tool	Function	Drawbacks and Non-Targeted Effects
Other sensory deterrents		
vi. Olfactory stimuli e.g., smoke and chilli bombs, chilli-grease fences [71,76,88–90] vii. Visual stimuli e.g., bonfires, flaming torches, lighting lamps, flashlights, light shining on compact disks hung on a string [45,89,91] viii. Acoustic stimuli e.g., shouting, fire crackers, carbide cannons, thunder flashes, drum beating, metal clanging, shot guns and playback calls [45,76,92,93]	• Used as deterrents to chase or keep elephants away from human habitats and agricultural lands • May be effective if used alternatively to avoid habituation	• Cost effectiveness of chilli-grease fences in reducing crop raiding is uncertain because it is labour intensive to maintain as it require frequent reapplication and washes off during rain [71,75,76,90] • Chilli bombs may have limited usage as wind direction cannot be controlled [39,71,89] • Elephants have suffered burn injuries due to flame torches being thrown at them, heightening risk of mortality [94,95] • Elephants habituate to these methods and sometimes even act aggressively in response to them [73,89,94] • Targets only small, localised areas (e.g., small village, paddy field etc.)
ix. Elephant drives [18,27,96,97]	• Elephants are pushed out of human habitats and into protected areas using people, vehicles, aircrafts, or trained elephants	• Large-scale elephant drives are very costly, time consuming, require considerable human resources and mainly drive away family herds but not the problem-causing lone male elephants [27,39] • Poses a risk to the people involved in moving elephants • Driven elephants become concentrated into small areas with insufficient resources and then suffer starvation or escape or leave these areas, repeating the cycle of HEC [27] • Causes severe stress to elephants [98]

Table 1. *Cont.*

HEC Mitigation Tool	Function	Drawbacks and Non-Targeted Effects
2. Removal of individual problem elephants		
i. Translocation	• Targeted problem elephants are tranquilised and transported away from their capture site to protected areas [99–101], wild elephant holding grounds [102] or alternatively captured and tamed [103,104]	• Expensive operation [35,73,105] regardless of whether translocated to other wilderness areas or into captivity • Translocated elephants typically do not stay in the areas where they are released, but instead return to their place of capture or disperse and settle in new areas and create new conflicts merely shifting the conflict from one place to another [2,100,101,106] • Elephant holding grounds are expensive to build and maintain, hormonal and reproductive control is required, and the facilities can only house a relatively small number of animals which may quickly reach capacity [107,108] • Difficulty in the taming process of wild and mature elephants which may also result in injury, trauma and subsequent death of the animal [108,109] • Increasing cost of maintenance of the high number of captured problem elephants in captivity [110]
ii. Killing of problem elephants	• Identified problem individuals known to cause frequent HEC incidents may be killed, aiming to eliminate the problem from the area [75]	• Degrade the genetic diversity of a population and impractical depending on the scale of HEC [108] • Using lethal methods to resolve HEC is controversial and considered ethically unacceptable in most contexts [108,111]
3. Early warning systems		
i. Traditional early warning systems e.g., watch huts and iron watch towers [76,82,112,113]	• Places from where people can monitor elephants and alert farmers and villages to scare and chase elephants away and prevent crop damage	• Labour intensive • Loss of sleep at night may affect personal health and social wellbeing of farmers [52,114]

Table 1. *Cont.*

HEC Mitigation Tool	Function	Drawbacks and Non-Targeted Effects
ii. Modern remote sensing methods e.g., Global Positioning System (GPS) collars [115], infrasonic call detectors [116], geophones [117] trip wire systems [71], drones and infrared triggered cameras [118]	• Monitoring elephant movement remotely using emerging technologies to warn authorities and villagers via automatically triggered sirens or phone messages when elephants are in close proximity to human habitats to prevent accidental encounters with elephants.	• Limited battery life of GPS collars, high risk and cost of collaring process [119] • Risk of damage to devices by elephants and people [71] • Development and installation of technology requiring large amount of financial resources [118] • Requires uninterrupted satellite and mobile network communication in remote and heterogenous landscapes for real-time monitoring of elephants
4. Human centric methods		
i. Providing financial relief e.g., compensation and insurance schemes [48–50,120]	• Financial support as compensation or through insurance schemes to provide immediate relief from elephant impacts [121]	• Impact assessments are subjective and difficult [122] • Process of reporting incidents and claiming compensation may be complicated and time consuming [50,120,122,123] • Amount of funds available are inadequate, are subject to fraudulent claims and corruption [39,123,124] • Depending on the extent of HEC, assessment of damage could be quite labour intensive [122]
ii. Creating awareness and capacity building [29,118,125–127]	• Educating local people about the importance of elephants, and how to prevent or reduce encounters with elephants or protect themselves to improve people's perception towards elephants • Training stakeholders especially wildlife officers and local communities to handle HEC situations and empowering local communities by providing resources for alternative income generation to help change people's attitudes	• Requires post-monitoring to ensure that human attitudes, behaviours and practices have actually changed given that information can easily be misinterpreted or ignored [128]
5. Habitat management		
i. Improving connectivity between habitats [129,130]	• Creating or securing forested paths between elephant habitats with minimum human interference to reduce HEC incidents [110]	• Need for legal protection to ensure these corridors are secured and regular monitoring of corridors [129] • Financial commitment for monitoring and maintenance of these corridors [130]

Table 1. *Cont.*

HEC Mitigation Tool	Function	Drawbacks and Non-Targeted Effects
ii. Improving habitat quality inside protected areas [55,82,131,132]	• Increasing carrying capacity inside protected areas by creating and maintaining salt licks, managing water sources, planting fodder species, maintaining grassland areas and removing invasive species etc. to attract elephants, thereby managing their distribution	• Increased densities of elephants resulting from improved habitat quality may not be sustainable due to overutilisation [133] • Selectively bred cultivated crops are also known to be more palatable and attractive for elephants regardless of the availability of other food [134] • Require regular monitoring and maintenance of salt licks and water holes as well as plants until they are established [81]

Exclusion of elephants from conflict areas or restricting elephants to protected areas aims to keep elephants away from humans and their interests and is ostensibly intended to avoid the need for the direct killing of elephants in accordance with cultural and societal expectations. Exclusion is often achieved by aversive conditioning where animals learn to associate a particular behaviour with an unpleasant stimuli, and hence cease or modify that behaviour [135–137]. A multitude of aversive stimuli are used against elephants which they learn to avoid by associating it with a warning stimulus (Table 2). However, large elephant populations live outside protected areas and boundaries created by humans do not always align with the ecological boundaries that elephants adhere to [22,118,138,139]. Thus, excluding animals from human habitats will not successfully mitigate HEC unless alternative routes and habitats are provided.

Table 2. Aversive conditioning tools used in attempts to mitigate conflict between humans and Asian elephants.

Tool	Warning Signal	Aversive Stimuli
Electric fences	Visual	Electric shock, mild pain
Trenches, canals, ditches etc.	Visual	Injury and immobility
Thorny plants	Visual	Mild pain, pricks, lacerations
Non-preferred crops	Visual and olfactory	Unpleasant taste
Bee fences	Auditory visual and olfactory	Painful bee sting
Smoke, chilli bombs	Visual and olfactory	Uncomfortable olfactory stimulus
Bonfires, flashlights, flaming torches etc.	Visual	Uncomfortable visual stimulus
Shouting, thunder flashes, firecrackers, carbide cannons, playback of calls (e.g., carnivore growls) etc.	Auditory	Fear- inducing uncomfortable auditory stimulus

As an alternative to excluding elephants from human habitats, identified problem elephants may be physically removed from a population by either killing or translocating them. Large-scale culling of elephants is no longer sanctioned in Asian elephant range countries [75], but massive culling and translocation operations conducted in Africa revealed long term social disruption in the remaining younger elephants who experienced the traumatic event [140]. One reason for large-scale culling of elephants in Africa is to manage large elephant populations that have exceeded carrying capacities [133] because it would otherwise cause irreversible damage to vegetation due to overutilisation by elephants, affecting the food availability for other species [141]. However, such vegetation transformation has not been observed by Asian elephants [6]. Removal of elephants may negatively affect the stability of the source population [78] and removed elephants may be replaced by other elephants which continue the conflict [18]. Translocation of elephants may be recommended as a last resort to save individuals or very small groups isolated from other elephant populations [78]. The removal of elephants by either killing or translocation also addresses only the symptom of HEC and is typically considered unfeasible and ethically unacceptable.

Various types of early warning systems are sometimes implemented to mitigate HEC, ranging from vigilance by farmers occupying traditional watchtowers to monitoring elephants using various remote sensing technologies (Table 1). The use of more modern and emerging technologies, are gaining a lot of interest and if financial and technological barriers can be overcome, they would immensely help in avoiding encounters with elephants [118]. However, early warning systems would still require humans to respond and chase the elephants away unless they are coupled with an aversive stimulus of some kind. A better tool would be an early warning system that would automate an effective aversive response without any human interaction with elephants.

Human centric methods are focused on encouraging human-elephant co-existence and developing tolerance towards elephants by providing financial relief or by educating stakeholders. The knowledge gap about HEC and the endangered status of elephants may intensify the conflict [142]. Even though financial relief has an immediate effect and addresses only the symptom of the problem, along with creating awareness, it helps to gain continuous support of stakeholders to mitigate HEC both in the short and the long term.

Habitat management through managing ecological corridors and enriching protected areas expects to reduce human-elephant interactions by reducing the need for elephants to venture into human-dominated habitats. Elephants are forest animals, but edge species, preferring habitats with intermediate disturbance rather than undisturbed forests [143–146]. Elephants are often attracted to landscapes disturbed by humans, thereby increasing the chances of HEC [31]. Alternatively, elephants may enter human-dominated landscapes simply because it is a connecting path leading to other resources such as water and mates [60]. Therefore, giving priority to proper land use planning and improving connectivity between elephant habitats [59] will be more effective to assist dispersal of elephants with minimum human encounters.

Overall, many of the current mitigation efforts either address the symptoms of HEC or are not dynamic or flexible enough to be modified as needs change, and therefore are successful only in the short term or are not sustainable [66]. Based on the functions and drawbacks highlighted above, the following can be suggested as ideal characteristics or objectives of tools that could successfully mitigate HEC:

1. Prevents HEC incidents before they occur
2. Keeps elephants in or out of designated areas
3. Targets specific individuals or small family groups
4. Does not require the death of the animal
5. Produces minimal harm to elephants
6. Does not harm or impede non-target species
7. Does not require the construction of permanent or immovable structures
8. Can be altered, moved, or removed as needed
9. Is long-lasting or sustainable
10. Is automated, or does not require substantial human input
11. Is inexpensive or cost-effective
12. Is culturally and socially acceptable

With current mitigation tools each having only some of these characteristics (Table 1), developing new and innovative tools remains a key priority for management and research. AGDs are one such potential tool and are essentially a combination of an exclusion method using aversive conditioning stimuli and an early warning system where people can be notified when elephants are nearby, addressing many of the above characteristics. AGDs have previously been suggested as a potential HEC mitigation method [108], but little progress has been made since that time.

3. Animal-Borne Aversive Geofencing Devices (AGDs): A Potential Tool for Reducing Conflict with Asian Elephants?

3.1. Use of AGDs on Domestic Animals

AGDs have been used on domestic pets (i.e., dogs) and livestock for many decades [147]. The first commercial AGD was patented in 1973 for dogs, where a hidden, signal-emitting wire placed around a predetermined boundary triggered the animal-borne collar to deliver an electric shock when the animal approached the wire [148]. In this way, dogs were contained in a residential backyard without the need for a visible fence. These dog training collars were modified and first used on livestock in 1987 when goats (*Capra hircus*) were also successfully contained in a designated area without a visible fence [149]. Since then, AGDs that are manually controlled or ones that use proximity based sensors have been used on other livestock species like cattle *Bos taurus* [150,151] and sheep *Ovis aries* [152,153] as well. Although generally considered effective, this approach still reflected the logistical limitations of a physical electric fence, including an inability to modify virtually fenced areas easily and establishing virtual fences in large landscapes.

Technical development of AGDs has evolved since then and modern AGDs are now able to deliver stimuli automatically in conjunction with real-time GPS tracking, user alerts, and data logging capabilities similar to most standard GPS tracking devices. They have proven to successfully restrict livestock movement to large and dynamic user-specific areas without proximity-based sensors [154], overcoming the limitations of earlier attempts. Farmers can now define a virtually fenced area, upload these boundaries onto an animal-borne device, deploy it on an animal, and then remotely monitor and control the movement of that animal in real-time. Animals attempting to cross a virtual boundary are first given an audible warning, which escalates if ignored, and then the ignored warnings are followed with an electric shock if the virtual fence is breached, shepherding the animal back to the safe zone if needed [62,63,155]. The locations of such virtual fences are temporally and spatially flexible, and therefore allow managers to change or alter the location of safe zones as needed. In other words, users can remotely move their animals from one location to another or allow/deny animal access to one location or another without being present. Experiments have shown that cattle and sheep learn to associate electric shock with the warning sound emitted by the collar after just a few attempts [153,156]. Key findings of some research conducted on virtual fencing with AGDs on livestock published from 2017–2022 (~last 5 years) are given in Appendix A (Table A1).

3.2. Use of AGDs on Wildlife

Even though responses of elephants to AGDs may vary from that of other animals, reviewing what is known from studies on other wild species may provide some insight into the potential and challenges that could be expected in conditioning elephants using AGDs. Scientific material published in the past 30 years (between 1993–2022) in the English language related to the use of AGDs on wild species were searched in Web of Science and Google Scholar using the following search string: ("shock collar*" OR "electric collar*" OR "training collar*" OR "electronic collar*" OR "e-collar*" OR "automated collar*" OR "virtual fencing collar*") AND ("wildlife management" OR "wildlife conservation" OR "*wildlife conflict*" OR "predator management" OR "crop damage"). The initial search (last performed on 16th August 2022) resulted in 127 records. The titles and abstracts of each document was screened and eight empirical studies that involved direct experimentation with animal-borne electric shock collars on a wild species were extracted. References within articles were checked, and four articles missing from the initial list were added. The resulting list of articles (n = 12) are summarised in Table 3.

Table 3. Summary of studies conducted with wild species using Aversive Geofencing Devices (AGDs).

	Study	Species (Captive/Wild)	No of Shock-Collared Animals	Aim	Delivery of Stimuli	Outcome
1.	Andelt et al. (1999) [157]	Coyote (captive)	5	Prevent attacks on livestock	Manual: Shock delivered as the coyote actively pursued a lamb and was about 2–5 m from the lamb.	Shock collars were successful in preventing attacks during all attempts (n = 13) by coyotes to attack lambs. The probability of attacks on lambs decreased and the coyotes avoided, retreated, and even showed submissive behaviours towards lambs. No attacks were attempted by coyotes during the last four months of the study showing sustained effects of aversive conditioning.
2.	Appleby, (2015) [158]	Dingo (wild)	4	Mitigating human-wildlife conflict	Manual?	During a series of trials conducted with shock collars, two dingoes responded to the shock by immediately halting the problem behaviour. The third animal became hesitant to approach a target after receiving two shocks over a few days. The fourth animal tested consistently fled after receiving a shock no matter what target behaviour was involved.
3.	Cooper et al. (2005) [159]	Island fox (wild)	~68/year	Prevent attacks on nests of an endangered species	Automatic: An antenna transmitting a signal, activated the shock collars if the animal approached within ~1–2 m of the transmitting antenna wire placed around a nest tree.	Study showed that shock collars have the potential to manage predators from approaching nests. The nests protected by antennae transmitting signals were more successful (64%) than those that were not protected (31%). However, high success rate of the protected nests was also due to multiple aspects that were involved during the study and not only due to fox deterrence.
4.	Gehring et al. (2006) [160]	Gray wolf (wild)	5	Area avoidance to prevent livestock depredation	Automatic: Collars activated automatically when detected 30–70 m from the transmitter.	A 14-day shock period was successful in reducing the frequency of approaches by wolves to baited sites by 50%. The study was then successful in preventing all pack members in five shock-collared wolf packs to avoid shock sites for more than 60 days after being exposed to shocks over a 40-day period.

Table 3. *Cont.*

	Study	Species (Captive/Wild)	No of Shock-Collared Animals	Aim	Delivery of Stimuli	Outcome
5.	Hawley et al. (2009) [161]	Gray wolf (wild)	5	Area avoidance to prevent livestock depredation	Automatic: Transmitters maintaining a shock zone with a 30 m radius, activated collars when the animal entered the shock zone.	Shock collared wolves spent less time and made fewer visits to baited sites compared to control animals during shocking period. But it is not clear if wolves were successfully conditioned because only a slight reduction in visitation was observed during post-shocking period with the shock collared wolves.
6.	Hawley et al. (2013) [162]	Gray wolf (captive)	16 *	Improve shock collar design	Manual: Activation using a hand-held device.	This study tested and improved shock collar designs for safety and efficacy to eliminate neck damage and was able to extend the battery life of the collar up to 80 days while effectively delivering a shock.
7.	Nolte et al. (2003) [163]	Black-tailed deer (captive)	6	Area avoidance to reduce food competition with livestock	Automatic: A sound followed by an electric shock was emitted from the collar when the animal approached a plot with a signal emitting wire buried beneath the ground around its perimeter.	Deer successfully learnt to avoid areas associated with the shock. However, avoidance of previously shocked areas (plots) stopped sometime after shock collars were deactivated.
8.	Rossler et al. (2012) [164]	Gray wolf (wild)	10	Area avoidance to prevent livestock depredation	Automatic: Collars activated when wolves were within a 70 m radius around the bait site.	Visitation and time spent in shock zones by shock-collared wolves were less compared to control wolves during the 40-day shock period and the 40-day post-shock period. During this study, shock collars were able to condition wolves to avoid specific sites long after the shocking period and reduce visitation by other pack members not wearing shock collars indicating social facilitation.

Table 3. *Cont.*

	Study	Species (Captive/Wild)	No of Shock-Collared Animals	Aim	Delivery of Stimuli	Outcome
9.	Schultz et al. (2005) [165]	Gray wolf (wild)	2	Area avoidance to prevent livestock depredation	Manual and automatic: Wolf was shocked using a hand-held unit every time her location indicated travel within 300 m of the cattle pasture during a preliminary study. A proximity-based sensor was then used to automatically emit a beep and a shock when the animal came within 400 m of the device.	Preliminary study showed that manually activated shock collar could keep a wolf away from a farm; however, it did not have a long-term effect on the wolf's behaviour. A wolf that was receiving a beep before the shock automatically and had learnt to avoid the farm successfully, later reacted to the sound warning alone and moved about 800 m away from the beeper within 7 min avoiding the shock. In contrast two other wolves who were not wearing shock collars either did not move at all or moved towards the target in response to the beeper.
10.	Shivik and Martin, (2000) [166]	Gray wolf (wild#)	3	Prevent attacks on livestock	Automatic: Shock collar on the wolf activated if it approached within ~1 m of the calf wearing an electronic device emitting signals.	Electric shock repelled wolves from calves and wolves did not attempt an attack after the first conditioning experience. The study showed that giving the shock at ~1 m helped wolves to recognise their undesirable behaviour and maintained distance from calves.
11.	Shivik et al. (2002) [167]	Gray wolf (wild#)	5	Prevent attacks on livestock	Automatic: Shock collar on the wolf activated if it approached within ~1 m of the calf wearing an electronic device emitting signals.	Unsuccessful in conditioning wolves not to attack livestock due to various logistical and behavioural reasons.
12.	Shivik et al. (2003) [168]	Gray wolf (captive)	10?	Area avoidance to prevent livestock depredation	Automatic: Signal emitting wires buried beneath the area of the food source activated the collar if a wolf approached within 2 m of the food source.	Study was not very successful in conditioning captive wolves with training collars due to logistical and behavioural variability.

* Four or six animals used in each of the five trials. Same animals may have been re-used in some trials. # Wild, but animals were temporarily held in captivity. ? indicates uncertainty.

According to the search results, research using AGDs has been conducted with five wild species: coyotes, grey wolves *Canis lupus*, dingoes *Canis familiaris*, island foxes *Urocyon littoralis* and black-tailed deer *Odocoileus hemionus*. The total number of wild animal studies conducted over the past 30 years are very few compared to the large number of studies available on livestock (see Appendix A). Even though most studies (n = 9) used an automatic shock delivery method, they all used proximity-based sensors, limiting the area of shock collars' use. While three studies showed longer-term effectiveness of shock collars in conditioning animals after collars were deactivated [157,160,164], three other studies showed that animals returned to showing their undesirable behaviour sometime after the deactivation of shock collars [161,163,165]. Only two studies [163,165] used sound as a warning stimulus before delivering a shock, and both these studies showed that it is possible to condition animals to avoid shock using a sound warning. Effectiveness and battery life of shock collars may also be augmented by coupling a warning (lights or sound) before electric shock is delivered [163]. These studies also emphasized that use of AGDs is a better alternative than lethal control.

Many drawbacks and limitations were highlighted in these studies such as skin necrosis due to electrodes, irritation due to the collar belt material [157,159,166,167], improper fitting of collars or displacement of electrodes [161], limited battery life [157,161,162], the need for automatic activation of the collar [157], limited range of shock collar activation [159], inconsistency in shocking devices [161], and the need to reduce the weight of the shock unit [162]. Logistical difficulties of working with wild animals also affected the success of studies [168]. Further, extensive effort and high cost of collaring wild animals [159,163] could limit the number of animals that can be targeted using this approach. Variability in responses to stimuli by individual animals [168] that may also have occurred due to inconsistent shock delivery [161] was emphasized. These studies were also affected by low sample sizes and low number of trials, limiting the opportunity to test the devices properly or condition the animals [167], resulting in inconclusive outcomes. The sample size in most studies was less than 10 individuals with only a few exceptions [159,162]. Automatically activated AGDs that can be deployed over large heterogenous landscapes have not yet been tested with wild species. Investigating and overcoming these drawbacks will be essential before AGDs can be reliably implemented as an HEC mitigation tool.

3.3. AGDs as a Potential HEC Mitigation Tool

AGDs could help prevent HEC incidents before they arise if elephants learn to recognise the warning stimuli and predict the receipt of the electric shock and avoid it by moving away. This will minimise direct human interaction with elephants and prevent HEC incidents. AGDs may therefore be a good alternative when it is impractical to permanently erect electric fences in large areas [159] given their application does not require development of permanent structures, allowing wildlife managers to easily create, move, modify, and remove the virtual fences when needed. Elephants are highly intelligent and have superior cognitive abilities [169,170], making them ideal candidates for aversive conditioning with AGDs.

While the concept of testing AGDs on wild elephants to manage their movement may be attractive, elephants may not respond to the electric stimuli the same way livestock do and information available on other wild species may not be sufficient to foresee the potential of AGDs as an HEC mitigation tool. Virtual fences will also have to be established in much larger, heterogenous and complex landscapes than those that livestock are typically managed in. Figure 1 shows a conceptual illustration of how AGDs are expected to work to mitigate HEC. Conditioning elephants using AGDs is a complex process. Electric shocks are received by the elephant in the first few instances, and the probability of the unwanted behaviour (e.g., moving towards a village) is expected to decrease in the future as the animal learns to avoid the electric shock [171]. However, if the unwanted behaviour would be fully extinguished and whether elephants would move in the desired direction in the absence of a visual stimulus or a physical barrier is unknown. Unlike other wild species tested so far, an agitated elephant moving towards a village or agricultural land could create an unpredictable and potentially dangerous situation. AGDs should have a sense of directionality which is achieved by applying the stimuli only when animals move towards the exclusion zone rather than their location per se, so that they can learn the virtual fences accurately [156]. This will allow the animal to predict and control the receipt of the aversive stimuli while minimising the stress [172,173] and move in the desired direction. Planning, designing and monitoring virtual fences should also be done carefully. Baseline studies of land use and movement of both humans and elephants needs to be evaluated on a case-by-case basis [60] and all stake holders such as authorities, researchers and villagers should work together in planning and designing the location of virtual fences. These virtual fences should then be continuously monitored and evaluated and be modified as and when appropriate. Keeping elephants in or out of a designated area using AGDs would be possible by designing virtual fences in such a way that a safe 'escape route' is clear and available.

Fitting AGDs on wild elephants would also be a complex and costly process [119], so AGDs cannot be deployed on all elephants. Since most crop raiding elephants are lone males [43,174,175], installing AGDs on identified problem-causing lone elephants and matriarchs of herds would be more appropriate. Social facilitation could be expected to occur in group living, long lived animals like elephants where a matriarch collared with an AGD may lead the rest of the herd to avoid the electric shock associated with the virtual fence [147,176]. Learning to avoid virtual fences through social facilitation has been shown to occur in cattle and sheep with only a proportion of the animal group collared with AGDs [177,178]. The potential for wolves to learn through social facilitation was also shown where the rest of the pack members not wearing shock collars learnt to avoid a baited site [164]. Monitoring elephant movement and habitat use using GPS collars is conducted widely in Asian elephant range countries [17,31,179,180]. Given that AGDs also fulfil the same function of a GPS collar, fitting AGDs may be conducted at a similar scale as part of ongoing research that involves GPS collaring on selected elephants.

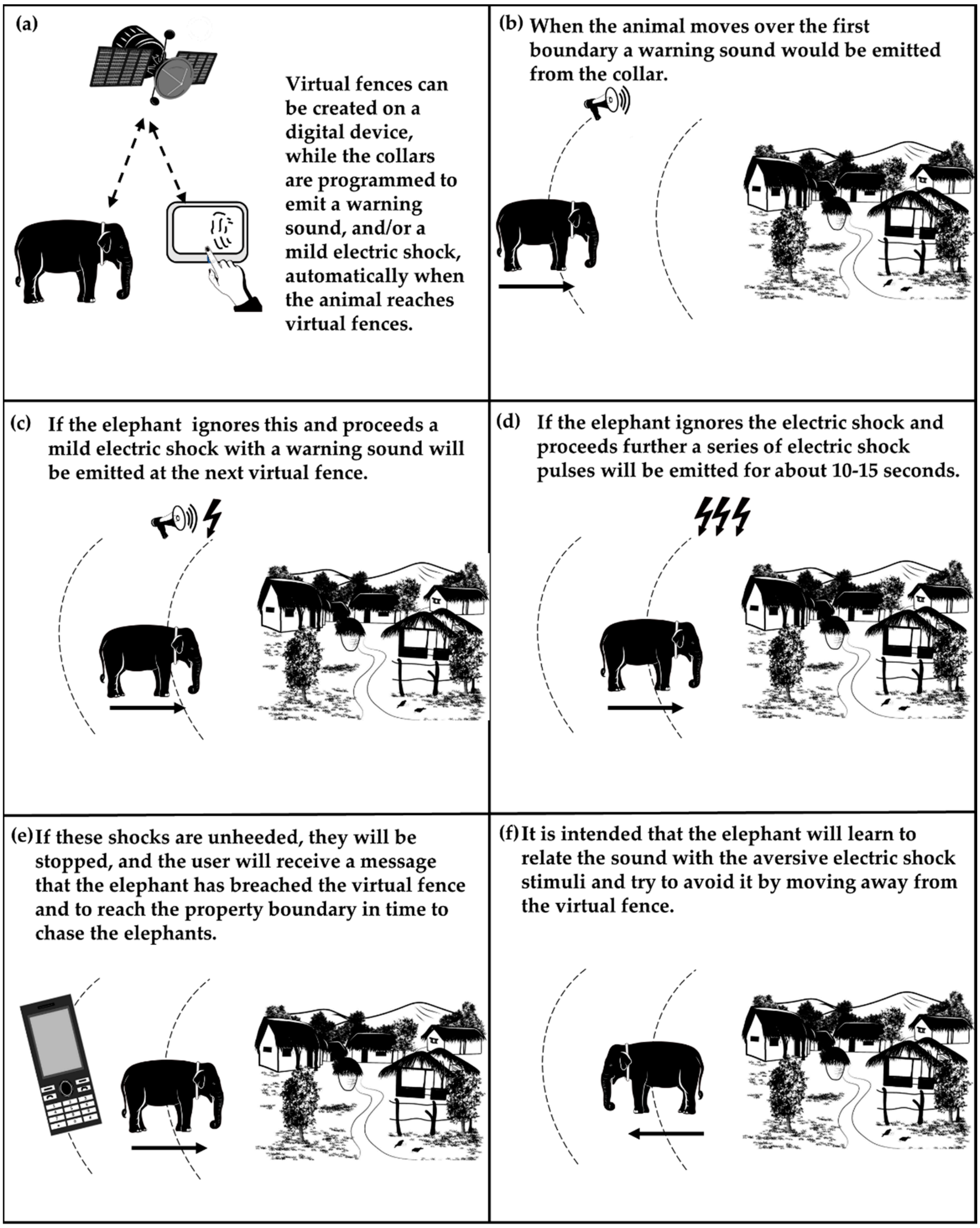

Figure 1. Conceptual diagram of how Aversive Geofencing Devices (AGDs) are expected to work to manage movement of a wild elephant. (**a**) Virtual fences are drawn on a digital device. (**b**) Sound warning is delivered as the elephant fitted with an AGD approaches first virtual fence. (**c**) Elephant approaches second virtual fence and receives both sound and electric stimuli. (**d**) Elephant proceeds further and receives electric shock as pulses. (**e**) A warning message is sent to villagers' mobile phones if the elephant ignores the electric shocks and proceeds further. (**f**) Elephant learns to turn away and avoid receiving electric shocks after few instances.

4. Progressing the Development of AGDs as a HEC Mitigation Tool

4.1. Developing and Testing the Efficacy of AGDs on Elephants

Elephants appear to be good candidates for the use of AGDs, but elephant's large size, strength, speed, and potentially dangerous behaviour poses a risk in testing AGDs on elephants. Individual variability in their capacity for learning and response to the electrical stimuli might also be expected [63,152,153,168,181]. Furthermore, elephants have several different sensitive locations on the neck where electric probes may be more or less helpful in influencing animal movement or be avoided to prevent any harm to the elephant [182]. How individuals perceive the pain from the electric shock [183] and their temperament [184] may also vary. Hence, there is no guarantee that use of AGDs will be immediately successful for elephants. To determine the efficacy of AGDs on elephants, pilot studies should be conducted using captive elephants under controlled conditions [158,185,186]. Identifying the most suitable location on the neck to deliver the shock, and the safest appropriate strength of the shock, should be of primary research interest [153]. Field trials will then need to be conducted to understand the learning ability of elephants to associate the warning signals with the electric shock and avoid it. Negative reinforcement is often practiced by mahouts during training and handling of captive elephants in Asia [187–189]. However, safety of the mahout, relationship between mahouts and elephants and mahouts' perception on testing AGDs on captive elephants should be considered during field trials. Exploration of the potential for captive elephants to learn through social facilitation would also be beneficial prior to testing of AGDs on wild elephants. Responses by captive elephants may not entirely represent wild elephant responses, but preliminary investigations with captive animals would still help resolve several uncertainties prior to work on wild elephants.

The longevity of AGDs must be considered given that frequent replacement of collars on wild elephants is not possible. GPS collars have limited battery life and are typically scheduled to collect GPS points every few hours [119]. However, AGDs will require real-time positioning of elephants and also generate sound and electric shock, thereby consuming a lot of battery capacity. Exploring options of harvesting energy using solar power, motion and body heat may be advantageous [147,190,191]. Maintaining uninterrupted communication between satellites and AGDs despite topographic barriers should be investigated [62], and the durability of the AGD is also an important factor requiring attention. In addition to being waterproof, the device may also have to be resistant to mud. AGDs should also be able to withstand strong movements such as head shaking or collar shaking using the trunk or rubbing of the collar against hard surfaces. Each of these issues need further exploration before AGDs will be ready for operational deployment on wild elephants.

4.2. AGDs and Elephant Welfare

AGDs typically expose animals to a high voltage electric shock with a very low amperage, delivered as pulses for a few milliseconds at a time [157,183], thereby minimising harm to the animal [192]. The strength of the shock from AGDs would also be much lower than what is received from electric fences [193]. Electricity will pass through and pain will be felt only between the contact points of the electrodes [194]. Further, when using AGDs the aversive stimulus is felt by the fewest number of possible animals and does not affect non-target individuals or species. Using devices that intentionally expose animals to pain naturally raise concerns about the ethical and welfare implications for the animal [158,195,196]. It might be expected that animals would show acute stress responses during early stages of learning, but after learning has occurred and animals know how to avoid the stimuli effectively, chronic stress levels should be no different from normal baseline levels [186,197]. Several studies have explored physiological stress levels using cortisol hormone and behavioural responses to understand the welfare of animals in relation to aversive conditioning [154,172,173,193,198–200]. If animals continue to show chronic stress responses and inability to learn, the experiment may need to be modified or discontinued with those animals [197]. Measuring cortisol hormone and behavioural time budgets are commonly used to assess stress levels of elephants [201–203]. Therefore, during preliminary studies, similar analysis should be done, as an indicator of welfare impacts associated with AGDs on elephants.

4.3. Public Acceptance for Using AGDs on Elephants

Obtaining acceptance of all stakeholders, local communities, line agencies, local administration and government is required to mainstream the use of AGDs. All approaches to managing HEC cause some sort of pain, distress, or disruption to elephants, but public acceptance of AGDs depends on how these welfare impacts compare to or are perceived to be compared to other HEC mitigation tools (Table 1). Use of electronic training collars on animals is not a common practice in Asian elephant range countries. Therefore, public reluctance to accept a novel technology may also be a challenge. In addition to the efficacy and welfare, successful adoption of new mitigation tools will be contingent on the probability of people to perceive it favourably, the capacity for the relevant stakeholders to implement or maintain it, and their ability to expand and adapt it on a wider scale [66]. Attitudes towards elephants may also affect the social acceptability of giving an electric shock to elephants using collars. This may vary significantly based on religious and cultural backgrounds and also depending on whether negative or positive interactions occur between humans and wild elephants [5,204]. Where negative perceptions are shown towards mitigation tools that have high efficacy, effort could be made to create awareness and change people's attitudes towards such HEC mitigation tools. Hence, sociological surveys should be conducted to understand attitudes of various stakeholders at a preliminary stage to determine public opinion and acceptability of using AGDs on elephants in the future.

5. Conclusions

Elephants are endangered and play a significant role in the ecosystem and culture. Conflict between humans and elephants is one of the most important environmental issues in Asian elephant range countries. A variety of approaches are used to mitigate HEC, although most have not been very successful given they are not flexible or dynamic enough to be modified according to elephants' behavioural and ecological needs. AGDs may overcome many of these issues, but require further development. AGDs may safely prevent elephant movement into human habitations and help humans and elephants coexist if elephants successfully learn to associate the non-aversive auditory stimulus with the aversive electric shock. Use of AGDs may be a more ethical choice than elephant removal. However, AGDs first require field-testing with captive elephants under controlled conditions to refine their design and optimise their efficacy and welfare impacts. Understanding public perceptions about AGDs is also important. AGDs will not be a 'silver bullet' for HEC, but they do overcome many of the limitations of current tools and may therefore become a powerful new management tool for reducing HEC in the future.

Author Contributions: Conceptualization, S.J.C.d.M. and B.L.A.; writing—original draft preparation, S.J.C.d.M.; writing—review and editing, S.S., R.K.d.M., A.D., D.K.W., T.M. and B.L.A.; supervision S.S., A.D., D.K.W., T.M. and B.L.A.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: S.J.C.d.M was jointly supported by the University of Southern Queensland, Australia (International PhD fees scholarship) and the National Institute of Fundamental Studies, Kandy, Sri Lanka (in-kind support). The project was funded by the National Research Council, Sri Lanka, grant number 19-046, awarded to S.S.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Authors thank Deepthi Madumali for the digital illustrations used. Winifred Hathi and Francis Robinson provided useful advice on elephant behaviour and management. Authors also thank the anonymous reviewers for their constructive comments.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Key findings of some research conducted on virtual fencing with Aversive Geofencing Devices (AGDs) on livestock published between 2017–2022.

	Study	Country	Summary
1	Aaser et al. (2022) [205]	Denmark	AGDs were successful in keeping the cattle within the virtual fences with no acute welfare impacts. However, there were individual variations between cows in their responses and were also influenced by stimuli received by other herd members.
2	Boyd et al. (2022) [62]	USA	This study focussed on excluding cattle from recently burned areas and AGDs were quite effective in limiting the use of burned areas by cattle.
3	Brunberg et al. (2017) [206]	Norway	The prototype device used was not very successful in keeping the sheep within the restricted zones and animal welfare may not be assured with this system.
4	Campbell et al. (2017) [154]	Australia	Cattle were able to associate the audio cue with the aversive stimuli from the AGDs and avoid moving virtual fences, thus animals did not associate the aversive stimuli with the location but responded to the audio cue from the collar.
5	Campbell et al. (2018) [155]	Australia	AGDs were able to successfully exclude most cattle from accessing a feed attractant but the rate of learning highly differed between individuals.
6	Campbell et al. (2019a) [207]	Australia	AGDs were successful in temporarily excluding a group of cattle from a riparian zone and animals re-entered the previously excluded area after fence deactivation.
7	Campbell et al. (2019b) [193]	Australia	AGDs were effective in containing cattle within a virtual fenced area without much impact on physiological stress levels or behavioural time budgets and showed no difference compared with those animals within a physical electric fence.
8	Campbell et al. (2020) [61]	Australia	AGDs were able to successfully exclude a group of cattle from an environmentally sensitive area across a period of 44 days, with the feed available in the protected zone doubled by the end of the experiment.
9	Campbell et al. (2021) [208]	Australia	Preliminary trials conducted on cattle and sheep demonstrated the potential to use AGDs for herding animals, however, further experimentation with updated versions of the device is required.
10	Colusso et al. (2020) [209]	Australia	Cows were trained to learn and respond to AGDs as individuals and in groups. When those trained in groups were tested individually, they were more likely to interact with virtual fences than those initially trained individually and then later tested in groups. This study demonstrated that those trained in groups relied on the responses of their conspecifics and for accurate learning of virtual fences, it is important that individual animals directly receive stimuli.
11	Colusso et al. (2021a) [210]	Australia	Experiments conducted with AGDs to evaluate the impact of feed restriction showed that the restriction of food may impact the exclusion of cows from a feed attractant, but later they quickly learnt to avoid receiving the electrical stimuli and stayed within the restricted zone.

Table A1. *Cont.*

	Study	Country	Summary
12	Colusso et al. (2021b) [211]	Australia	AGDs were successful in excluding cows from fresh pasture even when they were only provided with post-grazing residuals. However, there were individual variations in the number of stimuli received by animals and time spent in the exclusion zone.
13	Kearton et al. (2019) [200]	Australia	Experiment was conducted to understand the stress responses of sheep to AGDs compared to other commonly encountered stimuli such as a barking dog and restraint procedures. Results showed that electric stimuli on sheep had no significant effect on physiological stress levels and showed aversive behavioural responses that were less aversive compared to commonly practiced restraining procedures.
14	Kearton et al. (2020) [172]	Australia	Predictability and controllability of the aversive stimuli from AGDs minimises both physiological and behavioural stress responses during aversive conditioning.
15	Kearton et al. (2022) [212]	Australia	Maternal demonstrators exposed to virtual fences with AGDs may contribute to the learning of virtual fences by lambs. However, this study protocol was limited by several aspects and therefore, further exploration of this is recommended.
16	Keshavarzi et al. (2020) [178]	Australia	This study showed that cattle learned to avoid virtual fences through social facilitation where animals stayed within a restricted zone based on the response of conspecifics.
17	Langworthy et al. (2021) [213]	Australia	Virtual fencing using AGDs were 99% successful in containing a herd of dairy cows within a restricted zone compared to the physical electric fences.
18	Lomax et al. (2019) [63]	Australia	AGDs were successful in keeping cows within a designated area 99% of the time, however learning rate of individual animals varied.
19	Marini et al. (2018a) [214]	Australia	Over a period of 3 days, after an average of 8 interactions, sheep learned to associate the auditory cue with the aversive stimuli. After the collar was removed, the sheep moved into the exclusion zone after 30 min.
20	Marini et al. (2018b) [153]	Australia	Mean of three trials were required for the sheep to learn to associate the auditory cue with the electrical stimuli. After that 52% of the sheep avoided receiving the electric shock after hearing the auditory signal.
21	Marini et al. (2019) [215]	Australia	The group of sheep that received both an auditory cue followed by electrical stimuli were able to predict the receipt of electrical stimuli and thus showed more favourable responses to the fence compared to the group that only received an electrical cue. Animal's temperament showed no relationship on its learning ability.
22	Marini et al. (2020) [177]	Australia	The experiment with sheep showed that collaring 66% of a flock was enough to contain the entire flock within the exclusion zone indicating that sheep learn through social facilitation. However, collaring 33% of the flock did not prevent the flock from entering the exclusion zone.

Table A1. *Cont.*

	Study	Country	Summary
23	Marini et al. (2022) [216]	Australia	Study showed that virtual fencing is as effective as electric fencing and virtual fenced sheep did not differ in their normal grazing behaviour.
24	McSweeney et al. (2020) [217]	Ireland	When visual boundaries were removed, cows made more boundary challenges. Also, cows grazed less in inclusion zone implying they were stressed.
25	Muminov et al. (2019) [218]	Korea	Goats responded positively to both electric shock and warning sounds. Also, the designed collar was effective at automatically classifying main behaviour categories.
26	Ranches et al. (2021) [219]	USA	Cows showed increased distressed behaviours when first fitted with the collars. However, they quickly adapted to the AGD. Cows also learned to avoid the exclusion zone when fitted with an AGD. Upon removing the AGD cows resumed normal behaviours.
27	Verdon et al. (2020) [181]	Australia	Study shows that cows that have had prior experience with electric fences learn the virtual fence techniques much faster.
28	Verdon and Rawnsley, (2020) [220]	Australia	Older heifers (22 months) learn to avoid the electrical stimuli quicker than younger animals (12 months). When the younger animals were re-trained at 22 months, they did not show a significant difference compared to the original 22-month animals. This showed that prior learning at a young age does not have an effect in avoiding the electrical stimuli later in life.
29	Verdon et al. (2021a) [221]	Australia	The study comprised of four groups of cattle grazing in adjacent paddocks, where two control groups were contained within physical electric fences and the other two with AGDs. AGDs successfully contained one group of animals, but the second group frequently encroached the exclusion zone. Study suggested that when animals have visual contact of other conspecifics in adjacent paddocks, the efficacy of AGDs can be reduced.
30	Verdon et al. (2021b) [222]	Australia	Milk production, live weight and standing and lying behaviour budgets did not differ between electric and virtual fence cattle groups. There was no significant welfare or behaviour effects immediately following implementation of AGDs (days 1–3). However, there was an increase in milk cortisol and changes in behavioural time budgets later (after day 4) with the virtual fence group. Therefore, a longer study period is required to determine the welfare impacts of AGDs on lactating dairy cattle

References

1. Olivier, R. Distribution and Status of the Asian Elephant. *Oryx* **1978**, *14*, 379–424. [CrossRef]
2. Fernando, P.; Pastorini, J. Range-Wide Status of Asian Elephants. *Gajah* **2011**, *35*, 15–20.
3. Menon, V.; Tiwari, S.K.R. Population Status of Asian Elephants *Elephas maximus* and Key Threats. *Int. Zoo Yearb.* **2019**, *53*, 17–30. [CrossRef]
4. Sukumar, R. A Brief Review of the Status, Distribution and Biology of Wild Asian Elephants *Elephas maximus*. *Int. Zoo Yearb.* **2006**, *40*, 1–8. [CrossRef]
5. Gogoi, M. Emotional Coping among Communities Affected by Wildlife-Caused Damage in North-East India: Opportunities for Building Tolerance and Improving Conservation Outcomes. *Oryx* **2018**, *52*, 214–219. [CrossRef]
6. Sukumar, R. *The Living Elephants: Evolutionary Ecology, Behavior and Conservation*; Oxford University Press: New York, NY, USA, 2003, ISBN 0195107780.

7. Köpke, S.; Withanachchi, S.S.; Pathiranage, R.; Withanachchi, C.R.; Gamage, D.U.; Nissanka, T.S.; Warapitiya, C.C.; Nissanka, B.M.; Ranasinghe, N.N.; Senarathna, C.D.; et al. Human–Elephant Conflict in Sri Lanka: A Critical Review of Causal Explanations. *Sustainability* **2021**, *13*, 8625. [CrossRef]
8. Csuti, B. Elephants in Captivity. In *Biology, Medicine, and Surgery of Elephants*; Mikota, S., Fowler, M., Eds.; Blackwell Publishing: Oxford, UK, 2006; pp. 15–22.
9. Locke, P. Explorations in Ethnoelephantology: Social, Historical, and Ecological Intersections between Asian Elephants and Humans. *Environ. Soc.* **2013**, *4*, 79–97. [CrossRef]
10. McGaughey, C.A. The Elephant in Ancient and Modern Writings. *Br. Vet. J.* **1960**, *116*, 255–260. [CrossRef]
11. Riddle, H.S.; Christopher, C. Captive Elephants—An Overview. *J. Threat. Taxa* **2011**, *3*, 1826–1836. [CrossRef]
12. Maurer, G.; Gimenez, O.; Mulot, B.; Lescureux, N. Under Pressure: How Human-Wild-Captive Elephant Social-ecological System in Laos Is Teetering Due to Global Forces and Sociocultural Changes. *People Nat.* **2021**, *3*, 1047–1063. [CrossRef]
13. Bansiddhi, P.; Brown, J.L.; Thitaram, C.; Punyapornwithaya, V.; Somgird, C.; Edwards, K.L.; Nganvongpanit, K. Changing Trends in Elephant Camp Management in Northern Thailand and Implications for Welfare. *PeerJ* **2018**, *6*, e5996. [CrossRef] [PubMed]
14. Nijman, V. *An Assessment of the Live Elephant Trade in Thailand*; TRAFFIC International: Cambridge, UK, 2014.
15. Prakash, T.G.S.L.; Indrajith, W.A.A.D.U.; Aththanayaka, A.M.C.P.; Karunarathna, S.; Botejue, M.; Nijman, V.; Henkanaththegedara, S. Illegal Capture and Internal Trade of Wild Asian Elephants (*Elephas maximus*) in Sri Lanka. *Nat. Conserv.* **2020**, *42*, 51–69. [CrossRef]
16. Hankinson, E.; Nijman, V. Abdullah Asian Elephants: 15 Years of Research and Conservation. *J. Phys. Conf. Ser.* **2020**, *1460*, 012055. [CrossRef]
17. Sampson, C.; McEvoy, J.; Oo, Z.M.; Chit, A.M.; Chan, A.N.; Tonkyn, D.; Soe, P.; Songer, M.; Williams, A.C.; Reisinger, K.; et al. New Elephant Crisis in Asia-Early Warning Signs from Myanmar. *PLoS ONE* **2018**, *13*, e0194113. [CrossRef]
18. Perera, B.M.A.O. The Human-Elephant Conflict: A Review of Current Status and Mitigation Methods. *Gajah* **2009**, *30*, 41–52.
19. Nijman, V.; Shepherd, C.R. Emergence of Mong La on the Myanmar–China Border as a Global Hub for the International Trade in Ivory and Elephant Parts. *Biol. Conserv.* **2014**, *179*, 17–22. [CrossRef]
20. Williams, C.; Tiwari, S.K.R.; Goswami, V.R.; de Silva, S.; Kumar, A.; Baskaran, N.; Yoganand, K.; Menon, V. *Elephas maximus*; IUCN Red List of Threatened Species 2020: 2020; e.T7140A45818198. Available online: https://www.iucnredlist.org/species/7140/45818198 (accessed on 21 May 2021).
21. Liu, P.; Wen, H.; Harich, F.K.; He, C.; Wang, L.; Guo, X.; Zhao, J.; Luo, A.; Yang, H.; Sun, X.; et al. Conflict between Conservation and Development: Cash Forest Encroachment in Asian Elephant Distributions. *Sci. Rep.* **2017**, *7*, 6404. [CrossRef]
22. Fernando, P.; De Silva, M.K.C.R.; Jayasinghe, L.K.A.; Janaka, H.K.; Pastorini, J. First Country-Wide Survey of the Endangered Asian Elephant: Towards Better Conservation and Management in Sri Lanka. *Oryx* **2021**, *55*, 46–55. [CrossRef]
23. Songer, M.; Aung, M.; Allendorf, T.D.; Calabrese, J.M.; Leimgruber, P. Drivers of Change in Myanmar's Wild Elephant Distribution. *Trop. Conserv. Sci.* **2016**, *9*, 194008291667374. [CrossRef]
24. Leimgruber, P.; Gagnon, J.B.; Wemmer, C.; Kelly, D.S.; Songer, M.A.; Selig, E.R. Fragmentation of Asia's Remaining Wildlands: Implications for Asian Elephant Conservation. *Anim. Conserv.* **2003**, *6*, 347–359. [CrossRef]
25. Luo, L.; Wang, X.; Guo, H.; Zhu, L.; Ma, Y.; Yang, R.; Wang, S.; Wang, G.; Wang, M.; Shao, J.; et al. Eighteen Years (2001–2018) of Forest Habitat Loss across the Asian Elephant's Range and Its Drivers. *Sci. Bull.* **2022**, *67*, 1513–1516. [CrossRef]
26. The World Bank Countries and Economies. Available online: https://data.worldbank.org/country (accessed on 14 September 2022).
27. Fernando, P.; Prasad, T.; Janaka, H.K.; Ekanayaka, S.K.; Nishantha, H.G.; Pastorini, J. The Use of Radio-Tracking Data to Guide Development and Manage Elephants. *Wildlanka* **2015**, *3*, 12–19.
28. Padalia, H.; Ghosh, S.; Reddy, C.S.; Nandy, S.; Singh, S.; Kumar, A.S. Assessment of Historical Forest Cover Loss and Fragmentation in Asian Elephant Ranges in India. *Environ. Monit. Assess.* **2019**, *191*, 802. [CrossRef]
29. Othman, N.; Goossens, B.; Cheah, C.P.I.; Nathan, S.; Bumpus, R.; Ancrenaz, M. Shift of Paradigm Needed towards Improving Human–Elephant Coexistence in Monoculture Landscapes in Sabah. *Int. Zoo Yearb.* **2019**, *53*, 161–173. [CrossRef]
30. Chen, Y.; Atzeni, L.; Gibson, L.; Sun, Y.; Yang, Z.; Shi, K.; Dudgeon, D. Urban Expansion and Infrastructure Development Reduce Habitat Suitability for Asian Elephants in Southwestern China. *J. Wildl. Manag.* **2022**, *86*, e22204. [CrossRef]
31. Wadey, J.; Beyer, H.L.; Saaban, S.; Othman, N.; Leimgruber, P.; Campos-Arceiz, A. Why Did the Elephant Cross the Road? The Complex Response of Wild Elephants to a Major Road in Peninsular Malaysia. *Biol. Conserv.* **2018**, *218*, 91–98. [CrossRef]
32. Alfred, R.; Ahmad, A.H.; Payne, J.; Williams, C.; Ambu, L.N.; How, P.M.; Goossens, B. Home Range and Ranging Behaviour of Bornean Elephant (*Elephas maximus borneensis*) Females. *PLoS ONE* **2012**, *7*, e31400. [CrossRef]
33. Goswami, V.R.; Vasudev, D.; Oli, M.K. The Importance of Conflict-Induced Mortality for Conservation Planning in Areas of Human-Elephant Co-Occurrence. *Biol. Conserv.* **2014**, *176*, 191–198. [CrossRef]
34. Ganesh, S. Human Elephant Conflict Kills 1713 People, 373 Pachyderms in 3 Years. Available online: https://www.thehindu.com/news/national/human-elephant-conflict-kills-1713-people-373-pachyderms-in-3-years/article26225515.ece (accessed on 11 May 2020).
35. Prakash, T.G.S.L.; Wijeratne, A.W.; Fernando, P. Human-Elephant Conflict in Sri Lanka: Patterns and Extent. *Gajah* **2020**, *51*, 16–25.

36. Asian Elephant Specialist Group. *Asian Elephant Range States Meeting, Final Report*; IUCN-SSC Asian Elephant Specialist Group: Jakarta, Indonesia, 2017.
37. LaDue, C.A.; Eranda, I.; Jayasinghe, C.; Vandercone, R.P.G. Mortality Patterns of Asian Elephants in a Region of Human–Elephant Conflict. *J. Wildl. Manag.* **2021**, *85*, 794–802. [CrossRef]
38. Tang, R.; Li, W.; Zhu, D.; Shang, X.; Guo, X.; Zhang, L. Raging Elephants: Effects of Human Disturbance on Physiological Stress and Reproductive Potential in Wild Asian Elephants. *Conserv. Physiol.* **2020**, *8*, coz106. [CrossRef] [PubMed]
39. Fernando, P.; Kumar, M.A.; Williams, A.C.; Wikramanayake, E.; Aziz, T.; Singh, S.M. *Review of Human-Elephant Conflict Mitigation Measures Practiced in South Asia*; World Wide Fund for Nature: Gland, Switzerland, 2008.
40. Neupane, D.; Johnson, R.L.; Risch, T.S. How Do Land-use Practices Affect Human—Elephant Conflict in Nepal? *Wildl. Biol.* **2017**, *2017*, 1–9. [CrossRef]
41. Saha, S.K. Innovative Way of Human-Elephant Competition Mitigation. *J. Threat. Taxa* **2020**, *12*, 16494–16501. [CrossRef]
42. Thant, Z.M.; May, R.; Røskaft, E. Pattern and Distribution of Human-Elephant Conflicts in Three Conflict-Prone Landscapes in Myanmar. *Glob. Ecol. Conserv.* **2021**, *25*, e01411. [CrossRef]
43. Campos-Arceiz, A.; Takatsuki, S.; Ekanayaka, S.K.K.; Hasegawa, T. The Human-Elephant Conflict in Southeastern Sri Lanka: Type of Damage, Seasonal Patterns, and Sexual Differences in the Raiding Behavior of Elephants. *Gajah* **2009**, *31*, 5–14.
44. Ekanayaka, S.; Campos-Arceiz, A.; Rupasinghe, M.; Pastorini, J.; Fernando, P. Patterns of Crop Raiding by Asian Elephants in a Human-Dominated Landscape in Southeastern Sri Lanka. *Gajah* **2011**, *34*, 20–25. [CrossRef]
45. Nyhus, P.J.; Tilson, R.; Sumianto. Crop-Raiding Elephants and Conservation Implications at Way Kambas National Park, Sumatra, Indonesia. *Oryx* **2000**, *34*, 262–274. [CrossRef]
46. Sukumar, R. Ecology of the Asian Elephant in Southern India. II. Feeding Habits and Crop Raiding Patterns. *J. Trop. Ecol.* **1990**, *6*, 33–53. [CrossRef]
47. Webber, C.E.; Sereivathana, T.; Maltby, M.P.; Lee, P.C. Elephant Crop-Raiding and Human-Elephant Conflict in Cambodia: Crop Selection and Seasonal Timings of Raids. *Oryx* **2011**, *45*, 243–251. [CrossRef]
48. Karanth, K.K.; Gupta, S.; Vanamamalai, A. Compensation Payments, Procedures and Policies towards Human-Wildlife Conflict Management: Insights from India. *Biol. Conserv.* **2018**, *227*, 383–389. [CrossRef]
49. Chen, S.; Yi, Z.F.; Campos-Arceiz, A.; Chen, M.Y.; Webb, E.L. Developing a Spatially-Explicit, Sustainable and Risk-Based Insurance Scheme to Mitigate Human-Wildlife Conflict. *Biol. Conserv.* **2013**, *168*, 31–39. [CrossRef]
50. Li, W.; Liu, P.; Guo, X.; Wang, L.; Wang, Q.; Yu, Y.; Dai, Y.; Li, L.; Zhang, L. Human-Elephant Conflict in Xishuangbanna Prefecture, China: Distribution, Diffusion, and Mitigation. *Glob. Ecol. Conserv.* **2018**, *16*, e00462. [CrossRef]
51. Barua, M.; Bhagwat, S.A.; Jadhav, S. The Hidden Dimensions of Human-Wildlife Conflict: Health Impacts, Opportunity and Transaction Costs. *Biol. Conserv.* **2013**, *157*, 309–316. [CrossRef]
52. Jadhav, S.; Barua, M. The Elephant Vanishes: Impact of Human–Elephant Conflict on People's Wellbeing. *Health. Place* **2012**, *18*, 1356–1365. [CrossRef] [PubMed]
53. Nelson, A.; Bidwell, P.; Sillero-Zubiri, C. *A Review of Human-Elephant Conflict Management Strategies*; Wildlife Conservation Research Unit, Oxford University: Oxford, UK, 2003.
54. Chen, Y.; Marino, J.; Chen, Y.; Tao, Q.; Sullivan, C.D.; Shi, K.; Macdonald, D.W. Predicting Hotspots of Human-Elephant Conflict to Inform Mitigation Strategies in Xishuangbanna, Southwest China. *PLoS ONE* **2016**, *11*, e0162035. [CrossRef]
55. Zhang, L.; Wang, N. An Initial Study on Habitat Conservation of Asian Elephant (*Elephas maximus*), with a Focus on Human Elephant Conflict in Simao, China. *Biol. Conserv.* **2003**, *112*, 453–459. [CrossRef]
56. Shaffer, L.J.; Khadka, K.K.; Van Den Hoek, J.; Naithani, K.J. Human-Elephant Conflict: A Review of Current Management Strategies and Future Directions. *Front. Ecol. Evol.* **2019**, *6*, 235. [CrossRef]
57. Fernando, P.; Wikramanayake, E.D.; Janaka, H.K.; Jayasinghe, L.K.A.; Gunawardena, M.; Kotagama, S.W.; Weerakoon, D.; Pastorini, J. Ranging Behavior of the Asian Elephant in Sri Lanka. *Mamm. Biol.* **2008**, *73*, 2–13. [CrossRef]
58. Baskaran, N.; Balasubramaniam, M.; Swaminathan, S.; Desai, A.A. Home Range of Elephants in the Nilgiri Biosphere Reserve, South India. In *A Week With Elephants*; Daniel, J.C., Datye, H.S., Eds.; Bombay Natural History Society and Oxford University Press: Bombay/New Delhi, India, 1995; pp. 296–313.
59. Goswami, V.R.; Vasudev, D. Triage of Conservation Needs: The Juxtaposition of Conflict Mitigation and Connectivity Considerations in Heterogeneous, Human-Dominated Landscapes. *Front. Ecol. Evol.* **2017**, *4*, 1–7. [CrossRef]
60. Mumby, H.S.; Plotnik, J.M. Taking the Elephants' Perspective: Remembering Elephant Behavior, Cognition and Ecology in Human-Elephant Conflict Mitigation. *Front. Ecol. Evol.* **2018**, *6*, 1–8. [CrossRef]
61. Campbell, D.L.M.; Ouzman, J.; Mowat, D.; Lea, J.M.; Lee, C.; Llewellyn, R.S. Virtual Fencing Technology Excludes Beef Cattle from an Environmentally Sensitive Area. *Animals* **2020**, *10*, 1069. [CrossRef] [PubMed]
62. Boyd, C.S.; O'Connor, R.; Ranches, J.; Bohnert, D.W.; Bates, J.D.; Johnson, D.D.; Davies, K.W.; Parker, T.; Doherty, K.E. Virtual Fencing Effectively Excludes Cattle from Burned Sagebrush Steppe. *Rangel. Ecol. Manag.* **2022**, *81*, 55–62. [CrossRef]
63. Lomax, S.; Colusso, P.; Clark, C.E.F. Does Virtual Fencing Work for Grazing Dairy Cattle? *Animals* **2019**, *9*, 429. [CrossRef]
64. Linhart, S.B.; Roberts, J.D.; Schumake, S.A.; Johnson, R. Avoidance of Prey by Captive Coyotes Punished with Electric Shock. In Proceedings of the 7th Vertebrate Pest Conference, Monterey, CA, USA, 9–11 March 1976; University of California: Davis, CA, USA, 1976; Volume 7, pp. 302–306.
65. Hoare, R.E. Determinants of Human-Elephant Conflict in a Land-Use Mosaic. *J. Appl. Ecol.* **1999**, *36*, 689–700. [CrossRef]

66. Denninger Snyder, K.; Rentsch, D. Rethinking Assessment of Success of Mitigation Strategies for Elephant-Induced Crop Damage. *Conserv. Biol.* **2020**, *34*, 829–842. [CrossRef]
67. Montgomery, R.A.; Raupp, J.; Mukhwana, M.; Greenleaf, A.; Mudumba, T.; Muruthi, P. The Efficacy of Interventions to Protect Crops from Raiding Elephants. *Ambio* **2022**, *51*, 716–727. [CrossRef]
68. Liefting, Y.; de Jong, J.F.; Prins, H.H.T. A New Type of Elephant Fence: Permeable for People and Game but Not for Elephant. *Gajah* **2018**, *49*, 11–19.
69. Ponnusamy, V.; Chackrapani, P.; Lim, T.W.; Saaban, S.; Campos-Arceiz, A. Farmers' Perceptions and Attitudes towards Government-Constructed Electric Fences in Peninsular Malaysia. *Gajah* **2016**, *45*, 4–11.
70. Natarajan, L.; Kumar, A.; Qureshi, Q.; Desai, A.A.; Pandav, B. Evaluation of Wall-barriers to Manage Human Conflict with Asian Elephants in India. *Wildl. Soc. Bull.* **2021**, *45*, 215–220. [CrossRef]
71. Sugiyo; Ardiantiono; Santo, A.; Marthy, W.; Amama, F. Evaluating the Intervention Methods to Reduce Human-Elephant Conflict around Way Kambas National Park. In *Conserving Sumatran Wildlife Heritage for Sustainable Livelihood, Proceedings of the 3rd International Wildlife Symposium, Lampung, Indonesia, 18–20 October 2016*; University of Lampung: Lampung, Indonesia, 2016; pp. 30–36.
72. Pekor, A.; Miller, J.R.B.; Flyman, M.V.; Kasiki, S.; Kesch, M.K.; Miller, S.M.; Uiseb, K.; van der Merve, V.; Lindsey, P.A. Fencing Africa's Protected Areas: Costs, Benefits, and Management Issues. *Biol. Conserv.* **2019**, *229*, 67–75. [CrossRef]
73. Fernando, P.; Jayawardene, J.; Prasad, T.; Hendavitharana, W.; Pastorini, J. Current Status of Asian Elephants in Sri Lanka. *Gajah* **2011**, *35*, 93–103. [CrossRef]
74. Wijesinghe, N. Path to Solve Human-Elephant Conflict. Available online: https://www.dailynews.lk/2019/01/16/features/174403/path-solve-human-elephant-conflict (accessed on 14 February 2022).
75. Desai, A.A.; Riddle, H.S. *Human-Elephant Conflict in Asia*; U.S. Fish and Wildlife Service; Asian Elephant Support: Washington, DC, USA, 2015; p. 92.
76. Gunaryadi, D.; Sugiyo; Hedges, S. Community-Based Human–Elephant Conflict Mitigation: The Value of an Evidence-Based Approach in Promoting the Uptake of Effective Methods. *PLoS ONE* **2017**, *12*, e0173742. [CrossRef] [PubMed]
77. Hayward, M.W.; Kerley, G.I.H. Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes? *Biol. Conserv.* **2009**, *142*, 1–13. [CrossRef]
78. Saaban, S.; Yasak, M.N.; Gumal, M.; Oziar, A.; Cheong, F.; Shaari, Z.; Tyson, M.; Hedges, S. Viability and Management of the Asian Elephant (*Elephas maximus*) Population in the Endau Rompin Landscape, Peninsular Malaysia. *PeerJ* **2020**, *8*, e8209. [CrossRef]
79. Smith, D.; King, R.; Allen, B.L. Impacts of Exclusion Fencing on Target and Non-target Fauna: A Global Review. *Biol. Rev.* **2020**, *95*, 1590–1606. [CrossRef]
80. Osipova, L.; Okello, M.M.; Njumbi, S.J.; Ngene, S.; Western, D.; Hayward, M.W.; Balkenhol, N. Fencing Solves Human-Wildlife Conflict Locally but Shifts Problems Elsewhere: A Case Study Using Functional Connectivity Modelling of the African Elephant. *J. Appl. Ecol.* **2018**, *55*, 2673–2684. [CrossRef]
81. Mehta, P.; Kulkarni, J.; Athale, U. *There's Many a Way to Keep the Elephant Away. A Review of Techniques for Preventing Crop Damage by Elephants*; Wildlife Research and Conservation Society: Pune, India, 2020; p. 144.
82. Wahed, M.A.; Ullah, M.R.; Haseeb, M.I. *Human-Elephant Conflict Mitigation Measures: Lessons from Bangladesh*; IUCN, International Union for Conservation of Nature, Bangladesh Country Office: Dhaka, Bangladesh, 2016; p. 30.
83. Gross, E.M.; Drouet-Hoguet, N.; Subedi, N.; Gross, J. The Potential of Medicinal and Aromatic Plants (MAPs) to Reduce Crop Damages by Asian Elephants (*Elephas maximus*). *Crop Prot.* **2017**, *100*, 29–37. [CrossRef]
84. Dharmarathne, C.; Fernando, C.; Weerasinghe, C.; Corea, R. Project Orange Elephant Is a Conflict Specific Holistic Approach to Mitigating Human-Elephant Conflict in Sri Lanka. *Commun. Biol.* **2020**, *3*, 43. [CrossRef]
85. Ly, C.T.; Hung, V.; Anh, N.C.T.; Bao, H.D.; Quoc, P.D.P.; Khanh, H.T.; Van Minh, N.; Cam, N.T.H.; Cuong, C.D. A Pilot Study of Cultivating Non-Preferred Crops to Mitigate Human-Elephant Conflict in the Buffer Zone of Yok Don National Park, Vietnam. *Gajah* **2020**, *51*, 4–9.
86. Fernando, C.; Corea, R. An Assessment of Beehive Fences in Deterring Crop Raiding Elephants: A Case Study from Wasgamuwa, Sri Lanka. In Proceedings of the Association for Tropical Biodiversity and Conservation Asia Pacific Conference 2019, Thulhiriya, Sri Lanka, 10–13 September 2019; p. 71.
87. Water, A.; King, L.E.; Arkajak, R.; Arkajak, J.; Doormaal, N.; Ceccarelli, V.; Sluiter, L.; Doornwaard, S.M.; Praet, V.; Owen, D.; et al. Beehive Fences as a Sustainable Local Solution to Human-elephant Conflict in Thailand. *Conserv. Sci. Pract.* **2020**, *2*, e260. [CrossRef]
88. Baishya, H.K.; Dey, S.; Sarmah, A.; Sharma, A.; Gogoi, S.; Aziz, T.; Ghose, D.; Williams, A.C. Use of Chilli Fences to Deter Asian Elephants—A Pilot Study. *Gajah* **2012**, *36*, 11–13.
89. Davies, T.E.; Wilson, S.; Hazarika, N.; Chakrabarty, J.; Das, D.; Hodgson, D.J.; Zimmermann, A. Effectiveness of Intervention Methods against Crop-Raiding Elephants. *Conserv. Lett.* **2011**, *4*, 346–354. [CrossRef]
90. Hedges, S.; Gunaryadi, D. Reducing Human–Elephant Conflict: Do Chillies Help Deter Elephants from Entering Crop Fields? *Oryx* **2010**, *44*, 139. [CrossRef]
91. Thaufeek, U.L.; Padmalal, U.K.G.K.; Fernando, P. Land Use and Human-Elephant Conflict in the Sigiriya Sanctuary, Sri Lanka. *Gajah* **2014**, *40*, 26–30.

92. Nath, N.K.; Lahkar, B.P.; Brahma, N.; Dey, S.; Das, J.P.; Sarma, P.K.; Talukdar, B.K. An Assessment of Human-Elephant Conflict in Manas National Park, Assam, India. *J. Threat. Taxa* **2009**, *1*, 309–316. [CrossRef]
93. Thuppil, V.; Coss, R.G. Playback of Felid Growls Mitigates Crop-Raiding by Elephants *Elephas maximus* in Southern India. *Oryx* **2016**, *50*, 329–335. [CrossRef]
94. Aziz, M.A.; Shamsuddoha, M.; Maniruddin, M.; Morshed, H.M.; Sarker, R.; Islam, M.A. Elephants, Border Fence and Human-Elephant Conflict in Northern Bangladesh: Implications for Bilateral Collaboration towards Elephant Conservation. *Gajah* **2016**, *45*, 12–19.
95. de Silva, S.; Webber, C.E.; Weerathunga, U.S.; Pushpakumara, T.V.; Weerakoon, D.K.; Wittemyer, G. Demographic Variables for Wild Asian Elephants Using Longitudinal Observations. *PLoS ONE* **2013**, *8*, e82788. [CrossRef] [PubMed]
96. Pradhan, N.M.B.; Williams, A.C.; Dhakal, M. Current Status of Asian Elephants in Nepal. *Gajah* **2011**, *35*, 87–92.
97. Putri, A.; Al Azhari, M. Elephant Flying Squad, A Unique Approach to Reduce Human-Wildlife Conflict in Riau. Available online: https://jakartaglobe.id/news/elephant-flying-squad-unique-approach-to-reducing-human-wildlife-conflict-in-riau/ (accessed on 10 September 2022).
98. Vijayakrishnan, S.; Kumar, M.A.; Umapathy, G.; Kumar, V.; Sinha, A. Physiological Stress Responses in Wild Asian Elephants *Elephas maximus* in a Human-Dominated Landscape in the Western Ghats, Southern India. *Gen. Comp. Endocrinol.* **2018**, *266*, 150–156. [CrossRef]
99. Daim, M.S. Elephant Translocation- the Malaysian Approach. *Gajah* **1995**, *14*, 43–48.
100. Fernando, P.; Leimgruber, P.; Prasad, T.; Pastorini, J. Problem-Elephant Translocation: Translocating the Problem and the Elephant? *PLoS ONE* **2012**, *7*, e50917. [CrossRef] [PubMed]
101. Stüwe, M.; Abdul, J.B.; Nor, B.M.; Wemmer, C.M. Tracking the Movements of Translocated Elephants in Malaysia Using Satellite Telemetry. *Oryx* **1998**, *32*, 68–74. [CrossRef]
102. Fernando, P. Managing Elephants in Sri Lanka: Where We Are and Where We Need to Be. *Ceylon J. Sci. Biol. Sci.* **2015**, *44*, 1–11. [CrossRef]
103. Azmi, W.; Gunaryadi, D. Current Status of Asian Elephants in Indonesia. *Gajah* **2011**, *35*, 55–61.
104. Leimgruber, P.; Oo, Z.; Aung, M.; Kelly, D.; Wemmer, C.; Senior, B.; Songer, M. Current Status of Asian Elephants in Myanmar. *Gajah* **2011**, *35*, 76–86.
105. Saaban, S.; Othman, N.B.; Yasak, M.N.B.; Nor, B.M.; Ahmad, Z.; Campos-Arceiz, A. Current Status of Asian Elephants in Peninsular Malaysia. *Gajah* **2011**, *35*, 67–75.
106. Pinter-Wollman, N. Spatial Behaviour of Translocated African Elephants (*Loxodonta africana*) in a Novel Environment: Using Behaviour to Inform Conservation Actions. *Behaviour* **2009**, *146*, 1171–1192. [CrossRef]
107. Anthony, V. Horowpathana Elephant Holding Ground. Available online: https://www.themorning.lk/horowpathana-elephant-holding-ground/ (accessed on 10 January 2022).
108. Fernando, P. Managing "Problem Elephants". *Loris* **2011**, *25*, 32–36.
109. Lahdenperä, M.; Mar, K.U.; Courtiol, A.; Lummaa, V. Differences in Age-Specific Mortality between Wild-Caught and Captive-Born Asian Elephants. *Nat. Commun.* **2018**, *9*, 3023. [CrossRef]
110. Kuswanda, W.; Garsetiasih, R.; Gunawan, H.; Situmorang, R.O.P.; Hutapea, F.J.; Kwatrina, R.T.; Karlina, E.; Atmoko, T.; Zahrah, M.; Takandjandji, M.; et al. Can Humans and Elephants Coexist? A Review of the Conflict on Sumatra Island, Indonesia. *Diversity* **2022**, *14*, 420. [CrossRef]
111. Slotow, R.; Blackmore, A.; Henley, M.; Trendler, K.; Garaï, M. Could Culling of Elephants Be Considered Inhumane and Illegal in South African Law? *J. Int. Wildl. Law Policy* **2021**, *24*, 181–206. [CrossRef]
112. Chakraborty, S.; Paul, N. Efficacy of Different Human-Elephant Conflict Prevention and Mitigation Techniques Practiced in West Bengal, India. *Not. Sci. Biol.* **2021**, *13*, 11017. [CrossRef]
113. Yadav, B.R. Human-Elephant Relationships and Conflicts in Eastern Nepal. In *Endangered Elephants: Past, Present and Future*; Jayawardene, J., Ed.; Elephant Conservation Trust: Colombo, Sri Lanka, 2004; pp. 90–92.
114. Saif, O.; Kansky, R.; Palash, A.; Kidd, M.; Knight, A.T. Costs of Coexistence: Understanding the Drivers of Tolerance towards Asian Elephants *Elephas maximus* in Rural Bangladesh. *Oryx* **2020**, *54*, 603–611. [CrossRef]
115. Venkataraman, A.B.; Saandeep, R.; Baskaran, N.; Roy, M.; Madhivanan, A.; Sukumar, R. Using Satellite Telemetry to Mitigate Elephant-Human Conflict: An Experiment in Northern West Bengal, India. *Curr. Sci.* **2005**, *88*, 1827–1831.
116. Dabare, P.; Suduwella, C.; Sayakkara, A.; Sandaruwan, D.; Keppitiyagama, C.; De Zoysa, K.; Hewage, K.; Voigt, T. Listening to the Giants: Using Elephant Infra-Sound to Solve the Human-Elephant Conflict. In Proceedings of the 6th ACM Workshop on Real World Wireless Sensor Networks, Seoul, Koera, 1 November 2015; pp. 23–26.
117. Sugumar, S.J.; Jayaparvathy, R. An Early Warning System for Elephant Intrusion along the Forest Border Areas. *Curr. Sci.* **2013**, *104*, 1515–1526.
118. Chen, S.; Sun, G.-Z.; Wang, Y.; Huang, C.; Chen, Y.; Liu, P.; Deng, Y.; Cao, D.-F.; Zhang, M.-X.; Ong, S.; et al. A Multistakeholder Exercise to Identify Research and Conservation Priorities for Asian Elephants in China. *Glob. Ecol. Conserv.* **2021**, *27*, e01561. [CrossRef]
119. Pastorini, J.; Prasad, T.; Leimgruber, P.; Isler, K.; Fernando, P. Elephant GPS Tracking Collars: Is There a Best? *Gajah* **2015**, *43*, 15–25.

120. Karanth, K.K.; Gopalaswamy, A.M.; Prasad, P.K.; Dasgupta, S. Patterns of Human-Wildlife Conflicts and Compensation: Insights from Western Ghats Protected Areas. *Biol. Conserv.* **2013**, *166*, 175–185. [CrossRef]
121. Bandara, R.; Tisdell, C. Asian Elephants as Agricultural Pests: Economics of Control and Compensation in Sri Lanka. *Nat. Resour. J.* **2002**, *42*, 491–520.
122. Su, K.; Ren, J.; Yang, J.; Hou, Y.; Wen, Y. Human-Elephant Conflicts and Villagers' Attitudes and Knowledge in the Xishuangbanna Nature Reserve, China. *Int. J. Environ. Res. Public Health.* **2020**, *17*, 8910. [CrossRef]
123. Ogra, M.; Badola, R. Compensating Human-Wildlife Conflict in Protected Area Communities: Ground-Level Perspectives from Uttarakhand, India. *Hum. Ecol.* **2008**, *36*, 717–729. [CrossRef]
124. Tisdell, C.; Zhu, X. Protected Areas, Agricultural Pests and Economic Damage: Conflicts with Elephants and Pests in Yunnan, China. *Environmentalist* **1998**, *18*, 109–118. [CrossRef]
125. Abdullah, A.; Sayuti, A.; Hasanuddin, H.; Affan, M.; Wilson, G. People's Perceptions of Elephant Conservation and the Human-Elephant Conflict in Aceh Jaya, Sumatra, Indonesia. *Eur. J. Wildl. Res.* **2019**, *65*, 69. [CrossRef]
126. Jayewardene, J. Creating Awareness among School Children for Wild Elephant Conservation. *Gajah* **2011**, *34*, 41–45.
127. Ancrenaz, M.; Dabek, L.; O'Neil, S. The Costs of Exclusion: Recognizing a Role for Local Communities in Biodiversity Conservation. *PLoS Biol.* **2007**, *5*, e289. [CrossRef]
128. Dietsch, A.M.; Slagle, K.M.; Baruch-Mordo, S.; Breck, S.W.; Ciarniello, L.M. Education Is Not a Panacea for Reducing Human–Black Bear Conflicts. *Ecol. Modell.* **2018**, *367*, 10–12. [CrossRef]
129. Menon, V.; Tiwari, S.K. Elephant Corridors of India: An Analysis. In *Right of Passage: Elephant Corridors of India*; Menon, V., Tiwari, S.K., Ramkumar, K., Kyarong, S., Ganguly, U., Sukumar, R., Eds.; Conservation Reference Series No. 3; Wildlife Trust of India: New Delhi, India, 2017.
130. Bandara, T.W.M.T.W. Potentiality of Ecotourism in Enhancing Ethno-Zoological Values of Elephant Corridors for Mitigating Human-Elephant Conflict in Sri Lanka. *Int. J. Sci. Res. Publ.* **2020**, *10*, 9951. [CrossRef]
131. Bakri, M.A.; Yusof, E.; Jawing, A.; Mohammad, N.; Rahim, M.R.A.; Ilias, R.; Salim, N.; Saaban, S.; Hussin, M.Z.; Kasim, M.R.M. The Presence of Wildlife Species at Artificial Pasture and Artificial Salt Lick Sites at Protected Areas in Peninsular Malaysia. *J. Wildl. Natl. Park.* **2019**, *34*, 1–8.
132. Rishi, V. Wildlife Habitat Enrichment for Mitigating Human-Elephant Conflict by Biological Displacement of *Lantana*. *Indian For.* **2009**, *135*, 439–448.
133. van Aarde, R.; Whyte, I.; Pimm, S. Culling and the Dynamics of the Kruger National Park African Elephant Population. *Anim. Conserv.* **1999**, *2*, 287–294. [CrossRef]
134. Sukumar, R. *The Asian Elephant: Ecology and Management*; Cambridge University Press: New York, NY, USA, 1989.
135. Greggor, A.L.; Clayton, N.S.; Phalan, B.; Thornton, A. Comparative Cognition for Conservationists. *Trends Ecol. Evol.* **2014**, *29*, 489–495. [CrossRef] [PubMed]
136. Snijders, L.; Greggor, A.L.; Hilderink, F.; Doran, C. Effectiveness of Animal Conditioning Interventions in Reducing Human–Wildlife Conflict: A Systematic Map Protocol. *Environ. Evid.* **2019**, *8*, 10. [CrossRef]
137. Appleby, R.; Smith, B.; Bernede, L.; Jones, D. Utilising Aversive Conditioning to Manage the Behaviour of K'gari (Fraser Island) Dingoes (*Canis dingo*). *Pac. Conserv. Biol.* **2017**, *23*, 335–358. [CrossRef]
138. Fernando, P. Elephants in Sri Lanka: Past Present and Future. *Loris* **2000**, *22*, 38–44.
139. Madhusudan, M.D.; Sharma, N.; Raghunath, R.; Baskaran, N.; Bipin, C.M.; Gubbi, S.; Johnsingh, A.J.T.; Kulkarni, J.; Kumara, H.N.; Mehta, P.; et al. Distribution, Relative Abundance, and Conservation Status of Asian Elephants in Karnataka, Southern India. *Biol. Conserv.* **2015**, *187*, 34–40. [CrossRef]
140. Shannon, G.; Slotow, R.; Durant, S.M.; Sayialel, K.N.; Poole, J.; Moss, C.; McComb, K. Effects of Social Disruption in Elephants Persist Decades after Culling. *Front. Zool.* **2013**, *10*, 62. [CrossRef]
141. Cumming, D.H.M.; Fenton, M.B.; Rautenbach, I.L.; Taylor, R.D.; Cumming, G.S.; Cumming, M.S.; Dunlop, J.M.; Ford, A.G.; Hovorka, M.D.; Johnston, D.S.; et al. Elephants, Woodlands and Biodiversity in Southern Africa. *S. Afr. J. Sci.* **1997**, *93*, 231–236.
142. Ling, L.E.; Ariffin, M.; Manaf, L.A. A Qualitative Analysis of the Main Threats to Asian Elephant Conservation. *Gajah* **2016**, *44*, 16–22.
143. Fernando, P.; Leimgruber, P. Asian Elephants and Seasonally Dry Forests. In *The Ecology and Conservation of Seasonally Dry Forests in Asia*; McShea, W.J., Davies, S.J., Phumpakphan, N., Pattanavibool, A., Eds.; Smithsonian Institution Scholary Press: Washington, DC, USA, 2011; pp. 151–163.
144. Pastorini, J.; Janaka, H.K.; Nishantha, H.G.; Prasad, T.; Leimgruber, P.; Fernando, P. A Preliminary Study on the Impact of Changing Shifting Cultivation Practices on Dry Season Forage for Asian Elephants in Sri Lanka. *Trop. Conserv. Sci.* **2013**, *6*, 770–780. [CrossRef]
145. Ranjeewa, A.D.G.; Pastorini, J.; Isler, K.; Weerakoon, D.K.; Kottage, H.D.; Fernando, P. Decreasing Reservoir Water Levels Improve Habitat Quality for Asian Elephants. *Mamm. Biol.* **2018**, *88*, 130–137. [CrossRef]
146. Evans, L.J.; Asner, G.P.; Goossens, B. Protected Area Management Priorities Crucial for the Future of Bornean Elephants. *Biol. Conserv.* **2018**, *221*, 365–373. [CrossRef]
147. Anderson, D.M. Virtual Fencing—Past, Present and Future. *Rangel. J.* **2007**, *29*, 65–78. [CrossRef]
148. Peck, R.M. Method and Apparatus for Controlling an Animal. U.S. Patent 3753421, 21 October 1973.

149. Fay, P.K.; McElligott, V.T.; Havstad, K.M. Containment of Free-Ranging Goats Using Pulsed-Radio-Wave-Activated Shock Collars. *Appl. Anim. Behav. Sci.* **1989**, *23*, 165–171. [CrossRef]
150. Quigley, T.M.; Sanderson, H.R.; Tledemann, A.R.; Mclnnis, M.L. Livestock Control with Electrical and Audio Stimulation. *Rangelands* **1990**, *12*, 152–155.
151. Bishop-Hurley, G.J.; Swain, D.L.; Anderson, D.M.; Sikka, P.; Crossman, C.; Corke, P. Virtual Fencing Applications: Implementing and Testing an Automated Cattle Control System. *Comput. Electron. Agric.* **2007**, *56*, 14–22. [CrossRef]
152. Jouven, M.; Leroy, H.; Ickowicz, A.; Lapeyronie, P. Can Virtual Fences Be Used to Control Grazing Sheep? *Rangel. J.* **2012**, *34*, 111–123. [CrossRef]
153. Marini, D.; Meuleman, M.; Belson, S.; Rodenburg, T.; Llewellyn, R.; Lee, C. Developing an Ethically Acceptable Virtual Fencing System for Sheep. *Animals* **2018**, *8*, 33. [CrossRef]
154. Campbell, D.L.M.; Lea, J.; Farrer, W.; Haynes, S.; Lee, C. Tech-Savvy Beef Cattle? How Heifers Respond to Moving Virtual Fence Lines. *Animals* **2017**, *7*, 72. [CrossRef]
155. Campbell, D.L.M.; Lea, J.M.; Haynes, S.J.; Farrer, W.J.; Leigh-Lancaster, C.J.; Lee, C. Virtual Fencing of Cattle Using an Automated Collar in a Feed Attractant Trial. *Appl. Anim. Behav. Sci.* **2018**, *200*, 71–77. [CrossRef]
156. Lee, C.; Henshall, J.M.; Wark, T.J.; Crossman, C.C.; Reed, M.T.; Brewer, H.G.; Grady, J.O.; Fisher, A.D. Associative Learning by Cattle to Enable Effective and Ethical Virtual Fences. *Appl. Anim. Behav. Sci.* **2009**, *119*, 15–22. [CrossRef]
157. Andelt, W.F.; Phillips, R.L.; Gruver, K.S.; Guthrie, J.W. Coyote Predation on Domestic Sheep Deterred with Electronic Dog-Training Collar. *Wildl. Soc. Bull.* **1999**, *27*, 12–18.
158. Appleby, R. Dingo–Human Conflict: Attacks on Humans. In *The Dingo Debate: Origins, Behaviour and Conservation*; Smith, B., Ed.; CSIRO Publishing: Melbourne, Australia, 2015; pp. 131–158.
159. Cooper, D.M.; Kershner, E.L.; Garcelon, D.K. The Use of Shock Collars to Prevent Island Fox (Urocyon littoralis) Predation on the Endangered San Clemente Loggerhead Shrike (Lanius ludovicianus mearnsi). In Proceedings of the Sixth California Islands Symposium, Ventura, CA, USA, 1–3 December 2003; Garcelon, D.K., Schwemm, C.A., Eds.; National Park Service Technical Publication CHIS-05-01. Institute for Wildlife Studies: Arcata, CA, USA, 2005; pp. 287–297.
160. Gehring, T.M.; Hawley, J.E.; Davidson, S.J.; Rossler, S.T.; Cellar, A.C.; Schultz, R.N.; Wydeven, A.P.; VerCauteren, K.C. Are Viable Non-Lethal Management Tools Available for Reducing Wolf-Human Conflict? Preliminary Results from Field Experiments. In Proceedings of the 22nd Vertebrate Pest Conference, Berkeley, CA, USA, 6–9 March 2006; Timm, R.M., O'Brien, J.M., Eds.; University of California: Davis, CA, USA, 2006; Volume 22, pp. 2–6.
161. Hawley, J.E.; Gehring, T.M.; Schultz, R.N.; Rossler, S.T.; Wydeven, A.P. Assessment of Shock Collars as Nonlethal Management for Wolves in Wisconsin. *J. Wildl. Manag.* **2009**, *73*, 518–525. [CrossRef]
162. Hawley, J.E.; Rossler, S.T.; Gehring, T.M.; Schultz, R.N.; Callahan, P.A.; Clark, R.; Cade, J.; Wydeven, A.P. Developing a New Shock-Collar Design for Safe and Efficient Use on Wild Wolves. *Wildl. Soc. Bull.* **2013**, *37*, 416–422. [CrossRef]
163. Nolte, D.L.; Vercauteren, K.C.; Perry, K.R.; Adams, S.E. Training Deer to Avoid Sites through Negative Reinforcement. In Proceedings of the 10th Wildlife Damage Management Conference, Hot Springs, AR, USA, 6–9 April 2003; Fagerstone, K.A., Witmer, G.W., Eds.; Wildlife Damage Management Working Group of the Wildlife Society: Fort Collins, CO, USA, 2003; pp. 95–104.
164. Rossler, S.T.; Gehring, T.M.; Schultz, R.N.; Rossler, M.T.; Wydeven, A.P.; Hawley, J.E. Shock Collars as a Site-Aversive Conditioning Tool for Wolves. *Wildl. Soc. Bull.* **2012**, *36*, 176–184. [CrossRef]
165. Schultz, R.N.; Jonas, K.W.; Skuldt, L.H.; Wydeven, A.P. Experimental Use of Dog-Training Shock Collars to Deter Depredation by Gray Wolves. *Wildl. Soc. Bull.* **2005**, *33*, 142–148. [CrossRef]
166. Shivik, J.A.; Martin, D.J. Aversive and Disruptive Stimulus Applications for Managing Predation. In Proceedings of the 9th Wildlife Damage Management Conference, State College, PA, USA, 5–8 October 2000; Brittingham, M.C., Kays, J., McPeake, R., Eds.; Pennsylvania State University: State College, PA, USA, 2000; pp. 111–119.
167. Shivik, J.A.; Asher, V.; Bradley, L.; Kunkel, K.; Phillips, M.; Breck, S.; Bangs, E. Electronic Aversive Conditioning for Managing Wolf Predation. In Proceedings of the 20th Vertebrate Pest Conference, Reno, NV, USA, 4–7 March 2002; Timm, R.M., Schmidt, R.H., Eds.; University of California: Davis, CA, USA, 2002; pp. 227–231.
168. Shivik, J.A.; Treves, A.; Callahan, P. Nonlethal Techniques for Managing Predation: Primary and Secondary Repellents. *Conserv. Biol.* **2003**, *17*, 1531–1537. [CrossRef]
169. Bates, L.A.; Poole, J.H.; Byrne, R.W. Elephant Cognition. *Curr. Biol.* **2008**, *18*, 544–546. [CrossRef]
170. Hart, B.L.; Hart, L.A.; Pinter-Wollman, N. Large Brains and Cognition: Where Do Elephants Fit In? *Neurosci. Biobehav. Rev.* **2008**, *32*, 86–98. [CrossRef]
171. McLeod, S.A. Skinner—Operant Conditioning. Available online: http://www.simplypsychology.org/operant-conditioning.html (accessed on 14 October 2022).
172. Kearton, T.; Marini, D.; Cowley, F.; Belson, S.; Keshavarzi, H.; Mayes, B.; Lee, C. The Influence of Predictability and Controllability on Stress Responses to the Aversive Component of a Virtual Fence. *Front. Vet. Sci.* **2020**, *7*, 580523. [CrossRef]
173. Schalke, E.; Stichnoth, J.; Ott, S.; Jones-Baade, R. Clinical Signs Caused by the Use of Electric Training Collars on Dogs in Everyday Life Situations. *Appl. Anim. Behav. Sci.* **2007**, *105*, 369–380. [CrossRef]
174. Haturusinghe, H.S.; Weerakoon, D.K. Crop Raiding Behaviour of Elephants in the Northwestern Region of Sri Lanka. *Gajah* **2012**, *36*, 26–31.

175. Sukumar, R.; Gadgil, M. Male-Female Differences in Foraging on Crops by Asian Elephants. *Anim. Behav.* **1988**, *36*, 1233–1235. [CrossRef]
176. Jachowski, D.S.; Slotow, R.; Millspaugh, J.J. Good Virtual Fences Make Good Neighbors: Opportunities for Conservation. *Anim. Conserv.* **2014**, *17*, 187–196. [CrossRef]
177. Marini, D.; Kearton, T.; Ouzman, J.; Llewellyn, R.; Belson, S.; Lee, C. Social Influence on the Effectiveness of Virtual Fencing in Sheep. *PeerJ* **2020**, *8*, e10066. [CrossRef] [PubMed]
178. Keshavarzi, H.; Lee, C.; Lea, J.M.; Campbell, D.L.M. Virtual Fence Responses Are Socially Facilitated in Beef Cattle. *Front. Vet. Sci.* **2020**, *7*, 543158. [CrossRef] [PubMed]
179. de la Torre, J.A.; Wong, E.P.; Lechner, A.M.; Zulaikha, N.; Zawawi, A.; Abdul-Patah, P.; Saaban, S.; Goossens, B.; Campos-Arceiz, A. There Will Be Conflict—Agricultural Landscapes Are Prime, Rather than Marginal, Habitats for Asian Elephants. *Anim. Conserv.* **2021**, *24*, 720–732. [CrossRef]
180. Chan, A.N.; Wittemyer, G.; McEvoy, J.; Williams, A.C.; Cox, N.; Soe, P.; Grindley, M.; Shwe, N.M.; Chit, A.M.; Oo, Z.M.; et al. Landscape Characteristics Influence Ranging Behavior of Asian Elephants at the Human-Wildlands Interface in Myanmar. *Mov. Ecol.* **2022**, *10*, 6. [CrossRef]
181. Verdon, M.; Lee, C.; Marini, D.; Rawnsley, R. Pre-Exposure to an Electrical Stimulus Primes Associative Pairing of Audio and Electrical Stimuli for Dairy Heifers in a Virtual Fencing Feed Attractant Trial. *Animals* **2020**, *10*, 217. [CrossRef]
182. Deraniyagala, P.E.P. *Some Extinct Elephants, Their Relatives, and the Two Living Species*; Government Press: Colombo, Ceylon, 1955.
183. Lines, J.A.; van Driel, K.; Cooper, J.J. Characteristics of Electronic Training Collars for Dogs. *Vet. Rec.* **2013**, *172*, 288. [CrossRef]
184. Réale, D.; Reader, S.M.; Sol, D.; McDougall, P.T.; Dingemanse, N.J. Integrating Animal Temperament within Ecology and Evolution. *Biol. Rev.* **2007**, *82*, 291–318. [CrossRef] [PubMed]
185. Jonkel, C. Grizzly/ Brown Bears. In *The Handbook: Prevention and Control of Wildlife Damage*; Hygnstrom, S.E., Timm, R.M., Larson, G.E., Eds.; University of Nebraska-Lincoln: Lincoln, Nebraska, 1994; pp. C17–C23.
186. Lee, C.; Campbell, D.L.M. A Multi-Disciplinary Approach to Assess the Welfare Impacts of a New Virtual Fencing Technology. *Front. Vet. Sci.* **2021**, *8*, 637709. [CrossRef] [PubMed]
187. Bansiddhi, P.; Brown, J.L.; Thitaram, C. Welfare Assessment and Activities of Captive Elephants in Thailand. *Animals* **2020**, *10*, 919. [CrossRef] [PubMed]
188. Crawley, J.A.H.; Lahdenperä, M.; Seltmann, M.W.; Htut, W.; Aung, H.H.; Nyein, K.; Lummaa, V. Investigating Changes within the Handling System of the Largest Semi-Captive Population of Asian Elephants. *PLoS ONE* **2019**, *14*, e0209701. [CrossRef]
189. Crawley, J.A.H.; Lahdenperä, M.; Min Oo, Z.; Htut, W.; Nandar, H.; Lummaa, V. Taming Age Mortality in Semi-Captive Asian Elephants. *Sci. Rep.* **2020**, *10*, 1889. [CrossRef] [PubMed]
190. Nundrakwang, S.; Yingyong, P.; Isarakorn, D. Energy Harvesting for Self-Powered Systems. In Proceedings of the 2020 6th International Conference on Engineering, Applied Sciences and Technology (ICEAST), Chiang Mai, Thailand, 1–4 July 2020; pp. 1–4.
191. Wang, Z.; Ruan, Z.; Ng, W.S.; Li, H.; Tang, Z.; Liu, Z.; Wang, Y.; Hu, H.; Zhi, C. Integrating a Triboelectric Nanogenerator and a Zinc-Ion Battery on a Designed Flexible 3D Spacer Fabric. *Small Methods* **2018**, *2*, 1800150. [CrossRef]
192. Agrisellex Are Electric Fences a Serious Safety Risk to Humans? Available online: https://www.agrisellex.co.uk/blogs/blog/are-electric-fences-a-serious-safety-risk-to-humans (accessed on 24 April 2020).
193. Campbell, D.L.M.; Lea, J.M.; Keshavarzi, H.; Lee, C. Virtual Fencing Is Comparable to Electric Tape Fencing for Cattle Behavior and Welfare. *Front. Vet. Sci.* **2019**, *6*, 445. [CrossRef]
194. Whiting, T.L. Pain in Human and Non-Human Animals Caused by Electricity. *Can. Vet. J.* **2016**, *57*, 883–886.
195. Smith, B.P.; Appleby, R.G. Promoting Human–Dingo Co-Existence in Australia: Moving towards More Innovative Methods of Protecting Livestock Rather than Killing Dingoes (*Canis dingo*). *Wildl. Res.* **2018**, *45*, 1–15. [CrossRef]
196. Lee, C.; Fisher, A.D.; Reed, M.T.; Henshall, J.M. The Effect of Low Energy Electric Shock on Cortisol, β-Endorphin, Heart Rate and Behaviour of Cattle. *Appl. Anim. Behav. Sci.* **2008**, *113*, 32–42. [CrossRef]
197. Lee, C.; Colditz, I.G.; Campbell, D.L.M. A Framework to Assess the Impact of New Animal Management Technologies on Welfare: A Case Study of Virtual Fencing. *Front. Vet. Sci.* **2018**, *5*, 187. [CrossRef] [PubMed]
198. Christiansen, F.O.; Bakken, M.; Braastad, B.O. Behavioural Changes and Aversive Conditioning in Hunting Dogs by the Second-Year Confrontation with Domestic Sheep. *Appl. Anim. Behav. Sci.* **2001**, *72*, 131–143. [CrossRef]
199. Steiss, J.E.; Schaffer, C.; Ahmad, H.A.; Voith, V.L. Evaluation of Plasma Cortisol Levels and Behavior in Dogs Wearing Bark Control Collars. *Appl. Anim. Behav. Sci.* **2007**, *106*, 96–106. [CrossRef]
200. Kearton, T.; Marini, D.; Cowley, F.; Belson, S.; Lee, C. The Effect of Virtual Fencing Stimuli on Stress Responses and Behavior in Sheep. *Animals* **2019**, *9*, 30. [CrossRef]
201. Pokharel, S.S.; Seshagiri, P.B.; Sukumar, R. Assessment of Season-Dependent Body Condition Scores in Relation to Faecal Glucocorticoid Metabolites in Free-Ranging Asian Elephants. *Conserv. Physiol.* **2017**, *5*, cox039. [CrossRef] [PubMed]
202. de Mel, R.K.; Weerakoon, D.K.; Ratnasooriya, W.D. A Comparison of Stereotypic Behaviour in Asian Elephants at Three Different Institutions in Sri Lanka. *Gajah* **2013**, *38*, 25–29.
203. Laws, N.; Ganswindt, A.; Heistermann, M.; Harris, M.; Harris, S.; Sherwin, C. A Case Study: Fecal Corticosteroid and Behavior as Indicators of Welfare during Relocation of an Asian Elephant. *J. Appl. Anim. Welf. Sci.* **2007**, *10*, 349–358. [CrossRef]

204. Bandara, R.; Tisdell, C. The Net Benefit of Saving the Asian Elephant: A Policy and Contingent Valuation Study. *Ecol. Econ.* **2004**, *48*, 93–107. [CrossRef]
205. Aaser, M.F.; Staahltoft, S.K.; Korsgaard, A.H.; Trige-Esbensen, A.; Alstrup, A.K.O.; Sonne, C.; Pertoldi, C.; Bruhn, D.; Frikke, J.; Linder, A.C. Is Virtual Fencing an Effective Way of Enclosing Cattle? Personality, Herd Behaviour and Welfare. *Animals* **2022**, *12*, 842. [CrossRef]
206. Brunberg, E.I.; Bergslid, I.K.; Bøe, K.E.; Sørheim, K.M. The Ability of Ewes with Lambs to Learn a Virtual Fencing System. *Animal* **2017**, *11*, 2045–2050. [CrossRef]
207. Campbell, D.L.M.; Haynes, S.J.; Lea, J.M.; Farrer, W.J.; Lee, C. Temporary Exclusion of Cattle from a Riparian Zone Using Virtual Fencing Technology. *Animals* **2019**, *9*, 5. [CrossRef] [PubMed]
208. Campbell, D.L.M.; Marini, D.; Lea, J.M.; Keshavarzi, H.; Dyall, T.R.; Lee, C. The Application of Virtual Fencing Technology Effectively Herds Cattle and Sheep. *Anim. Prod. Sci.* **2021**, *61*, 1393–1402. [CrossRef]
209. Colusso, P.I.; Clark, C.E.F.; Lomax, S. Should Dairy Cattle Be Trained to a Virtual Fence System as Individuals or in Groups? *Animals* **2020**, *10*, 1767. [CrossRef]
210. Colusso, P.I.; Clark, C.E.F.; Green, A.C.; Lomax, S. The Effect of a Restricted Feed Ration on Dairy Cow Response to Containment from Feed Using a Virtual Fence. *Front. Anim. Sci.* **2021**, *2*, 710648. [CrossRef]
211. Colusso, P.I.; Clark, C.E.F.; Ingram, L.J.; Thomson, P.C.; Lomax, S. Dairy Cattle Response to a Virtual Fence When Pasture on Offer Is Restricted to the Post-Grazing Residual. *Front. Anim. Sci.* **2021**, *2*, 791228. [CrossRef]
212. Kearton, T.; Marini, D.; Lee, C.; Cowley, F.C. The Influence of Observing a Maternal Demonstrator on the Ability of Lambs to Learn a Virtual Fence. *Anim. Prod. Sci.* **2022**, *62*, 470–481. [CrossRef]
213. Langworthy, A.D.; Verdon, M.; Freeman, M.J.; Corkrey, R.; Hills, J.L.; Rawnsley, R.P. Virtual Fencing Technology to Intensively Graze Lactating Dairy Cattle. I: Technology Efficacy and Pasture Utilization. *J. Dairy Sci.* **2021**, *104*, 7071–7083. [CrossRef] [PubMed]
214. Marini, D.; Llewellyn, R.; Belson, S.; Lee, C. Controlling Within-Field Sheep Movement Using Virtual Fencing. *Animals* **2018**, *8*, 31. [CrossRef]
215. Marini, D.; Cowley, F.; Belson, S.; Lee, C. The Importance of an Audio Cue Warning in Training Sheep to a Virtual Fence and Differences in Learning When Tested Individually or in Small Groups. *Appl. Anim. Behav. Sci.* **2019**, *221*, 104862. [CrossRef]
216. Marini, D.; Cowley, F.; Belson, S.; Lee, C. Comparison of Virtually Fencing and Electrically Fencing Sheep for Pasture Management. *Anim. Prod. Sci.* **2022**, *62*, 1000–1005. [CrossRef]
217. McSweeney, D.; O'Brien, B.; Coughlan, N.E.; Férard, A.; Ivanov, S.; Halton, P.; Umstatter, C. Virtual Fencing without Visual Cues: Design, Difficulties of Implementation, and Associated Dairy Cow Behaviour. *Comput. Electron. Agric.* **2020**, *176*, 105613. [CrossRef]
218. Muminov, A.; Na, D.; Lee, C.W.; Kang, H.K.; Jeon, H.S. Monitoring and Controlling Behaviors of Livestock Using Virtual Fences. *J. Theor. Appl. Inf. Technol.* **2019**, *97*, 4909–4920.
219. Ranches, J.; O′Connor, R.; Johnson, D.; Davies, K.; Bates, J.; Boyd, C.; Bohnert, D.W.; Parker, T. Effects of Virtual Fence Monitored by Global Positioning System on Beef Cattle Behavior. *Transl. Anim. Sci.* **2021**, *5*, S144–S148. [CrossRef]
220. Verdon, M.; Rawnsley, R. The Effects of Dairy Heifer Age at Training on Rate of Learning and Retention of Learning in a Virtual Fencing Feed Attractant Trial. *Front. Anim. Sci.* **2020**, *1*, 618070. [CrossRef]
221. Verdon, M.; Horton, B.; Rawnsley, R. A Case Study on the Use of Virtual Fencing to Intensively Graze Angus Heifers Using Moving Front and Back-Fences. *Front. Anim. Sci.* **2021**, *2*, 663963. [CrossRef]
222. Verdon, M.; Langworthy, A.; Rawnsley, R. Virtual Fencing Technology to Intensively Graze Lactating Dairy Cattle. II: Effects on Cow Welfare and Behavior. *J. Dairy Sci.* **2021**, *104*, 7084–7094. [CrossRef]

2.2. Links and implications

This chapter discussed the drawbacks of current HEC mitigation tools based on scientific evidence and highlighted the need for new approaches such as AGDs to be investigated as a potential HEC mitigation tool. Although research findings of using AGDs on livestock species and other wild animals are encouraging, available information is not sufficient to predict how successful AGDs would be in managing elephant movement and how elephant wellbeing would be affected. Further this chapter highlighted the need for understanding social acceptability of using AGDs on elephants compared to other HEC mitigation tools. Thus, as recommended in this chapter, this thesis presents results of preliminary investigations conducted on (1) the efficacy of AGDs in managing elephant movement, (2) welfare impacts and (3) public opinion of using AGDs on elephants.

CHAPTER 3: PAPER 2 – CAUSES AND SOLUTIONS TO CONFLICT BETWEEN HUMANS AND ASIAN ELEPHANTS

3.1. Introduction

This chapter is the research manuscript titled “Causes and solutions to conflict between humans and Asian elephants” submitted to a journal and currently under consideration for publication. As highlighted in Chapter 2, HEC mitigation has become an enormous challenge for conserving and managing Asian elephants. Finding consensus amongst different stakeholders is important for identifying acceptable and effective HEC mitigation approaches. This chapter evaluates the opinion of different stakeholder groups on various aspects related to elephant conservation and HEC mitigation. This study identifies the similarities and differences between stakeholders to help understand potential areas of conflict that should be given attention when communicating and implementing programmes for HEC mitigation. Supplementary information submitted with this research article are given in Appendix A.

Causes and solutions to conflict between humans and Asian elephants

Surendranie J. Cabral de Mel[1,2]*, Saman Seneweera[2,3], Ashoka Dangolla[4], Devaka K. Weerakoon[5], Rachel King[6], Tek Maraseni[1,7], Benjamin L. Allen[1,8]

[1] Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia.

[2] National Institute of Fundamental Studies, Kandy, 20000, Sri Lanka.

[3] School of Agriculture and Food, Faculty of Sciences, The University of Melbourne, Parkville, VIC 3010, Australia.

[4] Department of Veterinary Clinical Sciences, University of Peradeniya, Peradeniya, 20400, Sri Lanka.

[5] Department of Zoology and Environmental Sciences, University of Colombo, Colombo 03, 00300, Sri Lanka.

[6] School of Mathematics, Physics and Computing, University of Southern Queensland, Toowoomba, QLD 4350, Australia.

[7] Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou, 730000, China.

[8] Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth, 6034, South Africa.

*Author for correspondence: surendranie.cabral@gmail.com

Running head: Causes and solutions to human-elephant conflict

Abstract

Many Asian elephant populations inhabit fragmented human-dominated landscapes and human-elephant conflict (HEC) has intensified in such regions, resulting in the death of hundreds of people and elephants each year. Controversy between stakeholders then arises as people debate the merits of proposed HEC mitigation approaches, but limited quantitative information exists on comparison of different stakeholder views towards elephant management. We conducted a survey to evaluate the opinions of experts, farmers and others who have and have not experienced HEC (n = 611), on the causes of HEC, the importance and conservation of elephants and co-existence with them, as well as on the acceptability and effectiveness of potential HEC mitigation methods. Logistic regression and the Potential for Conflict Index was used to assess consensus between stakeholder groups. Our analysis showed that all groups agreed with nine of the 10 causes of HEC assessed. Respondents had mostly positive attitudes towards the importance and conservation of elephants, but farmers who have experienced HEC disagreed that people should co-exist with elephants and instead supported the view that elephants should be removed from human habitats. All groups agreed on the acceptability and effectiveness of electric fencing, and early warning systems with Global Positioning System collars, infrasonic call detectors, and geophones. There was disagreement between the experts and other stakeholder groups on the acceptability and effectiveness of restricting elephants to protected areas and translocation of problem causing elephants to protected areas away from their capture site or to wild elephant holding grounds. While agreement between stakeholder groups on many aspects are encouraging for elephant conservation, we suggest that the disagreements identified should be given greater attention when planning and implementing HEC management programmes to minimise conflict between stakeholders.

Key words: Conservation, co-existence, expert opinion, human-elephant conflict, public opinion, wildlife management

1. Introduction

Mitigating human-wildlife conflict (HWC) is one of the biggest challenges faced by conservation biologists, and their focus on this issue is evident from the exponential rise in HWC related research in recent years (Marchini et al., 2019; König et al., 2020). Complicating this is a lack of agreement between different stakeholders on acceptable wildlife management strategies, particularly between experts and affected parties, which can result in controversy (Redpath et al., 2013; Kendal & Ford, 2018) and create difficulties in effectively implementing these strategies. This becomes especially challenging when addressing HWC with large, charismatic, culturally important and threatened species like Asian elephants *Elephas maximus* (Williams et al., 2020). Successfully conserving and promoting harmonious co-existence with elephants requires a greater understanding of stakeholder views towards their management.

Negative interactions between humans and Asian elephants results in the death of hundreds of humans and elephants each year across their range (Acharya et al., 2016; Qomariah et al., 2018; Ganesh, 2019; Prakash, Wijeratne, & Fernando, 2020). People also experience large scale crop loss and property damage caused by elephants (Saif et al., 2020; Nair & Jayson, 2021), and further suffer from hidden costs such as impacts on psychological and social wellbeing due to fear of safety, additional workload, lack of sleep, and loss of a family member or their livelihood (Barua, Bhagwat, & Jadhav, 2013; Guru & Das, 2021; Sampson et al., 2021). The severity of human-elephant conflict (HEC) may vary with factors such as availability of forest habitats, land use type (e.g. type of crops cultivated), season (e.g. harvesting period), human density and people's dependency on forest resources (Chartier, Zimmermann, & Ladle, 2011; Neupane, Johnson, & Risch, 2017; Sampson et al., 2019; Thant, May, & Røskaft, 2021, 2022; Tripathy, Liu, & Ranga, 2022). Many of the HEC mitigation approaches attempt to keep problem elephants away from human habitats by physically removing or deterring them (Shaffer et al., 2019; Cabral de Mel et al., 2022), but significant elephant numbers live in fragmented and heterogenous human-dominated landscapes (Madhusudan et al., 2015; Liu et al., 2017; Othman et al., 2019; Padalia et al., 2019; Fernando et al., 2021; Chen et al., 2022) and therefore is not a feasible approach. Human-elephant co-existence is the only way forward for elephant conservation and HEC mitigation (Fernando et al., 2021), but achieving this may be a very complex and difficult task.

People's desire for conservation and co-existence with elephants may depend on their exposure to wild elephants, concern for elephants and their habitat, awareness and involvement in environmental activities, urbanisation, age, gender, education, occupation, income and many other factors (Ogra, 2008; Barua, Tamuly, & Ahmed, 2010; van de Water & Matteson, 2018; Abdullah et al., 2019; Su et al., 2020; Tan et al., 2020). For those severely affected by HEC to be willing to co-exist with elephants, there will have to be reliable HEC mitigation tools in place to reduce threats to their lives and livelihoods in order for them to consider the benefits and feel the importance of sharing the land with elephants (Neupane et al., 2017; van de Water & Matteson, 2018; Tan et al., 2020; Ardiantiono et al., 2021). To resolve HEC in the long term it is important to identify and address the root causes of the problem (Shaffer et al., 2019), but approaches that provide immediate relief to affected people are also important. Developing consensus between stakeholders on different aspects related to elephant conservation and HEC mitigation will assist in planning and implementing conservation management programmes.

Participation of various stakeholders in planning and decision making is critical for the success of wildlife management programmes (Reed, 2008). However, it is often only the experts who are consulted in the formulation and implementation of HEC management strategies (Chen et al., 2021; Gross et al., 2022) and represented in the media (Barua, 2010). Experts – i.e. researchers, academics and representatives of non-governmental organisations (NGOs) and government authorities – are perceived to have the proper or more correct view on conservation and management of wildlife species (Lute et al., 2020). But the opinion of other stakeholders should also be integrated in the planning and decision-making process. These stakeholders include those experiencing HEC; particularly farmers whose livelihoods are directly affected (Neupane et al., 2017; van de Water & Matteson, 2018; Sampson et al., 2019) and also those who do not experience HEC but have a general awareness of it and may have the capacity to contribute towards conservation of elephants in their country (Bandara & Tisdell, 2003, 2004; Tan et al., 2020; Sampson et al., 2022). Evaluation of expert opinions (Can et al., 2014; Heeren et al., 2017; Lute et al., 2018, 2020) and comparing them with that of the public (Heneghan & Morse, 2019; van Eeden et al., 2019; Drijfhout, Kendal, & Green, 2022) may be helpful in identifying similarities but also conflicting views that could hinder implementing conservation and conflict mitigating strategies.

Studies comparing expert opinion with public opinion on Asian elephant conservation and HEC mitigation are very few and have been conducted only at community level. For example, Nayak & Swain, (2020) compared the opinions of 13 forest staff with those of local community members on several HEC mitigation tools, and Tripathy et al., (2022) conducted a survey with 36 experts in their study area to understand their opinion on policy instruments and HEC mitigation efforts. Pant et al., (2016) and Su et al., (2020) also supplemented their studies by conducting semi-structured interviews with key informants within local communities. Although these are useful, a broader study to understand similarities and differences in expert and public opinion would help to identify aspects that are already agreed, along with those that need greater attention when planning and implementing elephant conservation programmes. In this study we assess the perceptions of different stakeholder groups towards the causes of HEC, the importance and conservation of elephants and co-existence with them, as well as views on the acceptability and effectiveness of a variety of potential HEC mitigation tools. Our aim was to compare and contrast stakeholder perceptions and identify any areas of agreement or disagreement, with the intent to describe an acceptable pathway forward to improve the conservation and management of elephants.

2. Methodology

2.1 Ethics statement

The protocol and conduct of our data collection was approved by the Human Research Ethics Committee of the University of Southern Queensland, Australia (H21REA209) and the Institute of Biology, Sri Lanka (ERC IOBSL 258 01 2022). Our research was conducted in accordance with these approvals.

2.2 Data collection

2.2.1 Survey administration

We conducted an online and a paper-based questionnaire survey using convenience and snowball sampling (Atkinson & Flint, 2001; Dragan & Isaic-Maniu, 2013). The online survey targeted citizens/residents of the Asian elephant range countries (Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand and Vietnam) and experts who are conducting research or work related to Asian elephants from around the world. The self-administered paper-based survey targeted those in rural farming areas and areas experiencing HEC with difficulty accessing online surveys. This paper-based survey was conducted within Sri Lanka – the country with the highest density of Asian elephants, the highest number of elephant deaths, and second-highest number of human deaths resulting from HEC (Prakash et al., 2020). Both the online and paper-based surveys were similar except for minor changes to comply with the format and target groups and were made available in English, as well as Sinhala and Tamil, the two main languages spoken in Sri Lanka. The survey was designed in a manner that would require approximately 20 minutes for a respondent to complete the online or the paper-based survey. Data were collected from May–October 2022.

The online survey was developed using the University of Southern Queensland online survey tool. Participants were recruited by sharing the survey link on social media platforms and was particularly shared among people with a keen interest in wildlife, conservation, and animal welfare through the networks of NGOs and researchers. In addition, the links were shared via email directly to over 500 experts working on Asian elephants, including those working in NGOs, zoos, welfare activists, government authorities and researchers. Email addresses of elephant experts were obtained from research articles published in the last 20 years, and webpages of relevant organisations. Organizations who had received the link to the survey were asked to share the survey link among their expert staff members. The paper-based survey forms were distributed among participants with the support of volunteer field assistants. Respondents provided implied consent to participate in the survey by voluntarily completing and submitting their responses at the end of the online survey or by voluntarily completing and returning the paper-based survey form. The online survey and paper-based survey were completed by 513 and 130 respondents respectively. The data collected were non-identifiable to the researcher (i.e. names or any contact details were not collected).

2.2.2 Survey questions

The survey comprised of two main sections which mostly included close-ended multiple choice and five-point Likert-type questions. Section One requested information on the demography of participants such as age, gender, highest level of formal education, citizenship, religion and involvement in agriculture and in work related to Asian elephants etc. Requests for information on ethnicity, district of residence and monthly income were only made to Sri Lankan respondents. Section Two of the survey collected information on respondents' experience with HEC, and perception of elephants and HEC under four main categories, with responses on a bipolar scale (-2 to +2), as follows.

Category 1: Possibility of 10 factors being causes of HEC ("definitely not", "probably not", "neutral", "probably" and "definitely").

Category 2: Agreement on 11 statements concerning the importance and conservation of elephants and co-existence with them ("strongly disagree", "disagree", "neutral", "agree" and "strongly agree").

Category 3: Acceptability of 25 potential HEC mitigation tools ("unacceptable", "somewhat unacceptable", "neutral", "somewhat acceptable" and "acceptable").

Category 4: Perceived effectiveness of 25 potential HEC mitigation tools ("ineffective", "somewhat ineffective", "neutral", "somewhat effective" and "effective").

For Category 4, an additional option of "I do not know" was provided to avoid receiving responses from those totally unfamiliar with HEC mitigation tools; these responses were removed from the analysis. A short explanation was also provided for some of the HEC mitigation tools to help respondents in cases where the terminology may have been unfamiliar to them. Survey questions analysed in this study are provided in supplementary material (Tables S1–S5).

2.3 Data Analysis

Perceptions of respondents were analysed based on their social groups (experts, farmers and others) and their personal experience in HEC (HEC or no HEC). Respondents were identified as an "expert" if they had selected at least one answer to the question on current or previous involvement in work related to Asian elephants (Table S1). Respondents were identified as a "farmer" if they selected either farmer-annual crops, farmer-perennial crops or farmer-livestock to the question on involvement in fields related to agriculture (Table S1). Those who were neither experts nor farmers were categorised as "other". Respondents who selected a level of severity of HEC they have personally experienced and/or mentioned one or more HEC related problems they had experienced were classified as "HEC" and the others as "no HEC" (Table S2). Of the 643 completed surveys, 32 were omitted for technical reasons (e.g. respondents were neither a citizen/resident of a range country or worked on Asian elephants, or because responses were spurious) resulting in a total of 611 responses in the final analysis.

A logistic regression model (a generalised linear model with a binomial distribution and a logit link function) was used to compare how responses to each item varied depending on whether they are experts, farmers or others and whether they have experienced HEC or not. For this analysis, the responses on the five-point scale were collapsed to a binary variable with -2, -1 and 0 as a “negative/neutral” response and +1, +2 as a “positive” response. The decision to reduce the scale to a binary measure and use a logistic regression model instead of retaining the ordinal scale and applying ordinal logistic regression was made primarily because the analysis of the ordinal responses to some items did not meet the assumption of proportional odds. Transformation of the scale to a dichotomous one also performs well in such analysis compared to a five-point scale, simplifying the interpretation of data (Jeong & Lee, 2016). It also works particularly well when there are low frequencies of responses in extreme categories (DiStefano, Shi, & Morgan, 2021), as observed for some items in this study. Such transformation of scale was appropriate in this study given that the aim was to assess the direction of responses, i.e., the likelihood to perceive an item positively or not (e.g., agree or not). Analyses were conducted in R statistical software (R Core Team, 2022) using the ‘glm’ function and displayed using the R package forestplot (Gordon & Lumley, 2022). We then examined the mean responses given on the five-point scale (-2 to +2) and the level of consensus within six groups; expert-HEC, expert-no HEC, farmer-HEC, farmer-no HEC, other-HEC, other-no HEC using the Potential for Conflict Index$_2$ (PCI$_2$) (Vaske et al., 2010). PCI$_2$ values correspond to dispersion within the sample and ranges between 0 and 1, with 0 indicating complete consensus between respondents and 1 indicating no consensus or highest potential for conflict (responses are equally divided between the extreme responses) within a group. PCI$_2$ values were calculated and illustrated using the programmes provided by Vaske et al., (2010). The size of each bubble in the graphs depicts the PCI$_2$ value, with larger bubbles indicating high potential for conflict in the group, and the centre of the bubble indicates the mean score on the scale of the y axis for each group. Items analysed are italicised whenever mentioned in the results section. Phrases from the survey are shortened for some items here for the convenience of display. Full details can be found in the supplementary material (Table S5).

3. Results

From the 611 survey responses we analysed, respondents were predominantly between 18–35 years of age (52.9%, n = 323), while 32.2% (n = 197) and 14.9% (n = 91) were between 35–56 years and > 56 years, respectively (Table S1). Little more than half of the respondents were male (52.9%, n = 323) and 1.0%, 11.3% and 87.7%, of respondents had received education up to primary, secondary and tertiary level as the highest level of education respectively. Respondents were mainly Sri Lankans (81.7%, n = 499), followed by citizens of other Asian elephant range countries (13.8%, n = 84) and citizens from non-range countries (4.6%, n = 28; Table 1). There was a total of 158 individual experts in this study, corresponding to 25.9% of the study population. This included 70 Sri Lankans, 60 from other range countries and the 28 respondents from non-range countries (Table 1), who belonged to one or more of the following Asian elephant expert categories: Researchers and educators (n = 102), NGOs working on Asian elephants (n = 65), current or previous members of the International Union for Conservation of Nature Asian elephant specialist group (n = 31), zoo based organisations housing Asian elephants (n = 19), and government organisations working on Asian elephants (n = 27) (Table S3). Farmers in this study comprised 18.3% (n = 112) of our sample, of which the majority were involved in cultivation of annual crops (n = 85), followed by perennial crops (n = 21), and farming livestock (n = 6) (Table S1). Respondents who have experienced HEC comprised 38.1% (n = 233) of the total number of respondents (Table 1).

Table 1. Summary of the distribution of respondents according to citizenship under the social groups based on experience with human-elephant conflict (HEC)

	Expert-HEC (n = 65)		Expert- no HEC (n = 93)		Farmer-HEC (n = 85)		Farmer- no HEC (n = 27)		Other-HEC (n=83)		Other- no HEC (n = 258)		Total (n = 611)	
Citizenship	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Sri Lanka	31	47.7	39	41.9	84	98.8	26	96.3	80	96.4	239	92.6	499	81.7
Other range countries	29	44.6	31	33.3	1	1.2	1	3.7	3	3.6	19	7.4	84	13.8
non-range countries	5	7.7	23	24.7	0	0.0	0	0.0	0	0.0	0	0.0	28	4.6

3.1 Respondents' perception of the causes of HEC

Of the 10 items assessed under causes of HEC, all respondent groups had positive mean scores for nine of them, agreeing that they are probable causes of HEC (Figs. 1 and 2). There was relatively low consensus on *habitat loss due to natural causes* as a probable cause of HEC (PCI_2 range = 0.27–0.48). Compared to those who have not experienced HEC, respondents who have experienced HEC were less likely to perceive *habitat encroachment*, *unplanned development*, *poor land use planning* and *elephant migratory paths blocked* as a probable cause of HEC ($P < 0.05$, Fig. 1). Farmers were also less likely to perceive *habitat encroachment* and *poor land use planning* as probable causes of HEC, while others were less likely to perceive *agricultural expansion* and *elephants attracted to crops* as probable causes of HEC compared to experts ($P < 0.05$, Fig. 1). Both farmers and others were less likely to perceive *increasing human population* and more likely to perceive *not enough food in forests* as probable causes of HEC compared to experts ($P < 0.05$, Fig. 1). Expert-HEC and expert-no HEC had relatively low consensus (PCI_2 values 0.33, 0.24 respectively) on *not enough food in forests* being a probable cause of HEC compared to the other groups. Further, compared to experts, others were more likely to perceive *elephant migratory paths blocked* as a probable cause of HEC ($P = 0.04$). Among the nine statements agreed upon as a probable cause of HEC, the farmer-HEC group had the lowest positive mean scores for six of them; *habitat encroachment*, *increasing human population*, *unplanned development*, *poor land use planning*, *agricultural expansion* and *elephant migratory paths blocked* with very little or no overlap with other groups (Fig. 2). There was disagreement between groups on *increasing elephant population* as a probable cause, with expert-HEC and farmer-HEC having positive mean scores (0.11 and 0.54 respectively) and remaining four groups having negative mean scores (mean range from -0.02 to -0.33). Expert groups also had relatively high PCI_2 scores (expert-HEC = 0.38, expert-no HEC = 0.42) for *increasing elephant population* (Figs. 1 and 2). Logistic regression showed that compared to experts, others were less likely to perceive that *increasing elephant population* is a probable cause, while those who have experienced HEC were more likely to think that it is a probable cause of HEC ($P < 0.05$, Fig. 1).

Item	Variable	Odds ratio	p value	Mean (PCI)					
				Expert HEC	Expert No HEC	Farmer HEC	Farmer No HEC	Other HEC	Other No HEC
1. Habitat loss by natural causes +	Farmer	1.33	0.28	0.52 (0.48)	0.53 (0.48)	0.66 (0.27)	0.63 (0.35)	0.69 (0.31)	0.61 (0.41)
	Other	1.46	0.06						
	HEC	1.23	0.27						
2. Habitat encroachment +	Farmer	0.36	0.04	1.65 (0.12)	1.84 (0.08)	1.15 (0.18)	1.70 (0.00)	1.63 (0.03)	1.74 (0.04)
	Other	0.70	0.45						
	HEC	0.41	0.02						
3. Increasing elephant population	Farmer	1.13	0.63	0.11 (0.38)	-0.19 (0.42)	0.54 (0.18)	-0.15 (0.16)	-0.02 (0.28)	-0.33 (0.23)
	Other	0.58	0.01						
	HEC	1.94	<0.01						
4. Increasing human population +	Farmer	0.16	<0.01	1.72 (0.04)	1.72 (0.04)	0.87 (0.18)	1.48 (0.20)	1.46 (0.07)	1.47 (0.10)
	Other	0.30	0.02						
	HEC	0.81	0.51						
5. Unplanned development +	Farmer	0.54	0.15	1.51 (0.11)	1.77 (0.03)	1.24 (0.06)	1.63 (0.08)	1.54 (0.00)	1.72 (0.02)
	Other	1.15	0.73						
	HEC	0.42	0.01						
6. Poor land-use planning +	Farmer	0.45	0.04	1.54 (0.03)	1.76 (0.03)	0.94 (0.20)	1.74 (0.00)	1.34 (0.02)	1.69 (0.01)
	Other	0.94	0.88						
	HEC	0.15	<0.01						
7. Agricultural expansion +	Farmer	0.39	0.06	1.57 (0.03)	1.66 (0.04)	1.07 (0.12)	1.52 (0.00)	1.31 (0.02)	1.26 (0.12)
	Other	0.28	<0.01						
	HEC	0.97	0.92						
8. Not enough food in forests +	Farmer	2.49	0.01	0.89 (0.33)	0.87 (0.24)	1.06 (0.17)	1.41 (0.07)	1.14 (0.06)	1.09 (0.16)
	Other	1.82	0.01						
	HEC	1.11	0.65						
9. Elephant migratory paths blocked +	Farmer	0.76	0.47	1.48 (0.05)	1.56 (0.02)	1.13 (0.17)	1.56 (0.00)	1.51 (0.02)	1.63 (0.04)
	Other	2.13	0.04						
	HEC	0.44	0.01						
10. Elephants attracted to crops +	Farmer	0.41	0.08	1.52 (0.03)	1.52 (0.06)	1.21 (0.13)	1.41 (0.07)	1.24 (0.06)	1.16 (0.09)
	Other	0.32	<0.01						
	HEC	1.58	0.14						

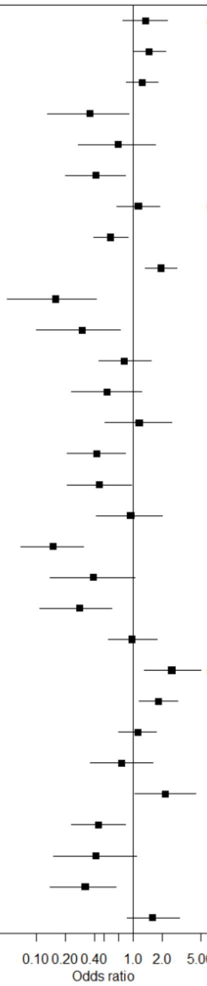

Figure 1 Forest plot for the logistic regression on the likelihood to perceive 10 items as causes of human-elephant conflict (HEC) by farmers and others relative to experts and those exposed to HEC relative to those who are not, along with mean and Potential for Conflict Index$_2$ (PCI) for each group. Black squares and horizontal lines indicate the odds ratio and the 95% confidence interval respectively. + indicates items with all positive mean scores.

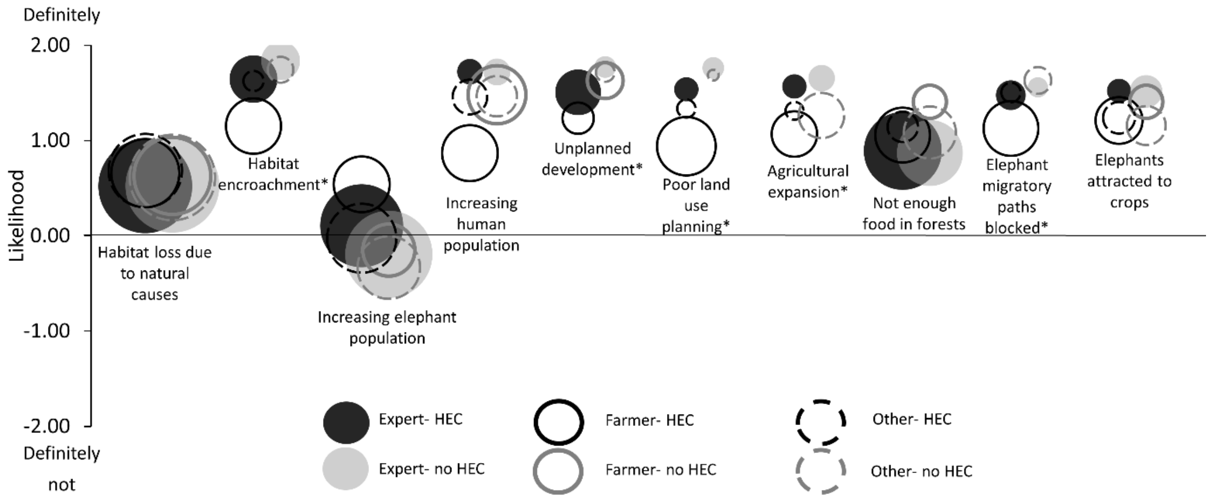

Figure 2 Bubble graph depicting the mean and Potential for Conflict Index$_2$ (PCI_2) for the likelihood of ten items being perceived as causes of human-elephant conflict (HEC) among experts, farmers and others with and without experience in HEC. Centre of the bubble indicates the mean score (on the scale of the y axis), and bubble size illustrates the magnitude of PCI_2 with larger bubbles indicating low consensus among respondents within groups. *Items having one or more groups not represented in the graph due to PCI_2 being 0.00.

3.2 Respondents' perception of the importance, conservation and co-existence with elephants

All respondent groups had positive mean scores for eight of the statements assessed (Figs. 3 and 4). However, the positive mean scores recorded for *remove humans from elephant habitats* were relatively low (range = 0.02 – 0.78), with the lowest recorded by the farmer-HEC group. Logistic regression showed that farmers were less likely to agree that elephants are *an endangered species*, and both farmers and others were less likely to agree on *humans taken over elephant habitats* compared to experts ($P < 0.05$, Fig. 3). Those who have experienced HEC were also less likely to agree with *humans taken over elephant habitat* and *remove humans from elephant habitats* compared to the rest of the respondents ($P < 0.05$, Fig. 3). All groups had negative mean scores for *elephants taken over human habitats*; however, farmer-HEC had the highest mean score and relatively lower consensus (mean = -0.28, PCI_2 = 0.26), and farmers were also more likely to agree with this statement compared to experts ($P < 0.05$, Fig. 3). Except for farmer-HEC (mean = -0.11), all groups had positive mean scores for *should try to co-exist with elephants* (mean range = 0.49–1.20). Compared to experts, both farmers and others were less likely to agree with this statement ($P < 0.05$, Fig.

3). Those who have experienced HEC were also less likely to agree with this statement compared to those who have not experienced HEC ($P < 0.05$, Fig. 3). There were both positive and negative mean scores for *remove elephants from human habitats* (mean range = -0.78–0.44) (Figs. 3 and 4). Logistic regression revealed that farmers and others compared to experts and those who have experienced HEC compared to those who have not were more likely to agree with this statement ($P < 0.05$, Fig. 3).

				Mean (PCI)					
Item	Variable	Odds ratio	p value	Expert HEC	Expert No HEC	Farmer HEC	Farmer No HEC	Other HEC	Other No HEC
1. Elephants should be protected +	Farmer	0.46	0.19	1.83 (0.00)	1.80 (0.07)	1.36 (0.04)	1.67 (0.13)	1.58 (0.04)	1.84 (0.07)
	Other	1.07	0.91						
	HEC	0.51	0.16						
2. Important part of the ecosystem +	Farmer	0.30	0.05	1.91 (0.00)	1.83 (0.04)	1.33 (0.04)	1.63 (0.13)	1.53 (0.04)	1.83 (0.05)
	Other	0.74	0.63						
	HEC	0.46	0.10						
3. Important for tourism +	Farmer	0.96	0.91	1.28 (0.05)	1.42 (0.18)	1.28 (0.04)	1.52 (0.12)	1.42 (0.04)	1.53 (0.11)
	Other	1.60	0.11						
	HEC	0.76	0.31						
4. Elephants benefit the rural economy +	Farmer	0.58	0.10	1.26 (0.03)	1.56 (0.09)	1.00 (0.15)	1.30 (0.11)	1.20 (0.17)	1.45 (0.09)
	Other	0.90	0.70						
	HEC	0.67	0.10						
5. Important role in the culture and religion +	Farmer	0.66	0.26	1.48 (0.06)	1.44 (0.14)	1.24 (0.02)	1.26 (0.22)	1.25 (0.03)	1.28 (0.17)
	Other	0.68	0.18						
	HEC	1.52	0.11						
6. An endangered species +	Farmer	0.47	0.03	1.45 (0.09)	1.63 (0.13)	0.94 (0.14)	1.15 (0.27)	1.27 (0.08)	1.39 (0.07)
	Other	0.66	0.18						
	HEC	0.73	0.21						
7. Humans taken over elephant habitat +	Farmer	0.12	<0.01	1.55 (0.00)	1.69 (0.00)	0.86 (0.14)	1.41 (0.12)	1.33 (0.04)	1.45 (0.10)
	Other	0.26	0.01						
	HEC	0.44	0.01						
8. Elephants taken over human habitats ^	Farmer	2.78	0.01	-1.09 (0.14)	-1.18 (0.17)	-0.28 (0.26)	-1.00 (0.16)	-0.71 (0.12)	-0.93 (0.15)
	Other	1.14	0.70						
	HEC	1.20	0.52						
9. Should try to co-exist with elephants	Farmer	0.21	<0.01	1.00 (0.19)	1.20 (0.13)	-0.11 (0.21)	0.74 (0.26)	0.49 (0.25)	0.80 (0.17)
	Other	0.38	<0.01						
	HEC	0.47	<0.01						
10. Remove humans from elephant habitats +	Farmer	0.76	0.29	0.38 (0.22)	0.47 (0.29)	0.02 (0.19)	0.78 (0.12)	0.51 (0.16)	0.67 (0.15)
	Other	1.20	0.35						
	HEC	0.56	<0.01						
11.Remove elephants from human habitats	Farmer	3.19	<0.01	-0.31 (0.29)	-0.78 (0.22)	0.44 (0.25)	-0.07 (0.21)	0.01 (0.25)	-0.28 (0.24)
	Other	1.92	0.01						
	HEC	2.00	<0.01						

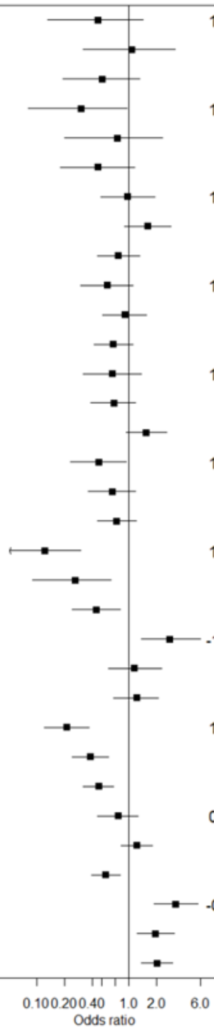

Figure 3 Forest plot for the logistic regression on the agreement of 11 statements related to importance, conservation and co-existence with elephants by farmers and others relative to experts and those exposed to human elephant conflict (HEC) relative to those who are not, along with mean and Potential for Conflict Index$_2$ (PCI) for each group. Black squares and horizontal lines indicate the odds ratio and the 95% confidence interval respectively. + and ^ indicate items with all positive or negative mean scores respectively.

.

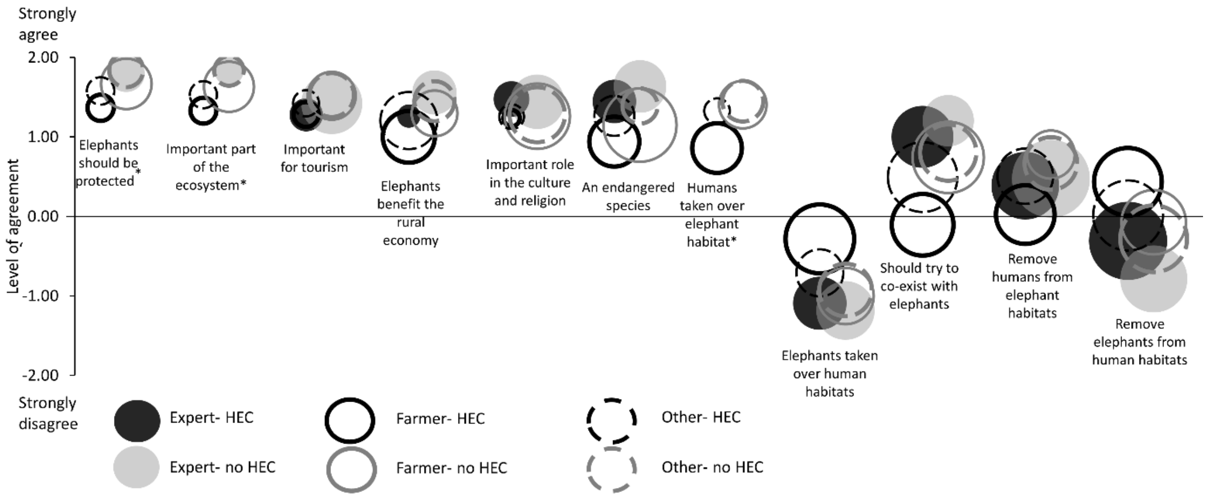

Figure 4 Bubble graph for mean and Potential for Conflict Index$_2$ (PCI_2) for agreement of different statements related to importance, conservation and co-existence with elephants among experts, farmers and others with and without experience in HEC. Centre of the bubble indicate the mean score (on the scale of the y axis) and bubble size illustrates the magnitude of PCI_2 with larger bubbles indicating low consensus among respondents within groups. *Items having one or more groups not represented in the graph due to PCI_2 being 0.00.

3.3 Respondents' perception of the acceptability of HEC mitigation tools

All groups had positive mean acceptability scores for *electric fencing*, *planting thorny plants*, *planting unpalatable crops*, *flashlights*, *bee fences*, providing early warning with Global Positioning System or *GPS collars, infrasonic call detectors* and *geophones*, as well as *compensation schemes* (Figs. 5, 6a and 6c). All respondent groups had negative mean acceptability scores for *killing problem elephants*, *taming problem elephants*, *sterilising elephants*, *jaw bombs*, *nail boards* and *shot guns,* perceiving them as unacceptable for HEC mitigation. Among the tools perceived acceptable by all groups, logistic regression revealed that both farmers and others were less likely to perceive that *planting thorny plants*, *planting unpalatable crops*, *flashlights*, *infrasonic call detectors*, *geophones* and *compensation schemes* as acceptable compared to experts ($P < 0.05$, Fig. 5). Further, compared to experts, others were less likely to perceive *electric fencing* as acceptable and those who have experienced HEC were less likely to perceive *GPS collars*, *infrasonic call detectors* and *geophones* as acceptable compared to those who have not experienced HEC ($P < 0.05$, Fig. 5). Among those tools with all negative mean acceptability scores, *taming problem elephants* was more likely to be perceived as acceptable by others compared to experts, and those who have experienced HEC compared to those who have not. Also, farmers relative to experts and those who have experienced HEC relative to those who have not were more likely to perceive *shot guns* as acceptable (P < 0.05, Fig. 5).

There was disagreement between groups for acceptability of *trenches and ditches*, *shouting*, *lighting bonfires*, *thunder flashes*, *firecrackers*, *smoke*, *restricting to protected areas*, *translocation*, *elephant holding grounds* and *elephant drives*, with mean acceptability scores all ranging from -0.77 to 0.76 and relatively low consensus within groups (PCI_2 range = 0.24 – 0.55; Fig. 5, 6a and 6c). Both farmers and others were less likely to perceive *shouting*, *lighting bonfires* and more likely to perceive *restricting to protected areas*, *translocation*, *elephant holding grounds* as acceptable compared to experts (P < 0.05, Fig. 5). Further, others were less likely to perceive *trenches and ditches* and *firecrackers* as acceptable compared to experts, while those who have experienced HEC were more likely to perceive *thunder flashes* as acceptable compared to those who have not experienced HEC (P < 0.01, Fig. 5).

Item	Variable	Odds ratio	p value	Expert HEC	Expert No HEC	Farmer HEC	Farmer No HEC	Other HEC	Other No HEC
1. Electric fencing +	Farmer	0.79	0.41	0.83 (0.31)	0.83 (0.30)	0.92 (0.18)	0.56 (0.30)	0.47 (0.27)	0.20 (0.38)
	Other	0.44	<0.01						
	HEC	1.15	0.47						
2. Trenches, ditches	Farmer	0.63	0.08	0.34 (0.36)	0.00 (0.55)	0.25 (0.30)	-0.15 (0.35)	-0.28 (0.38)	-0.39 (0.44)
	Other	0.51	<0.01						
	HEC	1.10	0.61						
3. Planting thorny plants +	Farmer	0.31	<0.01	1.06 (0.31)	1.25 (0.26)	0.44 (0.49)	0.89 (0.31)	0.72 (0.30)	0.79 (0.30)
	Other	0.46	<0.01						
	HEC	0.99	0.96						
4. Planting unpalatable crops +	Farmer	0.36	<0.01	0.94 (0.30)	1.19 (0.30)	0.19 (0.39)	1.07 (0.26)	0.84 (0.31)	0.84 (0.29)
	Other	0.55	0.01						
	HEC	0.70	0.06						
5. Shouting	Farmer	0.56	0.02	0.40 (0.49)	0.38 (0.41)	-0.13 (0.50)	0.07 (0.42)	0.20 (0.44)	0.17 (0.33)
	Other	0.58	0.01						
	HEC	1.07	0.70						
6. Lighting bon fires	Farmer	0.57	0.03	0.51 (0.40)	0.27 (0.52)	-0.04 (0.43)	0.67 (0.25)	0.39 (0.35)	0.17 (0.35)
	Other	0.58	0.01						
	HEC	1.03	0.89						
7. Flashlights +	Farmer	0.58	0.04	0.58 (0.40)	0.71 (0.46)	0.19 (0.45)	0.48 (0.33)	0.48 (0.44)	0.43 (0.30)
	Other	0.55	<0.01						
	HEC	0.92	0.65						
8. Thunder flashes	Farmer	1.59	0.07	0.03 (0.35)	-0.23 (0.47)	0.40 (0.40)	-0.04 (0.49)	0.14 (0.35)	-0.57 (0.37)
	Other	0.75	0.15						
	HEC	1.77	<0.01						
9. Firecrackers	Farmer	1.15	0.59	0.00 (0.43)	-0.37 (0.55)	0.08 (0.40)	0.07 (0.37)	-0.28 (0.39)	-0.75 (0.36)
	Other	0.53	<0.01						
	HEC	1.45	0.05						
10. Bee fences +	Farmer	0.71	0.19	0.45 (0.34)	0.86 (0.31)	0.29 (0.38)	0.93 (0.19)	0.78 (0.13)	0.55 (0.25)
	Other	0.69	0.06						
	HEC	0.92	0.64						
11. Smoke	Farmer	0.50	0.01	0.20 (0.28)	0.33 (0.33)	-0.26 (0.39)	-0.04 (0.30)	0.18 (0.36)	0.12 (0.27)
	Other	0.72	0.09						
	HEC	1.01	0.94						
12. Restricting to protected areas	Farmer	2.73	<0.01	-0.18 (0.51)	-0.22 (0.51)	0.76 (0.36)	0.59 (0.31)	0.52 (0.31)	0.42 (0.37)
	Other	2.12	<0.01						
	HEC	1.11	0.59						
13. Translocation	Farmer	3.39	<0.01	-0.55 (0.41)	-0.67 (0.37)	0.49 (0.45)	0.19 (0.49)	0.40 (0.37)	0.24 (0.41)
	Other	3.68	<0.01						
	HEC	1.25	0.25						
14. Elephant holding grounds	Farmer	1.98	0.01	-0.34 (0.44)	-0.77 (0.41)	0.33 (0.42)	0.00 (0.50)	0.30 (0.42)	0.18 (0.37)
	Other	2.84	<0.01						
	HEC	1.43	0.06						
15. Elephant drives	Farmer	1.53	0.11	-0.29 (0.42)	-0.65 (0.39)	0.09 (0.38)	0.04 (0.24)	-0.04 (0.29)	-0.18 (0.40)
	Other	1.51	0.05						
	HEC	1.36	0.11						
16. Killing problem elephants ^	Farmer	0.59	0.29	-1.25 (0.21)	-1.51 (0.18)	-1.36 (0.15)	-1.59 (0.12)	-1.29 (0.23)	-1.28 (0.17)
	Other	0.99	0.99						
	HEC	1.55	0.17						
17. Taming problem elephants ^	Farmer	1.80	0.05	-0.71 (0.38)	-1.15 (0.31)	-0.21 (0.37)	-0.48 (0.46)	-0.28 (0.42)	-0.66 (0.36)
	Other	1.74	0.02						
	HEC	1.61	0.02						
18. GPS collars +	Farmer	0.62	0.11	1.40 (0.05)	1.20 (0.27)	0.77 (0.18)	1.52 (0.08)	1.06 (0.25)	1.41 (0.09)
	Other	1.08	0.76						
	HEC	0.64	0.05						
19. Infrasonic call detectors +	Farmer	0.39	<0.01	1.48 (0.03)	1.52 (0.13)	0.81 (0.14)	1.48 (0.00)	1.05 (0.20)	1.39 (0.07)
	Other	0.56	0.04						
	HEC	0.58	0.02						
20. Geophones +	Farmer	0.18	<0.01	1.43 (0.08)	1.58 (0.02)	0.38 (0.18)	1.30 (0.07)	0.99 (0.17)	1.34 (0.07)
	Other	0.41	<0.01						
	HEC	0.49	<0.01						
21. Compensation schemes +	Farmer	0.22	<0.01	1.35 (0.14)	1.29 (0.18)	0.24 (0.41)	1.07 (0.15)	0.71 (0.24)	0.87 (0.20)
	Other	0.29	<0.01						
	HEC	0.80	0.25						
22. Sterilising elephants ^	Farmer	1.24	0.59	-1.05 (0.25)	-1.24 (0.24)	-0.91 (0.22)	-1.30 (0.29)	-1.31 (0.20)	-1.37 (0.20)
	Other	0.71	0.29						
	HEC	0.93	0.80						
23. Jaw bombs ^	Farmer	2.09	0.33	-1.60 (0.14)	-1.89 (0.00)	-1.52 (0.13)	-1.81 (0.09)	-1.58 (0.08)	-1.78 (0.10)
	Other	1.69	0.44						
	HEC	1.56	0.41						
24. Nail boards ^	Farmer	2.02	0.36	-1.51 (0.06)	-1.83 (0.04)	-1.51 (0.12)	-1.70 (0.00)	-1.69 (0.03)	-1.74 (0.06)
	Other	1.02	0.98						
	HEC	1.75	0.36						
25. Shot guns ^	Farmer	3.74	0.02	-1.58 (0.14)	-1.92 (0.04)	-1.04 (0.43)	-1.85 (0.00)	-1.80 (0.00)	-1.84 (0.06)
	Other	0.55	0.36						
	HEC	2.94	0.04						

Mean (PCI)

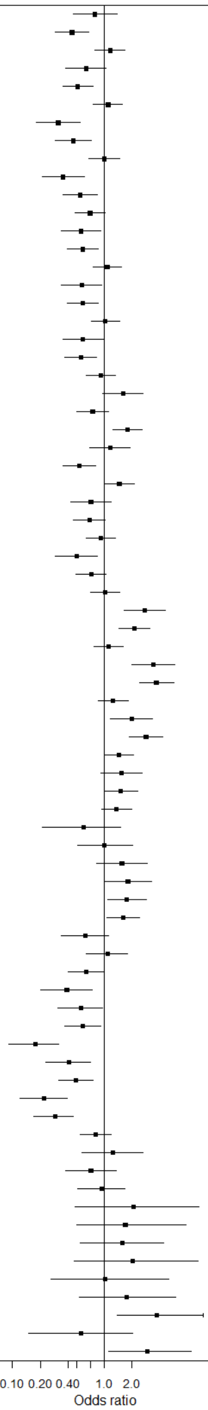

Figure 5 Forest plot for the logistic regression on the acceptability of 25 human elephant conflict (HEC) mitigation tools by farmers and others relative to experts and those exposed to HEC relative to those who are not, along with mean and Potential for Conflict Index$_2$ (PCI) for each group. Black squares and horizontal lines indicate the odds ratio and the 95% confidence interval respectively. GPS- Global Positioning System, + and ^ indicate items with all positive or negative mean scores respectively.

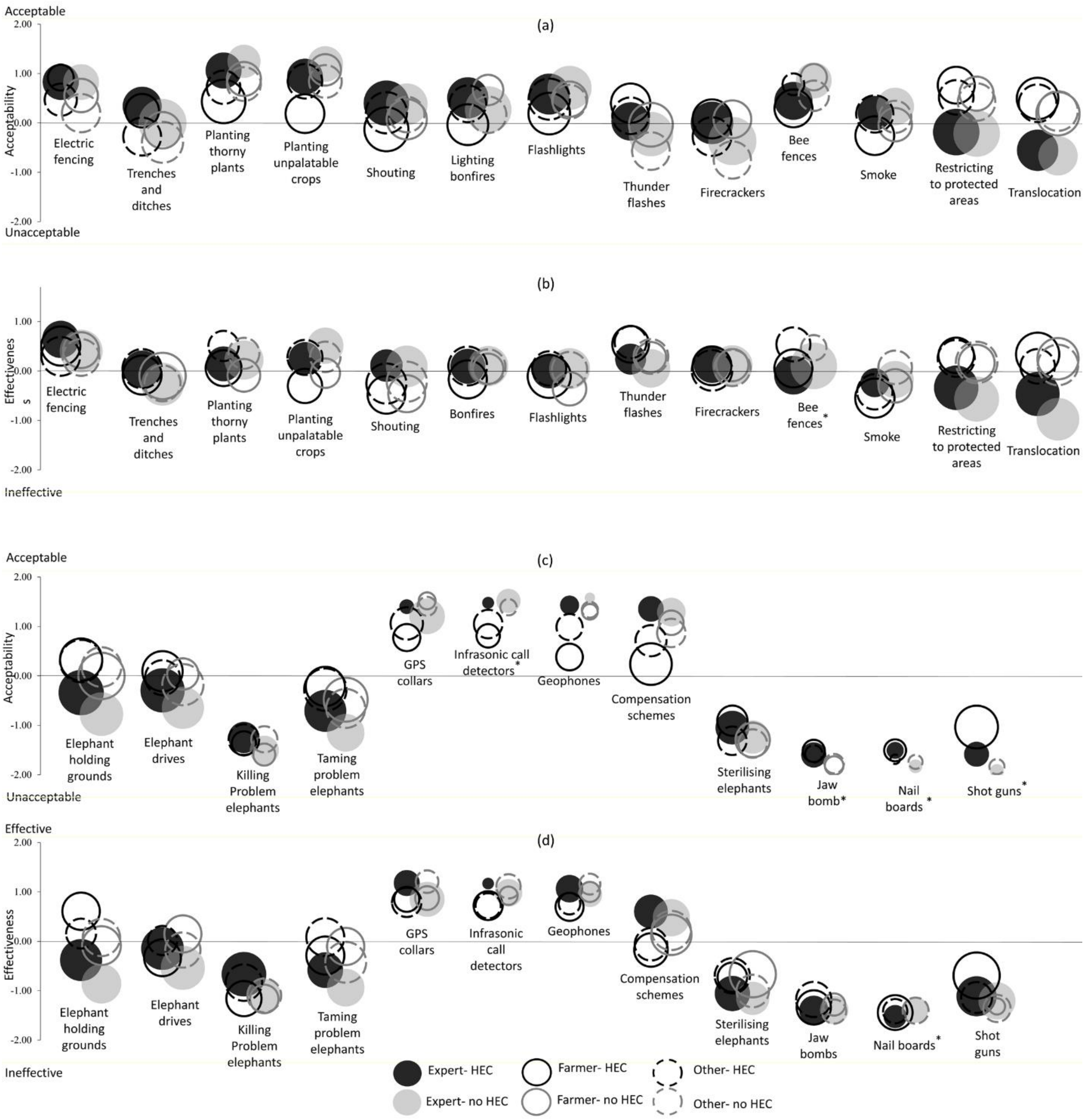

Figure 6 Bubble graphs for mean and Potential for Conflict Index$_2$ (PCI$_2$) for acceptability (a and c) and perceived effectiveness (b and d) for 25 human-elephant conflict (HEC) mitigation tools among experts, farmers and others with and without experience in HEC. Centre of the bubble indicate the mean score (on the scale of the y axis) and bubble size illustrates the magnitude of PCI$_2$ with larger bubbles indicating low consensus among respondents within groups. *Items having one or more groups not represented in the graph due to PCI$_2$ being 0.00. GPS- Global Positioning System.

3.4 Respondents' perception of the effectiveness of HEC mitigation tools

All respondent groups had positive mean effectiveness scores for six tools: *electric fencing*, *thunder flashes*, *firecrackers*, providing early warnings with *GPS collars*, *infrasonic call detectors*, and *geophones*, with the latter three having relatively high mean scores (mean range= 0.70–1.18) and consensus (PCI_2 range = 0.03–0.31) (Figs. 6b, 6d and 7). Those who have experienced HEC were more likely to perceive *thunder flashes* as an effective tool than those who have not (P = 0.03, Fig. 7). All groups had negative mean effectiveness scores for *killing of problem elephants*, *sterilising elephants*, *jaw bombs*, *nail boards* and *shot guns*, but with variable consensus levels (PCI_2 range = 0.00–0.58). There was disagreement between groups on the effectiveness of all other mitigation tools with mean scores ranging from -0.98 to 0.78 and PCI_2 from 0.00 to 0.54. Farmers were less likely to perceive *planting unpalatable crops* as effective compared to experts ($P < 0.01$, Fig. 7). Both farmers and others were less likely to perceive *shouting*, and *compensation schemes* as effective while they were more likely to perceive *restricting to protected areas*, *translocation* and *elephant holding grounds* as effective compared to experts ($P < 0.05$, Fig. 7). Those who have experienced HEC were also less likely to perceive *smoke* as effective compared to those who have not experienced HEC (P = 0.04, Fig. 7). In addition, others were also more likely to perceive *taming problem elephants* as an effective mitigation tool compared to experts ($P < 0.01$, Fig. 7).

Item	Variable	Odds ratio	p value	Mean (PCI) Expert HEC	Expert No HEC	Farmer HEC	Farmer No HEC	Other HEC	Other No HEC
1. Electric fencing +	Farmer	0.86	0.59	0.64 (0.32)	0.40 (0.43)	0.51 (0.39)	0.42 (0.33)	0.30 (0.38)	0.28 (0.35)
	Other	0.70	0.09						
	HEC	1.14	0.49						
2. Trenches, ditches	Farmer	0.94	0.81	0.03 (0.33)	-0.27 (0.43)	-0.08 (0.39)	-0.10 (0.54)	0.05 (0.39)	-0.25 (0.34)
	Other	0.85	0.47						
	HEC	1.22	0.34						
3. Planting thorny plants	Farmer	0.59	0.07	0.15 (0.28)	0.22 (0.35)	0.06 (0.33)	-0.09 (0.28)	0.51 (0.24)	0.36 (0.25)
	Other	1.13	0.59						
	HEC	1.17	0.45						
4. Planting unpalatable crops	Farmer	0.37	<0.01	0.26 (0.24)	0.51 (0.30)	-0.30 (0.31)	-0.04 (0.23)	0.28 (0.32)	0.29 (0.24)
	Other	0.69	0.10						
	HEC	0.80	0.28						
5. Shouting	Farmer	0.47	<0.01	0.11 (0.25)	0.09 (0.40)	-0.48 (0.36)	-0.46 (0.35)	-0.25 (0.41)	-0.21 (0.41)
	Other	0.63	0.02						
	HEC	0.80	0.24						
6. Lighting bon fires	Farmer	0.66	0.13	0.10 (0.28)	0.10 (0.37)	-0.17 (0.37)	0.05 (0.24)	0.10 (0.38)	0.09 (0.31)
	Other	0.91	0.66						
	HEC	1.00	0.99						
7. Flashlights	Farmer	0.84	0.51	0.00 (0.28)	0.05 (0.39)	-0.11 (0.47)	-0.36 (0.29)	0.05 (0.30)	0.03 (0.32)
	Other	0.87	0.50						
	HEC	1.03	0.87						
8. Thunder flashes +	Farmer	1.54	0.11	0.24 (0.22)	0.05 (0.34)	0.54 (0.35)	0.28 (0.24)	0.58 (0.27)	0.29 (0.31)
	Other	1.48	0.07						
	HEC	1.53	0.03						
9. Firecrackers +	Farmer	0.85	0.54	0.13 (0.31)	0.11 (0.38)	0.11 (0.38)	0.12 (0.27)	0.01 (0.42)	0.06 (0.34)
	Other	0.81	0.32						
	HEC	1.11	0.58						
10. Bee fences	Farmer	0.98	0.96	-0.08 (0.35)	0.10 (0.50)	0.05 (0.37)	0.78 (0.00)	0.54 (0.30)	0.47 (0.17)
	Other	1.10	0.70						
	HEC	0.95	0.81						
11. Smoke	Farmer	1.10	0.77	-0.24 (0.19)	-0.17 (0.32)	-0.55 (0.39)	-0.30 (0.29)	-0.42 (0.32)	0.07 (0.29)
	Other	1.45	0.13						
	HEC	0.63	0.04						
12. Restricting to protected areas	Farmer	1.81	0.03	-0.34 (0.46)	-0.57 (0.47)	0.32 (0.33)	0.17 (0.34)	0.26 (0.35)	0.17 (0.44)
	Other	2.15	<0.01						
	HEC	1.10	0.63						
13. Translocation	Farmer	3.11	<0.01	-0.46 (0.45)	-0.98 (0.42)	0.34 (0.47)	0.25 (0.43)	0.10 (0.31)	0.12 (0.42)
	Other	2.42	<0.01						
	HEC	1.16	0.46						
14. Elephant holding grounds	Farmer	2.90	<0.01	-0.38 (0.44)	-0.86 (0.39)	0.61 (0.39)	-0.09 (0.42)	0.16 (0.26)	0.08 (0.38)
	Other	2.23	<0.01						
	HEC	1.40	0.10						
15. Elephant drives	Farmer	0.91	0.77	-0.15 (0.46)	-0.54 (0.49)	-0.33 (0.38)	0.15 (0.38)	0.02 (0.24)	-0.18 (0.35)
	Other	0.96	0.86						
	HEC	1.13	0.58						
16. Killing problem elephants ^	Farmer	0.53	0.16	-0.67 (0.50)	-1.11 (0.29)	-1.16 (0.35)	-1.17 (0.23)	-0.84 (0.37)	-1.10 (0.32)
	Other	0.87	0.67						
	HEC	1.80	0.06						
17. Taming problem elephants	Farmer	1.73	0.10	-0.58 (0.32)	-0.94 (0.35)	-0.29 (0.40)	-0.11 (0.39)	0.08 (0.40)	-0.42 (0.46)
	Other	2.28	<0.01						
	HEC	1.51	0.07						
18. GPS collars +	Farmer	0.70	0.32	1.18 (0.17)	0.85 (0.31)	0.85 (0.18)	0.88 (0.17)	0.79 (0.25)	1.21 (0.15)
	Other	1.10	0.75						
	HEC	1.00	0.99						
19. Infrasonic call detectors +	Farmer	0.65	0.25	1.17 (0.03)	0.98 (0.19)	0.72 (0.24)	0.92 (0.10)	0.72 (0.19)	1.11 (0.17)
	Other	0.73	0.30						
	HEC	0.72	0.24						
20. Geophones +	Farmer	0.64	0.25	1.07 (0.19)	0.94 (0.15)	0.70 (0.22)	1.00 (0.12)	0.76 (0.14)	1.16 (0.13)
	Other	0.88	0.67						
	HEC	0.79	0.41						
21. Compensation schemes	Farmer	0.39	<0.01	0.6 (0.29)	0.48 (0.35)	-0.18 (0.32)	0.13 (0.45)	-0.06 (0.30)	0.22 (0.42)
	Other	0.44	<0.01						
	HEC	0.67	0.05						
22. Sterilising elephants ^	Farmer	1.42	0.45	-1.06 (0.31)	-1.16 (0.28)	-0.73 (0.25)	-0.67 (0.58)	-0.70 (0.35)	-1.01 (0.30)
	Other	1.21	0.61						
	HEC	1.16	0.66						
23. Jaw bombs ^	Farmer	1.03	0.95	-1.40 (0.21)	-1.39 (0.20)	-1.34 (0.33)	-1.28 (0.15)	-1.18 (0.35)	-1.42 (0.17)
	Other	1.13	0.76						
	HEC	1.79	0.09						
24. Nail boards ^	Farmer	1.26	0.71	-1.53 (0.14)	-1.39 (0.17)	-1.44 (0.34)	-1.48 (0.00)	-1.42 (0.17)	-1.40 (0.20)
	Other	1.35	0.55						
	HEC	1.16	0.73						
25. Shot guns ^	Farmer	1.40	0.38	-1.11 (0.40)	-1.21 (0.35)	-0.69 (0.58)	-1.32 (0.08)	-1.14 (0.27)	-1.36 (0.21)
	Other	0.70	0.29						
	HEC	1.73	0.06						

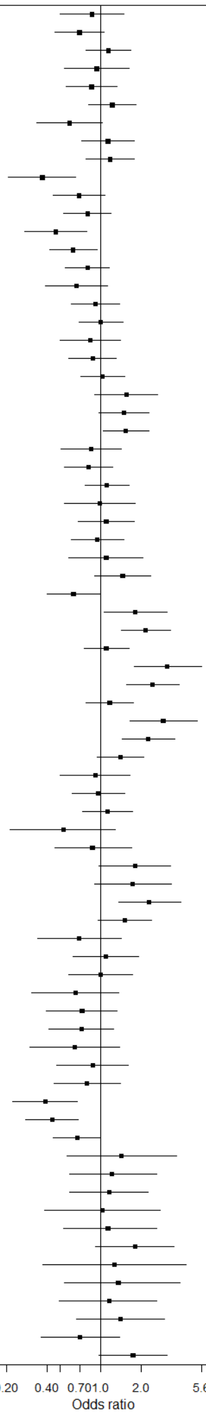

Figure 7 Forest plot for the logistic regression on the effectiveness of 25 human-elephant conflict (HEC) mitigation tools by farmers and others relative to experts and those exposed to HEC relative to those who are not, along with mean and Potential for Conflict Index$_2$ (PCI). Black squares and horizontal lines indicate the odds ratio and the 95% confidence interval respectively. GPS- Global Positioning System, + and ^ indicate items with all positive or negative mean scores respectively.

4. Discussion

We assessed views on Asian elephant conservation and HEC mitigation from a variety of stakeholder groups, including people with or without personal experience in HEC. We identified many similarities and differences in views towards the causes of HEC, towards the importance and conservation of elephants and possibility of co-existence with them, and towards the acceptability and effectiveness of potential HEC mitigation tools. All stakeholder groups agreed on most causes of HEC and had mostly positive attitudes towards elephant conservation (Figs. 1–4). However, farmers who have experienced HEC held divergent views to experts about the possibility of co-existence with elephants (Figs. 3 and 4), and HEC mitigation tools particularly around restricting elephants to protected areas, translocation and elephant holding grounds (Figs. 5–7). Understanding these similarities and differences in opinions can assist with the development of acceptable and effective HEC mitigation strategies to successfully achieve conservation goals (Engel et al., 2017; Heneghan & Morse, 2019; van Eeden et al., 2019; Drijfhout et al., 2022).

Despite the general agreement on most causes of HEC assessed, experts and farmers who have experienced HEC perceived an increasing elephant population as a probable cause of HEC while the other groups disagreed. There was also relatively low consensus on increasing elephant population within the expert groups (Figs. 1 and 2). Such lack of consensus between and within groups is probably because there are reports of range expansions and increases in several regional elephant populations (Sukumar, 2006; Baskaran et al., 2011; Fernando et al., 2011; Jigme & Williams, 2011; Singh et al., 2023) even though overall elephant numbers are declining or are very small in many range countries (Fernando & Pastorini, 2011; Menon & Tiwari, 2019). There was also relatively low consensus within groups on the idea that habitat loss due to natural causes is a cause of HEC (Figs. 1 and 2), but there is evidence that changes in climatic conditions may cause alterations in elephant distribution and could therefore create more HEC situations (Kanagaraj et al., 2019; Yang et al., 2022). Our respondents agree that attraction of elephants to cultivated crops and not having enough food for elephants in forests as probable causes of HEC. But there was relatively low consensus on the latter within expert groups (Figs. 1 and 2), probably because HEC incidents peak during the harvesting season but not during the dry season when there could be low availability of food in forests (Webber et al., 2011; Gubbi, 2012; Neupane et al., 2017). Elephants in Sri Lanka are known to move out of protected areas during the dry season (due to low availability of food) to feed in fallow land without causing conflict with people (Fernando et al., 2005). But the increasing use of longer cultivation periods or irrigated dry season cultivation may lead to increased conflict as elephants compete with humans for food during dry seasons (Pastorini et al., 2013; Anuradha et al., 2019). Where there is low agreement between stakeholders it will be beneficial to further investigate them under each HEC situation and communicate with stakeholders to build consensus, because addressing root causes is essential to successfully mitigate HEC.

We found mostly positive attitudes towards the importance and conservation of elephants, even among those affected by HEC (Figs. 3 and 4), similar to observations described in other studies (van de Water & Matteson, 2018; Sampson et al., 2019; Su et al., 2020; Tripathy et al., 2022). This may be linked to the majority of respondents identifying themselves as followers of Buddhism and Hinduism (Table S1) who consider elephants as sacred beings (Sukumar, 2003; Gogoi, 2018; Köpke et al., 2021). However, although all respondent groups agreed that humans have taken over elephant habitats and not vice versa (Abdullah et al., 2019; Sampson et al., 2019), the farmers who have experienced HEC were relatively less likely to have this view (Fig. 4). The farmer-HEC group also perceived that elephants should be removed from human habitats rather than removing humans, similar to perceptions reported in other studies (He et al., 2011; Sampson et al., 2019). Relocating people to mitigate HEC is practically impossible given the many social issues that arise from such a process (Su et al., 2020). Furthermore, the farmer-HEC group also disagreed with all other groups that people should try to co-exist with elephants (Fig. 4), and previous studies have reported likewise (van de Water & Matteson, 2018; Sampson et al., 2019; Ardiantiono et al., 2021). Experts working to resolve HEC need to recognise this disparity and provide farmers with sufficient assurance about their lives and livelihoods if co-existence with elephants is to be promoted amongst farmers.

Four HEC mitigation tools were perceived by all groups as both acceptable and effective (Figs. 5, and 6), though only electric fencing could be considered a common tool among them. Previous studies have shown that people generally perceive electric fencing to be an effective HEC mitigation tool (Ponnusamy et al., 2016; Neupane, Khatiwoda, & Budhathoki, 2018; van de Water & Matteson, 2018; Nayak & Swain, 2020), however, its effectiveness strongly depends on proper maintenance (Jasmine, Ghose, & Das, 2015; Liefting, de Jong, & Prins, 2018; Pekor et al., 2019). Electric fences are costly to build and maintain (Gunaryadi, Sugiyo, & Hedges, 2017), are often broken by elephants (Desai &

Riddle, 2015; Jasmine et al., 2015), limit elephant movement and gene flow (Hayward & Kerley, 2009; Estes et al., 2012; Puyravaud et al., 2022), and might only shift the problem from one place to another (Osipova et al., 2018). However, community based electric fences can be quite effective in managing HEC where the responsibility of fence maintenance is adopted by community members (Fernando et al., 2011; Fernando, 2020). The other three tools considered both acceptable and effective (early warning systems using GPS collars, infrasonic call detectors and geophones) are not widely used at present, have relatively limited information on their success, or are still under development (Venkataraman et al., 2005; Sugumar & Jayaparvathy, 2013; Dabare et al., 2015; Zeppelzauer, Hensman, & Stoeger, 2015). Despite this, the importance of early warning systems in preventing HEC incidents is being increasingly recognised as a good approach. For example, China has invested large amounts of funds on remotely triggered alarms, mobile warning messages, infrared triggered cameras and drones, which have been reported to be effective at detecting problems with elephants (Chen et al., 2021); but alone, most do not actually mitigate those problems, which still require people to use traditional methods to prevent elephants from entering their properties (Cabral de Mel et al., 2022; Gross et al., 2022). Nevertheless, the generally positive attitudes among people towards uncommon and sophisticated early warning systems may indicate a willingness in people to test and explore modern technologies to mitigate HEC. Technologies that both warn about and mitigate potential problems before they occur are most promising, and should be further investigated (Cabral de Mel et al., 2023).

All groups agreed on the unacceptability and ineffectiveness of many potentially lethal or harmful HEC mitigation tools (Figs. 6c and 6d). However, experts and other groups had opposing views on the acceptability and effectiveness of restricting elephants to protected areas and translocation of problem causing elephants to protected areas away from their capture site and wild elephant holding grounds (Fig. 6). Although experts have shown that these methods are ineffective in reducing HEC and negatively impact the wellbeing of elephants (Stüwe et al., 1998; Pinter-Wollman, 2009; Fernando, 2011, 2015; Fernando et al., 2012, 2015; Anthony, 2021), this awareness is lacking among the general public (van de Water & Matteson, 2018; Sampson et al., 2019; Talukdar & Choudhury, 2020). Experts need to pay attention to these opposing perceptions and communicate with local communities experiencing HEC why such methods are not viable options. There was lack of agreement on the acceptability and effectiveness of many of the traditional deterrents, but all groups had relatively positive opinions on the effectiveness of thunder flashes and firecrackers (Figs. 6b and 7). Community-based crop guarding using loud noises, explosives, fire and lights have shown to be effective in keeping elephants away (Nyhus, Tilson, & Sumianto, 2000; Hedges & Gunaryadi, 2010; Gunaryadi et al., 2017; van de Water & Matteson, 2018), however, they may be effective only in the short term as elephants quickly habituate to them (Davies et al., 2011; Fernando et al., 2011; Aziz et al., 2016). Therefore, they should be used alternatively with other interventions to ensure their effectiveness in the long term.

There were several other tools that were deemed acceptable by all groups, albeit with mixed views on their effectiveness (Figs. 6 and 7). For example, farmers in our study were more likely to feel that planting unpalatable crops is ineffective (Fig. 7) despite evidence that they may be effective and support the livelihoods of local communities (Gross et al., 2017; Dharmarathne et al., 2020; Ly et al., 2020). One reason for this may be the increased time and money required to change to alternative cropping or farming practices (Neupane et al., 2017). Experts and farmers who have experienced HEC also had relatively neutral or negative opinions on the effectiveness of bee fences, perhaps because their success against elephants in Africa (King et al., 2009, 2010) is not well reflected in studies on elephants in Asia (Sugiyo et al., 2016; Fernando & Corea, 2019; van de Water et al., 2020). Compensation schemes could be effective in providing relief to those affected and thereby improve people's tolerance levels towards co-existing with elephants (Jasmine et al., 2015; Chen et al., 2021), but similar to many other studies, respondents who have experienced HEC seem to feel that it is ineffective because reporting and claiming compensation is difficult, time-consuming, and the available funds are insufficient to cover the real losses (Bandara and Tisdell, 2002; Borah et al., 2022; Karanth et al., 2013; Ogra and Badola, 2008; Tisdell and Zhu, 1998). Such schemes are also prone to fraud (Ogra & Badola, 2008) and do not actually prevent the loss, but merely shift the cost of the losses from farmers to the general public via government or other management agencies. Regardless, the tools that are considered acceptable but sometimes ineffective (Table 2) represent those tools that are most likely to become effective in the future following sufficient research and development to improve them.

Table 2. Acceptability and effectiveness of human-elephant conflict (HEC) mitigation tools (sorted in the descending order of mean acceptability scores of experts exposed to HEC and agreed acceptability and effectiveness by all stakeholder groups). '√', 'X' and 'O' indicates all positive mean scores, all negative mean scores and mixed (positive and negative) scores by stakeholder groups respectively.

HEC mitigation tool	Acceptability	Effectiveness
Infrasonic call detectors	√	√
Geophones	√	√
GPS collars	√	√
Electric fencing	√	√
Compensation or insurance schemes	√	O
Live fences – planting thorny plants	√	O
Planting unpalatable crops	√	O
Flashlights	√	O
Bee fences	√	O
Lighting bon fires	O	O
Shouting to chase elephants	O	O
Trenches, ditches	O	O
Smoke	O	O
Thunder flashes	O	√
Firecrackers	O	√
Restricting elephants to protected areas	O	O
Elephant drives	O	O
Wild elephant holding grounds	O	O
Translocation	O	O
Capture and taming problem elephants	X	O
Sterilising elephants	X	X
Official culling of problem elephants	X	X
Nail boards	X	X
Shot guns	X	X
Jaw bombs	X	X

There are a few important limitations to our study. For example, although we have tried to formulate our survey questions carefully, some questions may have similar meanings to different people, and hence their results may be correlated (e.g. the causes of HEC associated with unplanned development, poor land-use planning, and agricultural expansion may be similar). Had the questions been formulated differently we may have obtained slightly different results. Our survey also asked what respondents thought about different aspects of HEC and their responses may be based on their perceptions, which may not be driven by a comprehensive ecological understanding. Good management decisions need to be evidence based, be rooted in biology and ecology of elephants, and they also need to be considered acceptable by key stakeholders.

5. Conclusion

In conclusion, we found that people generally agreed on most causes of HEC and had positive opinions towards elephant conservation, but those affected by HEC largely disagreed with the idea of co-existing with elephants and instead supported the removal of elephants from human habitats. Despite the apparent impasse, we identified several mutually acceptable tools that offer the best opportunities to mitigate HEC if or when issues affecting their inconsistent reliability can be overcome. We recommend that the views of those who experience HEC should be given special attention when formulating appropriate management strategies, and that researchers should focus their efforts on refining the effectiveness of tools and approaches considered mutually acceptable by all stakeholders. In this way, the frequency and severity of HEC may be reduced in the future, leading to better outcomes for both humans and elephants.

Acknowledgement

Authors sincerely thank Ruvinda K. de Mel, Umair Khaleelullah, Ashkar Thasleem, Sanjaya N. Weerakkody, Rukmal Ratnayake, Kulangana Theivendrarajah, Jael Nirubha Kanagaratnam, Dr. Gajavathany Kandasamy and Dr. Dishane K. Hewavithana, for their inputs and support in translating and proofreading the survey. We acknowledge the inputs provided by Mahesh Senarathna on data analysis. We greatly appreciate the support of the many volunteer field assistants in distributing the paper-based survey to collect data from respondents in rural farming communities in Sri Lanka. We are also deeply grateful to the experts and all other respondents for their active participation in the survey. The National Institute of Fundamental Studies, Sri Lanka provided in-kind support. S. J. Cabral de Mel was supported by an International Fees Research Scholarship from the University of Southern Queensland, Australia, and this study was funded by a grant awarded to S. Seneweera from the National Research Council, Sri Lanka (NRC 19-046, 2019).

Author contributions

SJC and BLA conceived the ideas, SJC, BLA, DKW, AD and TM designed the methodology, SJC collected the data, SJC and RK analysed and interpreted the data, SS acquired funding. BLA, DKW, AD, SS and TM were involved in supervision and project administration. SJC wrote the original manuscript. All authors contributed critically to the drafts, reviewed and edited the manuscript and gave final approval for publication.

References

Abdullah, A., Sayuti, A., Hasanuddin, H., Affan, M., & Wilson, G. (2019). People's perceptions of elephant conservation and the human-elephant conflict in Aceh Jaya, Sumatra, Indonesia. *Eur. J. Wildl. Res*. **65**, 69.

Acharya, K. P., Paudel, P. K., Neupane, P. R., & Köhl, M. (2016). Human-wildlife conflicts in Nepal: Patterns of human fatalities and injuries caused by large mammals. *PLoS One* **11**, e0161717.

Anthony, V. (2021). Horowpathana elephant holding ground. *the morning*. https://www.themorning.lk/horowpathana-elephant-holding-ground/.

Anuradha, J. M. P. N., Fujimura, M., Inaoka, T., & Sakai, N. (2019). The role of agricultural land use pattern dynamics on elephant habitat depletion and human-elephant conflict in Sri Lanka. *Sustainability* **11**, 2818.

Ardiantiono, Sugiyo, Johnson, P. J., Lubis, M. I., Amama, F., Sukatmoko, Marthy, W., & Zimmermann, A. (2021). Towards coexistence: Can people's attitudes explain their willingness to live with Sumatran elephants in Indonesia? *Conserv. Sci. Pract*. **3**, e520.

Atkinson, R., & Flint, J. (2001). Accessing hidden and hard-to-reach populations: Snowball research strategies. *Soc. Res. Updat.* **33**, 1–4.

Aziz, M. A., Shamsuddoha, M., Maniruddin, M., Morshed, H. M., Sarker, R., & Islam, M. A. (2016). Elephants, border fence and human-elephant conflict in northern Bangladesh: Implications for bilateral collaboration towards elephant conservation. *Gajah* **45**, 12–19.

Bandara, R., & Tisdell, C. (2002). Asian elephants as agricultural pests: economics of control and compensation in Sri Lanka. *Nat. Resour. J.* **42**, 491–520.

Bandara, R., & Tisdell, C. (2003). Comparison of rural and urban attitudes to the conservation of Asian elephants in Sri Lanka: Empirical evidence. *Biol. Conserv*. **110**, 327–342.

Bandara, R., & Tisdell, C. (2004). The net benefit of saving the Asian elephant: A policy and contingent valuation study. *Ecol. Econ.* **48**, 93–107.

Barua, M. (2010). Whose issue? Representations of human-elephant conflict in Indian and international media. *Sci. Commun*. **32**, 55–75.

Barua, M., Bhagwat, S. A., & Jadhav, S. (2013). The hidden dimensions of human-wildlife conflict: Health impacts, opportunity and transaction costs. *Biol. Conserv*. **157**, 309–316.

Barua, M., Tamuly, J., & Ahmed, R. A. (2010). Mutiny or clear sailing? Examining the role of the Asian elephant as a flagship species. *Hum. Dimens. Wildl*. **15**, 145–160.

Baskaran, N., Varma, S., Sar, C. K., & Sukumar, R. (2011). Current status of Asian elephants in India. *Gajah* **35**, 47–54.

Borah, B. C., Bhattacharya, A., Sarkar, P., & Choudhury, P. (2022). People’s perception on human-elephant conflict in Rani-Garbhanga reserve forest of Assam, India. *GeoJournal* **87**, 4127–4141.

Cabral de Mel, S. J., Seneweera, S., de Mel, R. K., Dangolla, A., Weerakoon, D. K., Maraseni, T., & Allen, B. L. (2022). Current and future approaches to mitigate conflict between humans and Asian elephants: The potential use of aversive geofencing devices. *Animals* **12**, 2965.

Cabral de Mel, S. J., Seneweera, S., de Mel, R. K., Medawala, M., Abeysinghe, N., Dangolla, A., Weerakoon, D. K., Maraseni, T., & Allen, B. L. (2023). Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement. *Appl. Anim. Behav. Sci*. **258**, 105822.

Can, Ö. E., D’Cruze, N., Garshelis, D. L., Beecham, J., & Macdonald, D. W. (2014). Resolving human-bear conflict: A global survey of countries, experts, and key factors. *Conserv. Lett*. **7**, 501–513.

Chartier, L., Zimmermann, A., & Ladle, R. J. (2011). Habitat loss and human-elephant conflict in Assam, India: Does a critical threshold exist? *Oryx* **45**, 528–533.

Chen, S., Sun, G.-Z., Wang, Y., Huang, C., Chen, Y., Liu, P., Deng, Y., Cao, D.-F., Zhang, M.-X., Ong, S., Zhang, Z.-Y., Yang, H.-P., Wang, Q.-Y., Wang, B., Zheng, X., Lei, Y., Li, C., Sun, J., Bao, M.-W., Yang, Z.-C., Guan, L., Sun, Y.-K., Zhou, F.-Y., Liu, J.-X., Li, L.-L., Wang, F., Corlett, R. T., Quan, R.-C., Chen, M.-Y., Zhang, L., Shi, K., & Campos-Arceiz, A. (2021). A multistakeholder exercise to identify research and conservation priorities for Asian elephants in China. *Glob. Ecol. Conserv*. **27**, e01561.

Chen, Y., Atzeni, L., Gibson, L., Sun, Y., Yang, Z., Shi, K., & Dudgeon, D. (2022). Urban expansion and infrastructure development reduce habitat suitability for Asian elephants in southwestern China. *J. Wildl. Manage*. **86**, e22204.

Dabare, P., Suduwella, C., Sayakkara, A., Sandaruwan, D., Keppitiyagama, C., De Zoysa, K., Hewage, K., & Voigt, T. (2015). Listening to the giants: Using elephant infra-sound to solve the human-elephant conflict. In *Proc. 6th ACM Work. Real World Wirel. Sens. Networks*. 23–26. Seoul.

Davies, T. E., Wilson, S., Hazarika, N., Chakrabarty, J., Das, D., Hodgson, D. J., & Zimmermann, A. (2011). Effectiveness of intervention methods against crop-raiding elephants. *Conserv. Lett*. **4**, 346–354.

Desai, A. A., & Riddle, H. S. (2015). Human-elephant conflict in Asia. Washington, DC, USA.

Dharmarathne, C., Fernando, C., Weerasinghe, C., & Corea, R. (2020). Project orange elephant is a conflict specific holistic approach to mitigating human-elephant conflict in Sri Lanka. *Commun. Biol*. **3**, 43.

DiStefano, C., Shi, D., & Morgan, G. B. (2021). Collapsing categories is often more advantageous than modeling sparse data: Investigations in the CFA framework. *Struct. Equ. Model. A Multidiscip. J.* **28**, 237–249.

Dragan, I.-M., & Isaic-Maniu, A. (2013). Snowball Sampling Completion. *J. Stud. Soc. Sci*. **5**, 160–177.

Drijfhout, M., Kendal, D., & Green, P. (2022). Mind the gap: Comparing expert and public opinions on managing overabundant koalas. *J. Environ. Manage*. **308**, 114621.

Engel, M. T., Vaske, J. J., Bath, A. J., & Marchini, S. (2017). Attitudes toward jaguars and pumas and the acceptability of killing big cats in the Brazilian Atlantic Forest: An application of the Potential for Conflict Index$_2$. *Ambio* **46**, 604–612.

Estes, J. G., Othman, N., Ismail, S., Ancrenaz, M., Goossens, B., Ambu, L. N., Estes, A. B., & Palmiotto, P. A. (2012). Quantity and configuration of available elephant habitat and related conservation concerns in the lower Kinabatangan Floodplain of Sabah, Malaysia. *PLoS One* **7**, e44601.

Fernando, C., & Corea, R. (2019). An assessment of beehive fences in deterring crop raiding elephants: A case study from Wasgamuwa, Sri Lanka. In *Assoc. Trop. Biodivers. Conserv. Asia Pacific Conf.* **2019**. 71. Thulhiriya.

Fernando, P. (2011). Managing 'problem elephants'. *Loris* **25**, 32–36.

Fernando, P. (2015). Managing elephants in Sri Lanka: where we are and where we need to be. *Ceylon J. Sci. (Biological Sci*. **44**, 1–11.

Fernando, P. (2020). Guide for implementing community-based electric fences for the effective mitigation of human-elephant conflict. Washington, DC, USA.

Fernando, P., De Silva, M. K. C. R., Jayasinghe, L. K. A., Janaka, H. K., & Pastorini, J. (2021). First country-wide survey of the Endangered Asian elephant: towards better conservation and management in Sri Lanka. *Oryx* **55**, 46–55.

Fernando, P., Jayawardene, J., Prasad, T., Hendavitharana, W., & Pastorini, J. (2011). Current status of Asian elephants in Sri Lanka. *Gajah* **35**, 93–103.

Fernando, P., Leimgruber, P., Prasad, T., & Pastorini, J. (2012). Problem-elephant translocation: Translocating the problem and the elephant? *PLoS One* **7**, e50917.

Fernando, P., & Pastorini, J. (2011). Range-wide status of Asian elephants. *Gajah* **35**, 15–20.

Fernando, P., Prasad, T., Janaka, H. K., Ekanayaka, S. K., Nishantha, H. G., & Pastorini, J. (2015). The use of radio-tracking data to guide development and manage elephants. *Wildlanka* **3**, 12–19.

Fernando, P., Wikramanayake, E., Weerakoon, D., Jayasinghe, L. K. A., Gunawardene, M., & Janaka, H. K. (2005). Perceptions and patterns of human–elephant conflict in old and new settlements in Sri Lanka: Insights for mitigation and management. *Biodivers. Conserv*. **14**, 2465–2481.

Ganesh, S. (2019). Human elephant conflict kills 1,713 people, 373 pachyderms in 3 years. https://www.thehindu.com/news/national/human-elephant-conflict-kills-1713-people-373-pachyderms-in-3-years/article26225515.ece.

Gogoi, M. (2018). Emotional coping among communities affected by wildlife-caused damage in north-east India: Opportunities for building tolerance and improving conservation outcomes. *Oryx* **52**, 214–219.

Gordon, M., & Lumley, T. (2022). Package 'forestplot'. Advanced forest plot using 'grid' graphics. Vienna.

Gross, E. M., Drouet-Hoguet, N., Subedi, N., & Gross, J. (2017). The potential of medicinal and aromatic plants (MAPs) to reduce crop damages by Asian elephants (*Elephas maximus*). *Crop Prot*. **100**, 29–37.

Gross, E. M., Pereira, J. G., Shaba, T., Bilério, S., Kumchedwa, B., & Lienenlüke, S. (2022). Exploring routes to coexistence: Developing and testing a human–elephant conflict-management framework for African elephant-range countries. *Diversity* **14**, 525.

Gubbi, S. (2012). Patterns and correlates of human-elephant conflict around a south Indian reserve. *Biol. Conserv*. **148**, 88–95.

Gunaryadi, D., Sugiyo, & Hedges, S. (2017). Community-based human–elephant conflict mitigation: The value of an evidence-based approach in promoting the uptake of effective methods. *PLoS One* **12**, e0173742.

Guru, B. K., & Das, A. (2021). Cost of human-elephant conflict and perceptions of compensation: evidence from Odisha, India. *J. Environ. Plan. Manag*. **64**, 1770–1794.

Hayward, M. W., & Kerley, G. I. H. (2009). Fencing for conservation: Restriction of evolutionary potential or a riposte to threatening processes? *Biol. Conserv.* **142**, 1–13.

He, Q., Wu, Z., Zhou, W., & Dong, R. (2011). Perception and attitudes of local communities towards wild elephant-related problems and conservation in Xishuangbanna, southwestern China. *Chinese Geogr. Sci.* **21**, 629–636.

Hedges, S., & Gunaryadi, D. (2010). Reducing human–elephant conflict: do chillies help deter elephants from entering crop fields? *Oryx* **44**, 139.

Heeren, A., Karns, G., Bruskotter, J., Toman, E., Wilson, R., & Szarek, H. (2017). Expert judgment and uncertainty regarding the protection of imperiled species. *Conserv. Biol*. **31**, 657–665.

Heneghan, M. D., & Morse, W. C. (2019). Acceptability of management actions and the potential for conflict following human-black bear encounters. *Soc. Nat. Resour*. **32**, 434–451.

Jasmine, B., Ghose, D., & Das, S. K. (2015). An attitude assessment of human-elephant conflict in a critical wildlife corridor within the Terai Arc Landscape, India. *J. Threat. Taxa* **7**, 6843–6852.

Jeong, H.-J., & Lee, W.-C. (2016). The level of collapse we are allowed: Comparison of different response scales in safety attitudes questionnaire. *Biometrics Biostat. Int. J.* **4**, 128–134.

Jigme, K., & Williams, C. (2011). Current status of Asian elephants in Bhutan. *Gajah* **35**, 25–28.

Kanagaraj, R., Araujo, M. B., Barman, R., Davidar, P., De, R., Digal, D. K., Gopi, G. V., Johnsingh, A. J. T., Kakati, K., Kramer-Schadt, S., Lamichhane, B. R., Lyngdoh, S., Madhusudan, M. D., Ul Islam Najar, M., Parida, J., Pradhan, N. M. B., Puyravaud, J., Raghunath, R., Rahim, P. P. A., Muthamizh Selvan, K., Subedi, N., Trabucco, A., Udayraj, S., Wiegand, T., Williams, A. C., & Goyal, S. P. (2019). Predicting range shifts of Asian elephants under global change. *Divers. Distrib*. **25**, 822–838.

Karanth, K. K., Gopalaswamy, A. M., Prasad, P. K., & Dasgupta, S. (2013). Patterns of human-wildlife conflicts and compensation: Insights from Western Ghats protected areas. *Biol. Conserv*. **166**, 175–185.

Kendal, D., & Ford, R. M. (2018). The role of social license in conservation. *Conserv. Biol*. **32**, 493–495.

King, L. E., Lawrence, A., Douglas-Hamilton, I., & Vollrath, F. (2009). Beehive fence deters crop-raiding elephants. *Afr. J. Ecol*. **47**, 131–137.

King, L. E., Soltis, J., Douglas-Hamilton, I., Savage, A., & Vollrath, F. (2010). Bee threat elicits alarm call in African elephants. *PLoS One* **5**, e10346.

König, H. J., Kiffner, C., Kramer-Schadt, S., Fürst, C., Keuling, O., & Ford, A. T. (2020). Human–wildlife coexistence in a changing world. *Conserv. Biol*. **34**, 786–794.

Köpke, S., Withanachchi, S. S., Pathiranage, R., Withanachchi, C. R., Gamage, D. U., Nissanka, T. S., Warapitiya, C. C., Nissanka, B. M., Ranasinghe, N. N., Senarathna, C. D., Schleyer, C., & Thiel, A. (2021). Human–elephant conflict in Sri Lanka: A critical review of causal explanations. *Sustainability* **13**, 8625.

Liefting, Y., de Jong, J. F., & Prins, H. H. T. (2018). A new type of elephant fence: permeable for people and game but not for elephant. *Gajah* **49**, 11–19.

Liu, P., Wen, H., Harich, F. K., He, C., Wang, L., Guo, X., Zhao, J., Luo, A., Yang, H., Sun, X., Yu, Y., Zheng, S., Guo, J., Li, L., & Zhang, L. (2017). Conflict between conservation and development: cash forest encroachment in Asian elephant distributions. *Sci. Rep*. **7**, 6404.

Lute, M. L., Carter, N. H., López-Bao, J. V., & Linnell, J. D. C. (2018). Conservation professionals agree on challenges to coexisting with large carnivores but not on solutions. *Biol. Conserv*. **218**, 223–232.

Lute, M. L., Carter, N. H., López-Bao, J. V., & Linnell, J. D. C. (2020). Conservation professionals' views on governing for coexistence with large carnivores. *Biol. Conserv*. **248**, 108668.

Ly, C. T., Hung, V., Anh, N. C. T., Bao, H. D., Quoc, P. D. P., Khanh, H. T., Minh, N. Van, Cam, N. T. H., & Cuong, C. D. (2020). A pilot study of cultivating non-preferred crops to mitigate human-elephant conflict in the buffer zone of Yok Don National Park , Vietnam. *Gajah* **51**, 4–9.

Madhusudan, M. D., Sharma, N., Raghunath, R., Baskaran, N., Bipin, C. M., Gubbi, S., Johnsingh, A. J. T., Kulkarni, J., Kumara, H. N., Mehta, P., Pillay, R., & Sukumar, R. (2015). Distribution, relative abundance, and conservation status of Asian elephants in Karnataka, southern India. *Biol. Conserv*. **187**, 34–40.

Marchini, S., Ferraz, K. M. P. M. B., Zimmermann, A., Guimarães-Luiz, T., Morato, R., Correa, P. L. P., & Macdonald, D. W. (2019). Planning for coexistence in a complex human-dominated world. In Frank, B., Glikman, J. A., & Marchini, S. (Eds.), *Human–wildlife Interact. Turn. Confl. into coexistence*. 414–438. Cambridge, United Kingdom: Cambridge University Press.

Menon, V., & Tiwari, S. K. R. (2019). Population status of Asian elephants *Elephas maximus* and key threats. *Int. Zoo Yearb.* **53**, 17–30.

Nair, R. P., & Jayson, E. A. (2021). Estimation of economic loss and identifying the factors affecting the crop raiding behaviour of Asian elephant (*Elephas maximus*) in Nilambur part of the southern Western Ghats, Kerala, India. *Curr. Sci.* **121**, 521.

Nayak, M., & Swain, P. K. (2020). From fear to festivity: Multi-stakeholder perspectives on human-elephant conflict and coexistence in India. *J. Public Aff.* **22**, e2496.

Neupane, B., Khatiwoda, B., & Budhathoki, S. (2018). Effectiveness of solar-powered fence in reducing human-wild elephant conflict (HEC) in Northeast Jhapa district, Nepal. *For. J. Inst. For. Nepal* **15**, 13–27.

Neupane, D., Johnson, R. L., & Risch, T. S. (2017). How do land-use practices affect human—elephant conflict in Nepal? *Wildlife Biol*. **2017**, wlb.00313.

Nyhus, P. J., Tilson, R., & Sumianto. (2000). Crop-raiding elephants and conservation implications at Way Kambas National Park, Sumatra, Indonesia. *Oryx* **34**, 262–274.

Ogra, M., & Badola, R. (2008). Compensating human–wildlife conflict in protected area communities: Ground-level perspectives from Uttarakhand, India. *Hum. Ecol*. **36**, 717–729.

Ogra, M. V. (2008). Human–wildlife conflict and gender in protected area borderlands: A case study of costs, perceptions, and vulnerabilities from Uttarakhand (Uttaranchal), India. *Geoforum* **39**, 1408–1422.

Osipova, L., Okello, M. M., Njumbi, S. J., Ngene, S., Western, D., Hayward, M. W., & Balkenhol, N. (2018). Fencing solves human-wildlife conflict locally but shifts problems elsewhere: A case study using functional connectivity modelling of the African elephant. *J. Appl. Ecol*. **55**, 2673–2684.

Othman, N., Goossens, B., Cheah, C. P. I., Nathan, S., Bumpus, R., & Ancrenaz, M. (2019). Shift of paradigm needed towards improving human–elephant coexistence in monoculture landscapes in Sabah. *Int. Zoo Yearb.* **53**, 161–173.

Padalia, H., Ghosh, S., Reddy, C. S., Nandy, S., Singh, S., & Kumar, A. S. (2019). Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. *Environ. Monit. Assess*. **191**, 802.

Pant, G., Dhakal, M., Pradhan, N. M. B., Leverington, F., & Hockings, M. (2016). Nature and extent of human-elephant *Elephas maximus* conflict in central Nepal. *Oryx* **50**, 724–731.

Pastorini, J., Janaka, H. K., Nishantha, H. G., Prasad, T., Leimgruber, P., & Fernando, P. (2013). A preliminary study on the impact of changing shifting cultivation practices on dry season forage for Asian elephants in Sri Lanka. *Trop. Conserv. Sci*. **6**, 770–780.

Pekor, A., Miller, J. R. B., Flyman, M. V., Kasiki, S., Kesch, M. K., Miller, S. M., Uiseb, K., van der Merve, V., & Lindsey, P. A. (2019). Fencing Africa's protected areas: Costs, benefits, and management issues. *Biol. Conserv*. **229**, 67–75.

Pinter-Wollman, N. (2009). Spatial behaviour of translocated African elephants (*Loxodonta africana*) in a novel environment: Using behaviour to inform conservation actions. *Behaviour* **146**, 1171–1192.

Ponnusamy, V., Chackrapani, P., Lim, T. W., Saaban, S., & Campos-Arceiz, A. (2016). Farmers' perceptions and attitudes towards government-constructed electric fences in Peninsular Malaysia. *Gajah* **45**, 4–11.

Prakash, T. G. S. L., Wijeratne, A. W., & Fernando, P. (2020). Human-elephant conflict in Sri Lanka: Patterns and extent. *Gajah* **51**, 16–25.

Puyravaud, J., Cushman, S. A., Reddy, P. A., Boominathan, D., Sharma, R., Arumugam, N., Selvan, K. M., Mohanraj, N., Arulmozhi, S., Rahim, A., Kalam, T., De, R., Udayraj, S., Luis, A., Najar, M. U. I., Raman, K., Krishnakumar, B. M., Goyal, S. P., & Davidar, P. (2022). Fencing can alter gene flow of Asian elephant populations within protected areas. *Conservation* **2**, 709–725.

Qomariah, I. N., Rahmi, T., Said, Z., & Wijaya, A. (2018). Conflict between human and wild Sumatran Elephant (*Elephas maximus sumatranus* Temminck, 1847) in Aceh Province, Indonesia. *Biodiversitas J. Biol. Divers*. **20**, 77–84.

R Core Team. (2022). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria.

Redpath, S. M., Young, J., Evely, A., Adams, W. M., Sutherland, W. J., Whitehouse, A., Amar, A., Lambert, R. A., Linnell, J. D. C., Watt, A., & Gutiérrez, R. J. (2013). Understanding and managing conservation conflicts. *Trends Ecol. Evol*. **28**, 100–109.

Reed, M. S. (2008). Stakeholder participation for environmental management: A literature review. *Biol. Conserv.* **141**, 2417–2431.

Saif, O., Kansky, R., Palash, A., Kidd, M., & Knight, A. T. (2020). Costs of coexistence: understanding the drivers of tolerance towards Asian elephants *Elephas maximus* in rural Bangladesh. *Oryx* **54**, 603–611.

Sampson, C., Glikman, J. A., Rodriguez, S. L., Tonkyn, D., Soe, P., O'Connor, D., Chit, A. M., & Leimgruber, P. (2022). Rural and urban views on elephants, conservation and poaching. *Oryx* **56**, 609–616.

Sampson, C., Leimgruber, P., Rodriguez, S., McEvoy, J., Sotherden, E., & Tonkyn, D. (2019). Perception of human–elephant conflict and conservation attitudes of affected communities in Myanmar. *Trop. Conserv. Sci*. **12**, 194008291983124.

Sampson, C., Rodriguez, S. L., Leimgruber, P., Huang, Q., & Tonkyn, D. (2021). A quantitative assessment of the indirect impacts of human-elephant conflict. *PLoS One* **16**, e0253784.

Shaffer, L. J., Khadka, K. K., Van Den Hoek, J., & Naithani, K. J. (2019). Human-elephant conflict: A review of current management strategies and future directions. *Front. Ecol. Evol*. **6**, 235.

Singh, A., Kumara, H. N., Mahato, S., & Velankar, A. D. (2023). Anthropogenic driven range expansion of Asian elephant *Elephas maximus* in an agricultural landscape and its consequences in South West Bengal, India. *J. Nat. Conserv*. **73**, 126374.

Stüwe, M., Abdul, J. B., Nor, B. M., & Wemmer, C. M. (1998). Tracking the movements of translocated elephants in Malaysia using satellite telemetry. *Oryx* **32**, 68–74.

Su, K., Ren, J., Yang, J., Hou, Y., & Wen, Y. (2020). Human-elephant conflicts and villagers' attitudes and knowledge in the Xishuangbanna Nature Reserve, China. *Int. J. Environ. Res. Public Health* **17**, 8910.

Sugiyo, Ardiantiono, Santo, A., Marthy, W., & Amama, F. (2016). Evaluating the intervention methods to reduce human-elephant conflict around Way Kambas National Park. In

Conserv. Sumatran Wildl. Herit. Sustain. Livelihood; Proc. 3rd Int. Wildl. Symp. 30–36. Lampung, Indonesia: University of Lampung.

Sugumar, S. J., & Jayaparvathy, R. (2013). An early warning system for elephant intrusion along the forest border areas. *Curr. Sci*. **104**, 1515–1526.

Sukumar, R. (2003). The living elephants: Evolutionary ecology, behavior and conservation. New York, USA: Oxford University Press.

Sukumar, R. (2006). A brief review of the status, distribution and biology of wild Asian elephants *Elephas maximus*. *Int. Zoo Yearb.* **40**, 1–8.

Talukdar, N. R., & Choudhury, P. (2020). Attitudes and perceptions of the local people on human–elephant conflict in the Patharia Hills Reserve Forest of Assam, India. *Proc. Zool. Soc.* **73**, 380–391.

Tan, A. S. L., de la Torre, J. A., Wong, E. P., Thuppil, V., & Campos-Arceiz, A. (2020). Factors affecting urban and rural tolerance towards conflict-prone endangered megafauna in Peninsular Malaysia. *Glob. Ecol. Conserv.* **23**, e01179.

Thant, Z. M., May, R., & Røskaft, E. (2021). Pattern and distribution of human-elephant conflicts in three conflict-prone landscapes in Myanmar. *Glob. Ecol. Conserv*. **25**, e01411.

Thant, Z. M., May, R., & Røskaft, E. (2022). Human–elephant coexistence challenges in Myanmar: An analysis of fatal elephant attacks on humans and elephant mortality. *J. Nat. Conserv.* **69**, 126260.

Tisdell, C., & Zhu, X. (1998). Protected areas, agricultural pests and economic damage: conflicts with elephants and pests in Yunnan, China. *Environmentalist* **18**, 109–118.

Tripathy, B. R., Liu, X., & Ranga, V. (2022). Demographic circumstances and people's sentiments towards elephants in the human–elephant conflict hotspot villages of Keonjhar forest division in Eastern India. *Diversity* **14**, 311.

van de Water, A., King, L. E., Arkajak, R., Arkajak, J., van Doormaal, N., Ceccarelli, V., Sluiter, L., Doornwaard, S. M., Praet, V., Owen, D., & Matteson, K. (2020). Beehive fences as a sustainable local solution to human-elephant conflict in Thailand. *Conserv. Sci. Pract.* **2**, e260.

van de Water, A., & Matteson, K. (2018). Human-elephant conflict in western Thailand: Socio-economic drivers and potential mitigation strategies. *PLoS One* **13**, 1–14.

van Eeden, L. M., Newsome, T. M., Crowther, M. S., Dickman, C. R., & Bruskotter, J. (2019). Social identity shapes support for management of wildlife and pests. *Biol. Conserv*. **231**, 167–173.

Vaske, J. J., Beaman, J., Barreto, H., & Shelby, L. B. (2010). An extension and further validation of the potential for conflict index. *Leis. Sci*. **32**, 240–254.

Venkataraman, A. B., Saandeep, R., Baskaran, N., Roy, M., Madhivanan, A., & Sukumar, R. (2005). Using satellite telemetry to mitigate elephant-human conflict: An experiment in northern West Bengal, India. *Curr. Sci*. **88**, 1827–1831.

Webber, C. E., Sereivathana, T., Maltby, M. P., & Lee, P. C. (2011). Elephant crop-raiding and human-elephant conflict in Cambodia: Crop selection and seasonal timings of raids. *Oryx* **45**, 243–251.

Williams, C., Tiwari, S. K. R., Goswami, V. R., de Silva, S., Kumar, A., Baskaran, N., Yoganand, K., & Menon, V. (2020). *Elephas maximus*. IUCN Red List Threat. Species 2020 e.T7140A45818198.

Yang, W., Ma, Y., Jing, L., Wang, S., Sun, Z., Tang, Y., & Li, H. (2022). Differential impacts of climatic and land use changes on habitat suitability and protected area adequacy across the Asian elephant's range. *Sustainability* **14**, 4933.

Zeppelzauer, M., Hensman, S., & Stoeger, A. S. (2015). Towards an automated acoustic detection system for free-ranging elephants. *Bioacoustics* **24**, 13–29.

3.2. Links and implications

Assessment of opinions of different stakeholder groups in this chapter showed that all groups agreed on many causes of HEC and had positive attitudes towards elephants, which is very encouraging for elephant conservation and HEC mitigation. However, farmers affected by HEC do not agree that co-existing with elephants is an option and perceive that elephants should be removed from human habitats. Experts should understand these conflicting opinions and care should be taken when communicating and implementing conservation and management objectives for elephants. Further, all stakeholder groups agreed on a few HEC mitigation tools as being both acceptable and effective. But even those HEC mitigation tools that are agreed upon as effective have several drawbacks. Hence, there is still a need for researchers to investigate alternative innovative and effective approaches to mitigate HEC.

CHAPTER 4: PAPER 3 – VIRTUAL FENCING OF CAPTIVE ASIAN ELEPHANTS FITTED WITH AN AVERSIVE GEOFENCING DEVICE TO MANAGE THEIR MOVEMENT

4.1. Introduction

This chapter is a research article published in *Applied Animal Behaviour Science* journal titled "Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement". As highlighted in Chapter 2, there are many drawbacks in most HEC mitigation tools; and as revealed in Chapter 3, experts and other stakeholders agree on only a few of these approaches as acceptable and effective. This situation urges researchers to explore innovative approaches to effectively mitigate HEC. This chapter explores the efficacy of a potentially new HEC mitigation tool: satellite-linked shock collars or AGDs, as introduced in Chapter 2. This chapter presents results of preliminary experiments conducted with captive Asian elephant to determine the possibility of managing elephant movement with AGDs, thereby reducing HEC incidents with wild elephants in the future. Supplementary information published with this research article are given in Appendix B.

4.2. Links and implications

This study demonstrated the potential of AGDs to manage captive elephant movement and encourages the further development of AGDs as an approach to mitigate HEC. This study also highlighted potential areas for improvement when experimenting with AGDs on captive elephants and makes several recommendations for future research to optimise and develop this technology before they can be tested on wild elephants. Further, this study emphasised that in addition to the efficacy of managing elephant movement, AGDs should also ensure that there are no undue negative impacts on elephant wellbeing. Further research to evaluate behavioural and physiological welfare impacts of using AGDs on elephants is encouraged.

CHAPTER 5: PAPER 4 –WELFARE IMPACTS ASSOCIATED WITH USING AVERSIVE GEOFENCING DEVICES ON CAPTIVE ASIAN ELEPHANTS

5.1. Introduction

This chapter is a research article published in *Applied Animal Behaviour Science* journal titled “Welfare impacts associated with using aversive geofencing devices on captive Asian elephants”. This chapter presents the results of the assessment of behavioural and physiological stress responses of captive Asian elephants involved in the experiments with AGDs in Chapter 4. This study assessed the activity budgets, specific anxiety/stress related behaviours and physiological stress using faecal cortisol metabolite (FCM) concentrations before, during and after the experiments in response to electric shocks from AGDs. Supplementary information related to this research article is given in Appendix C.

Applied Animal Behaviour Science 265 (2023) 105991

Contents lists available at ScienceDirect

Applied Animal Behaviour Science

journal homepage: www.elsevier.com/locate/applanim

Welfare impacts associated with using aversive geofencing devices on captive Asian elephants

Surendranie J. Cabral de Mel [a,b,*], Saman Seneweera [b,c], Ruvinda K. de Mel [d], Ashoka Dangolla [e], Devaka K. Weerakoon [f], Tek Maraseni [a,g], Benjamin L. Allen [a,h]

[a] Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia
[b] National Institute of Fundamental Studies, Kandy 20000, Sri Lanka
[c] School of Agriculture and Food, Faculty of Sciences, The University of Melbourne, Parkville, VIC 3010, Australia
[d] Centre for Behavioural and Physiological Ecology, Zoology, University of New England, Armidale, NSW 2351, Australia
[e] Department of Veterinary Clinical Sciences, University of Peradeniya, Peradeniya 20400, Sri Lanka
[f] Department of Zoology and Environmental Sciences, University of Colombo, Colombo 03, 00300, Sri Lanka
[g] Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
[h] Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth 6034, South Africa

ARTICLE INFO

Keywords:
Animal behaviour
Activity budgets
Electric shock collars
Faecal cortisol
Stress
Virtual fencing

ABSTRACT

Animal-borne aversive geofencing devices (AGDs, or satellite-linked shock collars) are commercially available and used on livestock to restrict their movement within a virtual boundary. This technology has potential application as a human-wildlife conflict mitigation tool, where problem animals might be conditioned to avoid human-dominated habitats by associating an audio warning with a subsequent electric shock, which is delivered if the audio warning is ignored. Ensuring that high standards of animal welfare are maintained when implementing such tools is important for acquiring manager and community acceptance of such approaches. We conducted two pilot experiments with eight captive Asian elephants using mild electric shocks from a modified dog-training collar fitted around the neck, as part of an ongoing effort to develop AGDs suitable for mitigating human-elephant conflict. As part of these experiments, we assessed elephants' behavioural and physiological stress before, during and after the experiments. During the experiments elephants wore collars for up to nine consecutive days and received a small number of electric shocks on 1–3 consecutive days. Bootstrapped principal component analysis showed that daily activity budgets of individual elephants on experiment days were not different from the pre-experiment days. Generalised linear mixed-effects model (GLMM) showed that anxiety/stress behaviours increased on the first day of acclimatising to the collar and on testing days (i.e. days they received shocks) of the first experiment, but not during the second experiment relative to pre-experiment days. Analysis of faecal cortisol metabolite (FCM) concentrations using GLMM showed that FCM concentrations were higher in samples collected ~24 hrs and ~48 hrs after testing days compared to baseline levels as expected given the lag time for excretion of cortisol metabolites. These elevated anxiety/stress behaviours and FCM concentrations returned to baseline levels shortly after the experiment. Therefore, we conclude that AGDs did not produce lasting behavioural or physiological stress effects in elephants during this short-term study but recommend further studies with a larger sample of elephants to confirm the transferability of these findings.

1. Introduction

Aversive conditioning involves influencing animals to modify an unwanted behaviour by associating it with an unpleasant stimulus, and has been applied in numerous ways to manage human-wildlife conflict (Appleby et al., 2017; Snijders et al., 2021, 2019). Virtual fencing using animal-borne electronic training collars (i.e. shock collars) is one such tool that has been tested on wild animals such as coyotes *Canis latrans* (Andelt et al., 1999), grey wolves *Canis lupus* (Rossler et al., 2012), dingoes *Canis familiaris* (Appleby, 2015), island foxes *Urocyon littoralis* (Cooper et al., 2005) and black-tailed deer *Odocoileus hemionus* (Nolte et al., 2003) to constrain their movement within a restricted space.

* Corresponding author at: Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia.
E-mail address: surendranie.cabral@gmail.com (S.J. Cabral de Mel).

https://doi.org/10.1016/j.applanim.2023.105991
Received 8 April 2023; Received in revised form 13 June 2023; Accepted 18 June 2023
Available online 20 June 2023

Shock collars have been widely used on domestic dogs and livestock species for several decades (Anderson, 2007). Modern satellite-linked shock collars or aversive geofencing devices (AGDs) have the ability of real-time tracking of animals using Global Positioning Systems (GPS) and automatically deliver warning sounds followed by an electric shock when an animal crosses virtual boundaries (Boyd et al., 2022; Campbell et al., 2020; Lomax et al., 2019). The advantage of AGDs is that as the animal learns to associate the warning sound with the electric shock, they can predict and avoid receiving the electric shock (Lee et al., 2018). In other words, animals can control the receipt of electric shocks, thereby reducing the anxiety and stress caused to themselves (Kearton et al., 2020; Lee and Campbell, 2021) and thus minimise the welfare impact of AGDs on their wellbeing. Cattle *Bos taurus* and sheep *Ovis aries* learn to avoid the electric shock from AGDs after just a few attempts to cross virtual fences (Lee et al., 2009; Marini et al., 2018), and these devices are now commercially available for use on livestock (Goliński et al., 2023). However, aversive conditioning with electric shock has been frequently debated, with some studies showing unacceptable welfare impacts on animals (China et al., 2020; Schilder and van der Borg, 2004; Ziv, 2017). Therefore, despite its effectiveness, concerns remain about the welfare impact of using such tools on animals.

Use of AGDs have been suggested as a potential tool to mitigate conflict between humans and Asian elephants *Elephas maximus* (Cabral de Mel et al., 2022; Fernando, 2011). Human-elephant conflict (HEC) is a widespread problem across the 13 countries that Asian elephants inhabit (Fernando and Pastorini, 2011), and resolving HEC has become very challenging since most conventional mitigation efforts lose their efficacy in the long-term (Shaffer et al., 2019). Therefore, it is important to investigate novel tools (such as AGDs) to condition problem causing wild elephants to avoid human habitats. But, exactly how AGDs might affect elephant wellbeing is unclear given their complex cognitive and social systems (Bates et al., 2008; Hart et al., 2008). Initial studies with AGDs should be conducted under controlled conditions, for example, with captive animals so that their wellbeing can be properly evaluated (Lee and Campbell, 2021). It can be expected that during early stages, as animals learn to relate the audio warning from the AGD with the electric shock that follows, they would show acute stress responses, but after learning to avoid the electric shock, stress levels to be no different from baseline levels (Lee et al., 2018; Lee and Campbell, 2021). Welfare impact of shock collars on dogs and livestock has been assessed by studying their behavioural and physiological stress responses, demonstrating negligible effects of using them on the welfare of study animals (Campbell et al., 2019, 2017; Kearton et al., 2020, 2019; Schalke et al., 2007; Steiss et al., 2007). Conducting such assessments during preliminary investigations of AGDs with captive elephants will likewise help understand how AGDs could affect the wellbeing of wild elephants if used as an HEC mitigation tool.

Impact on the behavioural welfare of elephants to AGDs may be assessed by studying the changes in activity budgets (Veasey, 2006). Additionally, stereotypic behaviours, which are abnormal repetitive, invariant behaviours induced by stress or frustration (Mason, 2006, 1991) could be used as a measure of elephant welfare in response to AGDs (de Mel et al., 2013; Glaeser et al., 2021; Rees, 2009). Furthermore, self-directed behaviours (SDBs) are a type of displacement behaviour commonly associated with anxiety and stress in primates (Daniel et al., 2008; Thatcher et al., 2021; Wallace et al., 2019). SDBs such as trunk related behaviours (touch self and trunk swing) and foot swing are reported among African elephants *Loxodonta africana* (Kahl and Armstrong, 2000; Mason and Veasey, 2010; Poole, 1999) and have been used as a measure of their anxiety and stress (Manning et al., 2022). Elephants may also develop distinct collar-related behaviours such as touching, grasping and shaking the collar used to fit the AGD around the elephant's neck (pers. obs.). These SDBs and collar related behaviours may also be related to anxiety and stress when conducting experiments with AGDs. Adrenal glucocorticoid hormones such as cortisol are often measured as an indicator of physiological stress, as they increase in circulation in response to stressful events (Moberg, 2000; Mormède et al., 2007). Cortisol in elephants can be measured using serum (Brown et al., 1995), hair (Pokharel et al., 2021), saliva (Dathe et al., 1992; Menargues et al., 2008), urine (Brown et al., 2010, 1995) and faeces (Laws et al., 2007; Watson et al., 2013). However, quantifying faecal cortisol metabolites (FCMs) is preferred for elephants since it is a non-invasive method that would not cause additional stress on the animal and is not substantially affected by the temporal variation in secretion as it measures an accumulation of hormones over a longer period (Bansiddhi et al., 2020; Touma and Palme, 2005). The physiological and biological validity of using faeces to measure adrenal glucocorticoid hormones of both African and Asian elephants are well established (Fanson et al., 2013; Kumar et al., 2014; Laws et al., 2007; Millspaugh et al., 2007; Stead et al., 2000; Wasser et al., 2000). These behavioural and physiological stress indicators may be assessed to determine the impact of using AGDs on an elephant's wellbeing.

We previously conducted a preliminary study with captive Asian elephants using a modified dog-training collar to assess the potential of AGDs to manage elephant movement (Cabral de Mel et al., 2023) during which, two experiments were conducted; (1) to determine the optimum strength of the electric shock required, and the ideal location on the neck of the elephant which would generate the desired aversive responses and (2) to determine the ability to condition elephants to avoid receiving an electric shock and prevent reaching a food reward with an audio warning. Elephants showed desirable aversive behaviours in response to mild electric shocks received from the collar and the potential for elephants to learn to avoid an electric shock by associating it with an audio warning. The results of the experiments were promising, demonstrating the potential for AGDs to be used as an HEC mitigation tool, but the welfare effects of these experiments were not reported (Cabral de Mel et al., 2023). Therefore, in this paper we analysed the behavioural and physiological stress responses shown by the captive elephants that participated in the experiments using modified dog-training collars. The objectives of this study were to determine the changes in activity budgets, anxiety/stress related behaviours and FCM concentrations on experiment days compared to pre-experiment days (baseline levels). It was expected that conducting experiments would not influence the normal activity budgets of elephants. Further, it was expected that there could be increases in anxiety/stress behaviours and FCM concentrations corresponding to some experiment days (e.g., testing days on which elephants experience electric shocks) but these would return to baseline levels during the post-test monitoring days indicating minimum welfare impacts on animals.

2. Methods

This study follows on from our previous study on two experiments conducted with captive Asian elephants using a modified dog-training collar (Cabral de Mel et al., 2023) conducted between June 2019 and May 2022. This study received approval from the University of Southern Queensland Animal Ethics Committee (19REA007) in Australia, and the Institute of Biology in Sri Lanka (ERC IOBSL 193 04 2019 and 252 08 2021). Permission was also granted by the Department of National Zoological Gardens, Sri Lanka (DZG/DEV/02/Research work/2019) to conduct this study. We quantified the welfare impacts of the experiments on the elephants in this study, which were conducted under the constant supervision of veterinarians, mahouts and researchers at all times. Mild pain or discomfort (i.e. aversion) was an expected part of this study. However, no animal had to be removed from the study at any point in time because undesirable reactions, and excessive pain or discomfort were not observed. We could not replace the use of live animals in this research given that we were exploring the effects of a novel tool on live animals, but we did reduce or limit the number of animals used in our pilot studies to those few needed to achieve our objectives. We further refined our methods by using a small number of captive elephants under constant supervision rather than using larger numbers of wild elephants where supervision would have been difficult or impossible.

2.1. Animals

This study was conducted with eight adult female Asian elephants (K1, M1, M2, M3, M4, S1, S2, S3 with ages 50, 40, 51, 31, 24, 24, 32 and 37 years respectively) held captive at Pinnawala Elephant Orphanage (PEO), Sri Lanka. All except S3 were born in the wild. M3 had been a resident of PEO for 16 years but had been in captivity for a much longer period before arriving at PEO. All other wild born elephants in the study were brought to PEO as orphans at an age between < 1–5 years and have been held at PEO for 24–46 years. All elephants, except M3, were part of a herd comprising of about 25 elephants, released daily into a ~3 ha open area to forage at 08:30 h. They were shepherded to and from a water body about 500 m away from the open area twice each day between 10:00 h and 12:00 h and between 14:00 h and 16:00 h. While in the open area they were supplemented with food (e.g. branches of jak fruit, coconut etc.) and water and were free to range within the entire area. These elephants were herded to their overnight sheds after returning from the water body in the evening, before being let free again the following morning. M3 was an individually managed working elephant that worked for about 1 hr each day delivering food to other elephants within PEO. It was taken to the water body twice a day between 09:45 h and 11:00 h and again between 14:00 h and 15:00 h, while it remained in the shed during the rest of the day. When taken to the water body M3 often laid recumbent and submerged in water, and while in the shed it was provided with food and water. These typical daily routines sometimes varied for all elephants. For example, if there were high water levels in the water body resulting from heavy rains and flooding elephants were not taken to the water body for their bath.

2.2. AGD experiments

A detailed description of our two experiments can be found in Cabral de Mel et al. (2023), along with results discussing the efficacy of AGDs at managing elephant movement. Here, we briefly summarise the experimental design (Table 1) and instead focus our discussion on the animal welfare effects of these experiments.

The two experiments were conducted using a modified dog-training collar, delivering an electric shock of 4 kV with no resistance at variable strengths (varying pulse frequencies). Experiment 1 involved testing different strengths of electric shocks, on two different locations on the neck of eight elephants to determine the ideal position and the optimum strength that would generate desired responses from elephants such as touching the neck/collar and stopping or changing the direction of movement. Experiment 2 was conducted several months later with five of the same elephants from Experiment 1. This involved conditioning elephants walking along a path towards a food reward, to avoid receiving an electric shock by responding appropriately to the prior audio warning by modifying its movement and not continuing towards the food reward. These two experiments were conducted between 08:30 h and 11:00 h, and each experimental session ranged between 30 and 45 min. The two experiments involved wearing a collar around the neck for 3–9 consecutive days and receiving one or more electric shocks on 1 day during Experiment 1 and 3 consecutive days during Experiment 2. Collars were removed each evening, on days elephants were fitted with them when the elephants returned to the sheds for the night and re-fitted in the following morning.

2.3. Monitoring welfare impacts of the AGD experiments

2.3.1. Assessment of behavioural welfare of elephants

An ethogram (Table 2) was constructed based on preliminary observations conducted at PEO and elephant behaviour categories described in published sources (Asher et al., 2015; de Mel et al., 2013; Glaeser et al., 2021; Manning et al., 2022; Olson, 2004; Wilson et al., 2006). Instantaneous focal sampling of behaviour (Martin and Bateson, 2007) was conducted every 15 s for 15 min during four sessions of the day; 08:00 h – 10:00 h, 10:00 h – 12:00 h, 12:00 h – 14:00 h and 14:00 h – 16:00 h for a total of one hour per day per animal to obtain a general sample of diurnal behaviour shown by each animal. Visual observations were conducted while elephants were not directed by mahouts. If at any time an elephant was interacting with a mahout during observation or if

Table 1
Summary of steps involved in Experiment 1[a] and Experiment 2[b] with days receiving electric shocks (see Cabral de Mel et al., 2023 for further details).

Day	Activity	Details		Receipt of electric shock by each elephant on experiment days; received (√) not received (x)							
				K1	M1[d]	M2	M3	M4	S1	S2[d]	S3[d]
Experiment 1[a]											
Day 1	Acclimatisation to wearing a collar	Elephants wore a dummy collar during the day and continued with their normal routine.		← NA →							
Day 2	Acclimatisation to wearing a collar										
Day 3	Acclimatisation to wearing a collar										
Day 4	Testing day	Elephants K1, M1 and S1, (n = 3)[c] wore the shock collar during testing, which was removed soon after. Elephants did not wear a collar during the rest of the day.	Elephants M2, M3, M4, S2 and S3, (n = 5)[c] wore the shock collar during testing which was replaced with the dummy collar soon after and continued to wear it for the rest of the day.	√	√	√	√	√	√	√	√
Day 5	Post-test monitoring day	Elephants did not wear a collar during Days 5 and 6 and continued with their normal routine.	Elephants wore a dummy collar during Days 5 and 6 and continued with their normal routine.	← NA →							
Day 6	Post-test monitoring day										
Day 7	Post-test monitoring day	Post-test monitoring not conducted on Days 7, 8 and 9[c].	Elephants did not wear a collar during Days 7, 8 and 9 and carried on with their normal routine.								
Day 8	Post-test monitoring day										
Day 9	Post-test monitoring day										
Experiment 2[b]											
Day 1	Training day	Elephants wore a dummy collar and were trained to walk along a path (~100 m) to a food reward, five times. Elephants then continued to wear a dummy collar and carried on with their normal routine during the rest of the day.		← NA →							
Day 2	Training day										
Day 3	Training day										
Day 4	Testing day 1	Elephants wore a shock collar during testing. Shock collar was then replaced by the dummy collar, and elephants continued their normal routine for the rest of the day.		√		√	√	√	√		
Day 5	Testing day 2			x	NA	√	x	√	√	NA	NA
Day 6	Testing day 3			√		√	x	√	√		
Day 7	Post-test monitoring day	Elephants wore a dummy collar during the day and carried on with their normal routine.		← NA →							
Day 8	Post-test monitoring day										
Day 9	Post-test monitoring day										

[a] Experiment 1- Assessing responses of elephants to mild electric shocks from a modified dog-training collar fitted on the neck.
[b] Experiment 2- A food attractant trial experiment conducted to condition elephants to associate an audio warning with a mild electric shock from a modified dog-training collar.
[c] Post-test monitoring procedure modified after conducting the experiment with first three elephants.
[d] M1, S2 and S3 were not involved in Experiment 2.

Table 2
Ethogram of elephant behaviours with subcategories considered in this study.

Behaviour category	Subcategory	Description
1. Feeding	Feeding	Depositing food items (or sometimes mud) in mouth, chewing and swallowing
	Foraging	Searching, acquiring, processing and picking up food item (or sometimes mud) using trunk
2. Movement		Taking two or more steps in any direction from one point to another using feet. Also included wading in shallow water (< 2 feet)
3. Environmental investigation		Investigating things in the environment. Included sniffing air, ground, urine, faeces and other inanimate objects other than food items using the tip of the trunk. Also included placing non-food material in mouth and moving its jaw in a chewing motion (e.g. plastic bottles) without ingestion of material.
4. Standing		Showing no movement, simply standing still on all four legs for short durations- momentary (< 5 s), with little or no leg movement and not showing any other behaviour
5. Comfort	Relaxing	Standing still upright, relaxed, eyes open or half closed for longer durations (> 5 s). The trunk may be still, and the tip may be lying on the ground
	Dozing	Standing still with no movements and eyes closed
	Lying down	Lying flat on either side of body (in lateral recumbence)
	Leaning	Leaning entire or part of body on another elephant or object, eyes open or half closed.
	Leg rest	Crosses one hind-leg in front of the other while standing so that one leg does not touch the ground
	Rubbing or scratching	Rubbing head, body or trunk on an object, wall or another elephant or scratching self with either trunk or legs or a stick
	Trunk resting	Placing trunk on an object or another elephant's body or holding trunk in mouth or laying the distal end of the trunk on the ground
	Dust bathing	Pick up dust using trunk and spraying over body
	Mud bathing	Pick up mud using trunk and spraying over body
	Wallowing	Lying down and wriggling body back and forth to cover the body in mud, dirt or sand
	Water spraying	Collecting water in trunk and spray or throw on body or into nearby space
	Fly swatting	Swatting flies by slapping branches against the skin
	Bathing	Lying in water or standing submerged in water (> 2 feet)
	Urinating	Discharging urine
	Defecating	Discharging dung
	Drinking	Collecting water in trunk and putting in mouth
6. Social	Antagonistic	Tail biting (biting the tail of another elephant), chasing (chasing another elephant- aggressively)
	Play	Head-to-head sparring (head-to-head contact between two elephants), trunk wrestling (trunk entwined with another elephant and pull or push another), mounting, chasing, rolling on one another
	Affiliative	Sniff/touch other elephants with tip of trunk, trunk extended towards another elephant for several seconds, placing trunk in another elephant's mouth or gentle head or body contact with another elephant (which does not lead to play or aggression)
7. Anxiety/stress	Stereotypy	Weaving (repeated moving of body from side to side), head bobbing (moving head up and down), head oscillation (weaving and head bobbing shown together resulting in a figure 8 movement of head)
	Self-directed behaviours	Touching self anywhere on the body with the tip of its own trunk or flick trunk in a swinging motion in and out and slaps own skin or directional trunk swing (back and forth) sometimes repetitively
	Collar	Touch, pull or hit collar using the trunk, shake collar using trunk or by rapidly shaking head.
8. Other		Any other behaviour not listed here

the elephant was not within the visual range, observations were paused and continued after the elephant had stopped interacting with the mahout or was located again, thus completing 15 min of observations during each session of the day. Behavioural observations were conducted for a total of 154 hrs. Elephants were first observed during the pre-experiment period (six months prior to conducting Experiment 1) to obtain a sample of baseline behaviours of each elephant. This included a total of 46 hrs, i.e., six different days or 6 hrs for each elephant, except for M4 which was observed for only four days. Then during Experiment 1 elephants were observed for 63 hrs, i.e., 6–9 days or 6–9 hrs for each elephant ($n = 8$) and during Experiment 2 elephants were observed for 45 hrs, i.e., 9 days or 9 hrs for each elephant ($n = 5$) (Table 1). Observations were conducted by a single observer (SJC). Intra-observer reliability was measured with the index of concordance (Martin and Bateson, 2007) using a video taken at the beginning of the study which was observed during the initial stage and then at the end of the study with 90% agreement between observations.

2.3.2. Assessment of physiological stress level of elephants

The physiological stress level of elephants was assessed using FCM concentration. The method for faecal sample collection and extraction of cortisol was adopted and modified for this study based on published sources (Palme et al., 2013; Wasser et al., 2000, 1996). A sample of ~50 g of fresh faeces (< 6 hrs since defecation) was collected between 08:00 h and 08:30 h from each elephant on pre-experiment and experiment days from the sheds where the elephants had spent the night. A total of 163 faecal samples were collected and analysed during this study. Fifty faecal samples were collected from the elephants to measure pre-experiment or baseline FCM concentrations for Experiment 1. This included 5–7 faecal samples from each elephant ($n = 8$) collected on different days within a three-month period prior to Experiment 1, which also included the sample collected on the morning of Day 1 before fitting the collar to begin Experiment 1. Only the faecal sample collected on the morning of Day 1 before fitting the collar to begin Experiment 2 was used to measure the pre-experiment or baseline FCM concentration for each elephant ($n = 5$) in Experiment 2. Faecal samples corresponding to each experiment day was then collected ~24 hrs later, i.e., on the following morning of each experiment day. This included 63 faecal samples, i.e., 6–9 samples from each elephant ($n = 8$) during Experiment 1 and 45 faecal samples, i.e., nine samples from each elephant ($n = 5$) during Experiment 2. During faecal sample collection, two to three portions from the centre of the bolus were taken, given cortisol distribution in faeces is not homogenous (Wasser et al., 1996) and cross-contamination with urine or other faecal matter is possible if portions had been taken from the outside of the bolus (Ganswindt et al., 2003). Each sample was placed in a well-sealed, labelled container, immediately stored in ice, and then stored in a −20 °C freezer at PEO within 1–2 hrs of collection. All collected samples were later transferred to a −20 °C freezer in the laboratory via a cool box with ice within 1.5 hrs at the end of each field visit.

To extract FCM, faecal samples were first thawed at room temperature. Wet faecal samples were mixed well for ~5 min with latex-gloved hands ensuring equal distribution of FCM in the sample. Approximately 0.6 g (avoiding large undigested material) of each well-mixed faecal sample was placed in a 15 ml centrifuge tube and mixed with 2 ml of 80% ethanol by vortexing for 30 min using a multitube vortex mixer.

Samples were then centrifuged at 2500 rpm for 25 min. The liquid supernatant was collected in 2 ml micro-centrifuge tubes, evaporated to dryness under a stream of nitrogen at 35 °C and stored at −20 °C until further analysis.

The concentration of FCM in faecal extracts was estimated using a commercially available multispecies enzyme-linked immunoabsorbent assay (ELISA) kit specific for cortisol (DetectX® Cortisol Immunoassay (EIA) kit, Arbor Assays, Ann Arbor, MI, USA). Following the steroid extraction protocol provided for DetectX Steroid Immunoassay Kits, dried faecal extracts were dissolved in 100 μl of ethanol and 25 μl of the supernatant was added to 475 μl of assay buffer and mixed (to reduce the ethanol concentration of the sample to ≤ 5%, as recommended) immediately prior to analysis. Protocol in the assay kit was followed and the absorbance was measured at 450 nm using a microplate reader. Serial dilution (n = 5) of pooled samples displaced parallel to the standard cortisol curve (ANCOVA, $F_{1,8} = 0.52$, $P = 0.50$), mean percentage recovery of pooled sample spiked with a set of standards with known cortisol concentrations was 98.9 ± 15.1%, intra-assay and inter-assay coefficient of variation was 7.1% and 9.2% respectively. FCM concentrations are expressed as ng/g of wet faeces. FCM extracts of samples collected from a particular elephant during one experiment was run on a single assay to minimise errors due to inter-assay variation.

2.4. Data analysis

All statistical analysis were conducted in RStudio (v 2022.07.2 Build 576) and R (v 4.2.2) (R Core Team, 2022).

2.4.1. Comparison of activity budgets

Activity budgets (number of observations of each behaviour category per day converted into percentages) during experimental days were compared with their pre-experiment (baseline) activity budgets using principal component analysis (PCA), followed by a bootstrapped PCA. This method was first described in Catlin-Groves et al. (2009) and adapted to analyse behaviour by Stafford et al. (2012), allowing comparison of entire activity budgets, and avoiding problems with dependence on repeated measures of behavioural data. The results of the bootstrapped PCA are displayed as a three-dimensional sphere plot using the RGL library and 'rgl.spheres' function for R (Murdoch and Adler, 2023). Each sphere represents the overall activity budget of each day, with the centre and the radius representing the mean of the first three principal components and the 95% confidence interval respectively. Overlapping of spheres indicate that the activity budgets are not significantly different ($\alpha = 0.05$). The cumulative proportion of variance explained by the first three principal components for each analysis were ≥ 0.95, thus the plots can be considered reliable. This analysis was conducted following the instructions and the code provided by Stafford et al. (2012), modifying it only to suit the number of cases (days in this study) for each analysis.

2.4.2. Analysis of anxiety/stress behaviours and FCM concentrations

The number of anxiety/stress behaviours observed per day (i.e., the frequency of anxiety/stress behaviours) during different experiment days were compared to that observed on pre-experiment days (baseline levels) using a generalised linear mixed-effects model (GLMM). Initial analyses with a Poisson distribution and log link function showed overdispersion (i.e. the variance of the counts was significantly greater than the mean), therefore, data were fitted with a negative binomial distribution and a log link function. FCM concentrations on days of Experiment 1 and 2 were compared with the respective baseline FCM concentrations using a GLMM with a gamma distribution and an inverse link function. Days of experiment were included as the fixed effect and elephant identity was included as a random effect to control for repeated measures taken of the same elephant for the GLMM of anxiety/stress behaviours and FCM concentrations. Analysis were conducted using the functions 'glmer' and 'glmer.nb' in the R package lme4 (Bates et al., 2015).

3. Results

3.1. Assessment of behavioural welfare of elephants

Comparison of daily activity budgets of individual elephants during pre-experiment days and the experiment days using sphere plots showed that all spheres overlap with each other (Figs. 1 and 2). This indicated that there is no detectable difference between the overall daily activity budgets. Percentage contribution of each behaviour category for individual elephants on different days of the study, are given in supporting information (Table S1). The behaviour of interest, the anxiety/stress behaviours shown by elephants during pre-experiment days, Experiment 1 and Experiment 2 ranged from 0–7% (mean = 2.57 ± 1.92%), 0–15% (mean = 3.65 ± 3.19%) and 0–6% (mean = 2.60 ± 1.80%) of their activity budgets respectively. There was an increase in the observed anxiety/stress behaviours on Day 1 (mean = 6.50 ± 5.01%, range = 1–15%), and Day 4 (mean = 5.62 ± 4.93%, range = 0–15%) during Experiment 1 compared to pre-experiment days (see Table 3). This trend in overall anxiety/stress behaviour can be seen in Fig. 3a, with collar related behaviours and SDBs particularly contributing to the total anxiety/stress behaviour on Days 1 and 4 respectively. Peaks on Days 1 and 4 can be clearly observed when the frequency of anxiety/stress behaviour shown by individual elephants are considered (Fig. 3b). Even though such differences of anxiety/stress behaviours were not detected in Experiment 2 (see Table 3 and Fig. 4a), an increase in this behaviour on Day 4 (first testing day) compared to other days could be observed in Fig. 4b with some elephants (e.g. K1 and M4). Stereotypic behaviour on pre-experiment days was only observed in M3 who followed a different daily routine (tethered in her shed during some periods during the day) with few other elephants (K1, M2 and S1) showing stereotypy on some experiment days (see Table S1).

3.2. Assessment of physiological stress level of elephants

FCM concentrations in samples collected ~48 hrs after the testing day of Experiment 1 (i.e. Day 5, mean = 2.93 ± 1.19 ng/g of wet faeces, range = 1.76–4.63, n = 8) was high compared to pre-experiment days of Experiment 1 (mean = 2.12 ± 0.69 ng/g of wet faeces, range = 0.84–3.65, n = 8) (Table 4, Fig. 5a). FCM concentrations in samples collected ~24 hrs after the first testing day of Experiment 2 (i.e. Day 4, mean = 3.66 ± 0.77 ng/g of wet faeces, range = 1.41–5.73, n = 5) were also higher than the FCM concentration in the pre-experiment samples collected prior to beginning Experiment 2 (mean = 2.38 ± 0.61 ng/g of wet faeces, range = 1.73–3.23, n = 5) (Table 4, Fig. 6a). Days on which peaks were observed varied between individual elephants during Experiment 1 (Fig. 5b) and Experiment 2 (Fig. 6b) with some elephants showing peaks for samples on Day 4 or 5 (i.e. in samples collected ~24 or 48 hrs after testing day of Experiment 1 and in samples collected ~24 hrs after the first and second testing day of Experiment 2). An increase in FCM concentrations in response to wearing a collar can be observed for M1 in the sample corresponding to Day 2 in Experiment 1 (Fig. 5b). Unexpected increases in FCM concentrations were also observed in some animals 3 days (~72 hrs) after receiving a shock. For example, M1, M2 and M4 (Fig. 5b) show an increase in FCM concentration on Day 6 or later during Experiment 1.

4. Discussion

Aversive conditioning of captive Asian elephants using AGDs appears to be effective at restricting their movements, but their possible welfare effects are largely unknown (Cabral de Mel et al., 2023). Our assessment of the welfare impacts of AGDs on elephants revealed that daily elephant activity was not affected by the receipt of the electric shocks (Figs. 1 and 2). Anxiety/stress behaviours and FCM concentrations temporarily

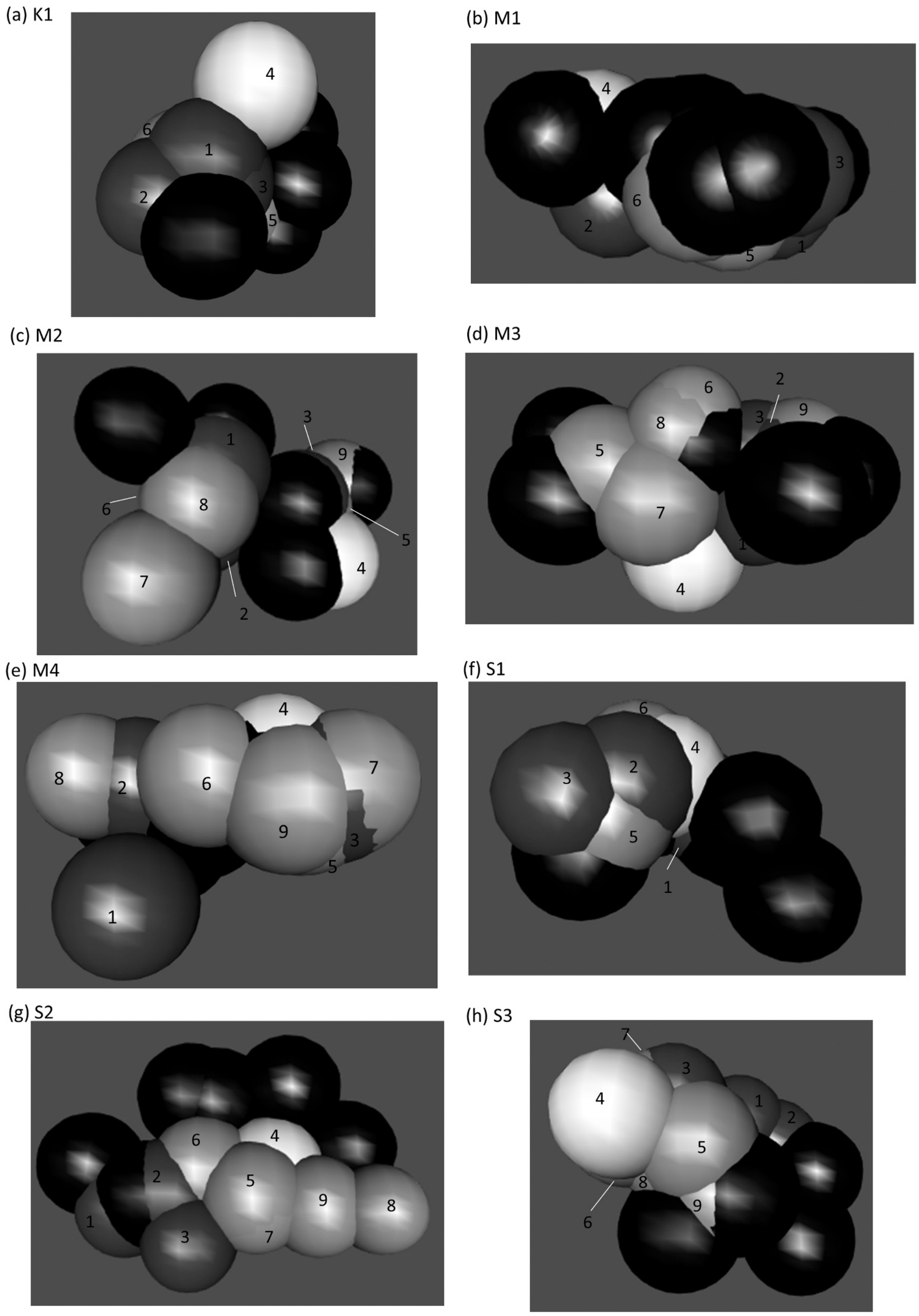

Fig. 1. Three-dimensional principal component sphere plot of activity budgets of the eight elephants; K1, M1, M2, M3, M4, S1, S2 and S3 (a–h respectively) that participated in Experiment 1 (assessing elephants' responses to mild electric shocks from a modified dog-training collar fitted on the neck). Black- pre-experiment days, dark grey- Days 1–3 (days of acclimatising to the dummy collar), white- Day 4 (testing day), light grey- Days 5–9 (post-test monitoring days). The first three principal components explain $\geq$ 95.0% of the total variance of the dataset.

increased as expected on initial days of wearing a collar and/or on days electric shocks were given but returned to prior baseline levels in the following days (Tables 3 and 4, Figs. 3–6). These results confirm that elephants show acute stress responses on specific days as expected, but do not show any lasting welfare effects after experiencing electric shocks. This suggests that AGDs might be used more broadly on Asian elephants with confidence that this management tool does not unduly influence normal elephant behaviour or cause unnecessary anxiety or stress.

Our study showed that the repeated use of AGDs did not influence the activity budgets of elephants. This result complements previous studies conducted with African elephants wearing GPS collars (Horback et al., 2012) and livestock species with electric shock collars (Aaser et al., 2022; Campbell et al., 2019, 2017; Marini et al., 2022; Verdon et al., 2021), which likewise showed no or negligible changes to their normal daily activity patterns as a result of wearing collars or receipt of shock. Collar-related behaviours contributed substantially to the increase in anxiety/stress behaviours on Day 1 of Experiment 1 (Fig. 3a), suggesting displeasure, hostility, or frustration in elephants towards having to wear a novel object on their body. But the low frequency of collar related behaviour during the rest of Experiment 1 and all days of Experiment 2 except on Day 4; the first testing day (Figs. 3a and 4a), indicates that elephants were no longer treating the collar as a novel or hostile object and had gradually habituated to wearing it. A study conducted on cattle showed similar results (Ranches et al., 2021). SDBs contributed substantially to the increase in anxiety/stress behaviours on Day 4 (testing day) of Experiment 1, suggesting a discomfort and distress caused by the electric shocks on that day. Although an increase in anxiety/stress

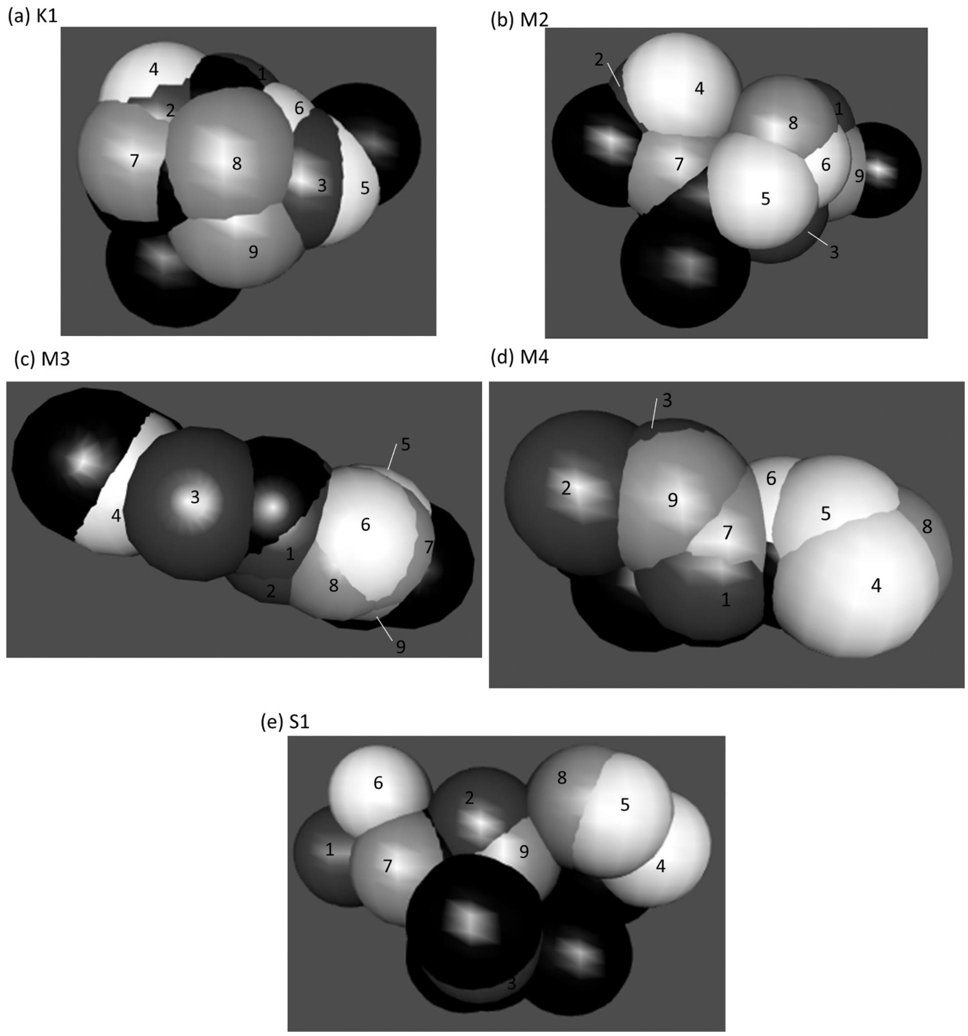

Fig. 2. Three-dimensional principal component sphere plot of activity budgets of the five elephants; K1, M2, M3, M4 and S1 (a–e respectively) that participated in Experiment 2 (a food attractant trial experiment conducted to condition elephants to associate a warning sound with a mild electric shock from a modified dog-training collar). Black- pre-experiment days, dark grey- Days 1–3 (training days), white- Days 4–6 (testing days), light grey- Days 7–9 (post-test monitoring days). The first three principal components explain ≥ 95.0% of the total variance of the dataset.

Table 3
Generalised linear mixed-effects model with negative binomial distribution and log link function for the frequency of anxiety/stress behaviours shown on different days of Experiment 1[a] and Experiment 2[b] with elephant identity as a random effect.

Experiment 1[a]				Experiment 2[b]			
Day	Estimate	Standard error	*P* value	Day	Estimate	Standard error	*P* value
Intercept (PE)[c]	1.816	0.150	< 0.001	Intercept (PE)[c]	1.897	0.187	< 0.001
Day 1	0.917	0.249	< 0.001	Day 1	0.123	0.269	0.646
Day 2	0.059	0.268	0.825	Day 2	-0.207	0.283	0.465
Day 3	0.436	0.257	0.089	Day 3	0.165	0.264	0.533
Day 4	0.711	0.250	< 0.001	Day 4	0.422	0.256	0.099
Day 5	0.237	0.261	0.362	Day 5	-0.572	0.306	0.062
Day 6	-0.142	0.277	0.608	Day 6	-0.306	0.289	0.289
Day 7	-0.128	0.336	0.703	Day 7	0.039	0.269	0.884
Day 8	-0.479	0.363	0.186	Day 8	-0.585	0.311	0.060
Day 9	0.196	0.326	0.547	Day 9	-0.431	0.299	0.150

[a] Experiment 1- Assessing elephants' responses to mild electric shocks from a modified dog-training collar fitted on the neck (n = 8).
[b] Experiment 2- A food attractant trial experiment conducted to condition elephants to associate a warning sound with a mild electric shock from a modified dog-training collar (n = 5).
[c] PE- Pre-experiment.

behaviours during Experiment 2 was not revealed (Table 3), some indication of distress caused by electric shock is evident from the increase in collar related behaviours (Fig. 4a) and peaks in anxiety/stress behaviours of individual elephants, except M2 (Fig. 4b) on Day 4 of Experiment 2.

In captive elephants, stereotyping is generally associated with being tethered, in limited space and in isolation (Greco et al., 2017, 2016; Horback et al., 2014; Varadharajan et al., 2016). This was also evident in our study. Only M3, who was tethered during some periods of the day, showed stereotypic behaviour throughout the study (on both pre-experiment and experiment days). But of those free-ranging elephants, only few showed stereotypic behaviour on some of the

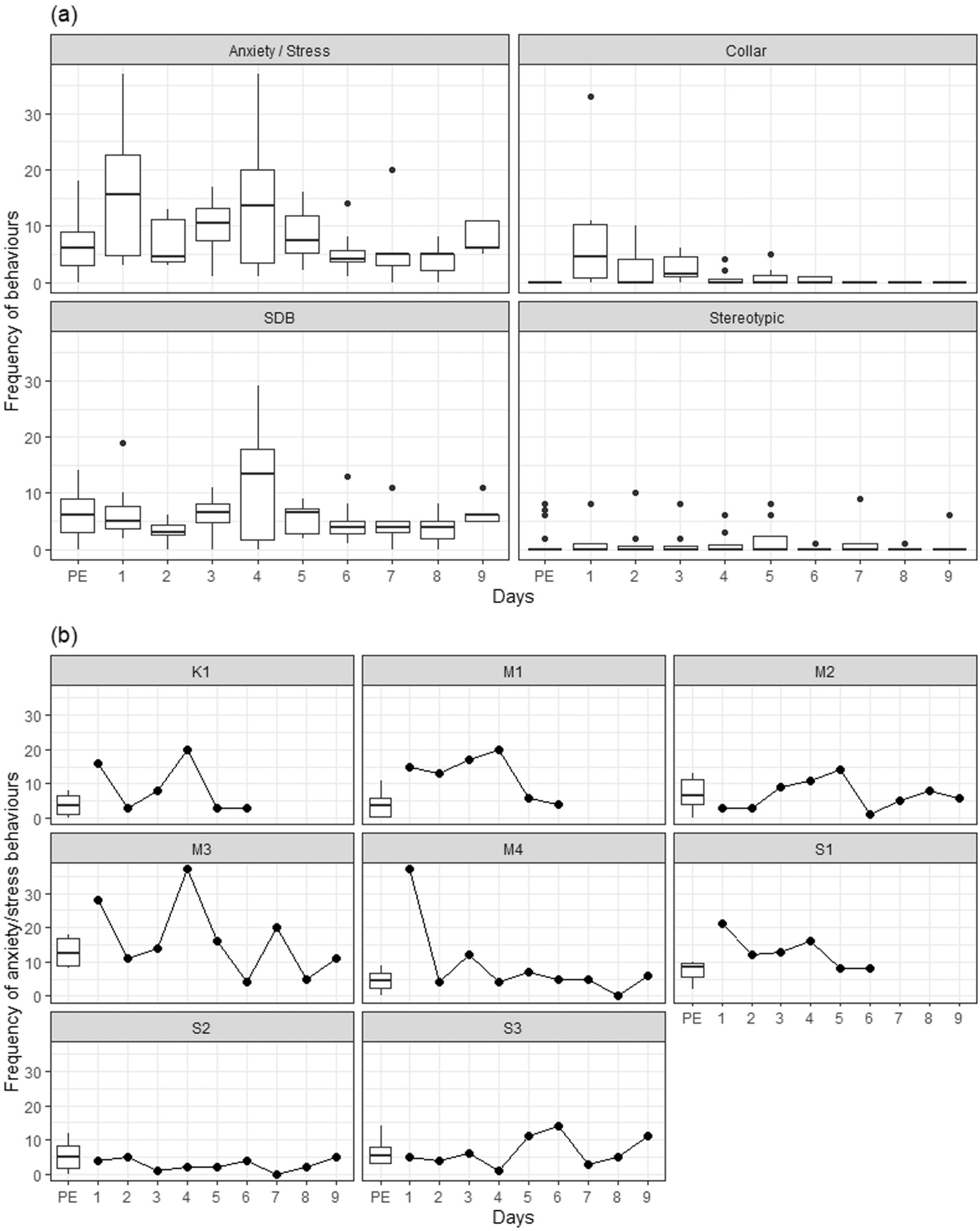

Fig. 3. Frequency of anxiety/stress behaviours of eight elephants on different days of Experiment 1 (assessing elephants' responses to mild electric shocks from a modified dog-training collar fitted on the neck). PE- pre-experiment days, Days 1–3- days of acclimatising to the dummy collar, Day 4- testing day, Days 5–9- post-test monitoring days. a. Box plots of anxiety/stress behaviours (Anxiety/Stress) and its subcategories; collar related behaviours (Collar), self-directed behaviours (SDB), stereotypic behaviours (Stereotypic) of the eight elephants. b. Box plot of anxiety/stress behaviours on pre-experiment days and connected scatter plot of anxiety/stress behaviours shown on experiment days by individual elephants (K1, M1, M2, M3, M4, S1, S2 and S3).

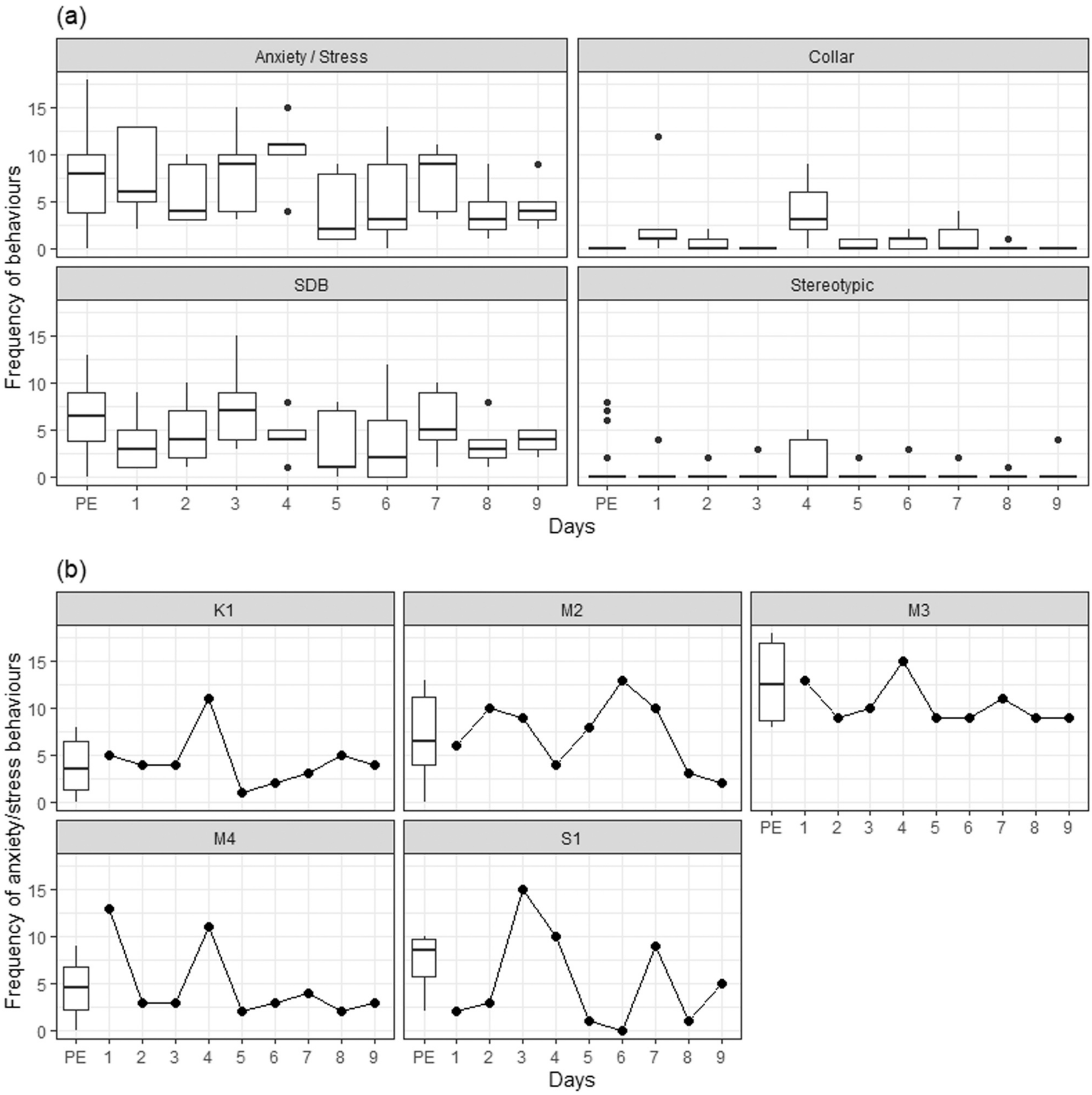

Fig. 4. Frequency of anxiety/stress behaviours of five elephants on different days of Experiment 2 (a food attractant trial experiment conducted to condition elephants to associate a warning sound with a mild electric shock from a modified dog-training collar). PE- pre-experiment days, Days 1–3- training days, Days 4–6- testing days, Days 7–9- post-test monitoring days. a. Box plots of anxiety/stress behaviours (Anxiety/Stress) and its subcategories; collar related behaviours (Collar), self-directed behaviours (SDB), stereotypic behaviours (Stereotypic). b. Box plot of anxiety/stress behaviours on pre-experiment days and connected scatter plot of anxiety/stress behaviours shown on experiment days by individual elephants (K1, M2, M3, M4 and S1).

experiment days (Table S1). Further, stereotypic behaviour may not always reflect the current welfare state, but instead may have developed and persisted due to an old stressor that may no longer exist (Mason and Latham, 2004), meaning that such behaviours may not always be a good welfare indicator on its own. SDBs are not yet well established as a welfare indicator for elephants (Mason and Veasey, 2010). But our study concurs with Manning et al. (2022) and suggests that they may be a useful indicator to assess behavioural welfare in captive Asian elephants, especially when they are free ranging in an open space.

Elevated FCM concentrations were recorded in faecal samples collected ~48 hrs after the testing day of Experiment 1 and ~24 hrs after first testing day of Experiment 2, compared to pre-experiment levels (Table 4). This was as expected given the excretion lag time for glucocorticoids which depends on the time taken for digesta to pass through the gut, which peaks after 12–58 hrs for Asian and African elephants (Ganswindt et al., 2003; Laws et al., 2007; Stead et al., 2000; Turczynski, 1993; Wasser et al., 1996). Similar increases in FCM concentrations in faecal samples have been observed in an Asian elephant two days after a stressful event (transportation and relocation) (Laws et al., 2007). Differences in the times of observing peaks between individual elephants and within the same elephant during the two experiments could be due to the differences in diets (e.g. differences in the amount of food

Table 4
Generalised linear mixed-effects model with a gamma distribution and inverse link function for the faecal cortisol metabolite concentrations (ng/g wet faeces) on days of Experiment 1[a] and Experiment 2[b] with elephant identity as a random effect.

Experiment 1[a]				Experiment 2[b]			
Day	Estimate	Standard error	*P* value	Day	Estimate	Standard error	*P* value
Intercept (PE)[c]	0.501	0.041	< 0.001	Intercept (PE0)[d]	0.544	0.087	< 0.001
Day 1	-0.022	0.048	0.653	Day 1	-0.018	0.065	0.776
Day 2	-0.078	0.043	0.069	Day 2	-0.044	0.062	0.482
Day 3	-0.016	0.049	0.748	Day 3	-0.038	0.063	0.542
Day 4	-0.080	0.043	0.062	Day 4	-0.130	0.055	0.019
Day 5	-0.129	0.038	< 0.001	Day 5	-0.083	0.059	0.162
Day 6	-0.064	0.044	0.152	Day 6	-0.007	0.066	0.916
Day 7	-0.101	0.054	0.063	Day 7	-0.074	0.060	0.217
Day 8	0.026	0.070	0.714	Day 8	-0.083	0.059	0.162
Day 9	-0.035	0.063	0.579	Day 9	-0.028	0.064	0.661

[a] Experiment 1- Assessing elephants' responses to mild electric shocks from a modified dog-training collar fitted on the neck, (n = 8).
[b] Experiment 2- A food attractant trial experiment conducted to condition elephants to associate a warning sound with a mild electric shock from a modified dog-training collar, (n = 5).
[c] PE- Pre-experiment samples collected prior to Experiment 1.
[d] PE0- Pre-experiment samples collected on the first day before beginning Experiment 2.

consumed on different days and preference for different types of food by individual elephants) or hepatic and gastrointestinal function of each animal on the specific days (Wasser et al., 1993). During Experiment 2, K1 who experienced electric shocks on Day 4 and 6, showed two FCM peaks in the samples collected ~48 hrs after each experience; M3, who received shocks only on Day 4, showed a peak in FCM concentration in the sample collected ~24 hrs later. The other three elephants received shocks on all three testing days (Days 4, 5 and 6) during Experiment 2, but showed only one peak in the sample collected ~24 hrs after the first testing day (Fig. 6b). Our failure to detect multiple peaks associated with multiple shocks may indicate that the elephants were no longer stressed by the shocks, and could instead predict the receipt of the electric shock from their previous experience (Lee et al., 2018). In other words, elephants appeared to be less stressed or anxious after the initial experiences with electric shocks.

Our results accord with previous studies on livestock species where elevated cortisol levels in response to electric shock returned to baseline levels immediately afterwards (Kearton et al., 2019; Lee et al., 2008). Similar observations have also been made with elephants whose elevated cortisol levels due to stressful relocation/transportation events returned to baseline levels with time (Dathe et al., 1992; Laws et al., 2007; Millspaugh et al., 2007). The frequency of anxiety/stress behaviours also followed the same pattern, returning to pre-experimental levels on post-test monitoring days. The additional peaks in FCM concentrations observed in samples collected after ~72 hrs (3 days) of receiving shocks in some elephants may have occurred due to hepatic circulation of the metabolites (Palme et al., 1996; Stead et al., 2000) or due to other stressful events that may have occurred after the testing day.

There was variation in the increase in the frequency of anxiety/stress behaviours and FCM concentrations in response to electric shocks by individual elephants. Some elephants showed only minor or negligible deflections (e.g. S2 and S3 in Fig. 3b, M2 and M3 in Fig. 4b, M3, S2 and S3 in Fig. 5b) while some others showed very sharp increases from baseline levels (e.g. M3 and M4 in Fig. 3b and K1, M1, S1 in Fig. 5b). This could be because of the differences in how shock is perceived by individuals, their sensitivities (Lines et al., 2013; Norell et al., 1983; Reinemann et al., 1999), temperament (Finkemeier et al., 2018; Réale et al., 2007), or their personalities (Found and Clair, 2018). Cortisol increases in response to different stressful situations in elephants have been shown to vary with individual personalities (Fanson et al., 2013), age, sex (Hambrecht et al., 2021), ovarian cycle phase, reproductive state (Boyle et al., 2015; Glaeser et al., 2020; Oliveira et al., 2008) and even seasonality (Menargues Marcilla et al., 2012). Similarly, behaviour of elephants are also known to depend on ovarian cycle phase (Slade-Cain et al., 2008) and may also vary depending on management routines (Elzanowski and Sergiel, 2006), availability of resources (food and space) (Lasky et al., 2021; Powell and Vitale, 2016) and environmental factors (Rees, 2002). For these reasons, a sound understanding of individual elephants' baseline or pre-treatment behaviour and cortisol levels is important for interpreting changes caused by using AGDs.

Conditions that affect stress levels of elephants could have potential consequences for their conservation (Pokharel et al., 2017; Tang et al., 2020) as stress levels may have an influence on their fitness, reproduction and survival (Busch and Hayward, 2009; Hing et al., 2016). Although our study showed that stress responses of captive elephants to AGDs are short-lived, it would be important to conduct long-term studies to determine how intermittent exposure to stimuli from AGDs could affect elephants' wellbeing. A recent study on cattle showed that animal-borne devices may influence social behaviours of animals (Buijs et al., 2023). GPS collars have been in use on wild elephants to monitor their movements for several decades and adverse impacts on their social behaviour have not been reported (de la Torre et al., 2021; Fernando et al., 2015; Pastorini et al., 2015; Sampson et al., 2018; Wadey et al., 2018). But how other elephants in a herd would respond if only the matriarch is wearing an AGD and is responding to the stimuli from AGDs would need to be investigated. Ensuring that there is negligible impact on elephants' wellbeing when using AGDs is vital and such assurance will also help gain acceptability and support of stakeholders to implement AGDs as an HEC mitigation tool in the future.

5. Conclusion

Use of electric shocks to manage animal behaviour have long been a controversial subject, but AGDs have been proven successful at managing the movement of domesticated livestock species with minimum welfare impact. AGDs have been identified as a potentially useful tool for resolving HEC, but a lack of knowledge on the potential welfare effects of AGDs has limited the adoption of this new technology. Our results give confidence that AGDs can be safely used to control elephant movement without lasting adverse effects on elephant welfare. We therefore encourage the continued development and use of AGDs on Asian elephants as an effective non-lethal tool to mitigate HEC. More broadly, we also encourage continued assessment of the animal welfare effects of these and other novel wildlife management tools so that stakeholders can have confidence that such tools can be used in an acceptable way.

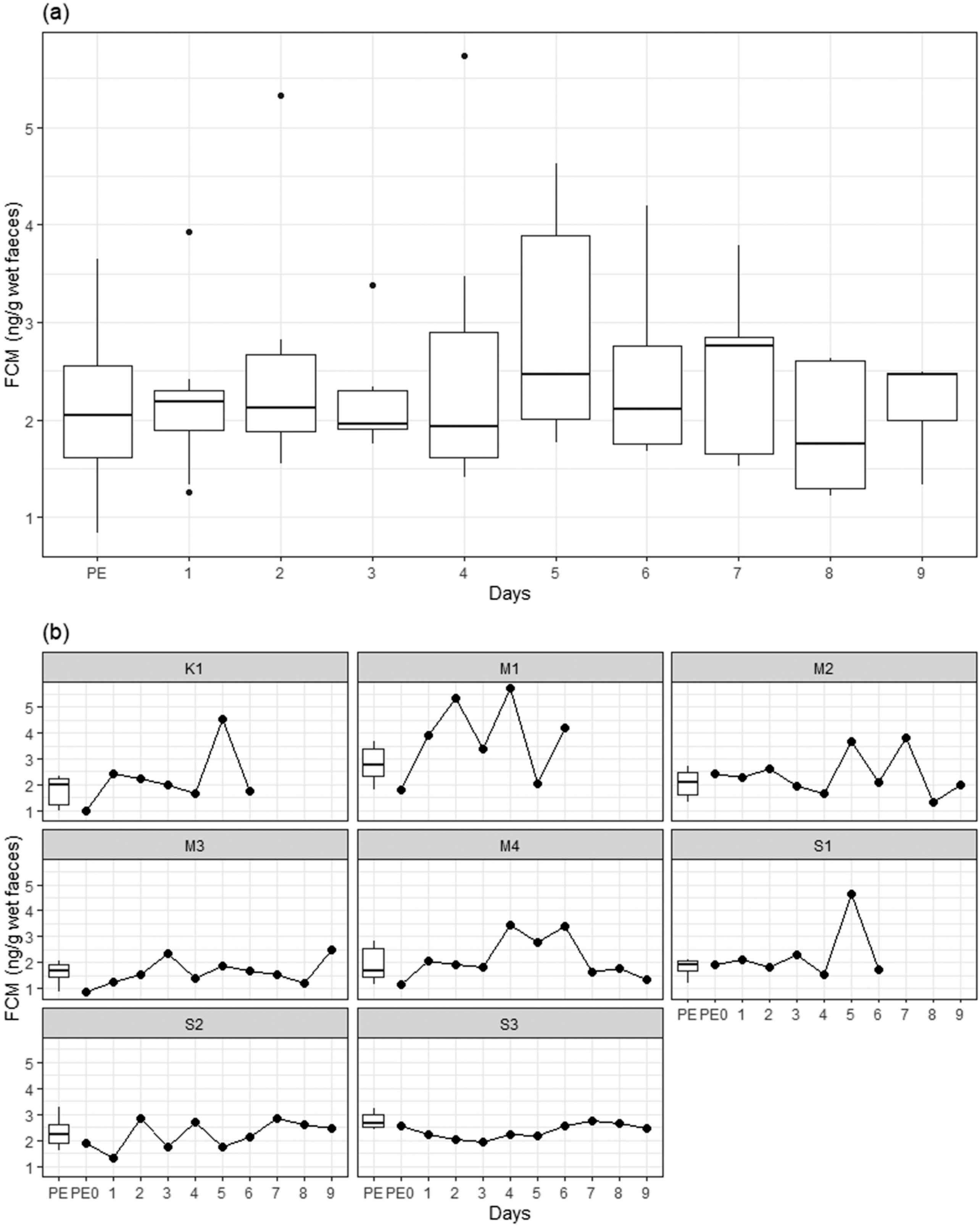

Fig. 5. Faecal cortisol metabolite (FCM) concentrations (ng/g wet faeces) in samples collected ~24 hrs after each day of Experiment 1 (assessing elephants' responses to mild electric shocks from a modified dog-training collar fitted on the neck) of eight elephants. PE- pre-experiment days, PE0- pre-experiment faecal sample collected on Day 1 before beginning Experiment 1, Days 1–3- days of acclimatising to the dummy collar, Day 4- testing day, Days 5–9- post-test monitoring days. a. Box plot of FCM concentrations of all elephants. b. Box plot of FCM concentration on pre-experiment days and connected scatter plot of FCM concentration on experiment days of individual elephants (K1, M1, M2, M3, M4, S1, S2 and S3).

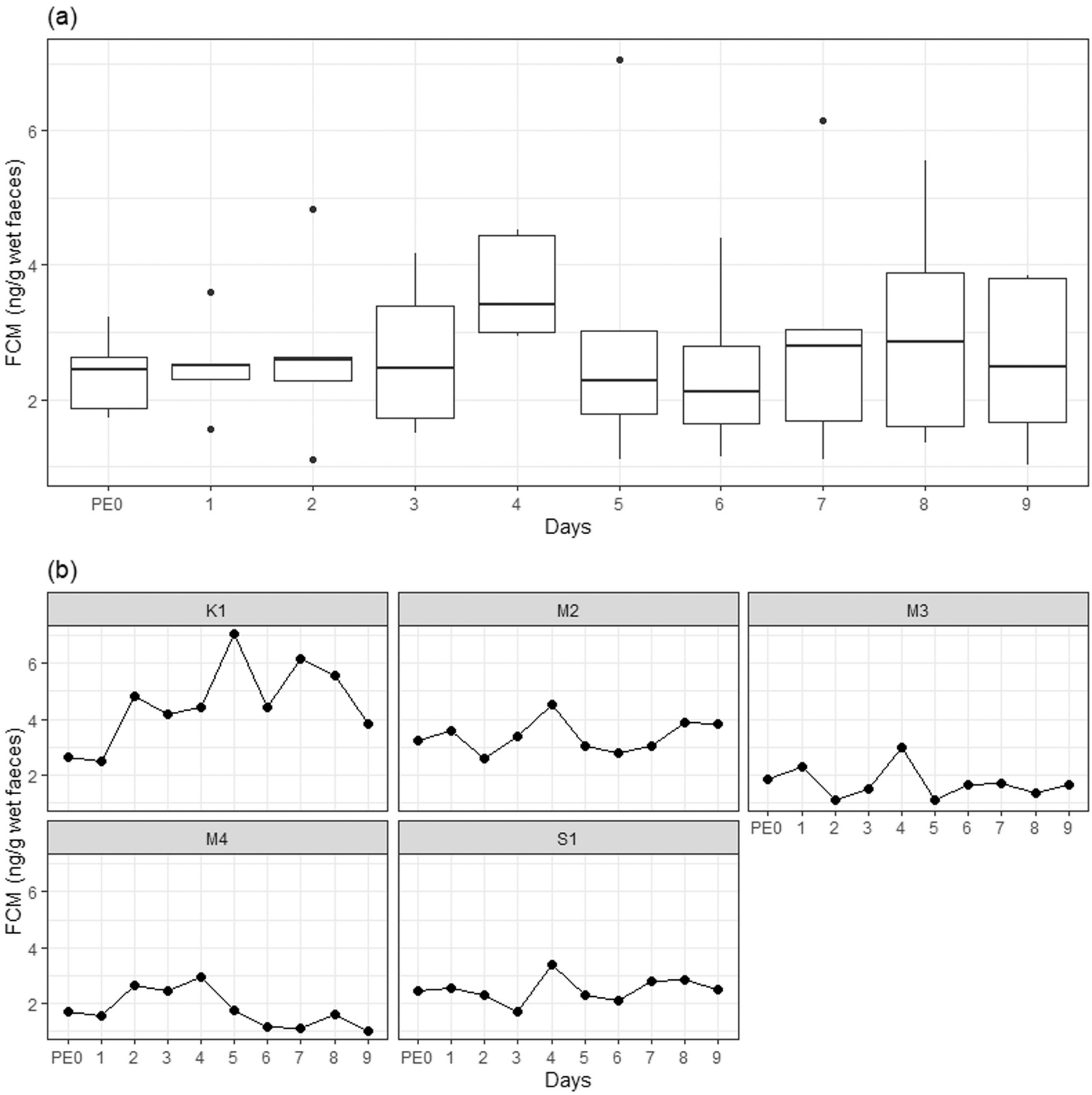

Fig. 6. Faecal cortisol metabolite (FCM) concentrations (ng/g wet faeces) in samples collected ~24 hrs after each day of Experiment 2 (a food attractant trial experiment conducted to condition elephants to associate a warning sound with a mild electric shock from a modified dog-training collar) of five elephants. PE0- pre-experiment faecal sample collected on Day 1 before beginning Experiment 2, Days 1–3- training days, Days 4–6- testing days, Days 7–9- post-test monitoring days. a. Box plot of FCM concentrations of all elephants. b. Connected scatter plot of FCM concentration on experiment days by individual elephants (K1, M2, M3, M4 and S1).

CRediT authorship contribution statement

Surendranie Judith Cabral de Mel: Conceptualisation, Design of study, Acquisition of data, Analysis and interpretation of data, Project administration, Writing – original draft, Writing – review and editing. **Saman Seneweera**: Funding acquisition, Project administration, Writing – review and editing, Supervision. **Ruvinda Kasun de Mel**: Design of study, Acquisition of data, Writing – review and editing. **Ashoka Dangolla**: Project administration, Writing – review and editing, Supervision. **Devaka Keerthi Weerakoon**: Design of study, Project administration, Writing – review and editing, Supervision. **Tek Maraseni**: Project administration, Writing – review and editing, Supervision. **Benjamin Lee Allen**: Conceptualisation, Design of study, Project administration, Writing – review and editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

Authors sincerely thank Ms. Renuka Bandaranayake and the Director Generals of the Department of National Zoological Gardens, Sri Lanka who held office during the study period for their support. Authors are very grateful to the staff of the PEO, especially the Deputy Directors; Mr. Mihiran Medawala and Mr. Navod Abeysinghe, the veterinarians; Dr. M. R. B. N. Bandara, Dr. H. P. Roshan Nimal Shantha Karunaratne, Dr. Kashmini Sumanasekera and Dr. Malith Liyanage, Chief curator Mr. Sanjaya Kumara Rathnayake, Assistant curators Mr. Asanka Kumara Dissanayake and Mr. Sameera P. Rathnayake, Chief Mahout Mr. Sumedha Tharanga Herath and all mahouts for their enormous support during this study. Authors sincerely appreciate the support and advice given by Professor Preethi Udagama and Ms. Isurika Weerasinghe of the University of Colombo, Dr. Ruchika Fernando and members of his laboratory of the University of Peradeniya and staff of the National Institute of Fundamental Studies, Sri Lanka in various stages of laboratory work during this research project. Authors also sincerely appreciate the assistance given by Ms. N. D. Hansani Vinodhya, Ms. Noyalin Mathews and all field assistants during data collection. Authors also thank the anonymous reviewers for their constructive comments. Peter Venkman assisted with the early development of some of the techniques described in this paper. The National Institute of Fundamental Studies, Sri Lanka provided in-kind support. S. J. Cabral de Mel was supported by an International Fees Research Scholarship from the University of Southern Queensland, Australia, and this study was funded by a grant awarded to S. Seneweera from the National Research Council, Sri Lanka (NRC 19–046, 2019).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.applanim.2023.105991.

References

Aaser, M.F., Staahltoft, S.K., Korsgaard, A.H., Trige-Esbensen, A., Alstrup, A.K.O., Sonne, C., Pertoldi, C., Bruhn, D., Frikke, J., Linder, A.C., 2022. Is virtual fencing an effective way of enclosing cattle? Personality, herd behaviour and welfare. Animals 12, 842. https://doi.org/10.3390/ani12070842.

Andelt, W.F., Phillips, R.L., Gruver, K.S., Guthrie, J.W., 1999. Coyote predation on domestic sheep deterred with electronic dog-training collar. Wildl. Soc. Bull. 27, 12–18.

Anderson, D.M., 2007. Virtual fencing - past, present and future. Rangel. J. 29, 65–78. https://doi.org/10.1071/RJ06036.

Appleby, R., 2015. Dingo–human conflict: Attacks on humans. In: Smith, B. (Ed.), The Dingo Debate: Origins, Behaviour and Conservation. CSIRO Publishing, Melbourne, Australia, pp. 131–158.

Appleby, R., Smith, B., Bernede, L., Jones, D., 2017. Utilising aversive conditioning to manage the behaviour of K'gari (Fraser Island) dingoes (*Canis dingo*). Pac. Conserv. Biol. 23, 335–358. https://doi.org/10.1071/PC17017.

Asher, L., Williams, E., Yon, L., 2015. Developing behavioural indicators, as part of a wider set of indicators, to assess the welfare of elephants in UK zoos, Defra Project WC1081. Bristol, UK.

Bansiddhi, P., Brown, J.L., Thitaram, C., Punyapornwithaya, V., Nganvongpanit, K., 2020. Elephant tourism in Thailand: A review of animal welfare practices and needs. J. Appl. Anim. Welf. Sci. 23, 164–177. https://doi.org/10.1080/10888705.2019.1569522.

Bates, D., Mächler, M., Bolker, B., Walker, S., 2015. Fitting linear mixed-effects models using lme4. J. Stat. Softw. 67, 1–48. https://doi.org/10.18637/jss.v067.i01.

Bates, L.A., Poole, J.H., Byrne, R.W., 2008. Elephant cognition. Curr. Biol. 18, 544–546. https://doi.org/10.1016/j.cub.2008.04.019.

Boyd, C.S., O'Connor, R., Ranches, J., Bohnert, D.W., Bates, J.D., Johnson, D.D., Davies, K.W., Parker, T., Doherty, K.E., 2022. Virtual fencing effectively excludes cattle from burned sagebrush steppe. Rangel. Ecol. Manag. 81, 55–62. https://doi.org/10.1016/j.rama.2022.01.001.

Boyle, S.A., Roberts, B., Pope, B.M., Blake, M.R., Leavelle, S.E., Marshall, J.J., Smith, A., Hadicke, A., Falcone, J.F., Knott, K., Kouba, A.J., 2015. Assessment of flooring renovations on African elephant (*Loxodonta africana*) behavior and glucocorticoid response. PLoS One 10, e0141009. https://doi.org/10.1371/journal.pone.0141009.

Brown, J.L., Wemmer, C.M., Lehnhardt, J., 1995. Urinary cortisol analysis for monitoring adrenal activity in elephants. Zoo. Biol. 14, 533–542. https://doi.org/10.1002/zoo.1430140606.

Brown, J.L., Kersey, D.C., Freeman, E.W., Wagener, T., 2010. Assessment of diurnal urinary cortisol excretion in Asian and African elephants using different endocrine methods. Zoo. Biol. 29, 274–283. https://doi.org/10.1002/zoo.20268.

Buijs, S., Weller, J., Budan, A., 2023. When the measurement affects the object – Impact of a multi-part head/neck mounted wearable device on dairy cow behaviour, health and productivity. Appl. Anim. Behav. Sci. 263, 105937 https://doi.org/10.1016/j.applanim.2023.105937.

Busch, D.S., Hayward, L.S., 2009. Stress in a conservation context: A discussion of glucocorticoid actions and how levels change with conservation-relevant variables. Biol. Conserv. 142, 2844–2853. https://doi.org/10.1016/j.biocon.2009.08.013.

Cabral de Mel, S.J., Seneweera, S., de Mel, R.K., Dangolla, A., Weerakoon, D.K., Maraseni, T., Allen, B.L., 2022. Current and future approaches to mitigate conflict between humans and Asian elephants: The potential use of aversive geofencing devices. Animals 12, 2965. https://doi.org/10.3390/ani12212965.

Cabral de Mel, S.J., Seneweera, S., de Mel, R.K., Medawala, M., Abeysinghe, N., Dangolla, A., Weerakoon, D.K., Maraseni, T., Allen, B.L., 2023. Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement. Appl. Anim. Behav. Sci. 258, 105822 https://doi.org/10.1016/j.applanim.2022.105822.

Campbell, D.L.M., Lea, J.M., Keshavarzi, H., Lee, C., 2019. Virtual fencing is comparable to electric tape fencing for cattle behavior and welfare. Front. Vet. Sci. 6, 445. https://doi.org/10.3389/fvets.2019.00445.

Campbell, D.L.M., Lea, J.M., Farrer, W.J., Haynes, S.J., Lee, C., 2017. Tech-savvy beef cattle? How heifers respond to moving virtual fence lines. Animals 7 (9), 72. https://doi.org/10.3390/ani7090072.

Campbell, D.L.M., Ouzman, J., Mowat, D., Lea, J.M., Lee, C., Llewellyn, R.S., 2020. Virtual fencing technology excludes beef cattle from an environmentally sensitive area. Animals 10, 1069. https://doi.org/10.3390/ani10061069.

Catlin-Groves, C.L., Kirkhope, C.L., Goodenough, A.E., Stafford, R., 2009. Use of confidence radii to visualise significant differences in principal components analysis: Application to mammal assemblages at locations with different disturbance levels. Ecol. Inform. 4, 147–151. https://doi.org/10.1016/j.ecoinf.2009.06.001.

China, L., Mills, D.S., Cooper, J.J., 2020. Efficacy of dog training with and without remote electronic collars vs. a focus on positive reinforcement. Front. Vet. Sci. 7, 508. https://doi.org/10.3389/fvets.2020.00508.

Cooper, D.M., Kershner, E.L., Garcelon, D.K., 2005. The use of shock collars to prevent island fox (*Urocyon littoralis*) predation on the endangered San Clemente loggerhead shrike (*Lanius ludovicianus mearnsi*). In: Garcelon, D.K., Schwemm, C.A. (Eds.), Proceedings of the Sixth California Islands Symposium. National Park Service Technical Publication CHIS-05-01. Institute for Wildlife Studies, Arcata, California, pp. 287–297.

Daniel, J.R., dos Santos, A.J., Vicente, L., 2008. Correlates of self-directed behaviors in captive *Cercopithecus aethiops*. Int. J. Primatol. 29, 1219–1226. https://doi.org/10.1007/s10764-008-9300-7.

Dathe, H.H., Kuckelkorn, B., Minnemann, D., 1992. Salivary cortisol assessment for stress detection in the Asian elephant (*Elephas maximus*): A pilot study. Zoo. Biol. 11, 285–289. https://doi.org/10.1002/zoo.1430110408.

de la Torre, J.A., Wong, E.P., Lechner, A.M., Zulaikha, N., Zawawi, A., Abdul-Patah, P., Saaban, S., Goossens, B., Campos-Arceiz, A., 2021. There will be conflict – agricultural landscapes are prime, rather than marginal, habitats for Asian elephants. Anim. Conserv. 24, 720–732. https://doi.org/10.1111/acv.12668.

de Mel, R.K., Weerakoon, D.K., Ratnasooriya, W.D., 2013. A comparison of stereotypic behaviour in Asian elephants at three different institutions in Sri Lanka. Gajah 38, 25–29.

Elzanowski, A., Sergiel, A., 2006. Stereotypic behavior of a female Asiatic elephant (*Elephas maximus*) in a zoo. J. Appl. Anim. Welf. Sci. 9, 223–232. https://doi.org/10.1207/s15327604jaws0903_4.

Fanson, K.V., Lynch, M., Vogelnest, L., Miller, G., Keeley, T., 2013. Response to long-distance relocation in Asian elephants (*Elephas maximus*): Monitoring adrenocortical activity via serum, urine, and feces. Eur. J. Wildl. Res. 59, 655–664. https://doi.org/10.1007/s10344-013-0718-7.

Fernando, P., 2011. Managing 'problem elephants'. Loris 25, 32–36.

Fernando, P., Pastorini, J., 2011. Range-wide status of Asian elephants. Gajah 35, 15–20.

Fernando, P., Prasad, T., Janaka, H.K., Ekanayaka, S.K., Nishantha, H.G., Pastorini, J., 2015. The use of radio-tracking data to guide development and manage elephants. Wildlanka 3, 12–19.

Finkemeier, M.-A., Langbein, J., Puppe, B., 2018. Personality research in mammalian farm animals: Concepts, measures, and relationship to welfare. Front. Vet. Sci. 5, 131. https://doi.org/10.3389/fvets.2018.00131.

Found, R., St. Clair, C.C., 2018. Personality influences wildlife responses to aversive conditioning. J. Wildl. Manag. 82, 747–755. https://doi.org/10.1002/jwmg.21449.

Ganswindt, A., Palme, R., Heistermann, M., Borragan, S., Hodges, J.K., 2003. Non-invasive assessment of adrenocortical function in the male African elephant (*Loxodonta africana*) and its relation to musth. Gen. Comp. Endocrinol. 134, 156–166. https://doi.org/10.1016/S0016-6480(03)00251-X.

Glaeser, S.S., Edwards, K.L., Wielebnowski, N., Brown, J.L., 2020. Effects of physiological changes and social life events on adrenal glucocorticoid activity in female zoo-housed Asian elephants (*Elephas maximus*). PLoS One 15, e0241910. https://doi.org/10.1371/journal.pone.0241910.

Glaeser, S.S., Shepherdson, D., Lewis, K., Prado, N., Brown, J.L., Lee, B., Wielebnowski, N., 2021. Supporting zoo Asian elephant (*Elephas maximus*) welfare and herd dynamics with a more complex and expanded habitat. Animals 11, 2566. https://doi.org/10.3390/ani11092566.

Goliński, P., Sobolewska, P., Stefańska, B., Golińska, B., 2023. Virtual fencing technology for cattle management in the pasture feeding system—A review. Agriculture 13, 91. https://doi.org/10.3390/agriculture13010091.

Greco, B.J., Meehan, C.L., Heinsius, J.L., Mench, J.A., 2017. Why pace? The influence of social, housing, management, life history, and demographic characteristics on locomotor stereotypy in zoo elephants. Appl. Anim. Behav. Sci. 194, 104–111. https://doi.org/10.1016/j.applanim.2017.05.003.
Greco, B.J., Meehan, C.L., Hogan, J.N., Leighty, K.A., Mellen, J., Mason, G.J., Mench, J. A., 2016. The days and nights of zoo elephants: Using epidemiology to better understand stereotypic behavior of African elephants (*Loxodonta africana*) and Asian elephants (*Elephas maximus*) in North American zoos. PLoS One 11, e0144276. https://doi.org/10.1371/journal.pone.0144276.
Hambrecht, S., Oerke, A.-K., Heistermann, M., Hartig, J., Dierkes, P.W., 2021. Effects of positive reinforcement training and novel object exposure on salivary cortisol levels under consideration of individual variation in captive African elephants (*Loxodonta africana*). Animals 11, 3525. https://doi.org/10.3390/ani11123525.
Hart, B.L., Hart, L.A., Pinter-Wollman, N., 2008. Large brains and cognition: Where do elephants fit in. Neurosci. Biobehav. Rev. 32, 86–98. https://doi.org/10.1016/j.neubiorev.2007.05.012.
Hing, S., Narayan, E.J., Thompson, R.C.A., Godfrey, S.S., 2016. The relationship between physiological stress and wildlife disease: Consequences for health and conservation. Wildl. Res. 43, 51–60. https://doi.org/10.1071/WR15183.
Horback, K.M., Miller, L.J., Andrews, J.R.M., Kuczaj, S.A., 2014. Diurnal and nocturnal activity budgets of zoo elephants in an outdoor facility. Zoo. Biol. 33, 403–410. https://doi.org/10.1002/zoo.21160.
Horback, K.M., Miller, L.J., Andrews, J., Kuczaj, S.A., Anderson, M., 2012. The effects of GPS collars on African elephant (*Loxodonta africana*) behavior at the San Diego Zoo Safari Park. Appl. Anim. Behav. Sci. 142, 76–81. https://doi.org/10.1016/j.applanim.2012.09.010.
Kahl, M.P., Armstrong, B.D., 2000. Visual and tactile displays in African elephants, *Loxodonta africana*: A progress report (1991-1997). Elephant 2, 19–21. https://doi.org/10.22237/elephant/1521732201.
Kearton, T., Marini, D., Cowley, F., Belson, S., Lee, C., 2019. The effect of virtual fencing stimuli on stress responses and behavior in sheep. Animals 9, 30. https://doi.org/10.3390/ani9010030.
Kearton, T., Marini, D., Cowley, F., Belson, S., Keshavarzi, H., Mayes, B., Lee, C., 2020. The influence of predictability and controllability on stress responses to the aversive component of a virtual fence. Front. Vet. Sci. 7, 580523 https://doi.org/10.3389/fvets.2020.580523.
Kumar, V., Palugulla Reddy, V., Kokkiligadda, A., Shivaji, S., Umapathy, G., 2014. Non-invasive assessment of reproductive status and stress in captive Asian elephants in three south Indian zoos. Gen. Comp. Endocrinol. 201, 37–44. https://doi.org/10.1016/j.ygcen.2014.03.024.
Lasky, M., Campbell, J., Osborne, J.A., Ivory, E.L., Lasky, J., Kendall, C.J., 2021. Increasing browse and social complexity can improve zoo elephant welfare. Zoo. Biol. 40, 9–19. https://doi.org/10.1002/zoo.21575.
Laws, N., Ganswindt, A., Heistermann, M., Harris, M., Harris, S., Sherwin, C., 2007. A case study: Fecal corticosteroid and behavior as indicators of welfare during relocation of an Asian elephant. J. Appl. Anim. Welf. Sci. 10, 349–358. https://doi.org/10.1080/10888700701555600.
Lee, C., Campbell, D.L.M., 2021. A multi-disciplinary approach to assess the welfare impacts of a new virtual fencing technology. Front. Vet. Sci. 8, 637709 https://doi.org/10.3389/fvets.2021.637709.
Lee, C., Colditz, I.G., Campbell, D.L.M., 2018. A framework to assess the impact of new animal management technologies on welfare: A case study of virtual fencing. Front. Vet. Sci. 5, 187. https://doi.org/10.3389/fvets.2018.00187.
Lee, C., Fisher, A.D., Reed, M.T., Henshall, J.M., 2008. The effect of low energy electric shock on cortisol, β-endorphin, heart rate and behaviour of cattle. Appl. Anim. Behav. Sci. 113, 32–42. https://doi.org/10.1016/j.applanim.2007.10.002.
Lee, C., Henshall, J.M., Wark, T.J., Crossman, C.C., Reed, M.T., Brewer, H.G., Grady, J. O., Fisher, A.D., 2009. Associative learning by cattle to enable effective and ethical virtual fences. Appl. Anim. Behav. Sci. 119, 15–22. https://doi.org/10.1016/j.applanim.2009.03.010.
Lines, J.A., van Driel, K., Cooper, J.J., 2013. Characteristics of electronic training collars for dogs. Vet. Rec. 172, 288 https://doi.org/10.1136/vr.101144.
Lomax, S., Colusso, P., Clark, C.E.F., 2019. Does virtual fencing work for grazing dairy cattle. Animals 9, 429. https://doi.org/10.3390/ani9070429.
Manning, P., Hauff, L., Padfield, C., Olivier, L., Ganswindt, A., Young, D., 2022. Can stress and anxiety be assessed in African elephants (*Loxodonta africana*) using self-directed behaviour? Appl. Anim. Behav. Sci. 256, 105746 https://doi.org/10.1016/j.applanim.2022.105746.
Marini, D., Cowley, F., Belson, S., Lee, C., 2022. Comparison of virtually fencing and electrically fencing sheep for pasture management. Anim. Prod. Sci. 62, 1000–1005. https://doi.org/10.1071/AN21459.
Marini, D., Meuleman, M., Belson, S., Rodenburg, T., Llewellyn, R., Lee, C., 2018. Developing an ethically acceptable virtual fencing system for sheep. Animals 8, 33. https://doi.org/10.3390/ani8030033.
Martin, P., Bateson, P., 2007. Measuring Behaviour: An Introductory Guide, 3rd ed..,. Cambridge University Press,, Cambridge, UK.
Mason, G., 2006. Stereotypic behaviour in captive animals: Fundamentals and implications for welfare and beyond. In: Mason, G., Rushen, J. (Eds.), Stereotypic Animal Behaviour: Fundamentals and Applications to Welfare. CABI, Wallingford, UK, pp. 325–356. https://doi.org/10.1079/9780851990040.0325.
Mason, G., Latham, N., 2004. Can't stop, won't stop: Is stereotypy a reliable wefare indicator? Anim. Welf. 13, 57–69.
Mason, G.J., 1991. Stereotypies: A critical review. Anim. Behav. 41, 1015–1037.
Mason, G.J., Veasey, J.S., 2010. How should the psychological well-being of zoo elephants be objectively investigated? Zoo. Biol. 29, 237–255. https://doi.org/10.1002/zoo.20256.
Menargues, A., Urios, V., Mauri, M., 2008. Welfare assessment of captive Asian elephants (*Elephas maximus*) and Indian rhinoceros (*Rhinoceros unicornis*) using salivary cortisol measurement. Anim. Welf. 17, 305–312. https://doi.org/10.1017/S096272860003222X.
Menargues Marcilla, A., Urios, V., Limiñana, R., 2012. Seasonal rhythms of salivary cortisol secretion in captive Asian elephants (*Elephas maximus*). Gen. Comp. Endocrinol. 176, 259–264. https://doi.org/10.1016/j.ygcen.2012.02.001.
Millspaugh, J.J., Burke, T., Van Dyk, G., Slotow, R., Washburn, B.E., Woods, R.J., 2007. Stress response of working African elephants to transportation and safari adventures. J. Wildl. Manag. 71, 1257–1260. https://doi.org/10.2193/2006-015.
Moberg, G.P., 2000. Biological response to stress: Implications for animal welfare. In: Moberg, G.P., Mencg, J.A. (Eds.), The Biology of Animal Stress: Basic Principles and Implications for Animal Welfare. CABI Publishing, Wallingford, UK, pp. 1–21. https://doi.org/10.1079/9780851993591.0001.
Mormède, P., Andanson, S., Aupérin, B., Beerda, B., Guémené, D., Malmkvist, J., Manteca, X., Manteuffel, G., Prunet, P., van Reenen, C.G., Richard, S., Veissier, I., 2007. Exploration of the hypothalamic-pituitary-adrenal function as a tool to evaluate animal welfare. Physiol. Behav. 92, 317–339. https://doi.org/10.1016/j.physbeh.2006.12.003.
Murdoch, D., Adler, D., 2023. rgl: 3D Visualization Using OpenGL. R Package Version 1.1.3. https://dmurdoch.github.io/rgl/.
Nolte, D.L., Vercauteren, K.C., Perry, K.R., Adams, S.E., 2003. Training deer to avoid sites through negative reinforcement. In: Fagerstone, K.A., Witmer, G.W. (Eds.), Proceedings of the 10th Wildlife Damage Management Conference. Wildlife Damage Management Working Group of the Wildlife Society, Fort Collins, Colorado, pp. 95–104.
Norell, R.J., Gustafson, R.J., Appleman, R.D., Overmier, J.B., 1983. Behavioral studies of dairy cattle sensitivity to electrical currents. Trans. ASAE 26, 1506–1511. https://doi.org/10.13031/2013.34160.
Oliveira, C.A., Felippe, E.C.G., Chelini, M.O.M., 2008. Serum cortisol and progestin concentrations in pregnant and non-pregnant Asian elephants (*Elephas maximus*). Res. Vet. Sci. 84, 361–363. https://doi.org/10.1016/j.rvsc.2007.05.009.
Olson, D. (Ed.), 2004. Elephant husbandry resource guide. Allen Press, Lawrence, USA.
Palme, R., Fischer, P., Schildorfer, H., Ismail, M.N., 1996. Excretion of infused 14C-steroid hormones via faeces and urine in domestic livestock. Anim. Reprod. Sci. 43, 43–63. https://doi.org/10.1016/0378-4320(95)01458-6.
Palme, R., Touma, C., Arias, N., Dominchin, M.F., Lepschy, M., 2013. Steroid extraction: Get the best out of faecal samples. Wien. Tierarztl. Mon. 100, 238–246.
Pastorini, J., Prasad, T., Leimgruber, P., Isler, K., Fernando, P., 2015. Elephant GPS tracking collars: Is there a best? Gajah 43, 15–25.
Pokharel, S.S., Seshagiri, P.B., Sukumar, R., 2017. Assessment of season-dependent body condition scores in relation to faecal glucocorticoid metabolites in free-ranging Asian elephants. Conserv. Physiol. 5, cox039. https://doi.org/10.1093/conphys/cox039.
Pokharel, S.S., Yoneda, H., Yanagi, M., Sukumar, R., Kinoshita, K., 2021. The tail-tale of stress: An exploratory analysis of cortisol levels in the tail-hair of captive Asian elephants. PeerJ 9, e10445. https://doi.org/10.7717/peerj.10445.
Poole, J.H., 1999. Signals and assessment in African elephants: Evidence from playback experiments. Anim. Behav. 58, 185–193. https://doi.org/10.1006/anbe.1999.1117.
Powell, D.M., Vitale, C., 2016. Behavioral changes in female Asian elephants when given access to an outdoor yard overnight. Zoo. Biol. 35, 298–303. https://doi.org/10.1002/zoo.21289.
R Core Team, 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. http://www.r-project.org/.
Ranches, J., O'Connor, R., Johnson, D., Davies, K., Bates, J., Boyd, C., Bohnert, D.W., Parker, T., 2021. Effects of virtual fence monitored by global positioning system on beef cattle behavior. Transl. Anim. Sci. 5, S144–S148. https://doi.org/10.1093/tas/txab161.
Réale, D., Reader, S.M., Sol, D., McDougall, P.T., Dingemanse, N.J., 2007. Integrating animal temperament within ecology and evolution. Biol. Rev. 82, 291–318. https://doi.org/10.1111/j.1469-185X.2007.00010.x.
Rees, P.A., 2002. Asian elephants (*Elephas maximus*) dust bathe in response to an increase in environmental temperature. J. Therm. Biol. 27, 353–358. https://doi.org/10.1016/S0306-4565(01)00100-0.
Rees, P.A., 2009. Activity budgets and the relationship between feeding and stereotypic behaviors in Asian elephants (*Elephas maximus*) in a zoo. Zoo. Biol. 28, 79–97. https://doi.org/10.1002/zoo.20200.
Reinemann, D.J., Stetson, L.E., Reilly, J.P., Laughlin, N.K., 1999. Dairy cow sensitivity to short duration electrical currents. Trans. Am. Soc. Agric. Eng. 42, 215–222. https://doi.org/10.13031/2013.13198.
Rossler, S.T., Gehring, T.M., Schultz, R.N., Rossler, M.T., Wydeven, A.P., Hawley, J.E., 2012. Shock collars as a site-aversive conditioning tool for wolves. Wildl. Soc. Bull. 36, 176–184. https://doi.org/10.1002/wsb.93.
Sampson, C., McEvoy, J., Oo, Z.M., Chit, A.M., Chan, A.N., Tonkyn, D., Soe, P., Songer, M., Williams, A.C., Reisinger, K., Wittemyer, G., Leimgruber, P., 2018. New elephant crisis in Asia-Early warning signs from Myanmar. PLoS One 13, e0194113. https://doi.org/10.1371/journal.pone.0194113.
Schalke, E., Stichnoth, J., Ott, S., Jones-Baade, R., 2007. Clinical signs caused by the use of electric training collars on dogs in everyday life situations. Appl. Anim. Behav. Sci. 105, 369–380. https://doi.org/10.1016/j.applanim.2006.11.002.
Schilder, M.B.H., van der Borg, J.A., 2004. Training dogs with help of the shock collar: Short and long term behavioural effects. Appl. Anim. Behav. Sci. 85, 319–334. https://doi.org/10.1016/j.applanim.2003.10.004.
Shaffer, L.J., Khadka, K.K., Van Den Hoek, J., Naithani, K.J., 2019. Human-elephant conflict: A review of current management strategies and future directions. Front. Ecol. Evol. 6, 235. https://doi.org/10.3389/fevo.2018.00235.

Slade-Cain, B.E., Rasmussen, L.E.L., Schulte, B.A., 2008. Estrous state influences on investigative, aggressive, and tail flicking behavior in captive female Asian elephants. Zoo. Biol. 27, 167–180. https://doi.org/10.1002/zoo.20181.

Snijders, L., Greggor, A.L., Hilderink, F., Doran, C., 2019. Effectiveness of animal conditioning interventions in reducing human–wildlife conflict: A systematic map protocol. Environ. Evid. 8, 10. https://doi.org/10.1186/s13750-019-0153-7.

Snijders, L., Thierij, N.M., Appleby, R., St. Clair, C.C., Tobajas, J., 2021. Conditioned taste aversion as a tool for mitigating human-wildlife conflicts. Front. Conserv. Sci. 2, 744704 https://doi.org/10.3389/fcosc.2021.744704.

Stafford, R., Goodenough, A.E., Slater, K., Carpenter, W., Collins, L., Cruickshank, H., Downing, S., Hall, S., McDonald, K., McDonnell, H., Overs, B., Spiers, L., Stetter, M., Zitzer, H., Hart, A.G., 2012. Inferential and visual analysis of ethogram data using multivariate techniques. Anim. Behav. 83, 563–569. https://doi.org/10.1016/j.anbehav.2011.11.020.

Stead, S.K., Meltzer, D.G.A., Palme, R., 2000. The measurement of glucocorticoid concentrations in the serum and faeces of captive African elephants (*Loxodonta africana*) after ACTH stimulation. J. S. Afr. Vet. Assoc. 71, 192–196.

Steiss, J.E., Schaffer, C., Ahmad, H.A., Voith, V.L., 2007. Evaluation of plasma cortisol levels and behavior in dogs wearing bark control collars. Appl. Anim. Behav. Sci. 106, 96–106. https://doi.org/10.1016/j.applanim.2006.06.018.

Tang, R., Li, W., Zhu, D., Shang, X., Guo, X., Zhang, L., 2020. Raging elephants: Effects of human disturbance on physiological stress and reproductive potential in wild Asian elephants. Conserv. Physiol. 8, coz106. https://doi.org/10.1093/conphys/coz106.

Thatcher, H.R., Downs, C.T., Koyama, N.F., 2021. The costs of urban living: Human–wildlife interactions increase parasite risk and self-directed behaviour in urban vervet monkeys. J. Urban Ecol. 7, 1–9. https://doi.org/10.1093/jue/juab031.

Touma, C., Palme, R., 2005. Measuring fecal glucocorticoid metabolites in mammals and birds: The importance of validation. Ann. N. Y. Acad. Sci. 1046, 54–74. https://doi.org/10.1196/annals.1343.006.

Turczynski, C.J., 1993. The endocrinology of musth in the male Asiatic elephant (*Elephas maximus*): Serum estradiol, serum LH and serum, fecal and urinary testosterone. PhD dissertation. Texas A&M University.

Varadharajan, V., Krishnamoorthy, T., Nagarajan, B., 2016. Prevalence of stereotypies and its possible causes among captive Asian elephants (*Elephas maximus*) in Tamil Nadu, India. Appl. Anim. Behav. Sci. 174, 137–146. https://doi.org/10.1016/j.applanim.2015.10.006.

Veasey, J., 2006. Concepts in the care and welfare of captive elephants. Int. Zoo. Yearb. 40, 63–79.

Verdon, M., Langworthy, A., Rawnsley, R., 2021. Virtual fencing technology to intensively graze lactating dairy cattle. II: Effects on cow welfare and behavior. J. Dairy Sci. 104, 7084–7094. https://doi.org/10.3168/jds.2020-19797.

Wadey, J., Beyer, H.L., Saaban, S., Othman, N., Leimgruber, P., Campos-Arceiz, A., 2018. Why did the elephant cross the road? The complex response of wild elephants to a major road in Peninsular Malaysia. Biol. Conserv. 218, 91–98. https://doi.org/10.1016/j.biocon.2017.11.036.

Wallace, E.K., Herrelko, E.S., Koski, S.E., Vick, S.-J., Buchanan-Smith, H.M., Slocombe, K.E., 2019. Exploration of potential triggers for self-directed behaviours and regurgitation and reingestion in zoo-housed chimpanzees. Appl. Anim. Behav. Sci. 221, 104878 https://doi.org/10.1016/j.applanim.2019.104878.

Wasser, S.K., Papageorge, S., Foley, C., Brown, J.L., 1996. Excretory fate of estradiol and progesterone in the African elephant (*Loxodonta africana*) and patterns of fecal steroid concentrations throughout the estrous cycle. Gen. Comp. Endocrinol. 102, 255–262. https://doi.org/10.1006/gcen.1996.0067.

Wasser, S.K., Thomas, R., Nair, P.P., Guidry, C., Southers, J., Lucas, J., Wildt, D.E., Monfort, S.L., 1993. Effects of dietary fibre on faecal steroid measurements in baboons (*Papio cynocephalus cynocephalus*). J. Reprod. Fertil. 97, 569–574.

Wasser, S.K., Hunt, K.E., Brown, J.L., Cooper, K., Crockett, C.M., Bechert, U., Millspaugh, J.J., Larson, S., Monfort, S.L., 2000. A generalized fecal glucocorticoid assay for use in a diverse array of nondomestic mammalian and avian species. Gen. Comp. Endocrinol. 120, 260–275. https://doi.org/10.1006/gcen.2000.7557.

Watson, R., Munro, C., Edwards, K.L., Norton, V., Brown, J.L., Walker, S.L., 2013. Development of a versatile enzyme immunoassay for non-invasive assessment of glucocorticoid metabolites in a diversity of taxonomic species. Gen. Comp. Endocrinol. 186, 16–24. https://doi.org/10.1016/j.ygcen.2013.02.001.

Wilson, M.L., Bashaw, M.J., Fountain, K., Kieschnick, S., Maple, T.L., 2006. Nocturnal behavior in a group of female African elephants. Zoo. Biol. 25, 173–186. https://doi.org/10.1002/zoo.20084.

Ziv, G., 2017. The effects of using aversive training methods in dogs—A review. J. Vet. Behav. 19, 50–60. https://doi.org/10.1016/j.jveb.2017.02.004.

5.2. Links and Implications

Outcomes of this short-term study suggest that AGDs may be safely used to control elephant movement without lasting undue impacts on elephant welfare, and encourages the further development of AGDs as a tool to mitigate HEC. Long-term studies with a larger sample of elephants are recommended to confirm the transferability of these findings. This study also highlighted that self-directed behaviours may be a useful indicator to assess behavioural welfare in captive Asian elephants and recommends that it be considered in future studies. Further, it emphasised the importance of similar research on other novel wildlife management tools to help stakeholders have confidence that animal wellbeing is not compromised by such approaches.

CHAPTER 6: PAPER 5 – ATTITUDES TOWARDS THE POTENTIAL USE OF AVERSIVE GEOFENCING DEVICES TO MANAGE WILD ELEPHANT MOVEMENT

6.1. Introduction

This chapter is the exact version of the research article published in *Animals* journal titled “Attitudes towards the potential use of aversive geofencing devices to manage wild elephant movement”. This chapter follows on from the recommendations made in Chapter 2, which highlighted the importance of understanding people’s perceptions on introducing AGDs as an HEC mitigation tool at a preliminary stage of its development. This chapter presents the analysis of responses received for the last section of the survey first described in Chapter 3, on people’s perceptions of the potential acceptability and effectiveness of AGDs on wild elephants. It is placed here in the thesis because its content directly relates to recommendations for future research. It also discusses and identifies potential areas for stakeholder conflict and challenges that can be expected in the future development and introduction of AGDs as an HEC mitigation tool. Supplementary information related to this research article is given in Appendix D.

animals

MDPI

Article

Attitudes towards the Potential Use of Aversive Geofencing Devices to Manage Wild Elephant Movement

Surendranie J. Cabral de Mel [1,2], Saman Seneweera [2,3], Ashoka Dangolla [4], Devaka K. Weerakoon [5], Tek Maraseni [1,6] and Benjamin L. Allen [1,7,*]

1 Institute for Life Sciences and the Environment, University of Southern Queensland, Toowoomba, QLD 4350, Australia; surendranie.cabral@gmail.com (S.J.C.d.M.); tek.maraseni@usq.edu.au (T.M.)
2 National Institute of Fundamental Studies, Kandy 20000, Sri Lanka; seneweera@gmail.com
3 School of Agriculture and Food, Faculty of Sciences, The University of Melbourne, Parkville, VIC 3010, Australia
4 Department of Veterinary Clinical Sciences, University of Peradeniya, Peradeniya 20400, Sri Lanka; adangolla@gmail.com
5 Department of Zoology and Environmental Sciences, University of Colombo, Colombo 00300, Sri Lanka; devakaw@gmail.com
6 Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, Lanzhou 730000, China
7 Centre for African Conservation Ecology, Nelson Mandela University, Port Elizabeth 6034, South Africa
* Correspondence: benjamin.allen@usq.edu.au

Simple Summary: Human-elephant conflict (HEC) has intensified in the recent decades and poses a great threat to Asian elephant conservation. Aversive geofencing devices (AGDs) or animal-borne satellite-linked shock collars might become a useful tool to help reduce HEC incidents. AGDs may be used on problem causing elephants, to train them to move away from human-dominated landscapes by associating the receipt of electric shocks with preceding audio warnings given from the AGD as they approach virtual boundaries. We assessed the opinions of experts, farmers, and others who have and have not experienced HEC towards the potential use of AGDs on Asian elephants. Most respondents had positive opinions on the potential effectiveness of AGDs in managing elephant movement (62.2%). About 62.8% respondents also expressed positive responses for the acceptability of AGDs if pilot studies with captive elephants have been successful in managing their movements. Some respondents perceived AGDs to be unacceptable because they are unethical or harmful and would be unsuccessful given wild elephants may respond differently to AGDs than captive elephants. Respondents identified several potential challenges for implementing AGDs as an elephant management tool. These issues need attention when developing AGDs to increase support from stakeholders and to effectively reduce HEC incidents in the future.

Abstract: Aversive geofencing devices (AGDs) or animal-borne satellite-linked shock collars might become a useful tool to mitigate human-elephant conflict (HEC). AGDs have the potential to condition problem elephants to avoid human-dominated landscapes by associating mild electric shocks with preceding audio warnings given as they approach virtual boundaries. We assessed the opinions of different stakeholders (experts, farmers, and others who have and have not experienced HEC; n = 611) on the potential use of AGDs on Asian elephants. Most respondents expressed positive opinions on the potential effectiveness of AGDs in managing elephant movement (62.2%). About 62.8% respondents also provided positive responses for the acceptability of AGDs if pilot studies with captive elephants have been successful in managing their movements. Some respondents perceived AGDs to be unacceptable because they are unethical or harmful and would be unsuccessful given wild elephants may respond differently to AGDs than captive elephants. Respondents identified acceptability, support and awareness of stakeholders, safety and wellbeing of elephants, logistical difficulties, durability and reliable functionality of AGDs, and uncertainties in elephants' responses to AGDs as potential challenges for implementing AGDs. These issues need attention when developing AGDs to increase support from stakeholders and to effectively reduce HEC incidents in the future.

check for updates

Citation: Cabral de Mel, S.J.; Seneweera, S.; Dangolla, A.; Weerakoon, D.K.; Maraseni, T.; Allen, B.L. Attitudes towards the Potential Use of Aversive Geofencing Devices to Manage Wild Elephant Movement. *Animals* **2023**, *13*, 2657. https://doi.org/10.3390/ani13162657

Academic Editors: Bruce Alexander Schulte and Chase LaDue

Received: 24 July 2023
Revised: 11 August 2023
Accepted: 14 August 2023
Published: 18 August 2023

Keywords: conservation; electric shock collars; *Elephas maximus*; human-elephant conflict; public opinion; virtual fencing; wildlife management

1. Introduction

The majority of Asian elephant *Elephas maximus* populations inhabit fragmented habitats dispersed among human-dominated landscapes. Thus, negative interactions between humans and elephants are inevitable [1–5]. Human-elephant conflict (HEC) is spread across all the 13 Asian elephant range countries (Bangladesh, Bhutan, Cambodia, China, India, Indonesia, Laos, Malaysia, Myanmar, Nepal, Sri Lanka, Thailand, and Vietnam) and is the biggest challenge for the conservation of this endangered species [6]. As a result of HEC, hundreds of human lives are lost each year and farmers in rural communities experience large scale economic losses from crop and property damage [7–11]. Hundreds of elephants also die annually from intentional or unintentional human actions that directly or indirectly result from HEC. Unintentional deaths of elephants may be caused by accidents such as falling into agricultural wells and abandoned quarries or gem pits, colliding with trains, traps or snares setup for other animals, and electrocution from contact with low lying electric power lines or lethal electric fences [5,12–16]. Intentional deaths occur from poaching for elephant body parts [17–19], but the majority are due to retaliation against conflict-causing elephants by using jaw bombs (explosives placed in fruits which are then offered to elephants), or poisoning or shooting [15,19,20]. Despite the religious and cultural significance of elephants in the region [21–23], many people may be driven to retaliate out of desperation to protect their lives and livelihoods.

Lethal control is considered by most people to be unacceptable [24] and is no longer permitted in most range countries [25,26]. Rather, removal of problem elephants from conflict areas by translocation, domestication, or driving them into protected areas are commonly practiced to mitigate HEC [27–31]. Government authorities are compelled to take such extreme action due to public and political pressure. However, these measures have typically proven to be ineffective in reducing HEC and rather intensify it or severely compromise the wellbeing of elephants, sometimes even causing death to the animal [27,28,32–35]. HEC mitigation approaches readily available to people, such as various physical and biological barrier methods or repellent techniques, have numerous drawbacks or are ineffective in the long-term given that elephants quickly habituate to them [36–38]. Electric fences may be the most effective HEC mitigation method, if properly built and maintained [39–41]. But inherent problems of electric fences, such as lack of flexibility once they are constructed, restriction of movement, and access to resources for both elephants and non-targeted species [25,42,43] emphasise the need to explore more innovative methods, to provide effective solutions to mitigate HEC.

Animal-borne satellite-linked electric shock collars or aversive geofencing devices (AGDs) are a potentially effective but perhaps controversial tool suggested for managing conflicts with Asian elephants [26,38]. AGDs were first used as a virtual fencing system for domestic pets and were designed to deliver a shock when an animal wearing the collar approached a signal-emitting wire hidden around a predetermined area [44]. Modern AGDs, now commercially used on livestock species have real-time Global Positioning System (GPS) tracking capabilities and can be programmed to deliver an audio warning followed by a mild electric shock automatically whenever an animal attempts to cross a virtual boundary [45]. These devices have successfully trained cattle *Bos taurus* and sheep *Ovis aries* to associate an audio warning with an unpleasant or aversive electric shock and avoid it by altering their movement whenever they hear the audio warning [46–48]. Similarly, AGDs may have the potential to condition elephants to alter their movement and avoid human-dominated landscapes. This approach has also been tested on several wild canid species to minimise human-wildlife conflict or prevent predation, and has been identified as an acceptable alternative to lethal control [49–52]. AGDs could also act as an early warning system which can automatically send a message to mobile phones warning villagers and wildlife managers about the presence of a problem elephant near the village and the potential breaches of virtual fences by those elephants that ignore the audio warnings and electric shocks [38]. AGDs could, therefore, help reduce conflict incidents with problem causing elephants.

Although the use of electric shocks to manage domestic pets and livestock species have been in existence for many decades [53], their use is still debated over animal ethics and welfare concerns [54–58]. Part of the reason for this debate may be the many nuances associated with the way electric shocks are used with these species, e.g., the strength of the shock, or whether shocks are delivered by humans or if animals can avoid the shock if they choose, and the possible stress that it would cause on the animal. Non-lethal electric fences used for elephants typically deliver electric shocks of 5500–10,000 V with very low amperage (~5 mA) and a pulse duration of about a few milliseconds [25,40,59,60], and are generally perceived as an acceptable HEC mitigation tool [61]. AGDs used on livestock are also designed to deliver shocks with similar characteristics, but use a much lower voltage (e.g., ~800 V [47,62]) and lower energy than that given from electric fences used for these species [63]. Similarly, a much milder electric shock than that used in elephant electric fences might be used with AGDs for elephants as well [64]. However, compared to capturing and attaching collars with AGDs on other smaller or domesticated animals, fitting AGDs on elephants would pose a risk to both elephants and humans involved in the collaring process [65].

Stakeholders' interests and ideas about managing wildlife, especially on controversial management tools may differ [66–72]. Public opinion can also be stronger when it comes to large, charismatic, and symbolic species [73–75]. Understanding the opinions of stakeholders towards potentially controversial but otherwise effective human-wildlife conflict mitigation approaches is important for their successful implementation. We previously conducted pilot studies on AGDs which revealed that electric shocks (~4000 V, ~51.7 µs, with no resistance) from a modified dog-training collar delivered on the neck of captive Asian elephants produces desirable aversive responses, and that there is potential to condition elephants to avoid the shock with a prior audio warning [64]. Furthermore, our assessment of behavioural and physiological stress responses to electric shocks of these captive elephants showed that the expected increase in acute stress responses returned to normal levels soon afterwards [76]. These studies revealed promising results for the potential use of AGDs to manage wild elephants, but their successful use may depend on their acceptability just as much as their efficacy [36,77], which was not assessed in these studies. Evaluating and considering the views of experts and non-experts, and those who are and are not affected by HEC is important for developing consensus around the successful deployment of AGDs. Therefore, in this study we aimed to assess the perceptions of different stakeholders towards the potential use of AGDs as an HEC mitigation tool. We further explored the respondents' stated reasons for unacceptability and solicited their views on potential challenges that could be faced when developing AGDs. The overall aim of the study was to identify issues that may need further research as the development and use of AGDs continue.

2. Materials and Methods

2.1. Survey Administration

We conducted an online and paper-based questionnaire survey from May–October 2022 to evaluate people's opinion on the potential use of AGDs as an HEC mitigation tool. Participants were enlisted using convenience and snowball sampling. The online survey targeted citizens or residents of the Asian elephant range countries, as well as experts from around the world involved in research or other work related to Asian elephants. The online survey was created using the University of Southern Queensland web-based survey tool and was shared with potential participants using social media. Email addresses of experts were obtained from published research articles or relevant organisation websites, and personal emails were sent with the survey link inviting them to participate in the survey. The paper-based survey was conducted in Sri Lanka, a country experiencing very high levels of HEC incidents [8], and targeted the rural farming communities in areas experiencing HEC with limited facilities to participate in the online survey. With the support of volunteer field assistants, self-administered survey forms were distributed among people and completed forms were collected later. The survey was made available in English as well as Sinhala and Tamil languages, the two main languages spoken in Sri Lanka. Individual respondents were not identifiable from the data (i.e., individual identifiers were not collected) and all respondents provided implied consent by completing and submitting the survey voluntarily. This study was approved by the Human Research Ethics Committee of the University of Southern Queensland, Australia (H21REA209) and the Institute of Biology, Sri Lanka (ERC IOBSL 258 01 2022).

2.2. Survey Questions

The concept of AGDs was briefly explained with illustrations at the beginning of the survey to provide respondents with a basic understanding on how AGDs are expected to manage elephant movement (Figure 1). The initial section of the survey collected demographic information of respondents such as age, gender, education level, citizenship, religion, and involvement in agriculture and in work related to Asian elephants (Table S1). Respondents' experiences with HEC were collected by asking the severity level and type of HEC they faced (Table S2). People's opinions on AGDs were collected using four closed-ended questions and three optional open-ended questions. The four closed-ended questions were 5-point Likert-type questions with responses on a bipolar scale (−2 to +2). These questions considered (1) How likely it would be for elephants to learn to avoid an electric shock from AGDs, (2) How acceptable it is to give an electric shock to an elephant using an AGD, (3) How effective AGDs would be in managing elephant movement, and (4) Would the use of AGDs on wild elephants be acceptable if pilot studies conducted with captive elephants are proven successful. The three optional open-ended questions collected respondents' feedback on (1) Reasons for unacceptability, (2) Potential challenges in implementing AGDs, and (3) Any other comments on the use of AGDs.

2.3. Data Analysis

We analysed responses from 611 respondents based on three social groups (experts, farmers and others) and whether or not they have experienced HEC (HEC or no HEC). Respondents were categorised as a "farmer" or "expert" if they had indicated their involvement in farming (annual crops or perennial crops or livestock) or work related to Asian elephants in their responses to the survey (see Table S1). Those who did not belong to either of the groups were categorised as "other". Respondents were categorised as "HEC" if they had selected a severity level of HEC they experienced and/or mentioned at least one HEC related problem they have experienced (see Table S2), while the remaining respondents were categorised as "no-HEC".

We analysed the responses for the Likert-type questions using a logistic-regression model (a generalised linear model with a binomial distribution and a logit link function), by collapsing the responses to a binary variable (−2, −1 and 0 as a "negative/neutral" response and +1, +2 as a "positive" response). Such transformation of scale avoids issues with low frequency of responses in some response categories and simplifies the interpretation of data [78,79]. We used the 'glm' function and the forestplot package [80] in the R statistical software [81] for this analysis. We used the Potential for Conflict Index$_2$ (PCI$_2$) [82] to examine the mean responses given on the five-point scale (−2 to +2) and the level of consensus within the six groups: expert-HEC, expert-no HEC, farmer-HEC, farmer-no HEC, other-HEC, and other-no HEC. PCI$_2$ values range between 0 and 1 and depict the dispersion within the sample, with 0 indicating highest consensus within a group of respondents and 1 indicating the lowest consensus within a group (i.e., all responses are divided between the extreme response categories equally). We used the programs provided by Vaske et al. [82] to calculate and graph PCI_2 and mean values. The centre and the size of the bubble in the graph depict the mean score on the scale of the y axis and the PCI_2 value, respectively. High potential for conflict within a group is depicted by larger bubbles and low potential for conflict within a group is depicted by smaller bubbles. Each analysed question (item) was reduced to shorter phrases for the convenience of display and are italicised when mentioned in the Results section (below). Table S3 contains the full-length questions. Responses to the open-ended questions were categorised according to themes, and due to the ambiguity in interpretation of the responses the approximate number of respondents commenting under each category are given within parenthesis.

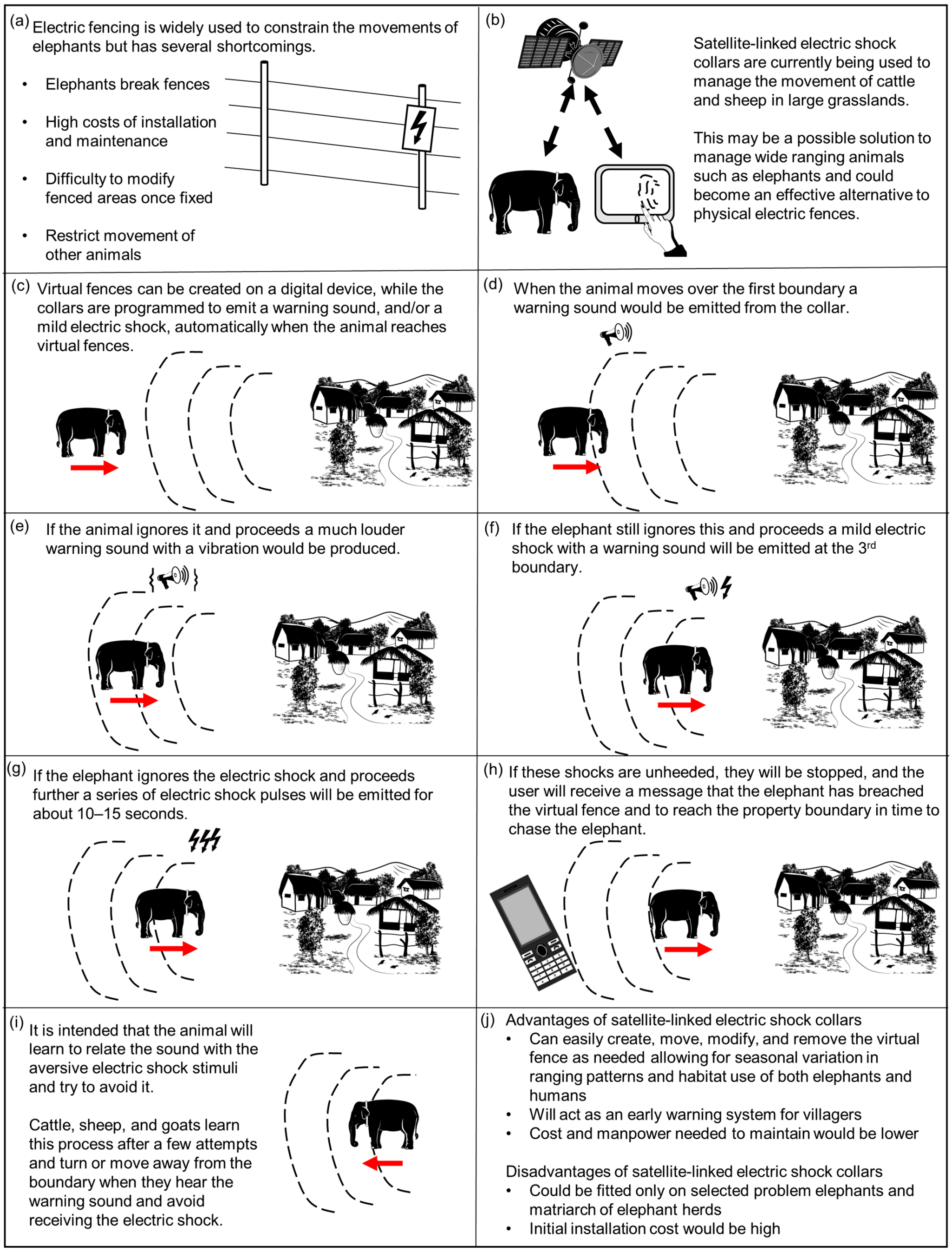

Figure 1. How aversive geofencing devices (satellite-linked electric shock collars) could be used to manage elephant movement.

3. Results

Out of the 611 responses we analysed in this study, 25.9% (n = 158) were classified as experts. Of these, 65 had experienced HEC and 93 had not. These experts included 70 Sri Lankan citizens, 60 from other range countries, and 28 from non-range countries (Table S1). Farmers comprised 18.3% (n = 112) of the respondents. Of these, 85 had experienced HEC and 27 had not. The remaining 341 respondents classified as others included 83 who had experienced HEC and 258 who had not. A total of 38.1% (n = 233) of respondents had experienced HEC (Table S2).

Overall, more than 50% of all respondents had positive responses for all items except for *acceptability of using AGDs on elephants*, for which only 44.2% (n = 270) of respondents had positive opinions (Figure 2). The logistic regression did not reveal detectable differences in opinions for all four items between the stakeholder groups; farmers and others compared to experts or those who had experienced HEC compared to those who had not ($p > 0.05$, Figure 2). All respondent groups had positive mean scores for *likelihood of elephants learning to avoid the electric shocks from AGDs* and *effectiveness of AGDs in managing elephant movement* with relatively high consensus (PCI_2 range = 0.00–0.20, Figure 3). Mean scores for *acceptability of using AGDs on elephants* ranged from −0.03 to 0.48 (PCI_2 range = 0.12–0.41), while the mean scores for *acceptability, if pilot studies on captive elephants have been successful* ranged from 0.37 to 1.22 (PCI_2 range = 0.15–0.45, Figure 3). Provided with the condition 'if pilot studies on captive elephants have been successful', acceptability scores increased by a mean difference of 0.57 ($t = 11.50$, $df = 610$, $p < 0.001$).

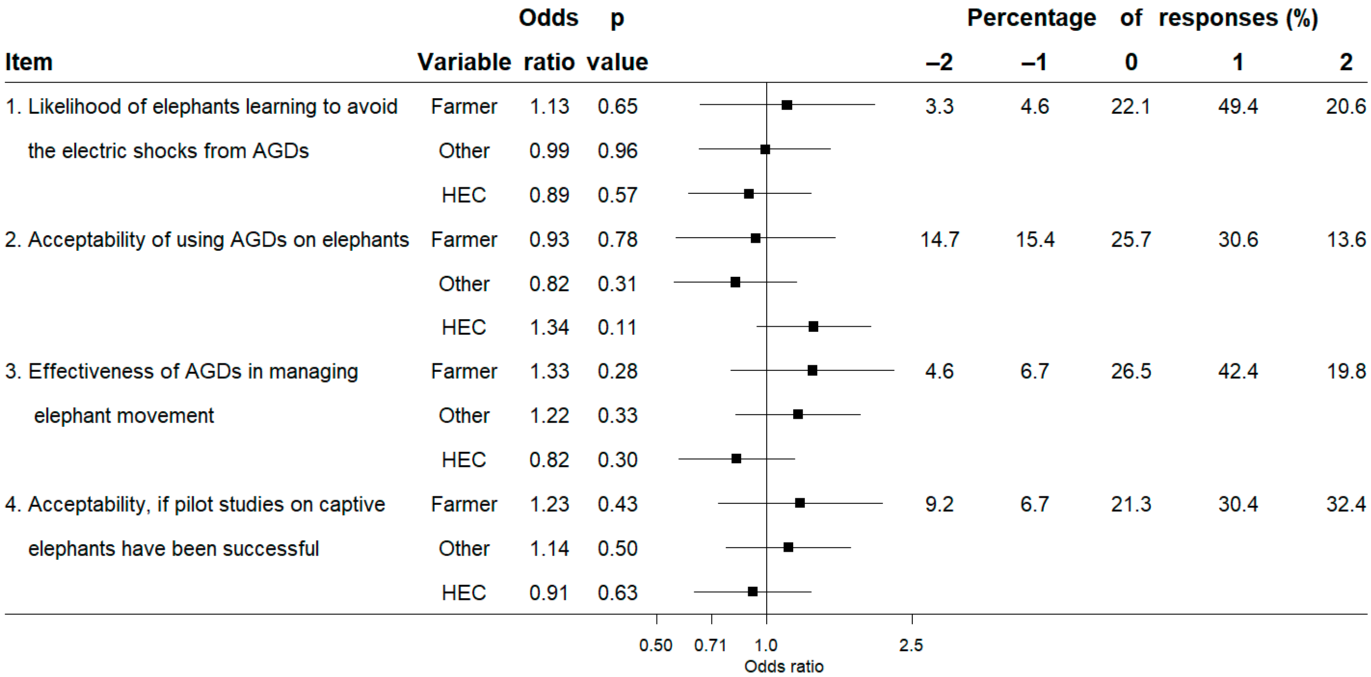

Figure 2. Forest plot for the logistic regression on the attitudes towards use of aversive geofencing devices (AGDs) as a human-elephant conflict (HEC) mitigation tool by farmers and others relative to experts and those who have experienced HEC relative to those who have not along with overall percentage responses for each item. Black squares and horizontal lines indicate the odds ratio and the 95% confidence interval, respectively.

Of the total respondents, 15.9% (n = 97) selected "unacceptable" or "somewhat unacceptable" for *acceptability, if pilot studies on captive elephants have been successful* (Figure 2). These respondents were represented by all six groups: 13.8% of expert-HEC (n = 9), 30.1% of expert-no HEC (n = 28), 7.1% farmer-HEC (n = 6), 11.1% of farmer-no HEC (n = 3), 14.5% of other-HEC (n = 12), and 15.1% of other-no HEC (n = 39) (Table S3). Of these 97 respondents, 61 offered reasons for the unacceptability of AGDs, which mostly indicated that they perceived AGDs to be unethical, cruel or harmful to elephants (~41), and that it is an approach they considered to be unfeasible or would be unsuccessful because wild elephant behaviour would be different from captive elephants (~25). About 300 respondents provided feedback on the potential challenges in implementing AGDs and/or other comments. These comments can be categorised under five themes: (1) acceptability, support and awareness of stakeholders (~46), (2) safety and wellbeing of elephants (~68), (3) logistical difficulties (~169), (4) durability and reliable functionality of AGDs (~91), and (5) uncertainties in elephants' responses to AGDs (~62). Selected comments offered as reasons for unacceptability and potential challenges are discussed below and provided as Supplementary Material (Tables S4 and S5, respectively).

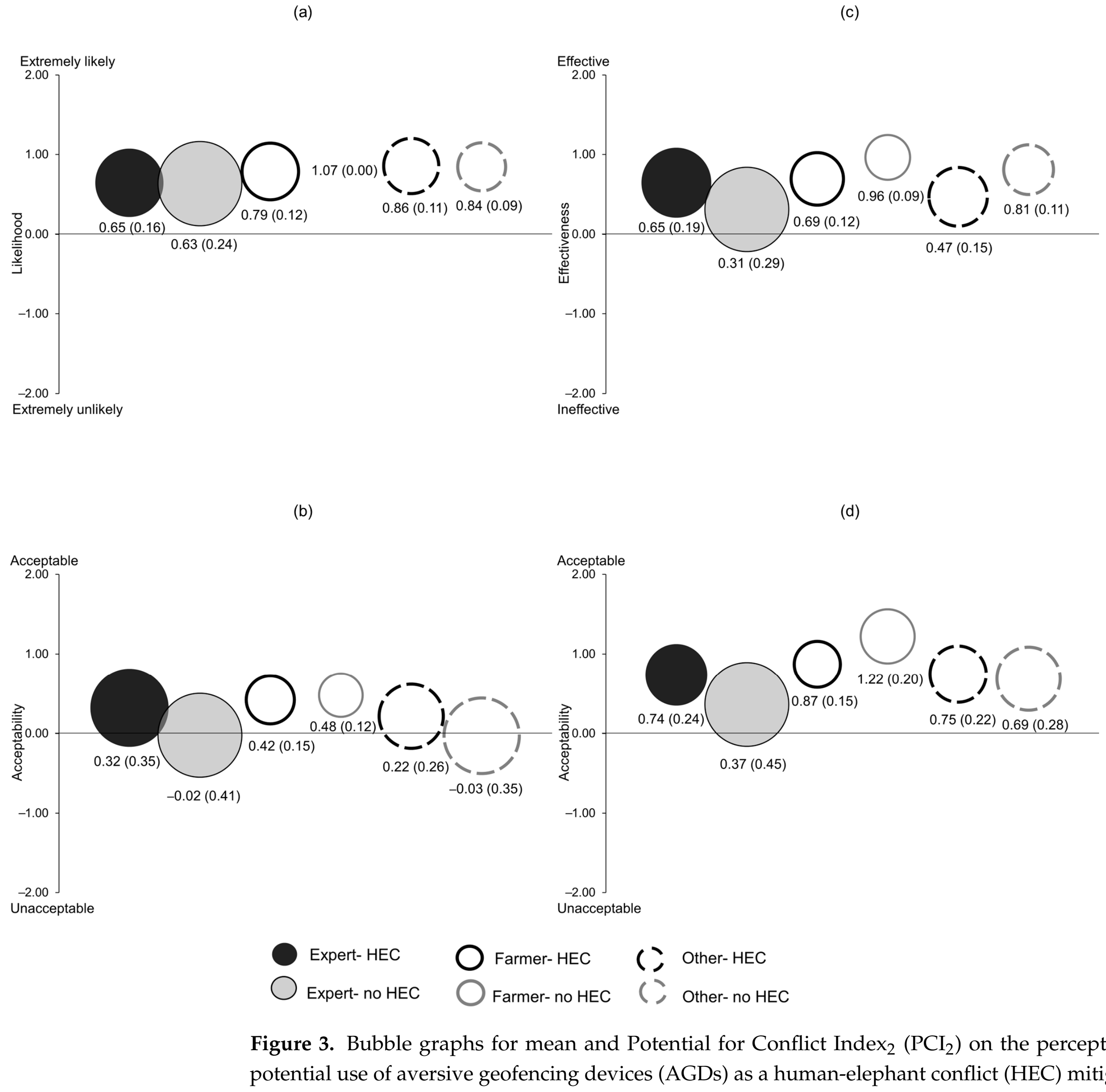

Figure 3. Bubble graphs for mean and Potential for Conflict Index$_2$ (PCI$_2$) on the perception of potential use of aversive geofencing devices (AGDs) as a human-elephant conflict (HEC) mitigation tool among experts, farmers and others who have and have not experienced HEC. (**a**) Likelihood of elephants learning to avoid the electric shocks from AGDs, (**b**) Acceptability of using AGDs on elephants, (**c**) Effectiveness of AGDs in managing elephant movement, (**d**) Acceptability, if pilot studies on captive elephants have been successful. Centre of the bubble indicates the mean score (on the scale of the y axis) and bubble size illustrates the magnitude of PCI$_2$, with larger bubbles indicating low consensus among respondents within groups. Values under each bubble indicate mean and PCI$_2$ value within parenthesis.

4. Discussion

We explored the perceptions towards the potential use of AGDs to manage elephant movement by surveying different stakeholder groups whose opinions and support is vital for the successful implementation of AGDs as an HEC mitigation tool. We found that respondents had similar views towards AGDs regardless of whether they were experts, farmers or others, and whether or not they had personal experience with HEC; each group largely felt the same towards AGDs (Figure 2). Elephants are intelligent animals with superior cognitive skills [83,84], a trait acknowledged by the general public with usage of phrases such as "memory like an elephant" or "an elephant never forgets" [85,86]. This understanding may have contributed to all respondent groups agreeing on the likelihood of elephants learning to associate the AGDs' warning sound with the impending electric shock, thereby avoiding the shock and highlighting the potential effectiveness of AGDs in managing elephant movement (Figure 3a,c). When questioned about the acceptability of managing elephants in this way, the expert-no HEC and other-no HEC groups were relatively neutral, while all other groups considered it somewhat acceptable (Figure 3b). People tend to perceive a novel HEC mitigation tool as increasingly favourable as their knowledge on its effectiveness improves [77]. Similarly, our results suggested that if evidence can be provided that AGDs can effectively manage the movement of captive elephants, then the acceptability of using AGDs on wild elephants would increase among all groups (Figure 3d). However, the relatively lower acceptability and higher potential for conflict within the expert-no HEC group, even if such evidence is provided, indicates that building consensus among all experts on AGDs may pose some challenges.

Most people were either ambivalent or considered AGDs to be acceptable (Figure 1), but those who considered AGDs to be unacceptable may be categorised into two main groups based on their stated reasons for unacceptability: (1) those who see AGDs as unethical or harmful, and (2) those who feel that AGDs will be unsuccessful in managing wild elephant movements (Table S4). These opinions may be due to "conflict over values and conflict over evidence", as highlighted by Donfrancesco et al. [72]. If scientific evidence can be provided on the effectiveness of AGDs from preliminary trials with wild elephants, it will help develop consensus with the latter group. But the views of those who consider AGDs to be unethical might vary under different severity levels of HEC [87], for example, when HEC results in frequent death of humans and elephants, rather than a low frequency of crop damage. Obtaining social acceptability and the support of stakeholders is important and was also suggested by our respondents as a potential challenge for implementing AGDs. One respondent even pointed out that some may consider elephants as non-human persons with rights (Table S5, see also Riddle, [88]; Lev and Barkai, [89] and Locke, [90]), and therefore, using methods where humans 'control' animals may be perceived as unethical. People's opinion towards management approaches may change with more awareness of the actual situation [74]. Proper dialog between relevant groups on the severity of HEC experienced in many regions and whether retaliatory killing, other HEC mitigation approaches or use of AGDs would be ethically justifiable and effective in such situations will be important.

Respondents questioned the impact on the mental and physical wellbeing of elephants in response to electric shocks. Previous studies conducted on other species [63,91–95] and with captive Asian elephants [76] showed that the expected increase in acute stress levels measured using behavioural (e.g., aversive or anxiety/stress related behaviours) and physiological (e.g., cortisol hormone levels, heart rate, body temperature) responses to electric shock rapidly returned to baseline levels soon after experiencing them. Further, by ensuring that stimuli are delivered only when the elephant moved in the 'wrong' direction and not based on its location, will permit elephants to learn accurately and move in the 'right' direction to avoid the shock [96]. Coupling the electric shock with the audio warning provides the ability for elephants to predict and control the receipt of shocks [97,98], which would further reduce their acute stress response levels as shown for cattle [94]. After elephants learn to predict and control the receipt of shock, chronic stress responses to

AGDs might be negligible compared to baseline levels [63,95]. The impact of electric shocks from AGDs on elephants' wellbeing would, therefore, be negligible or no different to that experienced with other HEC mitigation tools, though this needs further investigation.

Many respondents had reasonable concerns about logistical challenges during implementation of AGDs. For example, collaring wild elephants and planning virtual fences will be a very difficult task (Table S5, see also Pastorini et al. [65]). Fitting collars on wild elephants to monitor their movements has been practiced for many years [4,17,28,32,65], but AGDs should preferably be used on selected problem elephants or in HEC scenarios where no other acceptable approach has been effective [38]. AGDs should not be considered as a replacement for all other existing HEC mitigation approaches. While elephant herds are sometimes known to raid crops [32,99,100], it is primarily the male elephants that are involved in direct confrontations with people [32,101] and crop raiding [102–105]. AGDs could help reduce these HEC incidents if used on those types of problem elephants. To successfully reduce HEC incidents with problem elephants using AGDs, it is important to incorporate both human and elephant needs and ensure connectivity between elephant habitats when planning virtual fences [106,107]. Therefore, conducting baseline studies to understand the land use patterns of humans and elephants and the unique situation of HEC where AGDs are to be implemented are required to design virtual fences appropriately [38].

Our study also revealed several other potential challenges that should be resolved during the research and development process of AGDs. These include ensuring reliability of the technology (e.g., consistency and accuracy of delivering audio and electrical stimuli, maintaining uninterrupted satellite communication), durability of the device (e.g., weather resistance, long lasting battery life), and resolving uncertainties in elephant's behavioural responses to electric shocks (e.g., individual variations in responses or potential to show aggressive behaviours, possibility to learn through social facilitation and possibility of habituation to the stimuli) (Table S5). These possible challenges have been identified and discussed in Cabral de Mel et al. [38,64] and should be further investigated. Given the general support or lack of widespread opposition towards AGDs, the next step would be designing and developing a wearable, prototype AGD and optimising it by further testing with captive elephants to provide evidence on its efficacy in managing elephant movement with minimum impact on elephant wellbeing. Once many of the uncertainties are resolved and with the acceptance and support of stakeholders, this prototype device can then be modified (if necessary) and trialled on selected wild elephants in a high-HEC area to further assess its efficacy.

5. Conclusions

AGDs are an innovative tool used to manage animal movement and could help manage Asian elephant movement too. However, the successful use of AGDs is most likely to occur when consideration is given to all stakeholder views. Our study showed that the majority of respondents had confidence that elephants will learn to avoid the shock from AGDs by altering their movement when presented with the audio warning and thereby effectively mitigate HEC. Most respondents were also neutral or generally accepting towards the use of AGDs. Providing evidence that AGDs reliably and effectively manage captive elephant movement without compromising elephant wellbeing would further improve the acceptability of AGDs among stakeholders. Such favourable views, especially among people experiencing HEC, are important to receive support for the successful implementation of AGDs. We expect that there will still be a small proportion of stakeholders who will object to the use of AGDs on elephants irrespective of its efficacy or general acceptability in managing captive elephant movement, so such views should be further evaluated to discover how they may vary depending on different HEC scenarios. Proper communication and awareness among stakeholders about the outcome of preliminary research on AGDs should build consensus among stakeholders around the more widespread use of AGDs in the future.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ani13162657/s1, Table S1: Socioeconomic details of all respondents analysed in the study; Table S2: Personal experience of respondents in human-elephant conflict (HEC); Table S3: Full length question of the items analysed in the study; Table S4: Selected list of reasons provided by respondents for unacceptability of using aversive geofencing devices on elephants; Table S5: Selected list of feedback received from respondents for potential challenges and other comments on aversive geofencing devices.

Author Contributions: Conceptualization, S.J.C.d.M. and B.L.A.; methodology, S.J.C.d.M., D.K.W., A.D., T.M. and B.L.A.; formal analysis, S.J.C.d.M.; investigation, S.J.C.d.M.; data curation, S.J.C.d.M.; writing—original draft preparation, S.J.C.d.M.; writing—review and editing, S.J.C.d.M., S.S., D.K.W., A.D., T.M. and B.L.A.; visualization, S.J.C.d.M.; supervision, S.S., D.K.W., A.D., T.M. and B.L.A.; project administration, S.J.C.d.M., S.S., D.K.W., A.D., T.M. and B.L.A.; funding acquisition, S.S. All authors have read and agreed to the published version of the manuscript.

Funding: S.J.C.d.M. was jointly supported by the University of Southern Queensland, Australia (International Fees Research Scholarship) and the National Institute of Fundamental Studies, Kandy, Sri Lanka (in-kind support). The project was funded by the National Research Council, Sri Lanka, grant number 19-046, awarded to S.S.

Institutional Review Board Statement: This study was approved by the Human Research Ethics Committee of the University of Southern Queensland, Australia (H21REA209) and the Institute of Biology, Sri Lanka (ERC IOBSL 258 01 2022).

Informed Consent Statement: Data collected were non-identifiable and all respondents provided implied consent by completing and submitting the survey voluntarily.

Data Availability Statement: The authors confirm that the supporting data of these findings are available within the article and its Supplementary Materials. The summarised data generated during the current study are available from the corresponding author on reasonable request.

Acknowledgments: Authors sincerely thank Ruvinda K. de Mel, Umair Kaleelullah, Ashkar Thasleem, Sanjaya N. Weerakkody, Rukmal Ratnayake, Kulangana Theivendrarajah, Jael Nirubha Kanagaratnam, Gajavathany Kandasamy, and Dishane K. Hewavithana for their inputs and support in translating and proofreading the survey. Authors also thank Deepthi Madumali for the digital illustrations used. We greatly appreciate the support of the many volunteer field assistants in distributing the paper-based survey to collect data from respondents in rural farming communities in Sri Lanka. We are also deeply grateful to all respondents for their active participation in the survey and providing valuable feedback on AGDs. We acknowledge Rachel King of the University of Southern Queensland and Mahesh Senarathna for their valuable inputs on statistical analysis. Authors also thank the anonymous reviewers for their constructive comments.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Padalia, H.; Ghosh, S.; Reddy, C.S.; Nandy, S.; Singh, S.; Kumar, A.S. Assessment of Historical Forest Cover Loss and Fragmentation in Asian Elephant Ranges in India. *Environ. Monit. Assess.* **2019**, *191*, 802. [CrossRef] [PubMed]
2. Fernando, P.; De Silva, M.K.C.R.; Jayasinghe, L.K.A.; Janaka, H.K.; Pastorini, J. First Country-Wide Survey of the Endangered Asian Elephant: Towards Better Conservation and Management in Sri Lanka. *Oryx* **2021**, *55*, 46–55. [CrossRef]
3. Liu, P.; Wen, H.; Harich, F.K.; He, C.; Wang, L.; Guo, X.; Zhao, J.; Luo, A.; Yang, H.; Sun, X.; et al. Conflict between Conservation and Development: Cash Forest Encroachment in Asian Elephant Distributions. *Sci. Rep.* **2017**, *7*, 6404. [CrossRef]
4. Wadey, J.; Beyer, H.L.; Saaban, S.; Othman, N.; Leimgruber, P.; Campos-Arceiz, A. Why Did the Elephant Cross the Road? The Complex Response of Wild Elephants to a Major Road in Peninsular Malaysia. *Biol. Conserv.* **2018**, *218*, 91–98. [CrossRef]
5. Othman, N.; Goossens, B.; Cheah, C.P.I.; Nathan, S.; Bumpus, R.; Ancrenaz, M. Shift of Paradigm Needed towards Improving Human–Elephant Coexistence in Monoculture Landscapes in Sabah. *Int. Zoo Yearb.* **2019**, *53*, 161–173. [CrossRef]
6. Williams, C.; Tiwari, S.K.R.; Goswami, V.R.; de Silva, S.; Kumar, A.; Baskaran, N.; Yoganand, K.; Menon, V. *Elephas maximus*. Available online: https://www.iucnredlist.org/species/7140/45818198 (accessed on 17 June 2023).
7. Acharya, K.P.; Paudel, P.K.; Neupane, P.R.; Köhl, M. Human-Wildlife Conflicts in Nepal: Patterns of Human Fatalities and Injuries Caused by Large Mammals. *PLoS ONE* **2016**, *11*, e0161717. [CrossRef] [PubMed]
8. Prakash, T.G.S.L.; Wijeratne, A.W.; Fernando, P. Human-Elephant Conflict in Sri Lanka: Patterns and Extent. *Gajah* **2020**, *51*, 16–25.

9. Ganesh, S. Human Elephant Conflict Kills 1713 People, 373 Pachyderms in 3 Years. Available online: https://www.thehindu.com/news/national/human-elephant-conflict-kills-1713-people-373-pachyderms-in-3-years/article26225515.ece (accessed on 11 May 2020).
10. Karanth, K.K.; Gupta, S.; Vanamamalai, A. Compensation Payments, Procedures and Policies towards Human-Wildlife Conflict Management: Insights from India. *Biol. Conserv.* **2018**, *227*, 383–389. [CrossRef]
11. Nair, R.P.; Jayson, E.A. Estimation of Economic Loss and Identifying the Factors Affecting the Crop Raiding Behaviour of Asian Elephant (*Elephas maximus*) in Nilambur Part of the Southern Western Ghats, Kerala, India. *Curr. Sci.* **2021**, *121*, 521. [CrossRef]
12. Palei, N.C.; Palei, H.S.; Rath, B.P.; Kar, C.S. Mortality of the Endangered Asian Elephant *Elephas maximus* by Electrocution in Odisha, India. *Oryx* **2014**, *48*, 602–604. [CrossRef]
13. Williams, A.C.; Johnsingh, A.J.T.; Krausman, P.R. Elephant-Human Conflicts in Rajaji National Park, Northwestern India. *Wildl. Soc. Bull.* **2001**, *29*, 1097–1104.
14. Perera, B.M.A.O. The Human-Elephant Conflict: A Review of Current Status and Mitigation Methods. *Gajah* **2009**, *30*, 41–52.
15. LaDue, C.A.; Eranda, I.; Jayasinghe, C.; Vandercone, R.P.G. Mortality Patterns of Asian Elephants in a Region of Human–Elephant Conflict. *J. Wildl. Manag.* **2021**, *85*, 794–802. [CrossRef]
16. Kalam, T.; Kumar Baishya, H.; Smith, D. Lethal Fence Electrocution: A Major Threat to Asian Elephants in Assam, India. *Trop. Conserv. Sci.* **2018**, *11*, 194008291881728. [CrossRef]
17. Sampson, C.; McEvoy, J.; Oo, Z.M.; Chit, A.M.; Chan, A.N.; Tonkyn, D.; Soe, P.; Songer, M.; Williams, A.C.; Reisinger, K.; et al. New Elephant Crisis in Asia-Early Warning Signs from Myanmar. *PLoS ONE* **2018**, *13*, e0194113. [CrossRef]
18. Nijman, V.; Shepherd, C.R. Emergence of Mong La on the Myanmar–China Border as a Global Hub for the International Trade in Ivory and Elephant Parts. *Biol. Conserv.* **2014**, *179*, 17–22. [CrossRef]
19. Qomariah, I.N.; Rahmi, T.; Said, Z.; Wijaya, A. Conflict between Human and Wild Sumatran Elephant (*Elephas maximus sumatranus* Temminck, 1847) in Aceh Province, Indonesia. *Biodivers. J. Biol. Divers.* **2018**, *20*, 77–84. [CrossRef]
20. Gubbi, S.; Swaminath, M.H.; Poornesha, H.C.; Bhat, R.; Raghunath, R. An Elephantine Challenge: Human-Elephant Conflict Distribution in the Largest Asian Elephant Population, Southern India. *Biodivers. Conserv.* **2014**, *23*, 633–647. [CrossRef]
21. Gogoi, M. Emotional Coping among Communities Affected by Wildlife-Caused Damage in North-East India: Opportunities for Building Tolerance and Improving Conservation Outcomes. *Oryx* **2018**, *52*, 214–219. [CrossRef]
22. Sukumar, R. *The Living Elephants: Evolutionary Ecology, Behavior and Conservation*; Oxford University Press: New York, NY, USA, 2003; ISBN 0195107780.
23. Köpke, S.; Withanachchi, S.S.; Pathiranage, R.; Withanachchi, C.R.; Gamage, D.U.; Nissanka, T.S.; Warapitiya, C.C.; Nissanka, B.M.; Ranasinghe, N.N.; Senarathna, C.D.; et al. Human–Elephant Conflict in Sri Lanka: A Critical Review of Causal Explanations. *Sustainability* **2021**, *13*, 8625. [CrossRef]
24. Allen, B.L.; Bobier, C.; Dawson, S.; Fleming, P.J.S.; Hampton, J.; Jachowski, D.; Kerley, G.I.H.; Linnell, J.D.C.; Marnewick, K.; Minnie, L.; et al. Why Humans Kill Animals and Why We Cannot Avoid It. *Sci. Total Environ.* **2023**, *896*, 165283. [CrossRef] [PubMed]
25. Desai, A.A.; Riddle, H.S. *Human-Elephant Conflict in Asia*; U.S. Fish and Wildlife Service; Asian Elephant Support: Washington, DC, USA, 2015.
26. Fernando, P. Managing 'Problem Elephants'. *Loris* **2011**, *25*, 32–36.
27. Fernando, P.; Leimgruber, P.; Prasad, T.; Pastorini, J. Problem-Elephant Translocation: Translocating the Problem and the Elephant? *PLoS ONE* **2012**, *7*, e50917. [CrossRef]
28. Fernando, P.; Prasad, T.; Janaka, H.K.; Ekanayaka, S.K.; Nishantha, H.G.; Pastorini, J. The Use of Radio-Tracking Data to Guide Development and Manage Elephants. *Wildlanka* **2015**, *3*, 12–19.
29. Azmi, W.; Gunaryadi, D. Current Status of Asian Elephants in Indonesia. *Gajah* **2011**, *35*, 55–61.
30. Leimgruber, P.; Oo, Z.; Aung, M.; Kelly, D.; Wemmer, C.; Senior, B.; Songer, M. Current Status of Asian Elephants in Myanmar. *Gajah* **2011**, *35*, 76–86.
31. Saaban, S.; Othman, N.B.; Yasak, M.N.B.; Nor, B.M.; Ahmad, Z.; Campos-Arceiz, A. Current Status of Asian Elephants in Peninsular Malaysia. *Gajah* **2011**, *35*, 67–75.
32. de la Torre, J.A.; Wong, E.P.; Lechner, A.M.; Zulaikha, N.; Zawawi, A.; Abdul-Patah, P.; Saaban, S.; Goossens, B.; Campos-Arceiz, A. There Will Be Conflict—Agricultural Landscapes Are Prime, Rather than Marginal, Habitats for Asian Elephants. *Anim. Conserv.* **2021**, *24*, 720–732. [CrossRef]
33. Vijayakrishnan, S.; Kumar, M.A.; Umapathy, G.; Kumar, V.; Sinha, A. Physiological Stress Responses in Wild Asian Elephants *Elephas maximus* in a Human-Dominated Landscape in the Western Ghats, Southern India. *Gen. Comp. Endocrinol.* **2018**, *266*, 150–156. [CrossRef]
34. Lahdenperä, M.; Mar, K.U.; Courtiol, A.; Lummaa, V. Differences in Age-Specific Mortality between Wild-Caught and Captive-Born Asian Elephants. *Nat. Commun.* **2018**, *9*, 3023. [CrossRef] [PubMed]
35. Stüwe, M.; Abdul, J.B.; Nor, B.M.; Wemmer, C.M. Tracking the Movements of Translocated Elephants in Malaysia Using Satellite Telemetry. *Oryx* **1998**, *32*, 68–74. [CrossRef]
36. Denninger Snyder, K.; Rentsch, D. Rethinking Assessment of Success of Mitigation Strategies for Elephant-induced Crop Damage. *Conserv. Biol.* **2020**, *34*, 829–842. [CrossRef] [PubMed]

37. Shaffer, L.J.; Khadka, K.K.; Van Den Hoek, J.; Naithani, K.J. Human-Elephant Conflict: A Review of Current Management Strategies and Future Directions. *Front. Ecol. Evol.* **2019**, *6*, 235. [CrossRef]
38. Cabral de Mel, S.J.; Seneweera, S.; de Mel, R.K.; Dangolla, A.; Weerakoon, D.K.; Maraseni, T.; Allen, B.L. Current and Future Approaches to Mitigate Conflict between Humans and Asian Elephants: The Potential Use of Aversive Geofencing Devices. *Animals* **2022**, *12*, 2965. [CrossRef] [PubMed]
39. Ponnusamy, V.; Chackrapani, P.; Lim, T.W.; Saaban, S.; Campos-Arceiz, A. Farmers' Perceptions and Attitudes towards Government-Constructed Electric Fences in Peninsular Malaysia. *Gajah* **2016**, *45*, 4–11.
40. Liefting, Y.; de Jong, J.F.; Prins, H.H.T. A New Type of Elephant Fence: Permeable for People and Game but Not for Elephant. *Gajah* **2018**, *49*, 11–19.
41. Pekor, A.; Miller, J.R.B.; Flyman, M.V.; Kasiki, S.; Kesch, M.K.; Miller, S.M.; Uiseb, K.; van der Merve, V.; Lindsey, P.A. Fencing Africa's Protected Areas: Costs, Benefits, and Management Issues. *Biol. Conserv.* **2019**, *229*, 67–75. [CrossRef]
42. Hayward, M.W.; Kerley, G.I.H. Fencing for Conservation: Restriction of Evolutionary Potential or a Riposte to Threatening Processes? *Biol. Conserv.* **2009**, *142*, 1–13. [CrossRef]
43. Smith, D.; King, R.; Allen, B.L. Impacts of Exclusion Fencing on Target and Non-target Fauna: A Global Review. *Biol. Rev.* **2020**, *95*, 1590–1606. [CrossRef]
44. Peck, R.M. Method and Apparatus for Controlling an Animal. U.S. Patent 3753421, 21 August 1973.
45. Goliński, P.; Sobolewska, P.; Stefańska, B.; Golińska, B. Virtual Fencing Technology for Cattle Management in the Pasture Feeding System—A Review. *Agriculture* **2023**, *13*, 91. [CrossRef]
46. Campbell, D.L.M.; Ouzman, J.; Mowat, D.; Lea, J.M.; Lee, C.; Llewellyn, R.S. Virtual Fencing Technology Excludes Beef Cattle from an Environmentally Sensitive Area. *Animals* **2020**, *10*, 1069. [CrossRef] [PubMed]
47. Boyd, C.S.; O'Connor, R.; Ranches, J.; Bohnert, D.W.; Bates, J.D.; Johnson, D.D.; Davies, K.W.; Parker, T.; Doherty, K.E. Virtual Fencing Effectively Excludes Cattle from Burned Sagebrush Steppe. *Rangel. Ecol. Manag.* **2022**, *81*, 55–62. [CrossRef]
48. Marini, D.; Meuleman, M.; Belson, S.; Rodenburg, T.; Llewellyn, R.; Lee, C. Developing an Ethically Acceptable Virtual Fencing System for Sheep. *Animals* **2018**, *8*, 33. [CrossRef]
49. Andelt, W.F.; Phillips, R.L.; Gruver, K.S.; Guthrie, J.W. Coyote Predation on Domestic Sheep Deterred with Electronic Dog-Training Collar. *Wildl. Soc. Bull.* **1999**, *27*, 12–18.
50. Rossler, S.T.; Gehring, T.M.; Schultz, R.N.; Rossler, M.T.; Wydeven, A.P.; Hawley, J.E. Shock Collars as a Site-Aversive Conditioning Tool for Wolves. *Wildl. Soc. Bull.* **2012**, *36*, 176–184. [CrossRef]
51. Appleby, R. Dingo–Human Conflict: Attacks on Humans. In *The Dingo Debate: Origins, Behaviour and Conservation*; Smith, B., Ed.; CSIRO Publishing: Melbourne, Australia, 2015; pp. 131–158.
52. Cooper, D.M.; Kershner, E.L.; Garcelon, D.K. The Use of Shock Collars to Prevent Island Fox (*Urocyon littoralis*) Predation on the Endangered San Clemente Loggerhead Shrike (*Lanius ludovicianus mearnsi*). In Proceedings of the Sixth California Islands Symposium, Ventura, CA, USA, 1–3 December 2003; Garcelon, D.K., Schwemm, C.A., Eds.; National Park Service Technical Publication CHIS-05-01. Institute for Wildlife Studies: Arcata, CA, USA, 2005; pp. 287–297.
53. Anderson, D.M. Virtual Fencing—Past, Present and Future. *Rangel. J.* **2007**, *29*, 65–78. [CrossRef]
54. Blackwell, E.J.; Bolster, C.; Richards, G.; Loftus, B.A.; Casey, R.A. The Use of Electronic Collars for Training Domestic Dogs: Estimated Prevalence, Reasons and Risk Factors for Use, and Owner Perceived Success as Compared to Other Training Methods. *BMC Vet. Res.* **2012**, *8*, 93. [CrossRef]
55. China, L.; Mills, D.S.; Cooper, J.J. Efficacy of Dog Training with and without Remote Electronic Collars vs. a Focus on Positive Reinforcement. *Front. Vet. Sci.* **2020**, *7*, 508. [CrossRef]
56. Masson, S.; Nigron, I.; Gaultier, E. Questionnaire Survey on the Use of Different E-Collar Types in France in Everyday Life with a View to Providing Recommendations for Possible Future Regulations. *J. Vet. Behav.* **2018**, *26*, 48–60. [CrossRef]
57. Masson, S.; de la Vega, S.; Gazzano, A.; Mariti, C.; Pereira, G.D.G.; Halsberghe, C.; Muser Leyvraz, A.; McPeake, K.; Schoening, B. Electronic Training Devices: Discussion on the Pros and Cons of Their Use in Dogs as a Basis for the Position Statement of the European Society of Veterinary Clinical Ethology. *J. Vet. Behav.* **2018**, *25*, 71–75. [CrossRef]
58. Brunberg, E.I.; Bergslid, I.K.; Bøe, K.E.; Sørheim, K.M. The Ability of Ewes with Lambs to Learn a Virtual Fencing System. *Animal* **2017**, *11*, 2045–2050. [CrossRef] [PubMed]
59. Fernando, P. *Guide for Implementing Community-Based Electric Fences for the Effective Mitigation of Human-Elephant Conflict*; The World Bank: Washington, DC, USA, 2020.
60. Kamdar, A.; Baishya, H.K.; Nagendra, H.; Ratnam, J.; Smith, D.; Sekar, N. Human–Elephant Conflict Mitigation as a Public Good: What Determines Fence Maintenance? *Ecol. Soc.* **2022**, *27*, 24. [CrossRef]
61. Cabral de Mel, L.S.J. Efficacy and Welfare of Aversive Geofencing Devices for Managing the Movements of Asian Elephants. Ph.D. Thesis, University of Southern Queenaland, Toowoomba, Australia, 2023.
62. Campbell, D.L.M.; Lea, J.M.; Haynes, S.J.; Farrer, W.J.; Leigh-Lancaster, C.J.; Lee, C. Virtual Fencing of Cattle Using an Automated Collar in a Feed Attractant Trial. *Appl. Anim. Behav. Sci.* **2018**, *200*, 71–77. [CrossRef]
63. Campbell, D.L.M.; Lea, J.M.; Keshavarzi, H.; Lee, C. Virtual Fencing Is Comparable to Electric Tape Fencing for Cattle Behavior and Welfare. *Front. Vet. Sci.* **2019**, *6*, 445. [CrossRef] [PubMed]

64. Cabral de Mel, S.J.; Seneweera, S.; de Mel, R.K.; Medawala, M.; Abeysinghe, N.; Dangolla, A.; Weerakoon, D.K.; Maraseni, T.; Allen, B.L. Virtual Fencing of Captive Asian Elephants Fitted with an Aversive Geofencing Device to Manage Their Movement. *Appl. Anim. Behav. Sci.* **2023**, *258*, 105822. [CrossRef]
65. Pastorini, J.; Prasad, T.; Leimgruber, P.; Isler, K.; Fernando, P. Elephant GPS Tracking Collars: Is There a Best? *Gajah* **2015**, *43*, 15–25.
66. van Eeden, L.M.; Newsome, T.M.; Crowther, M.S.; Dickman, C.R.; Bruskotter, J. Social Identity Shapes Support for Management of Wildlife and Pests. *Biol. Conserv.* **2019**, *231*, 167–173. [CrossRef]
67. van Eeden, L.M.; Newsome, T.M.; Crowther, M.S.; Dickman, C.R.; Bruskotter, J. Diverse Public Perceptions of Species' Status and Management Align with Conflicting Conservation Frameworks. *Biol. Conserv.* **2020**, *242*, 108416. [CrossRef]
68. Drijfhout, M.; Kendal, D.; Green, P. Mind the Gap: Comparing Expert and Public Opinions on Managing Overabundant Koalas. *J. Environ. Manag.* **2022**, *308*, 114621. [CrossRef]
69. Bobier, C.A.; Allen, B.L. Compassionate Conservation Is Indistinguishable from Traditional Forms of Conservation in Practice. *Front. Psychol.* **2022**, *13*, 750313. [CrossRef]
70. Lute, M.L.; Carter, N.H.; López-Bao, J.V.; Linnell, J.D.C. Conservation Professionals Agree on Challenges to Coexisting with Large Carnivores but Not on Solutions. *Biol. Conserv.* **2018**, *218*, 223–232. [CrossRef]
71. Donfrancesco, V.; Ciucci, P.; Salvatori, V.; Benson, D.; Andersen, L.W.; Bassi, E.; Blanco, J.C.; Boitani, L.; Caniglia, R.; Canu, A.; et al. Unravelling the Scientific Debate on How to Address Wolf-Dog Hybridization in Europe. *Front. Ecol. Evol.* **2019**, *7*, 175. [CrossRef]
72. Donfrancesco, V.; Allen, B.L.; Appleby, R.; Behrendorff, L.; Conroy, G.; Crowther, M.S.; Dickman, C.R.; Doherty, T.; Fancourt, B.A.; Gordon, C.E.; et al. Understanding Conflict among Experts Working on Controversial Species: A Case Study on the Australian Dingo. *Conserv. Sci. Pract.* **2023**, *5*, e12900. [CrossRef]
73. Johnson, B.B.; Sciascia, J. Views on Black Bear Management in New Jersey. *Hum. Dimens. Wildl.* **2013**, *18*, 249–262. [CrossRef]
74. Drijfhout, M.; Kendal, D.; Green, P.T. Understanding the Human Dimensions of Managing Overabundant Charismatic Wildlife in Australia. *Biol. Conserv.* **2020**, *244*, 108506. [CrossRef]
75. Engel, M.T.; Vaske, J.J.; Bath, A.J.; Marchini, S. Attitudes toward Jaguars and Pumas and the Acceptability of Killing Big Cats in the Brazilian Atlantic Forest: An Application of the Potential for Conflict Index2. *Ambio* **2017**, *46*, 604–612. [CrossRef]
76. Cabral de Mel, S.J.; Seneweera, S.; de Mel, R.K.; Dangolla, A.; Weerakoon, D.K.; Maraseni, T.; Allen, B.L. Welfare Impacts Associated with Using Aversive Geofencing Devices on Captive Asian Elephants. *Appl. Anim. Behav. Sci.* **2023**, *265*, 105991. [CrossRef]
77. Noga, S.R.; Kolawole, O.D.; Thakadu, O.; Masunga, G. Small Farmers' Adoption Behaviour: Uptake of Elephant Crop-Raiding Deterrent Innovations in the Okavango Delta, Botswana. *Afr. J. Sci. Technol. Innov. Dev.* **2015**, *7*, 408–419. [CrossRef]
78. Jeong, H.-J.; Lee, W.-C. The Level of Collapse We Are Allowed: Comparison of Different Response Scales in Safety Attitudes Questionnaire. *Biom. Biostat. Int. J.* **2016**, *4*, 128–134. [CrossRef]
79. DiStefano, C.; Shi, D.; Morgan, G.B. Collapsing Categories Is Often More Advantageous than Modeling Sparse Data: Investigations in the CFA Framework. *Struct. Equ. Model. A Multidiscip. J.* **2021**, *28*, 237–249. [CrossRef]
80. Gordon, M.; Lumley, T. Package 'Forestplot'. Advanced Forest Plot Using 'Grid' Graphics 2022. Available online: https://cran.r-project.org/web/packages/forestplot/forestplot.pdf (accessed on 27 February 2023).
81. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2022.
82. Vaske, J.J.; Beaman, J.; Barreto, H.; Shelby, L.B. An Extension and Further Validation of the Potential for Conflict Index. *Leis. Sci.* **2010**, *32*, 240–254. [CrossRef]
83. Hart, B.L.; Hart, L.A.; Pinter-Wollman, N. Large Brains and Cognition: Where Do Elephants Fit in? *Neurosci. Biobehav. Rev.* **2008**, *32*, 86–98. [CrossRef]
84. Bates, L.A.; Poole, J.H.; Byrne, R.W. Elephant Cognition. *Curr. Biol.* **2008**, *18*, 544–546. [CrossRef]
85. Gabriele an Elephant Never Forgets. Available online: https://blogs.transparent.com/english/an-elephant-never-forgets/ (accessed on 26 March 2023).
86. Gibbs, R.W., Jr.; Gerrig, R.J. How Context Makes Metaphor Comprehension Seem "Special". *Metaphor Symb. Act.* **1989**, *4*, 145–158. [CrossRef]
87. Tan, A.S.L.; de la Torre, J.A.; Wong, E.P.; Thuppil, V.; Campos-Arceiz, A. Factors Affecting Urban and Rural Tolerance towards Conflict-Prone Endangered Megafauna in Peninsular Malaysia. *Glob. Ecol. Conserv.* **2020**, *23*, e01179. [CrossRef]
88. Riddle, D.I. Evolving Notions of Nonhuman Personhood. *J. Ethics Emerg. Technol.* **2014**, *24*, 4–19. [CrossRef]
89. Lev, M.; Barkai, R. Elephants Are People, People Are Elephants: Human–Proboscideans Similarities as a Case for Cross Cultural Animal Humanization in Recent and Paleolithic Times. *Quat. Int.* **2016**, *406*, 239–245. [CrossRef]
90. Locke, P. Elephants as Persons, Affective Apprenticeship, and Fieldwork with Nonhuman Informants in Nepal. *HAU J. Ethnogr. Theory* **2017**, *7*, 353–376. [CrossRef]
91. Schalke, E.; Stichnoth, J.; Ott, S.; Jones-Baade, R. Clinical Signs Caused by the Use of Electric Training Collars on Dogs in Everyday Life Situations. *Appl. Anim. Behav. Sci.* **2007**, *105*, 369–380. [CrossRef]
92. Steiss, J.E.; Schaffer, C.; Ahmad, H.A.; Voith, V.L. Evaluation of Plasma Cortisol Levels and Behavior in Dogs Wearing Bark Control Collars. *Appl. Anim. Behav. Sci.* **2007**, *106*, 96–106. [CrossRef]

93. Kearton, T.; Marini, D.; Cowley, F.; Belson, S.; Lee, C. The Effect of Virtual Fencing Stimuli on Stress Responses and Behavior in Sheep. *Animals* **2019**, *9*, 30. [CrossRef]
94. Kearton, T.; Marini, D.; Cowley, F.; Belson, S.; Keshavarzi, H.; Mayes, B.; Lee, C. The Influence of Predictability and Controllability on Stress Responses to the Aversive Component of a Virtual Fence. *Front. Vet. Sci.* **2020**, *7*, 580523. [CrossRef] [PubMed]
95. Campbell, D.L.M.; Lea, J.M.; Farrer, W.J.; Haynes, S.J.; Lee, C. Tech-Savvy Beef Cattle? How Heifers Respond to Moving Virtual Fence Lines. *Animals* **2017**, *7*, 72. [CrossRef] [PubMed]
96. Lee, C.; Henshall, J.M.; Wark, T.J.; Crossman, C.C.; Reed, M.T.; Brewer, H.G.; Grady, J.O.; Fisher, A.D. Associative Learning by Cattle to Enable Effective and Ethical Virtual Fences. *Appl. Anim. Behav. Sci.* **2009**, *119*, 15–22. [CrossRef]
97. Lee, C.; Colditz, I.G.; Campbell, D.L.M. A Framework to Assess the Impact of New Animal Management Technologies on Welfare: A Case Study of Virtual Fencing. *Front. Vet. Sci.* **2018**, *5*, 187. [CrossRef]
98. Lee, C.; Campbell, D.L.M. A Multi-Disciplinary Approach to Assess the Welfare Impacts of a New Virtual Fencing Technology. *Front. Vet. Sci.* **2021**, *8*, 637709. [CrossRef]
99. Nath, N.K.; Lahkar, B.P.; Brahma, N.; Dey, S.; Das, J.P.; Sarma, P.K.; Talukdar, B.K. An Assessment of Human-Elephant Conflict in Manas National Park, Assam, India. *J. Threat. Taxa* **2009**, *1*, 309–316. [CrossRef]
100. Ramkumar, K.; Ramakrishnan, B.; Saravanamuthu, R. Crop Damage by Asian Elephants *Elephas maximus* and Effectiveness of Mitigating Measures in Coimbatore Forest Division, South India. *Int. Res. J. Biol. Sci.* **2014**, *3*, 1–11.
101. Neupane, D.; Johnson, R.L.; Risch, T.S. How Do Land-use Practices Affect Human—Elephant Conflict in Nepal? *Wildl. Biol.* **2017**, *2017*, wlb.00313. [CrossRef]
102. Haturusinghe, H.S.; Weerakoon, D.K. Crop Raiding Behaviour of Elephants in the Northwestern Region of Sri Lanka. *Gajah* **2012**, *36*, 26–31.
103. Campos-Arceiz, A.; Takatsuki, S.; Ekanayaka, S.K.K.; Hasegawa, T. The Human-Elephant Conflict in Southeastern Sri Lanka: Type of Damage, Seasonal Patterns, and Sexual Differences in the Raiding Behavior of Elephants. *Gajah* **2009**, *31*, 5–14.
104. Sukumar, R. A Brief Review of the Status, Distribution and Biology of Wild Asian Elephants *Elephas maximus*. *Int. Zoo Yearb.* **2006**, *40*, 1–8. [CrossRef]
105. Sukumar, R. The Management of Large Mammals in Relation to Male Stratefies and Conflict with People. *Biol. Conserv.* **1991**, *55*, 93–102. [CrossRef]
106. Mumby, H.S.; Plotnik, J.M. Taking the Elephants' Perspective: Remembering Elephant Behavior, Cognition and Ecology in Human-Elephant Conflict Mitigation. *Front. Ecol. Evol.* **2018**, *6*, 122. [CrossRef]
107. Goswami, V.R.; Vasudev, D. Triage of Conservation Needs: The Juxtaposition of Conflict Mitigation and Connectivity Considerations in Heterogeneous, Human-Dominated Landscapes. *Front. Ecol. Evol.* **2017**, *4*, 144. [CrossRef]

6.2. Links and implications

Public sentiment towards the potential use of AGDs as an HEC mitigation tool was very encouraging given most respondents perceive that it would be effective in mitigating HEC. This study also revealed that the acceptability of AGDs will further improve with scientific evidence on its reliability in managing captive elephant movement with minimum welfare impacts. This encourages the further investigations of AGDs with captive elephants to optimise the technology before being introduced to wild elephants. This study also emphasises that conflicting opinions should be given consideration to build consensus among stakeholders for successful implementation of AGDs as an HEC mitigation tool in the future.

CHAPTER 7: DISCUSSION AND CONCLUSION

7.1. Key findings

Human-elephant conflict (HEC) is a major challenge for conserving Asian elephants. The review in Chapter 2 identified many drawbacks in the current HEC mitigation approaches, highlighted their lack of flexibility to accommodate elephant needs and loss of effectiveness in the long term, and recognised the potential of AGDs as a novel HEC mitigation tool. Our review identified 12 ideal characteristics in an HEC mitigation tool:

1. Prevents HEC incidents before they occur,
2. Keeps elephants in or out of designated areas,
3. Targets specific individuals or small family groups,
4. Does not require the death of the animal,
5. Produces minimal harm to elephants,
6. Does not harm or impede non-target species,
7. Does not require the construction of permanent or immovable structures,
8. Can be altered, moved, or removed as needed,
9. Is long-lasting or sustainable,
10. Is automated, or does not require substantial human input,
11. Is inexpensive or cost-effective, and
12. Is culturally and socially acceptable.

If AGDs can successfully condition wild elephants to avoid human-dominated habitats, they will address many of the above characteristics. This review also identified three primary research areas to determine the potential of developing AGDs as an HEC mitigation tool. They are (1) evaluating the efficacy of AGDs on captive elephants under controlled conditions, (2) assessing behavioural and physiological impact of AGDs on elephants, and (3) assessing public perceptions to identify conflicting opinions that would need attention during the development and implementation of AGDs, which I attempted to address in this thesis.

The assessment of perceptions on causes of and solutions to HEC in Chapter 3 provided an understanding of areas that need more consensus between different stakeholder groups to improve elephant management. These areas should also be given consideration when planning and implementing HEC mitigation programmes to introduce AGDs in the future. Our study revealed that all stakeholder groups agreed on many causes of HEC and the importance and conservation of elephants. But farmers who had experienced HEC disagreed with experts that people should try to co-exist with elephants and feel that elephants should be removed from human habitats. In addition, attitudes towards HEC mitigation tools showed that all stakeholder groups agreed on the acceptability and effectiveness of few tools. Although, this is encouraging for HEC mitigation, these tools also have their inherent drawbacks which only emphasized the need to investigate additional approaches such as AGDs as potential HEC mitigation tools.

Experiments in Chapter 4 provided evidence that AGDs can be effective in managing captive elephant movement, highlighting their potential as an HEC mitigation tool. This study revealed that elephants displayed desirable behaviours to an electric shock of 4 kV from a modified dog-training collar delivered at the upper position tested on the neck and at higher stimuli strengths. This study also showed that the stimuli (audio warnings or electric shocks) from the AGD was successful in keeping elephants from reaching the food reward at the end of a path 77.8% of the time. But most remarkably, our experiment showed that the audio warning delivered prior to the shock was successful in conditioning elephants to avoid the electric stimulation 47.2% of the time. These findings suggested that AGDs are a promising method to manage elephant movement and that further development as an HEC mitigation tool can be encouraged.

The assessment of behavioural and physiological stress responses of elephants to AGDs in Chapter 5 revealed that there were no long-lasting welfare impacts on the elephants involved in the experiments in Chapter 4. The daily activity budgets of individual elephants were not influenced by the experiments and the expected increase of stress behaviours and FCM concentrations returned to baseline levels shortly after the experiments. Thus, this study showed that AGDs can be safely used to control elephant movement without lasting impacts on elephant welfare.

The analysis of stakeholder attitudes towards AGDs in Chapter 6 revealed that people had a generally positive opinion on AGDs. All stakeholder groups perceived that elephants are likely to learn to avoid virtual fences by associating the audio warning with the electric shock and would be effective in minimising HEC incidents. Further our results show that acceptability would improve with evidence on the effectiveness and assurance of elephants' wellbeing when using AGDs. This social survey also identified areas of concern that should be given consideration during the development and implementation of AGDs. This study emphasised the need for proper communication with relevant stakeholders to build consensus on conflicting opinions towards AGDs to gain their support to effectively implement it as an HEC mitigation tool in the future.

7.2. Contributions to the field of study

This thesis focussed on exploring a new method to effectively mitigate HEC. It achieved its overall aim by taking a multidisciplinary approach to collating a basic understanding of the potential utility of and providing evidence to support further research and development of AGDs as an HEC mitigation tool. Identification of the agreements and disagreements between stakeholders on the causes and solutions of HEC in this study would be useful when planning and implementing HEC mitigation programmes. This knowledge will guide decision makers to take greater care and draw their attention to potentially conflicting opinions when communicating HEC mitigation approaches with relevant stakeholders. The preliminary experiments with captive elephants conducted during this study demonstrated that AGDs have the potential to condition captive elephants to modify their movement behaviour and documented the (mild and acceptable) behavioural and physiological stress responses by elephants to electric shocks delivered from a collar. Additionally, this study also showed the importance of assessing views of stakeholders towards a novel wildlife management tool such as AGDs, so that areas that needs attention during research and development can be identified and prioritised. More broadly, this study contributed to research on Asian elephants by enhancing knowledge on elephant behaviour and physiology, conducting experimental research with captive elephants and people’s attitudes towards HEC mitigation. Wildlife managers and conservation biologists can adopt the multidisciplinary approach taken in this study to likewise assess novel wildlife management approaches for other species to improve their management and conservation programmes.

7.3. Limitation and recommendations for future research

Several shortcomings could be identified in the empirical studies presented in this thesis, which should be considered to improve future research.

In the sociological survey (Chapters 3 and 6) conducted in this study, although the expert groups had a good representation of participants from around the world, respondents of all the other stakeholder groups were mainly from Sri Lanka. Therefore, the expressed opinions of respondents in our work may not be representative of public opinion in all the other range countries. Future studies may benefit from collaborative research with other range countries to compare and understand the perceptions of different stakeholders. Also, our survey responses are based on HEC placed in a general context to get a broader understanding of perceptions of various aspects of HEC and the potential use of AGDs. However, perception of stakeholders on these may vary depending on different HEC scenarios (Tan et al., 2020). The opinions could be further evaluated by asking respondents how much they would agree or disagree under different HEC scenarios, especially where disagreements were identified (Engel et al., 2017; Heneghan and Morse, 2019); for example, how much respondents would agree with co-existence, translocation of a problem elephant, restricting elephants to protected areas, or elephant holding grounds when there is low frequency of crop raiding, high frequency of crop raiding or frequent lethal encounters with elephants. Such assessment may provide a better understanding of people's perception to develop and implement HEC mitigation approaches specific for each HEC situation. Individuals within each stakeholder group may not be homogenous either. Further classification of respondents by asking them to identify whether they are strong animal rights activists, conservationist, etc. (van Eeden et al., 2019) may help to better understand people's perception of AGDs and other HEC mitigation tools.

Ranking HEC mitigation tools based on their potential welfare impacts to elephants may also be helpful. For example, Sharp and Saunders, (2011) have proposed a model for ranking the humaneness of different animal management tools, which have been applied by others to novel situations (Allen et al., 2019), and might be applied to HEC mitigation tools as well. This may help stakeholders explore and determine the acceptability of different HEC mitigation tools, including AGDs.

As highlighted in Chapters 4 and 5, our field experiments with AGDs using captive elephants were limited by sample sizes and various logistical issues. The sample size was limited by the number of captive elephants available to be tested within the given facility, funds, and the time frame. The logistical difficulty of safely handling large numbers of elephants also limited our sample sizes. However, future studies might benefit from a larger sample of elephants if these issues could be overcome. An alternative approach to the design of Experiments 1 and 2 of Chapter 4 would be to give one shock level to each individual animal and obtain the mean response of different groups to identify the optimum shock level, and not reuse the same animals again in Experiment 2. Use of naïve animals in these types of experiments are recommended because previous exposure to electrical stimuli may influence the behavioural responses, learning and stress response of animals (Campbell et al., 2018; Kearton et al., 2019; Lee et al., 2009; Verdon et al., 2020). But this was not possible in our study given the limited number of elephants available to us and welfare and safety concerns over shocking large numbers of potentially dangerous animals. We were also unexpectedly limited to experimenting with female elephants due to a variety of logistical issues. As male elephants are mostly responsible for crop raiding incidents (Campos-Arceiz et al., 2009; Sukumar and Gadgil, 1988), we recommend that future AGD studies be conducted with male elephants to understand their behavioural responses to electric shocks. When studying male elephants, attention should also be given to how their behaviour could vary during musth and non-musth periods.

As identified in Chapter 4, various external factors may have also affected elephants' behavioural responses, so future research should try to avoid such issues. Additionally, to confirm if elephants learnt to associate the audio warning with the aversive stimulus and did not relate the path with the electric shock, repeating the experiment with the same elephant on different paths is recommended. The methodology of AGD experiments may also be modified by pairing the electric shock with the audio warning to improve predictability and controllability of receiving the electric shock and further reduce stress on the animal (Kearton et al., 2020; Lee et al., 2018). Our study used a manually operated modified dog-training collar and provided a basic understanding of how elephants would respond to AGDs. But future research should be conducted with fully automated AGDs developed specifically for elephants and should be tested on free-ranging captive elephants in a larger space by attempting to restrict their movement to a particular area of an enclosure. Long-term studies may also be conducted to determine if elephants would refrain from crossing previously established virtual fences even after deactivation of collars (Campbell et al., 2019a). Studying behavioural and physiological stress responses during such long-term studies may be difficult but would provide more evidence to confirm welfare impacts on elephants and increase social acceptability for AGDs. Further, as done for cattle (Campbell et al., 2019b), comparing the welfare impact of virtual fencing using AGDs to traditional physical electric fences will be valuable. It is also recommended to investigate if elephants can learn to recognise virtual fences through social facilitation when collars are put only on a few individual elephants in a group (Marini et al., 2020). This will help learn the possibility of using AGDs on the matriarch of a wild elephant herd to manage the movement of the entire herd.

7.4. Conclusion

The development of AGDs for elephants is still in its early stages, but our preliminary work provided evidence of its potential as an HEC mitigation tool. Through further research on the technology, efficacy and animal welfare, AGDs may be optimised for use on wild elephants. If AGDs can be developed into the field-testing stage with wild elephants, they might one day become a sustainable solution for HEC in areas where human-elephant co-existence is the only option. AGDs may not be the sole solution or a replacement for all other HEC mitigation approaches. But AGDs might be used on identified problem causing elephants in places where no other approach has been effective in reducing HEC incidents. It is also important to implement other effective and acceptable HEC mitigation approaches in conjunction with AGDs to offset any risk that AGDs fail to deter elephants. This is especially important during the initial stages of implementation when elephants are learning to recognise virtual fences. Excluding elephants from human-dominated landscapes using AGDs however, could result in limiting access to important resources (e.g. food, water and mates) they previously depended on, and there may be concern that elephants could suffer from inadequate nutrition and poor welfare. Therefore, enrichment of elephant habitats and maintaining habitat connectivity is important to ensure that elephants have access to sufficient resources and reduce their attraction to human-dominated landscapes. Further, proper land use planning and awareness among stakeholders will also help effective implementation of AGDs. The adaptive nature of AGDs with the ability to modify virtual fences to suite human and elephant needs through continuous monitoring and evaluation could revolutionise HEC mitigation. The use of AGDs may also be a more ethical choice than lethal control, translocation or domestication of problem elephants. I hope that the findings of this study will aid in the development of this technology and, in the long run, assist to safeguard both humans and elephants in the future

REFERENCES

Acharya, K.P., Paudel, P.K., Neupane, P.R., Köhl, M., 2016. Human-wildlife conflicts in Nepal: Patterns of human fatalities and injuries caused by large mammals. *PLoS ONE* 11, e0161717. https://doi.org/10.1371/journal.pone.0161717

Alfred, R., Ahmad, A.H., Payne, J., Williams, C., Ambu, L.N., How, P.M., Goossens, B., 2012. Home range and ranging behaviour of Bornean elephant (*Elephas maximus borneensis*) females. *PLoS ONE* 7, e31400. https://doi.org/10.1371/journal.pone.0031400

Allen, B.L., Allen, L.R., Ballard, G., Drouilly, M., Fleming, P.J.S., Hampton, J.O., Hayward, M.W., Kerley, G.I.H., Meek, P.D., Minnie, L., O'Riain, M.J., Parker, D.M., Somers, M.J., 2019. Animal welfare considerations for using large carnivores and guardian dogs as vertebrate biocontrol tools against other animals. *Biological Conservation* 232, 258–270. https://doi.org/10.1016/j.biocon.2019.02.019

Asian Elephant Specialist Group, 2017. Asian elephant range states meeting, final report. IUCN-SSC Asian Elephant Specialist Group, Jakarta, Indonesia.

Bandara, R., Tisdell, C., 2004. The net benefit of saving the Asian elephant: A policy and contingent valuation study. *Ecological Economics* 48, 93–107. https://doi.org/10.1016/j.ecolecon.2003.01.001

Banks, S.C., Piggott, M.P., Stow, A.J., Taylor, A.C., 2007. Sex and sociality in a disconnected world: a review of the impacts of habitat fragmentation on animal social interactions. *Canadian Journal of Zoology* 85, 1065–1079. https://doi.org/10.1139/Z07-094

Barrett, L.P., Benson-Amram, S., 2021. Multiple assessments of personality and problem-solving performance in captive Asian elephants (*Elephas maximus*) and African savanna elephants (*Loxodonta africana*). *Journal of Comparative Psychology* 135, 406–419. https://doi.org/10.1037/com0000281

Barrett, L.P., Stanton, L.A., Benson-Amram, S., 2019. The cognition of 'nuisance' species. *Animal Behaviour* 147, 167–177. https://doi.org/10.1016/j.anbehav.2018.05.005

Baskaran, N., Balasubramaniam, M., Swaminathan, S., Desai, A.A., 1993. Home range of elephants in the Nilgiri Biosphere Reserve, South India, in: Daniel, J.C., Datye, H.S. (Eds.), *A Week with Elephants: Proceedings of the International Seminar on the Conservation of Asian Elephant*. Bombay Natural History Society and Oxford University Press, Bombay, India, pp. 296–313.

Baskaran, N., Varma, S., Sar, C.K., Sukumar, R., 2011. Current status of Asian elephants in India. *Gajah* 35, 47–54.

Bates, L.A., Poole, J.H., Byrne, R.W., 2008. Elephant cognition. *Current Biology* 18, 544–546. https://doi.org/10.1016/j.cub.2008.04.019

Blackwell, E.J., Bolster, C., Richards, G., Loftus, B.A., Casey, R.A., 2012. The use of electronic collars for training domestic dogs: estimated prevalence, reasons and risk factors for use, and owner perceived success as compared to other training methods. *BMC Veterinary Research* 8, 93. https://doi.org/10.1186/1746-6148-8-93

Boyd, C.S., O'Connor, R., Ranches, J., Bohnert, D.W., Bates, J.D., Johnson, D.D., Davies, K.W., Parker, T., Doherty, K.E., 2022. Virtual fencing effectively excludes cattle from burned sagebrush steppe. *Rangeland Ecology & Management* 81, 55–62. https://doi.org/10.1016/j.rama.2022.01.001

Byrne, R.W., Bates, L., Moss, C.J., 2009. Comparative cognition&behavior reviews. *Elephant cognition* 4, 65–79.

Cabral de Mel, S.J., Seneweera, S., de Mel, R.K., Dangolla, A., Weerakoon, D.K., Maraseni, T., Allen, B.L., 2022. Current and future approaches to mitigate conflict between humans and Asian elephants: The potential use of aversive geofencing devices. *Animals* 12, 2965. https://doi.org/10.3390/ani12212965

Campbell, D.L.M., Haynes, S., Lea, J., Farrer, W., Lee, C., 2019a. Temporary Exclusion of Cattle from a Riparian Zone Using Virtual Fencing Technology. *Animals* 9, 5. https://doi.org/10.3390/ani9010005

Campbell, D.L.M., Lea, J.M., Farrer, W.J., Haynes, S.J., Lee, C., 2017. Tech-Savvy Beef Cattle? How Heifers Respond to Moving Virtual Fence Lines. *Animals* 7, 72. https://doi.org/10.3390/ani7090072

Campbell, D.L.M., Lea, J.M., Haynes, S.J., Farrer, W.J., Leigh-Lancaster, C.J., Lee, C., 2018. Virtual fencing of cattle using an automated collar in a feed attractant trial. *Applied Animal Behaviour Science* 200, 71–77. https://doi.org/10.1016/j.applanim.2017.12.002

Campbell, D.L.M., Lea, J.M., Keshavarzi, H., Lee, C., 2019b. Virtual fencing is comparable to electric tape fencing for cattle behavior and welfare. *Frontiers in Veterinary Science* 6, 445. https://doi.org/10.3389/fvets.2019.00445

Campos-Arceiz, A., Takatsuki, S., Ekanayaka, S.K.K., Hasegawa, T., 2009. The human-elephant conflict in Southeastern Sri Lanka: Type of damage, seasonal patterns, and sexual differences in the raiding behavior of elephants. *Gajah* 31, 5–14.

Caughley, G., 1995. Comments on elephants in Burma. *Gajah* 14, 1–9.

Chen, S., Yi, Z.F., Campos-Arceiz, A., Chen, M.Y., Webb, E.L., 2013. Developing a spatially-explicit, sustainable and risk-based insurance scheme to mitigate human-wildlife conflict. *Biological Conservation* 168, 31–39. https://doi.org/10.1016/j.biocon.2013.09.017

Csuti, B., 2006. Elephants in Captivity, in: Mikota, S., Fowler, M. (Eds.), *Biology, Medicine, and Surgery of Elephants*. Blackwell Publishing, Oxford, UK, pp. 15–22.

Dale, R., Plotnik, J.M., 2017. Elephants know when their bodies are obstacles to success in a novel transfer task. *Scientific Reports* 7, 1–11. https://doi.org/10.1038/srep46309

de Silva, S., Wu, T., Nyhus, P., Weaver, A., Thieme, A., Johnson, J., Wadey, J., Mossbrucker, A., Vu, T., Neang, T., Chen, B.S., Songer, M., Leimgruber, P., 2023. Land-use change is associated with multi-century loss of elephant ecosystems in Asia. *Scientific Reports* 13, 5996. https://doi.org/10.1038/s41598-023-30650-8

Denninger Snyder, K., Rentsch, D., 2020. Rethinking assessment of success of mitigation strategies for elephant-induced crop damage. *Conservation Biology* 34, 829–842. https://doi.org/10.1111/cobi.13433

Elephant Family, 2018. Skinned- The growing appetite for Asian elephants. London, UK.

Engel, M.T., Vaske, J.J., Bath, A.J., Marchini, S., 2017. Attitudes toward jaguars and pumas and the acceptability of killing big cats in the Brazilian Atlantic Forest: An application of the Potential for Conflict Index2. *Ambio* 46, 604–612. https://doi.org/10.1007/s13280-017-0898-6

Evans, G.H., 1910. Elephants and their diseases, A treatise on elephants. Government Printing, Rangoon.

Fernando, P., 2015. Managing elephants in Sri Lanka: where we are and where we need to be. *Ceylon Journal of Science (Biological Sciences)* 44, 1–11. https://doi.org/10.4038/cjsbs.v44i1.7336

Fernando, P., 2011. Managing ‘problem elephants’. *Loris* 25, 32–36.

Fernando, P., 2000. Elephants in Sri Lanka : past present and future. *Loris* 22, 38–44.

Fernando, P., De Silva, M.K.C.R., Jayasinghe, L.K.A., Janaka, H.K., Pastorini, J., 2021. First country-wide survey of the Endangered Asian elephant: towards better conservation and management in Sri Lanka. *Oryx* 55, 46–55. https://doi.org/10.1017/S0030605318001254

Fernando, P., Kumar, M.A., Williams, A.C., Wikramanayake, E., Aziz, T., Singh, S.M., 2008a. Review of human-elephant conflict mitigation measures practiced in South Asia. World Wide Fund for Nature.

Fernando, P., Pastorini, J., 2011. Range-wide status of Asian elephants. *Gajah* 35, 15–20.

Fernando, P., Prasad, T., Janaka, H.K., Ekanayaka, S.K., Nishantha, H.G., Pastorini, J., 2015. The use of radio-tracking data to guide development and manage elephants. *Wildlanka* 3, 12–19.

Fernando, P., Vidya, T.N.C., Payne, J., Stuewe, M., Davison, G., Alfred, R.J., Andau, P., Bosi, E., Kilbourn, A., Melnick, D.J., 2003. DNA analysis indicates that Asian elephants are native to Borneo and are therefore a high priority for conservation. *PLoS Biology* 1, 110–115. https://doi.org/10.1371/journal.pbio.0000006

Fernando, P., Wikramanayake, E.D., Janaka, H.K., Jayasinghe, L.K.A., Gunawardena, M., Kotagama, S.W., Weerakoon, D., Pastorini, J., 2008b. Ranging behavior of the Asian elephant in Sri Lanka. *Mammalian Biology* 73, 2–13. https://doi.org/10.1016/j.mambio.2007.07.007

Ganesh, S., 2019. Human elephant conflict kills 1,713 people, 373 pachyderms in 3 years. https://www.thehindu.com/news/national/human-elephant-conflict-kills-1713-people-373-pachyderms-in-3-years/article26225515.ece (accessed 11 May 2020).

Gogoi, M., 2018. Emotional coping among communities affected by wildlife-caused damage in north-east India: Opportunities for building tolerance and improving conservation outcomes. *Oryx* 52, 214–219. https://doi.org/10.1017/S0030605317001193

Goliński, P., Sobolewska, P., Stefańska, B., Golińska, B., 2023. Virtual fencing technology for cattle management in the pasture feeding system—A review. *Agriculture* 13, 91. https://doi.org/10.3390/agriculture13010091

Gopala, A., Hadian, O., Sunarto, Sitompul, A., Williams, A., Leimgruber, P., Chambliss, S.E., Gunaryadi, D., 2011. *Elephas maximus* ssp. *sumatranus*. *The IUCN Red List of Threatened Species 2011*. http://dx.doi.org/10.2305/IUCN.UK.2011-%0A2.RLTS.T199856A9129626.en (accessed 17 June 2023).

Goswami, V.R., Vasudev, D., 2017. Triage of conservation needs: The juxtaposition of conflict mitigation and connectivity considerations in heterogeneous, human-dominated landscapes. *Frontiers in Ecology and Evolution* 4, 144. https://doi.org/10.3389/fevo.2016.00144

Hankinson, E., Nijman, V., Abdullah, 2020. Asian elephants: 15 years of research and conservation. *Journal of Physics: Conference Series* 1460, 012055.

https://doi.org/10.1088/1742-6596/1460/1/012055

Hart, B.L., Hart, L.A., Pinter-Wollman, N., 2008. Large brains and cognition: Where do elephants fit in? *Neuroscience and Biobehavioral Reviews* 32, 86–98. https://doi.org/10.1016/j.neubiorev.2007.05.012

Heneghan, M.D., Morse, W.C., 2019. Acceptability of management actions and the potential for conflict following human-black bear encounters. *Society & Natural Resources* 32, 434–451. https://doi.org/10.1080/08941920.2018.1556756

Irie-Sugimoto, N., Kobayashi, T., Sato, T., Hasegawa, T., 2008. Evidence of means–end behavior in Asian elephants (*Elephas maximus*). *Animal Cognition* 11, 359–365. https://doi.org/10.1007/s10071-007-0126-z

Jacobson, S.L., Dechanupong, J., Horpiencharoen, W., Yindee, M., Plotnik, J.M., 2023. Innovating to solve a novel puzzle: wild Asian elephants vary in their ability to problem solve. *Animal Behaviour*. https://doi.org/10.1016/j.anbehav.2023.08.019

Jacobson, S.L., Puitiza, A., Snyder, R.J., Sheppard, A., Plotnik, J.M., 2022. Persistence is key: investigating innovative problem solving by Asian elephants using a novel multi-access box. *Animal Cognition* 25, 657–669. https://doi.org/10.1007/s10071-021-01576-3

Jayantha, D., 2011. Smuggling young elephants – a story of wildlife trade from Sri Lanka. *Solitaire* 22, 15–16.

Johnson, B.B., Sciascia, J., 2013. Views on black bear management in New Jersey. *Human Dimensions of Wildlife* 18, 249–262. https://doi.org/10.1080/10871209.2013.792021

Kearton, T., Marini, D., Cowley, F., Belson, S., Keshavarzi, H., Mayes, B., Lee, C., 2020. The influence of predictability and controllability on stress responses to the aversive component of a virtual fence. *Frontiers in Veterinary Science* 7, 580523. https://doi.org/10.3389/fvets.2020.580523

Kearton, T., Marini, D., Cowley, F., Belson, S., Lee, C., 2019. The effect of virtual fencing stimuli on stress responses and behavior in sheep. *Animals* 9, 30. https://doi.org/10.3390/ani9010030

Kendal, D., Ford, R.M., 2018. The role of social license in conservation. *Conservation Biology* 32, 493–495. https://doi.org/10.1111/cobi.12994

Khounboline, K., 2007. Human-elephant conflict (HEC) pilot study in southern Lao PDR. *Gajah* 26, 18–20.

König, H.J., Kiffner, C., Kramer-Schadt, S., Fürst, C., Keuling, O., Ford, A.T., 2020. Human–wildlife coexistence in a changing world. *Conservation Biology* 34, 786–794.

https://doi.org/10.1111/cobi.13513
Köpke, S., Withanachchi, S.S., Pathiranage, R., Withanachchi, C.R., Gamage, D.U., Nissanka, T.S., Warapitiya, C.C., Nissanka, B.M., Ranasinghe, N.N., Senarathna, C.D., Schleyer, C., Thiel, A., 2021. Human–elephant conflict in Sri Lanka: A critical review of causal explanations. *Sustainability* 13, 8625. https://doi.org/10.3390/su13158625
Kurt, F., Hartl, G.B., Tiedemann, R., 1995. Tuskless bulls in Asian elephant *Elephas maximus*. History and population genetics of a man-made phenomenon. *Acta Theriologica* 40, 125–143. https://doi.org/10.4098/at.arch.95-51
LaDue, C.A., Eranda, I., Jayasinghe, C., Vandercone, R.P.G., 2021. Mortality patterns of Asian elephants in a region of human–elephant conflict. *The Journal of Wildlife Management* 85, 794–802. https://doi.org/10.1002/jwmg.22012
Lainé, N., 2018. Asian elephant conservation: Too elephantocentric? Towards a biocultural approach of conservation. *Asian Bioethics Review* 10, 279–293. https://doi.org/10.1007/s41649-018-0070-z
Lee, C., Campbell, D.L.M., 2021. A multi-disciplinary approach to assess the welfare impacts of a new virtual fencing technology. *Frontiers in Veterinary Science* 8, 637709. https://doi.org/10.3389/fvets.2021.637709
Lee, C., Colditz, I.G., Campbell, D.L.M., 2018. A framework to assess the impact of new animal management technologies on welfare: A case study of virtual fencing. *Frontiers in Veterinary Science* 5, 187. https://doi.org/10.3389/fvets.2018.00187
Lee, C., Henshall, J.M., Wark, T.J., Crossman, C.C., Reed, M.T., Brewer, H.G., Grady, J.O., Fisher, A.D., 2009. Associative learning by cattle to enable effective and ethical virtual fences. *Applied Animal Behaviour Science* 119, 15–22. https://doi.org/10.1016/j.applanim.2009.03.010
Leimgruber, P., Gagnon, J.B., Wemmer, C., Kelly, D.S., Songer, M.A., Selig, E.R., 2003. Fragmentation of Asia's remaining wildlands: Implications for Asian elephant conservation. *Animal Conservation* 6, 347–359. https://doi.org/10.1017/S1367943003003421
Leimgruber, P., Senior, B., Uga, Aung, M., Songer, M.A., Mueller, T., Wemmer, C., Ballou, J.D., 2008. Modeling population viability of captive elephants in Myanmar (Burma): Implications for wild populations. *Animal Conservation* 11, 198–205. https://doi.org/10.1111/j.1469-1795.2008.00172.x
Liu, P., Wen, H., Harich, F.K., He, C., Wang, L., Guo, X., Zhao, J., Luo, A., Yang, H., Sun,

X., Yu, Y., Zheng, S., Guo, J., Li, L., Zhang, L., 2017. Conflict between conservation and development: cash forest encroachment in Asian elephant distributions. *Scientific Reports* 7, 6404. https://doi.org/10.1038/s41598-017-06751-6

Locke, P., 2013. Explorations in ethnoelephantology: Social, historical, and ecological intersections between Asian elephants and humans. *Environment and Society* 4, 79–97. https://doi.org/10.3167/ares.2013.040106

Luo, L., Wang, X., Guo, H., Zhu, L., Ma, Y., Yang, R., Wang, S., Wang, G., Wang, M., Shao, J., Liu, C., 2022. Eighteen years (2001–2018) of forest habitat loss across the Asian elephant's range and its drivers. *Science Bulletin* 67, 1513–1516. https://doi.org/10.1016/j.scib.2022.04.013

Madden, F., 2004. Creating coexistence between humans and wildlife: Global perspectives on local efforts to address human–wildlife conflict. *Human Dimensions of Wildlife* 9, 247–257. https://doi.org/10.1080/10871200490505675

Madhusudan, M.D., Sharma, N., Raghunath, R., Baskaran, N., Bipin, C.M., Gubbi, S., Johnsingh, A.J.T., Kulkarni, J., Kumara, H.N., Mehta, P., Pillay, R., Sukumar, R., 2015. Distribution, relative abundance, and conservation status of Asian elephants in Karnataka, southern India. *Biological Conservation* 187, 34–40. https://doi.org/10.1016/j.biocon.2015.04.003

Marchini, S., Ferraz, K.M.P.M.B., Zimmermann, A., Guimarães-Luiz, T., Morato, R., Correa, P.L.P., Macdonald, D.W., 2019. Planning for coexistence in a complex human-dominated world, in: Frank, B., Glikman, J.A., Marchini, S. (Eds.), *Human–Wildlife Interactions: Turning Conflict into Coexistence*. Cambridge University Press, Cambridge, UK, pp. 414–438. https://doi.org/10.1017/9781108235730.022

Marini, D., Kearton, T., Ouzman, J., Llewellyn, R., Belson, S., Lee, C., 2020. Social influence on the effectiveness of virtual fencing in sheep. *PeerJ* 8, e10066. https://doi.org/10.7717/peerj.10066

Marini, D., Meuleman, M., Belson, S., Rodenburg, T., Llewellyn, R., Lee, C., 2018. Developing an ethically acceptable virtual fencing system for sheep. *Animals* 8, 33. https://doi.org/10.3390/ani8030033

Marino, A., Braschi, C., Ricci, S., Salvatori, V., Ciucci, P., 2016. Ex post and insurance-based compensation fail to increase tolerance for wolves in semi-agricultural landscapes of central Italy. *European Journal of Wildlife Research* 62, 227–240. https://doi.org/10.1007/s10344-016-1001-5

Masson, S., de la Vega, S., Gazzano, A., Mariti, C., Pereira, G.D.G., Halsberghe, C., Muser Leyvraz, A., McPeake, K., Schoening, B., 2018a. Electronic training devices: Discussion on the pros and cons of their use in dogs as a basis for the position statement of the European Society of Veterinary Clinical Ethology. *Journal of Veterinary Behavior* 25, 71–75. https://doi.org/10.1016/j.jveb.2018.02.006

Masson, S., Nigron, I., Gaultier, E., 2018b. Questionnaire survey on the use of different e-collar types in France in everyday life with a view to providing recommendations for possible future regulations. *Journal of Veterinary Behavior* 26, 48–60. https://doi.org/10.1016/j.jveb.2018.05.004

McGaughey, C.A., 1960. The elephant in ancient and modern writings. *British Veterinary Journal* 116, 255–260. https://doi.org/10.1016/S0007-1935(17)44154-6

Menon, V., Tiwari, S.K.R., 2019. Population status of Asian elephants *Elephas maximus* and key threats. *International Zoo Yearbook* 53, 17–30. https://doi.org/10.1111/izy.12247

Milman, O., 2013. Ranger corruption 'impeding global fight against poaching.' *The Guardian*. http://www.theguardian.com/environment/2013/mar/27/ranger-corruption-impeding-fight-poaching

Montgomery, R.A., Raupp, J., Mukhwana, M., Greenleaf, A., Mudumba, T., Muruthi, P., 2022. The efficacy of interventions to protect crops from raiding elephants. *Ambio* 51, 716–727. https://doi.org/10.1007/s13280-021-01587-x

Mumby, H.S., Plotnik, J.M., 2018. Taking the elephants' perspective: Remembering elephant behavior, cognition and ecology in human-elephant conflict mitigation. *Frontiers in Ecology and Evolution* 6, 122. https://doi.org/10.3389/fevo.2018.00122

Nair, R.P., Jayson, E.A., 2021. Estimation of economic loss and identifying the factors affecting the crop raiding behaviour of Asian elephant (*Elephas maximus*) in Nilambur part of the southern Western Ghats, Kerala, India. *Current Science* 121, 521. https://doi.org/10.18520/cs/v121/i4/521-528

Nelson, A., Bidwell, P., Sillero-Zubiri, C., 2003. A review of human-elephant conflict management strategies, People and Wildlife Initiative. Wildlife Conservation Research Unit, Oxford University, Oxford, UK.

Nijman, V., 2014. An assessment of the live elephant trade in Thailand. TRAFFIC International, Cambridge, UK.

Nijman, V., Shepherd, C.R., 2014. Emergence of Mong La on the Myanmar–China border as a global hub for the international trade in ivory and elephant parts. *Biological*

Conservation 179, 17–22. https://doi.org/10.1016/j.biocon.2014.08.010

Noga, S.R., Kolawole, O.D., Thakadu, O., Masunga, G., 2015. Small farmers' adoption behaviour: Uptake of elephant crop-raiding deterrent innovations in the Okavango Delta, Botswana. *African Journal of Science, Technology, Innovation and Development* 7, 408–419. https://doi.org/10.1080/20421338.2015.1096511

Olivier, R., 1978. Distribution and status of the Asian elephant. *Oryx* 14, 379–424. https://doi.org/10.1017/S003060530001601X

Othman, N., Goossens, B., Cheah, C.P.I., Nathan, S., Bumpus, R., Ancrenaz, M., 2019. Shift of paradigm needed towards improving human–elephant coexistence in monoculture landscapes in Sabah. *International Zoo Yearbook* 53, 161–173. https://doi.org/10.1111/izy.12226

Padalia, H., Ghosh, S., Reddy, C.S., Nandy, S., Singh, S., Kumar, A.S., 2019. Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. *Environmental Monitoring and Assessment* 191, 802. https://doi.org/10.1007/s10661-019-7696-5

Perera, B.M.A.O., 2009. The human-elephant conflict: A review of current status and mitigation methods. *Gajah* 30, 41–52.

Plotnik, J.M., de Waal, F.B.M., Moore, D., Reiss, D., 2010. Self-Recognition in the Asian elephant and future directions for cognitive research with elephants in zoological settings. *Zoo Biology* 29, 179–191. https://doi.org/10.1002/zoo.20257

Plotnik, J.M., Jacobson, S.L., 2022. A "thinking animal" in conflict: studying wild elephant cognition in the shadow of anthropogenic change. *Current Opinion in Behavioral Sciences* 46, 1–8. https://doi.org/10.1016/j.cobeha.2022.101148

Plotnik, J.M., Lair, R., Suphachoksahakun, W., De Waal, F.B.M., 2011. Elephants know when they need a helping trunk in a cooperative task. *Proceedings of the National Academy of Sciences of the United States of America* 108, 5116–5121. https://doi.org/10.1073/pnas.1101765108

Prakash, T.G.S.L., Indrajith, W.A.A.D.U., Aththanayaka, A.M.C.P., Karunarathna, S., Botejue, M., Nijman, V., Henkanaththegedara, S., 2020a. Illegal capture and internal trade of wild Asian elephants (*Elephas maximus*) in Sri Lanka. *Nature Conservation* 42, 51–69. https://doi.org/10.3897/natureconservation.42.57283

Prakash, T.G.S.L., Wijeratne, A.W., Fernando, P., 2020b. Human-elephant conflict in Sri Lanka: Patterns and extent. *Gajah* 51, 16–25.

Qomariah, I.N., Rahmi, T., Said, Z., Wijaya, A., 2018. Conflict between human and wild Sumatran Elephant (*Elephas maximus sumatranus* Temminck, 1847) in Aceh Province, Indonesia. *Biodiversitas Journal of Biological Diversity* 20, 77–84. https://doi.org/10.13057/biodiv/d200110

Ramakrishnan, U., Santosh, J., Sukumar, R., 1998. The population and conservation status of Asian elephants in the Periyar Tiger Reserve, Southern India. *Current Science* 74, 110–113.

Redpath, S.M., Young, J., Evely, A., Adams, W.M., Sutherland, W.J., Whitehouse, A., Amar, A., Lambert, R.A., Linnell, J.D.C., Watt, A., Gutiérrez, R.J., 2013. Understanding and managing conservation conflicts. *Trends in Ecology & Evolution* 28, 100–109. https://doi.org/10.1016/j.tree.2012.08.021

Reed, M.S., 2008. Stakeholder participation for environmental management: A literature review. *Biological Conservation* 141, 2417–2431. https://doi.org/10.1016/j.biocon.2008.07.014

Riddle, H.S., Christopher, C., 2011. Captive elephants - an overview. *Journal of Threatened Taxa* 3, 1826–1836. https://doi.org/10.11609/jott.o2620.1826-36

Riddle, H.S., Rasmussen, B., Schmitt, D.L., 2003. Are captive elephants important for conservation. *Gajah* 22, 57–61.

Riddle, H.S., Schulte, B.A., Desai, A.A., Meer, L. van der, 2010. Elephants - a conservation overview. *Journal of Threatened Taxa* 2, 653–661. https://doi.org/10.11609/jott.o2024.653-61

Saif, O., Kansky, R., Palash, A., Kidd, M., Knight, A.T., 2020. Costs of coexistence: understanding the drivers of tolerance towards Asian elephants *Elephas maximus* in rural Bangladesh. *Oryx* 54, 603–611. https://doi.org/10.1017/S0030605318001072

Sampson, C., McEvoy, J., Oo, Z.M., Chit, A.M., Chan, A.N., Tonkyn, D., Soe, P., Songer, M., Williams, A.C., Reisinger, K., Wittemyer, G., Leimgruber, P., 2018. New elephant crisis in Asia-Early warning signs from Myanmar. *PLoS ONE* 13, e0194113. https://doi.org/10.1371/journal.pone.0194113

Santiapillai, C., Suva, A., Karyawasam, C., Esufali, S., Jayaniththi, S., Basnayake, M., Unantenne, V., Wijeyamohan, S., 1999. Trade in Asian elephant ivory in Sri Lanka. *Oryx* 33, 176–180. https://doi.org/10.1046/j.1365-3008.1999.00041.x

Schalke, E., Stichnoth, J., Ott, S., Jones-Baade, R., 2007. Clinical signs caused by the use of electric training collars on dogs in everyday life situations. *Applied Animal Behaviour*

Science 105, 369–380. https://doi.org/10.1016/j.applanim.2006.11.002

Shaffer, L.J., Khadka, K.K., Van Den Hoek, J., Naithani, K.J., 2019. Human-elephant conflict: A review of current management strategies and future directions. *Frontiers in Ecology and Evolution* 6, 235. https://doi.org/10.3389/fevo.2018.00235

Sharma, R., Goossens, B., Heller, R., Rasteiro, R., Othman, N., Bruford, M.W., Chikhi, L., 2018. Genetic analyses favour an ancient and natural origin of elephants on Borneo. *Scientific Reports* 8, 880. https://doi.org/10.1038/s41598-017-17042-5

Sharp, T., Saunders, G., 2011. A model for assessing the relative humaneness of pest animal control methods., 2nd ed. Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, ACT.

Shepherd, C., Nijman, V., 2008. Elephant and ivory trade in Myanmar, TRAFFIC, Petaling Jaya, Malaysia.

Songer, M., Aung, M., Allendorf, T.D., Calabrese, J.M., Leimgruber, P., 2016. Drivers of change in Myanmar’s wild elephant distribution. *Tropical Conservation Science* 9, 194008291667374. https://doi.org/10.1177/1940082916673749

Steiss, J.E., Schaffer, C., Ahmad, H.A., Voith, V.L., 2007. Evaluation of plasma cortisol levels and behavior in dogs wearing bark control collars. *Applied Animal Behaviour Science* 106, 96–106. https://doi.org/10.1016/j.applanim.2006.06.018

Sukumar, R., 2006. A brief review of the status, distribution and biology of wild Asian elephants *Elephas maximus*. *International Zoo Yearbook* 40, 1–8. https://doi.org/10.1111/j.1748-1090.2006.00001.x

Sukumar, R., 2003. The living elephants: Evolutionary ecology, behavior and conservation. Oxford University Press, New York, USA.

Sukumar, R., 1989. The Asian Elephant: Ecology and Management. Cambridge University Press, New York, USA.

Sukumar, R., Gadgil, M., 1988. Male-female differences in foraging on crops by Asian elephants. *Animal Behaviour* 36, 1233–1235. https://doi.org/10.1016/S0003-3472(88)80084-8

Tan, A.S.L., de la Torre, J.A., Wong, E.P., Thuppil, V., Campos-Arceiz, A., 2020. Factors affecting urban and rural tolerance towards conflict-prone endangered megafauna in Peninsular Malaysia. *Global Ecology and Conservation* 23, e01179. https://doi.org/10.1016/j.gecco.2020.e01179

The World Bank, 2022. Countries and economies. https://data.worldbank.org/country

(accessed 14 September 2022).
van Eeden, L.M., Newsome, T.M., Crowther, M.S., Dickman, C.R., Bruskotter, J., 2019. Social identity shapes support for management of wildlife and pests. *Biological Conservation* 231, 167–173. https://doi.org/10.1016/j.biocon.2019.01.012

Vancuylenberg, B.W.B., 1977. Feeding behaviour of the asiatic elephant in South-East Sri Lanka in relation to conservation. *Biological Conservation* 12, 33–54. https://doi.org/10.1016/0006-3207(77)90056-8

Verdon, M., Lee, C., Marini, D., Rawnsley, R., 2020. Pre-exposure to an electrical stimulus primes associative pairing of audio and electrical stimuli for dairy heifers in a virtual fencing feed attractant trial. *Animals* 10, 217. https://doi.org/10.3390/ani10020217

Vidya, T.N.C., Sukumar, R., 2005. Social and reproductive behaviour in elephants. *Current Science* 89, 1200–1207.

Wadey, J., Beyer, H.L., Saaban, S., Othman, N., Leimgruber, P., Campos-Arceiz, A., 2018. Why did the elephant cross the road? The complex response of wild elephants to a major road in Peninsular Malaysia. *Biological Conservation* 218, 91–98. https://doi.org/10.1016/j.biocon.2017.11.036

Williams, C., Tiwari, S.K.R., Goswami, V.R., de Silva, S., Kumar, A., Baskaran, N., Yoganand, K., Menon, V., 2020. *Elephas maximus*. *The IUCN Red List of Threatened Species 2020*. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T7140A45818198.en (accessed 17 June 2023).

Wisumperuma, D., 2004. Human-elephant relationships in Sri Lanka: An historical and archaeological perspective, in: *Endangered Elephants, Past Present and Future*. Biodiversity and Elephant Conservation Trust, Rajagiriya, Sri Lanka, pp. 6–12.

Zhang, L., Wang, N., 2003. An initial study on habitat conservation of Asian elephant (*Elephas maximus*), with a focus on human elephant conflict in Simao, China. *Biological Conservation* 112, 453–459. https://doi.org/10.1016/S0006-3207(02)00335-X

APPENDIX A: SUPPLEMENTARY INFORMATION FOR CHAPTER 3

Supplementary material for “Causes and solutions to conflict between humans and Asian elephants”.

Table S1. Socioeconomic details of all respondents analysed in the study

		Expert-HEC (n=65)		Expert- no HEC (n=93)		Farmer-HEC (n=85)		Farmer-no HEC (n=27)		Other-HEC (n=83)		Other- no HEC (n=258)		Total (n=611)	
Item	Categories	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Age	18-35	21	32.3	37	39.8	33	38.8	17	63.0	56	67.5	159	61.6	323	52.9
	36-55	35	53.8	38	40.9	31	36.5	7	25.9	20	24.1	66	25.6	197	32.2
	>56	9	13.8	18	19.4	21	24.7	3	11.1	7	8.4	33	12.8	91	14.9
Gender	Female	16	24.6	35	37.6	23	27.1	7	25.9	46	55.4	161	62.4	288	47.1
	Male	49	75.4	58	62.4	62	72.9	20	74.1	37	44.6	97	37.6	323	52.9
Highest education qualification	Primary	0	0.0	0	0.0	3	3.5	0	0.0	0	0.0	3	1.2	6	1.0
	Secondary	4	6.2	5	5.4	18	21.2	6	22.2	9	10.8	27	10.5	69	11.3
	Tertiary	61	93.8	88	94.6	64	75.3	21	77.8	74	89.2	228	88.4	536	87.7
Religion	Buddhism	26	40.0	28	30.1	77	90.6	21	77.8	58	69.9	155	60.1	365	59.7
	Christianity	5	7.7	15	16.1	1	1.2	4	14.8	8	9.6	58	22.5	91	14.9
	Hinduism	18	27.7	12	12.9	6	7.1	1	3.7	10	12.0	19	7.4	66	10.8
	Islam	3	4.6	6	6.5	0	0.0	0	0.0	3	3.6	7	2.7	19	3.1
	Other	12	18.5	26	28.0	1	1.2	1	3.7	4	4.8	15	5.8	59	9.7
	Not applicable	1	1.5	6	6.5	0	0.0	0	0.0	0	0.0	4	1.6	11	1.8
Citizenship	Bangladesh	1	1.5	3	3.2	0	0.0	0	0.0	0	0.0	1	0.4	5	0.8
	China	0	0.0	2	2.2	0	0.0	0	0.0	0	0.0	0	0.0	2	0.3
	India	12	18.5	17	18.3	1	1.2	1	3.7	2	2.4	15	5.8	48	7.9
	Indonesia	0	0.0	1	1.1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2
	Malaysia	0	0.0	3	3.2	0	0.0	0	0.0	0	0.0	0	0.0	3	0.5
	Myanmar	1	1.5	3	3.2	0	0.0	0	0.0	0	0.0	1	0.4	5	0.8
	Nepal	7	10.8	1	1.1	0	0.0	0	0.0	1	1.2	1	0.4	10	1.6
	Sri Lanka	31	47.7	39	41.9	84	98.8	26	96.3	80	96.4	239	92.6	499	81.7
	Thailand	5	7.7	1	1.1	0	0.0	0	0.0	0	0.0	1	0.4	7	1.1
	Vietnam	3	4.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	0.5
	Other	5	7.7	23	24.7	0	0.0	0	0.0	0	0.0	0	0.0	28	4.6

Item	Categories	Expert-HEC (n=65) n	%	Expert- no HEC (n=93) n	%	Farmer-HEC (n=85) n	%	Farmer-no HEC (n=27) n	%	Other-HEC (n=83) n	%	Other- no HEC (n=258) n	%	Total (n=611) n	%
Involvement in agriculture	Farmer-annual crops					71	83.5	14	51.9					85	13.9
	Farmer-perennial crops					9	10.6	12	44.4					21	3.4
	Farmer-livestock					5	5.9	1	3.7					6	1.0
	Government officer-Agriculture	7	10.8	0	0.0					13	15.7	3	1.2	23	3.8
	Researcher or educator-Agriculture	18	27.7	19	20.4					4	4.8	19	7.4	60	9.8
	General interest in Agriculture	10	15.4	14	15.1					29	34.9	70	27.1	123	20.1
	Not applicable	30	46.2	60	64.5					37	44.6	166	64.3	293	48.0
Involvement in work related to Asian elephants	Member of the IUCN Asian elephant specialist group	11	16.9	20	21.5									31	5.1
	Zoo based organisation housing Asian elephants	8	12.3	11	11.8									19	3.1
	Non-governmental organisation working on Asian elephants	22	33.8	43	46.2									65	10.6
	Research/ educator on Asian elephants	38	58.5	64	68.8									102	16.7
	Government organisation working on Asian elephants	19	29.2	8	8.6									27	4.4

Table S2. Personal experience in human-elephant conflict

Item	Categories	Expert- HEC (n=65) n	%	Farmer- HEC (n=93) n	%	Other- HEC (n=83) n	%	Total (n=233) n	%
Severity of HEC	No problem	14	21.5	2	2.4	21	25.3	37	15.9
	Minor problem	15	23.1	15	17.6	27	32.5	57	24.5
	Moderate problem	15	23.1	32	37.6	25	30.1	72	30.9
	Major problem	12	18.5	23	27.1	8	9.6	43	18.5
	Serious problem	9	13.8	13	15.3	2	2.4	24	10.3
Types of problems experiences	Property damage	29	44.6	25	29.4	21	25.3	75	32.2
	Crop damage	38	58.5	77	90.6	52	62.7	167	71.7
	Physical injury	19	29.2	4	4.7	8	9.6	31	13.3
	Death of family member	8	12.3	7	8.2	5	6.0	20	8.6
	Fear	27	41.5	25	29.4	30	36.1	82	35.2
	Damage to livestock	7	10.8	6	7.1	7	8.4	20	8.6
Duration of HEC experiences	<1 year	1	1.5	1	1.2	4	4.8	6	2.6
	1-5 years	7	10.8	16	18.8	18	21.7	41	17.6
	5-10 years	12	18.5	6	7.1	10	12.0	28	12.0
	>10 years	26	40.0	32	37.6	11	13.3	69	29.6
	All my life	5	7.7	28	32.9	16	19.3	49	21.0
	Not applicable	14	21.5	2	2.4	24	28.9	40	17.2

Table S3. Asian elephant experts based on country of citizenship

Involvement in work related to Asian elephants	Number of respondents based on citizenship: Bangladesh	China	India	Indonesia	Malaysia	Myanmar	Nepal	Sri Lanka	Thailand	Vietnam	Other	Total
IUCN Asian Elephant Specialist Group	2	0	4	1	2	0	3	4	0	1	14	31
Zoo based organisation housing Asian elephants	0	0	1	0	0	0	0	10	0	0	8	19
Non-Government Organisation - working on Asian elephants	1	0	17	1	2	1	2	23	0	0	18	65
Researcher/ educator working on Asian elephants	4	2	21	0	2	4	4	34	6	2	23	102
Government authority- working on Asian elephants	1	0	4	0	0	0	2	16	0	2	2	27
Total Number of experts	4	2	29	1	3	4	8	70	6	3	28	158

Table S4. Socio-economic details of Sri Lankan respondents

Item	Categories	HEC (n = 195) n	%	no-HEC (n = 304) n	%	Total (n = 499) n	%
District	Ampara	18	9.2	1	0.3	19	3.8
	Anuradhapura	48	24.6	5	1.6	53	10.6
	Badulla	5	2.6	4	1.3	9	1.8
	Batticaloa	3	1.5	0	0.0	3	0.6
	Colombo	13	6.7	102	33.6	115	23.0
	Galle	2	1.0	13	4.3	15	3.0
	Gampaha	4	2.1	52	17.1	56	11.2
	Hambantota	9	4.6	4	1.3	13	2.6
	Jaffna	2	1.0	3	1.0	5	1.0
	Kaluthara	2	1.0	18	5.9	20	4.0
	Kandy	18	9.2	30	9.9	48	9.6
	Kegalle	3	1.5	10	3.3	13	2.6
	Kurunegala	8	4.1	17	5.6	25	5.0
	Mannar	0	0.0	1	0.3	1	0.2
	Matale	3	1.5	5	1.6	8	1.6
	Matara	0	0.0	12	3.9	12	2.4
	Moneragala	10	5.1	0	0.0	10	2.0
	Mullaitivu	0	0.0	1	0.3	1	0.2
	Nuwara Eliya	1	0.5	6	2.0	7	1.4
	Polonnaruwa	24	12.3	0	0.0	24	4.8
	Puttalam	4	2.1	4	1.3	8	1.6
	Rathnapura	5	2.6	8	2.6	13	2.6
	Trincomalee	8	4.1	4	1.3	12	2.4
	Vavuniya	5	2.6	4	1.3	9	1.8
Ethnicity	Burgher	1	0.5	2	0.7	3	0.6
	Muslim	5	2.6	4	1.3	9	1.8
	Sinhala	168	86.2	271	89.1	439	88.0
	Tamil	19	9.7	19	6.3	38	7.6
	Other	2	1.0	8	2.6	10	2.0
Income	No income	26	13.3	35	11.5	61	12.2
	< Rs 25,000	31	15.9	12	3.9	43	8.6
	Rs. 25,000 - 50,000	66	33.8	67	22.0	133	26.7
	Rs. 50,000- 100,000	37	19.0	80	26.3	117	23.4
	Rs1 00,000 - 200,000	23	11.8	57	18.8	80	16.0
	>Rs.200,000	12	6.2	53	17.4	65	13.0

Table S5. Full question as given in the survey for each item analysed in the study

Category	Question	Item
Category 1: Causes of HEC	According to your knowledge, rate the likelihood of the following as reasons/ causes for human-elephant conflict?	
	Loss of elephant habitats due to natural causes (fire, pest, disease, climate change etc)	1. Habitat loss by natural causes
	Humans have encroached elephant habitats	2. Habitat encroachment
	Elephant population is increasing	3. Increasing elephant population
	Human population is increasing	4. Increasing human population
	Unplanned development	5. Unplanned development
	Poor land-use planning	6. Poor land-use planning
	Agricultural expansion	7. Agricultural expansion
	Elephants do not have enough food in the forest	8. Not enough food in forests
	Blocking of elephant migratory paths	9. Elephant migratory paths blocked
	Elephants are attracted to crops	10. Elephants attracted to crops
Category 2: Importance, conservation and co-existence	How well do you agree or disagree with the following statements?	
	Elephants should be protected	1. Elephants should be protected
	Elephants are important part of the ecosystem	2. Important part of the ecosystem
	Elephants are important for the tourism industry and in turn develops country's economy	3. Important for tourism
	Elephant conservation could benefit rural economy through eco-tourism	4. Elephants benefit the rural economy
	Elephants play a very important role in the country's culture and religion	5. Important role in the culture and religion
	Elephants are endangered species	6. An endangered species
	Humans have taken over elephant habitat	7. Humans taken over elephant habitat
	Elephants have taken over human habitats	8. Elephants taken over human habitats
	Humans should try to co-exist with elephants	9. Should try to co-exist with elephants
	Humans should be removed from elephant habitats	10. Remove humans from elephant habitats
	Elephants should be removed from human habitats	11.Remove elephants from human habitats

Category	Question	Item
Category 3 Acceptability of HEC mitigation tools	Comparing with the severity of the issue in the country how acceptable are the following mitigation methods in an ethical and elephant welfare point of view? If you have no opinion on any of the below mitigation methods, please select "Neutral".	
Category 4 Effectiveness of HEC mitigation tools	What do you think of the effectiveness of the following methods implemented by the government or practiced by farmers in mitigating human elephant conflict? If you are not aware of or are not practicing any of the below mitigation methods in your country, please select DO NOT KNOW.	
	Electric fencing	1. Electric fencing
	Trenches, ditches	2. Trenches, ditches
	Live fences – planting thorny plants like Agave, Bael	3. Planting thorny plants
	Planting unpalatable crops (e.g. citrus plants)	4. Planting unpalatable crops
	Shouting to chase elephants	5. Shouting
	Lighting bon fires	6. Lighting bon fires
	Flashlights	7. Flashlights
	Thunder flashes (Ali wedi),	8. Thunder flashes
	Firecrackers	9. Firecrackers
	Bee fences	10. Bee fences
	Smoke	11. Smoke
	Restricting elephants to protected areas	12. Restricting to protected areas
	Translocation (targeted problem elephants are tranquilised and transported to protected areas away from their capture site)	13. Translocation
	Translocating problem elephants to wild elephant holding grounds	14. Elephant holding grounds
	Elephant drives (elephants are pushed to restricted areas using people, vehicles, aircrafts, and sometimes trained elephants)	15. Elephant drives
	Official culling of problem elephants	16. Killing problem elephants
	Capture and taming problem elephants	17. Taming problem elephants
	Tracking elephants with GPS collars and provide early warning via mobile messages	18. GPS collars
	Remote sensing using Infrasonic call detectors and provide early warning via mobile messages	19. Infrasonic call detectors
	Remote sensing using Geophones and provide early warning via mobile messages	20. Geophones
	Providing compensation or insurance schemes	21. Compensation schemes
	Sterilising elephants	22. Sterilising elephants
	Jaw bombs (makeshift explosives placed in fruits to deliberately harm the elephant- Hakka patas)	23. Jaw bombs
	Nail boards	24. Nail boards
	Shot guns	25. Shot guns

APPENDIX B: SUPPLEMENTARY INFORMATION FOR CHAPTER 4

Supplementary material for 'Virtual fencing of captive Asian elephants fitted with an aversive geofencing device to manage their movement'

Preliminary study conducted using the prototype electric shock collar

Methods

A customised and prototype electronic shock collar was developed to deliver an electric stimulus of ~4 kV peak to peak with no resistance, with an energy output of less than 1/4th the energy delivered from a typical energiser used for electric fences (EFs) in Sri Lanka. This collar was tested on two female, adult, captive Asian elephants (Elephant IDs: M4, S1).

The collar was fitted on the animal with the two electrodes positioned closer to the dorsal midline of the elephant's neck, and the animal was allowed to acclimatise to the collar for about 30 min. While observing the elephant carefully, a brief series of electric shocks (~1 s duration) were then delivered, up to a maximum of four times, with a minimum 2 min rest period between each shock. Involuntary and voluntary responses to the shocks were recorded. The collar was subsequently removed and the animal's wellbeing and stress levels were also monitored for four consecutive days (results not shown). The device stopped working during testing on the second elephant (S1) due to strong tugging and shaking of the device by the elephant, or perhaps due to weak communication between the remote control and the collar during the experiment. Hence, only two shocks could be delivered to S1 before testing had to be discontinued.

Results and Discussion:

The two elephants tested during the preliminary study exhibited immediate but short-term involuntary responses including strong body flinching or muscle twitching. These were followed by voluntary agitation behaviours such as shaking the collar; vocalisation and locomotory behaviours such as turning 360^{o}; or turning and walking away, forwards, or backwards, and also turning and running (Table S1).

Table S1. Frequency of visible behavioural responses of two captive Asian elephants (S1 and M4) to each shock (n = 6) from the prototype collar.

Behaviour category	Frequency
Involuntary	6
Agitation	5
Locomotory	6

The prototype collar generated stronger responses compared to the dog-training collar tested earlier (see main text). The strength of this prototype device may therefore be more suitable for wild elephants for whom the milder shock from the dog collar may not be sufficient to generate desirable responses. This prototype device may be further modified to deliver even more lower voltages and tested on captive elephants to determine a more optimum stimuli strength that could be utilized on wild elephants.

APPENDIX C: SUPPLEMENTARY INFORMATION FOR CHAPTER 5

Supplementary information for ‘Welfare impacts associated with using aversive geofencing devices on captive Asian elephants’

Table S1. Percentage frequencies (rounded to a whole number) of behaviours shown by elephants during Experiment 1 and Experiment 2

Elephant ID	Behaviours	Pre-experiment days						Days of Experiment 1									Days of Experiment 2								
								1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
K1	Feeding	49	50	46	36	45	38	30	31	36	25	43	31				50	54	38	55	37	45	52	45	39
	Environmental investigation	6	4	7	4	2	7	2	4	0	6	2	3				3	4	7	3	3	3	7	9	9
	Standing	3	0	0	3	9	6	2	0	4	11	1	1				2	0	2	0	0	0	0	0	2
	Comfort	26	36	32	51	31	24	44	54	45	33	42	47				37	31	42	30	46	41	27	36	34
	Social	3	2	1	2	2	3	4	0	0	0	0	1				0	0	0	0	2	0	3	0	2
	Movement	13	7	11	1	11	20	12	10	12	17	11	16				6	9	9	7	12	10	10	8	12
	Stereotypy	0	0	0	0	0	0	0	0	0	1	0	0				0	0	0	2	0	0	0	0	0
	Self-directed behaviours	0	1	3	3	0	2	3	1	3	7	1	1				1	2	2	2	0	0	0	2	2
	Collar	0	0	0	0	0	0	3	0	0	0	0	0				1	0	0	1	0	1	1	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0
M1	Feeding	30	34	49	32	27	10	17	37	20	42	24	32												
	Environmental investigation	9	6	4	2	0	19	9	4	9	7	6	3												
	Standing	4	5	2	0	9	3	1	0	0	1	1	0												
	Comfort	46	40	30	53	53	50	49	30	54	30	47	48												
	Social	0	0	1	1	1	2	1	2	1	2	2	1												
	Movement	11	11	12	11	10	13	17	22	10	10	18	14												
	Stereotypy	0	0	0	0	0	0	0	0	0	0	0	0												
	Self-directed behaviours	0	4	2	1	0	2	2	1	4	8	2	2												
	Collar	0	0	0	0	0	0	4	4	2	0	0	0												
	Other	0	0	0	0	0	1	0	0	0	0	0	0												

Elephant ID	Behaviours	Pre-experiment days						Days of Experiment 1									Days of Experiment 2								
								1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
M2	Feeding	63	47	20	32	29	29	48	40	30	23	27	46	52	49	22	51	29	43	32	42	48	29	47	54
	Environmental investigation	4	2	13	17	14	27	10	12	15	27	17	11	24	15	14	1	9	14	9	17	9	14	9	6
	Standing	2	1	8	2	2	3	2	2	4	6	1	3	2	4	2	2	0	0	0	0	0	3	0	0
	Comfort	26	38	49	37	37	30	31	22	40	35	39	24	13	24	50	37	51	30	53	37	36	43	42	30
	Social	0	0	0	2	1	4	1	6	1	0	3	0	0	0	2	0	0	2	0	0	0	1	0	1
	Movement	5	10	5	5	13	5	7	17	7	5	8	15	7	5	8	7	7	7	4	1	0	6	1	8
	Stereotypy	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
	Self-directed behaviours	0	2	5	5	4	2	1	1	3	4	3	1	2	3	2	2	4	4	2	3	5	4	1	1
	Collar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
M3	Feeding	23	24	45	52	36	21	25	26	30	27	45	40	36	40	26	34	33	44	50	25	29	27	30	26
	Environmental investigation	10	5	9	3	3	7	5	5	2	7	7	2	9	4	3	4	6	3	5	5	3	4	5	6
	Standing	1	0	3	1	1	0	0	0	1	6	1	0	1	0	1	0	1	0	0	0	0	0	0	0
	Comfort	63	63	32	37	54	68	58	64	61	44	41	55	45	53	66	56	56	49	39	63	63	64	62	64
	Social	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Movement	0	1	3	0	2	0	0	0	0	1	0	1	1	0	0	1	0	0	0	3	1	0	0	0
	Stereotypy	1	3	2	3	1	1	3	4	3	2	3	0	4	1	2	2	1	1	2	1	1	1	0	2
	Self-directed behaviours	2	3	5	4	2	3	8	1	2	12	3	1	4	2	2	3	3	3	3	3	3	4	3	2
	Collar	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0
	Other	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Elephant ID	Behaviours	Pre-experiment days						Days of Experiment 1									Days of Experiment 2								
								1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
M4	Feeding	39	35	52	42			42	51	26	35	28	41	26	56	30	40	55	49	30	35	38	42	30	48
	Environmental investigation	7	2	3	7			7	3	3	1	8	7	6	7	9	2	6	3	4	4	2	6	5	4
	Standing	1	0	1	0			3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	Comfort	35	47	24	27			24	32	52	49	48	42	54	27	47	37	27	36	52	52	47	39	55	36
	Social	2	2	0	1			1	0	2	0	1	0	0	2	3	3	0	0	1	0	0	0	0	1
	Movement	15	12	20	19			8	12	12	13	12	8	12	8	8	13	10	11	8	9	12	12	9	10
	Stereotypy	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Self-directed behaviours	1	2	0	4			1	0	3	0	1	2	2	0	2	0	1	1	2	0	1	1	1	1
	Collar	0	0	0	0			14	2	2	2	2	0	0	0	0	5	1	0	3	0	0	0	0	0
	Other	0	0	0	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
S1	Feeding	30	30	50	35	25	21	27	44	52	36	47	38				21	41	27	58	56	33	28	55	39
	Environmental investigation	5	5	17	18	14	16	13	8	8	10	12	12				6	5	10	9	2	0	4	3	7
	Standing	7	3	1	1	6	6	2	0	0	0	1	1				1	0	0	0	0	0	1	0	0
	Comfort	37	48	20	20	32	35	26	20	16	22	20	17				63	44	35	18	27	61	51	31	39
	Social	0	2	1	3	2	2	6	3	3	2	2	3				1	0	2	0	2	0	0	0	2
	Movement	20	9	9	20	17	16	18	20	16	23	15	26				8	9	20	11	12	6	12	11	11
	Stereotypy	0	0	0	0	0	0	0	1	1	0	0	0				0	0	0	0	0	0	0	0	0
	Self-directed behaviours	1	3	2	3	4	4	4	2	3	7	3	3				0	0	6	0	0	0	2	0	2
	Collar	0	0	0	0	0	0	4	2	1	0	0	0				0	1	0	4	1	0	2	0	0
	Other	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0	0	0	0	0

Elephant								Days of Experiment 1									Days of Experiment 2								
ID	Behaviours	Pre-experiment days						1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
S2	Feeding	17	28	51	17	30	52	55	48	52	31	39	41	39	27	33									
	Environmental investigation	11	13	5	13	11	7	5	4	1	7	2	6	2	0	2									
	Standing	1	1	1	2	4	3	2	2	0	4	1	1	1	0	0									
	Comfort	45	34	31	59	28	16	27	34	42	48	49	38	49	68	59									
	Social	1	0	2	0	3	6	1	0	1	1	0	1	2	2	0									
	Movement	19	21	10	7	22	16	8	10	4	8	8	11	7	2	4									
	Stereotypy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	Self-directed behaviours	5	3	0	2	2	0	2	2	0	1	1	2	0	1	2									
	Collar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	Other	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
S3	Feeding	52	62	34	25	41	35	49	53	37	27	33	28	35	33	33									
	Environmental investigation	5	11	8	13	12	10	5	9	2	4	5	7	6	10	8									
	Standing	1	0	2	6	6	5	0	0	4	3	1	0	1	0	1									
	Comfort	22	18	34	35	15	37	38	29	51	56	44	53	52	46	35									
	Social	2	4	3	7	3	1	3	0	0	2	1	4	0	1	5									
	Movement	15	4	16	12	17	11	3	7	4	8	11	3	5	8	14									
	Stereotypy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									
	Self-directed behaviours	3	1	3	2	6	1	2	2	2	0	4	5	1	2	4									
	Collar	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0									
	Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0									

APPENDIX D: SUPPLEMENTARY INFORMATION FOR CHAPTER 6

Supplementary information for 'Attitudes towards the potential use of aversive geofencing devices to manage wild elephant movement'.

Table S1. Socioeconomic details of all respondents analysed in the study

		Expert-HEC[1] (n=65)		Expert- no HEC[1] (n=93)		Farmer-HEC[1] (n=85)		Farmer-no HEC[1] (n=27)		Other-HEC[1] (n=83)		Other- no HEC[1] (n=258)		Total (n=611)	
Item	Categories	n	%	n	%	n	%	n	%	n	%	n	%	n	%
Age	18-35	21	32.3	37	39.8	33	38.8	17	63.0	56	67.5	159	61.6	323	52.9
	36-55	35	53.8	38	40.9	31	36.5	7	25.9	20	24.1	66	25.6	197	32.2
	>56	9	13.8	18	19.4	21	24.7	3	11.1	7	8.4	33	12.8	91	14.9
Gender	Female	16	24.6	35	37.6	23	27.1	7	25.9	46	55.4	161	62.4	288	47.1
	Male	49	75.4	58	62.4	62	72.9	20	74.1	37	44.6	97	37.6	323	52.9
Highest education qualification	Primary	0	0.0	0	0.0	3	3.5	0	0.0	0	0.0	3	1.2	6	1.0
	Secondary	4	6.2	5	5.4	18	21.2	6	22.2	9	10.8	27	10.5	69	11.3
	Tertiary	61	93.8	88	94.6	64	75.3	21	77.8	74	89.2	228	88.4	536	87.7
Religion	Buddhism	26	40.0	28	30.1	77	90.6	21	77.8	58	69.9	155	60.1	365	59.7
	Christianity	5	7.7	15	16.1	1	1.2	4	14.8	8	9.6	58	22.5	91	14.9
	Hinduism	18	27.7	12	12.9	6	7.1	1	3.7	10	12.0	19	7.4	66	10.8
	Islam	3	4.6	6	6.5	0	0.0	0	0.0	3	3.6	7	2.7	19	3.1
	Other	12	18.5	26	28.0	1	1.2	1	3.7	4	4.8	15	5.8	59	9.7
	Not applicable	1	1.5	6	6.5	0	0.0	0	0.0	0	0.0	4	1.6	11	1.8
Citizenship	Bangladesh	1	1.5	3	3.2	0	0.0	0	0.0	0	0.0	1	0.4	5	0.8
	China	0	0.0	2	2.2	0	0.0	0	0.0	0	0.0	0	0.0	2	0.3
	India	12	18.5	17	18.3	1	1.2	1	3.7	2	2.4	15	5.8	48	7.9
	Indonesia	0	0.0	1	1.1	0	0.0	0	0.0	0	0.0	0	0.0	1	0.2
	Malaysia	0	0.0	3	3.2	0	0.0	0	0.0	0	0.0	0	0.0	3	0.5
	Myanmar	1	1.5	3	3.2	0	0.0	0	0.0	0	0.0	1	0.4	5	0.8
	Nepal	7	10.8	1	1.1	0	0.0	0	0.0	1	1.2	1	0.4	10	1.6
	Sri Lanka	31	47.7	39	41.9	84	98.8	26	96.3	80	96.4	239	92.6	499	81.7
	Thailand	5	7.7	1	1.1	0	0.0	0	0.0	0	0.0	1	0.4	7	1.1
	Vietnam	3	4.6	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	3	0.5
	Other	5	7.7	23	24.7	0	0.0	0	0.0	0	0.0	0	0.0	28	4.6

Item	Categories	Expert-HEC[1] (n=65) n	%	Expert- no HEC[1] (n=93) n	%	Farmer-HEC[1] (n=85) n	%	Farmer-no HEC[1] (n=27) n	%	Other-HEC[1] (n=83) n	%	Other- no HEC[1] (n=258) n	%	Total (n=611) n	%
Involvement in agriculture	Farmer-annual crops					71	83.5	14	51.9					85	13.9
	Farmer-perennial crops					9	10.6	12	44.4					21	3.4
	Farmer-livestock					5	5.9	1	3.7					6	1.0
	Government officer-Agriculture	7	10.8	0	0.0					13	15.7	3	1.2	23	3.8
	Researcher or educator-Agriculture	18	27.7	19	20.4					4	4.8	19	7.4	60	9.8
	General interest in Agriculture	10	15.4	14	15.1					29	34.9	70	27.1	123	20.1
	Not applicable	30	46.2	60	64.5					37	44.6	166	64.3	293	48.0
Involvement in work related to Asian elephants	Member of the IUCN[2] Asian elephant specialist group	11	16.9	20	21.5									31	5.1
	Zoo based organisation housing Asian elephants	8	12.3	11	11.8									19	3.1
	Non-governmental organisation working on Asian elephants	22	33.8	43	46.2									65	10.6
	Research/ educator on Asian elephants	38	58.5	64	68.8									102	16.7
	Government organisation working on Asian elephants	19	29.2	8	8.6									27	4.4

[1] HEC: human-elephant conflict

[2] IUCN: International Union for Conservation of Nature

Table S2. Personal experience of respondents in human-elephant conflict (HEC)

Item	Categories	Expert- HEC (n=65)		Farmer- HEC (n=93)		Other- HEC (n=83)		Total (n=233)	
		n	%	n	%	n	%	n	%
Severity of HEC	No problem	14	21.5	2	2.4	21	25.3	37	15.9
	Minor problem	15	23.1	15	17.6	27	32.5	57	24.5
	Moderate problem	15	23.1	32	37.6	25	30.1	72	30.9
	Major problem	12	18.5	23	27.1	8	9.6	43	18.5
	Serious problem	9	13.8	13	15.3	2	2.4	24	10.3
Types of problems experiences	Property damage	29	44.6	25	29.4	21	25.3	75	32.2
	Crop damage	38	58.5	77	90.6	52	62.7	167	71.7
	Physical injury	19	29.2	4	4.7	8	9.6	31	13.3
	Death of family member	8	12.3	7	8.2	5	6.0	20	8.6
	Fear	27	41.5	25	29.4	30	36.1	82	35.2
	Damage to livestock	7	10.8	6	7.1	7	8.4	20	8.6

Table S3. Full length question of the items analysed in the study

Question	Item	Responses	Percentage of responses (%) Expert-HEC[1] (n=65)	Expert-no HEC[1] (n=93)	Farmer - HEC[1] (n=85)	Farmer - no HEC[1] (n=27)	Other-HEC[1] (n=83)	Other-no HEC[1] (n=258)
1. Satellite linked shock collars may have the potential to manage elephant movement by acting as virtual fences. How likely do you think elephants would be able to learn to relate the warning sound with the electric shock and avoid the shock like cattle and sheep?	Likelihood for elephants to learn to avoid the electric shocks from AGDs[2]	Extremely unlikely	4.6	6.5	2.4	0.0	2.4	2.7
		Unlikely	6.2	9.7	5.9	0.0	4.8	2.3
		Neutral	18.5	15.1	23.5	18.5	24.1	24.8
		Likely	61.5	51.6	47.1	55.6	42.2	48.1
		Extremely likely	9.2	17.2	21.2	25.9	26.5	22.1
2. How acceptable it is to give an electric shock to an elephant using a GPS collar	Acceptability of using AGDs[2] on elephants	Unacceptable	13.8	17.2	8.2	3.7	13.3	17.8
		Somewhat unacceptable	12.3	24.7	3.5	7.4	9.6	19.4
		Neutral	18.5	16.1	41.2	37.0	30.1	23.3
		Somewhat acceptable	38.5	26.9	31.8	40.7	36.1	26.7
		Acceptable	16.9	15.1	15.3	11.1	10.8	12.8
3. How effective do you think satellite linked shock collars would be in managing elephant movement?	Effectiveness of AGDs[2] in managing elephant movement	Ineffective	4.6	8.6	2.4	3.7	4.8	3.9
		Somewhat ineffective	9.2	17.2	7.1	0.0	8.4	2.3
		Neutral	20.0	21.5	29.4	25.9	33.7	26.7
		Somewhat effective	49.2	39.8	41.2	37.0	41.0	43.0
		Effective	16.9	12.9	20.0	33.3	12.0	24.0
4. If a pilot study using electric shock collars is conducted on captive elephants and is proven that elephants do learn to avoid shock when they hear the warning sound, would it then be acceptable to be tested on wild elephants	Acceptability, if pilot studies on captive elephants have been successful	Unacceptable	7.7	16.1	7.1	0.0	4.8	10.1
		Somewhat unacceptable	6.2	14.0	0.0	11.1	9.6	5.0
		Neutral	21.5	12.9	32.9	11.1	24.1	20.5
		Somewhat acceptable	33.8	31.2	18.8	22.2	28.9	34.5
		Acceptable	30.8	25.8	41.2	55.6	32.5	29.8

[1] HEC: human-elephant conflict

[2] AGDs: aversive geofencing devices

Table S4. Selected list of reasons provided by respondents for unacceptability of using aversive geofencing devices on elephants

Theme	Examples
Unethical/ cruel/ harmful to elephants	"Cruelty to animals"
	"It's not a solution I can agree, there has to be a natural way!, culturally not acceptable"
	"No animal should harm during a research. It is against their will"
	"Elephants should be left alone without being harmed in the forest. It will endanger their normal lives"
	"I disagree with this concept as it would disturb the natural behaviour of elephants. It's no different than Jurassic Park T-Rex"
	"Cannot approve experimenting on animals to manage everything according to human needs"
	"This may violate natural habits of elephants and their senses"
	"They should be allowed to live their natural life"
	"Male elephant is usually more likely to go closer to human settlements and farm. The shock from the collar is something that the elephant cannot control unlike the electric fencing. I am afraid the shock will add to stress level of this elephant especially if the male elephant is in musth etc"
	"Unethical, inhumane and harmful. Such intrusive techniques on endangered species is completely unethical. Firstly this cruel technique would not be able to predict how the elephant will respond. It might make the animal more dangerous and uncontrollable."
	"Adding tracking collars alone affects the natural behaviour of the elephants. Having a shock collar may be effective but it may effect how they behave in the wild. Even when the shock isn't present, the sensation of the collar may cause fear and paranoia. In particular when this is put on the matriarch, it could affect the stability of the entire herd."
	"It may cause cardiac arrest or any other health related issues for the elephant"
	"Seems too cruel and controlling"
	"I am ethically against doing this to a wild animal."
	"This cruel and unethical. There are no problem elephants only problem locations. So site specific mitigation measures should be practiced to reduce/manage the human-elephant conflict. Just because there is a technology available and someone think this is novel and there is money to do this we shouldn't be doing do such tests/research."
	"Elephants should be able to live without human influence even without a collar. I will also affect the aesthetic beauty"
	"GPS electric collars are different from physical barriers such as electric fences. They have the potential to cause psychological trauma to elephants by giving the elephant a shock from a device which is installed on its own body. It is like installing electric collars on the necks of human prisoners."
	"Either captive or wild, the elephant has to be anesthetized to place the collar. It is a risk to their life. Shocking will affect their natural behaviours."
	"Cannot approve harming animals"
	"Involving captive elephants is also harmful"
	"Shock collars are inhumane, elephants may not understand what happens and may panic and aggravate the conflict. Animal right groups should oppose this"
	"Wild elephants are not the reason for the beginning of this conflict. The reason is the acts of humans. So, punishing and experimenting with using wild elephants is unacceptable and it is unethical. Although they are animals, they have the blood and flesh that feel the pain. Therefore, experimenting with painful stuff is unacceptable. There should have practical solutions which are not painful for elephants as well as for humans. These artificial solutions cannot cure this problem."

Theme	Examples
	"Because the elephant would learn that the sound is a warning signal for the shock, and it would constantly be in state of stress/anxiety whether it would get a shock. I believe this is inhumane." "Shock collars can create fear, anxiety and aggression in animas towards people or other animals. They are natural animals so have to let be" "Electric shock could harm or cause death to the animal, the animals mental health could be affected and could act even more aggressively" "Electric shock could harm the elephants" "Giving an electric shock to any animal cannot be accepted" "Animals are innocent, and testing shocks on elephants can harm them," "No animal should be used for experiment. Animals should be protected" "There is a possibility that the shock could harm elephants, die or even act aggressively in response to the shock"
Would be unfeasible or unsuccessful	"Difficult task" "After wearing the collar, the Elephant herd might reject the individual elephant in my opinion this method may show some progress but not the solution." "Behaviour of captive elephants and wild elephants are different" "Because it will ultimately don't work for the wild as well." "Pilot tests on captive elephants will be probably successful, such as electric fencing is working very well with captive for instance. But it does not prove that the system will be efficient for wild ones in search of highly energetic food. Wild elephants may probably learn at the beginning but, with time, they could also learn that electric shocks will are a bearable pain (10-15 sec) for accessing farmed food, such as elephants learnt to cope with electric fencing. Apart from these potential technical limitations, installing permanent collars on wild elephants is highly intrusive with non-zero risks when sedating the animal. I don't believe that segregating humans and animals is the way to promote co-existence - should be more about land planning, community-led solutions, etc." "Captive elephants behave differently from wild elephants" "Not effective. Domestic elephants are more fond with people. If they were used, the may be adversed." "Firstly, elephants have to be captured and fitted with collars. These collars will have to stay on the elephants permanently unlike other radio collars which can be removed after a certain time. Instead of satellite linked collars, one can use trip alarms which will warn the farmers. Trip alarm are much cheaper and does not involve the capture of elephants." "The behavioural patterns of captive elephant may differ from wild elephants. Wild elephants are more tolerant to pain that captured ones." "Captive elephants may not behave the same way as wild elephants If electric shock is effective in stopping male elephants then electric fences should also work, but it is not the case at present. High cost to put collars on many elephants, practical problems in sedating animals, risk to humans involved in it. Early warning systems through sms or alarm sounds when elephants cross virtual fences would be great." "Elephant being an intelligent species can also remembers it as a bad memory and can also show retaliation unlike captive elephant on which you have experimented and which is also used to humans. Shock collars are more problematic than fences." "Captive elephant behaviour is different" "Captive elephants are different from wild. The direction in which the elephant would move after receiving the shock in uncertain. When stressed out the elephant might not know in which direction it should move"

Table S5. Selected list of feedback received from respondents for potential challenges and other comments on aversive geofencing devices

Theme	Examples
(1) Stakeholder acceptability, support and awareness	"Will be difficult to implement with the government"
	"Culturally not acceptable"
	"Selecting a suitable community to implement this will be difficult, Will need a lot of effort to educate and create awareness among people regarding this process. It will be challenging to coordinate between govt authorities, local communities and other institutions to implement this."
	"Adoption of technology by the affected communities"
	"Political influence"
	"Educating the villagers., Stakeholders must be adequately educated and corporation from the govt must be assured."
	"The attitudes of wildlife and environmental activists"
	"Employing local workers to see program through, corrupt politicians, local people trying to profit through implementation programs"
	"People living in conflict areas may initially be reluctant to accept this solution. Most of them are asking for electric fences. "
	"Animal right activists may oppose"
	"Coming into an agreement with the majority, educating villagers regarding the technology"
	"Ethical, religious, and cultural issues when implementing"
	"Legal issues and consent of the host country"
	"If the health and welfare harms of attaching and using an electric shock collar are outweighed by the desired effectiveness and benefits, then the ethical questions become once of risk/benefit balance. If elephants are considered as having rights, for example in accordance of the five freedoms or as 'non-human persons', then you'd probably have to find another way."
	"Animal rights groups will oppose use of this technology"
	"The ethical consideration when implementing these methods, specially how to explain them to wildlife conservationist and general public who loves elephants. Will governments spend more money on such technology that require a lot of investment, considering the cause of the problem and the existing methods they are already aware of."
	"One of the key challenges is how the message is communicated to the public (efficacy, risks, costs, etc). There are a lot of animal welfare activists these days, which is not wrong, but they may not always be practical, or they may not fully understand the issues on the ground. Also, this technology may work well for tuskers, but I am not sure about family groups; ie; there are no clear matriarchs for family groups in Sabah, Malaysia, based on my observation."
	"Attitude of environmentalists/ animal welfare activists/ community towards elephants being subjected to electric shock" training or coordination required for officials/ those who would conduct the monitoring
	"Preventing abuse in its use by statutory agencies (following political directive)."
	"Educating the communities about this, coming to an agreement to implement this with the government and with the laws and regulation in the country will be difficult"
	"Government support, unwillingness to take risks"
	"Education, people need to be educated about this. It also needs to be ethical"
	"Government support"
	"I think the key challenge will be managing animal rights activists and welfare groups. If an international animal rights groups hears of this practice occurring, the proponents will most likely experience a high level of online abuse and attacks by westerners. While potentially an effective solution, the perceived welfare issues will be very difficult to justify to animal rights groups. Animal rights groups are already making elephant conservation very difficult, and electric collars will fuel their online abuse (and they will gain more donations). Sadly, this may perpetuate the further racism and stereotypes about locals not caring for elephants. For this reason, I don't think electric collars are a good idea to mitigate HEC."

Theme	Examples
	"Farmers and civilians who live in areas with elephant interactions should be well educated for the method to be more effective." "Lack of awareness among people" "Lack of knowledge about this in people in rural areas" "Legal issues, animal welfare/rights NGO's that are against any kind of invasive treatment" "The government should be encouraged for this" "It can be implemented successfully only if the operational explanation related to the above vibration belt is given to the farmers and beneficiaries"
(2) Safety and wellbeing of elephants	"Should use a shock type that does not harm the elephant" "Does the satellite link collar endanger the life of the animal" "Elephants could be harmed mentally and physically affecting their lifestyles. Should ensure animals safety" "The only problem that i have with it is the doubt of safety of the electric collar on the elephant. If it were to malfunction it will hurt the animal." "Would expect minimal harm on elephants" "Long-term impact on an elephant's behaviour is critical from a conservation point of view." "Should ensure that the collars do not interfere with elephants physical " "Poachers may be able to identify animals with their collars" "Possible harm to elephants due to radiation, its best to see if there are long terms harms to elephants" "Elephants could be harmed if the shocks are received multiple times" "The inherent risks of demobilising an elephant " I think this is a very serious and potentially harmful intrusion into the elephant's bodily autonomy and could have a potential to drive them "mad" instead of providing a viable solution. "Wellbeing of the elephants." "If elephants crosses all VFs then the action taken should not be harmful to the animal There could negative effects on the animal (chances of cancer) due to receiving electric shock for long periods" "Should ensure that it does not harm the elephant. " "May cause long term effects to the individual, which might not come to light if unnoticed or research lacks." "Giving electric shocks might negatively affect them and might do some damages to their nervous system if they frequently subjected to this." "It is not good for their mental health" "Increased stress level of the problem animal, shocks might increase the anger of the animal" "Harm to elephant during capture" "There is a risk anaesthetising an elephant and you don't want to do that with a well-behaved elephant (especially females)." "Negative impact on elephant behaviour?" "Warning collars would be alright as long as there's no physical harm to the animal." "Ensuring that the pain experienced by the elephant is no greater than that delivered by an electric fence i.e. that there is no harm caused to the overall health and life of the animal." "A safe way needs to be found for placing the collars. Using tranquilisers can be very dangerous for elephants and a full risk assessment and method statement needs to be prepared" "Could it be disadvantageous to an elephant when involved in a fight, Poachers will be able to identify animals with the collars," "I hope this would not impact elephants in a negative way" "Mental and physical health of elephants"

Theme	Examples
	"If a shock/set of shocks is missed when an elephant leaves a designated habitat area, there might be a risk of it getting shocks when it tries to re-enter the habitat area, leading to a traumatic and painful (and counterproductive) experience; logistics and health risks of repeatedly recapturing elephants if the collars need repair/replacement; Collaring younger animals that are still growing might risk strangulation, meaning collaring them more than occasionally could lead to a high monitoring burden/risk of unconscionable animal welfare costs"
	"Should find out if elephants mental health could be affected by this"
	"Could be life threatening to elephants"
	"Safety of animals"
	"Risk to animals during tranquilisation"
	"Mental stress to the animal"
	"Hope the electric shock from the collar is not life threatening to the elephants."
	" Will this shock affect the elephant's body, health and well-being of life in the long term? Is it harmful to their nerves, brain or any organ, Is it harmful to their population behaviour (mating, selecting a mating partner, competition) Is it changing their ecological behaviour? migration?"
	"Could interfere with elephants' natural behaviour"
	"Understanding the negative impact that the collar can cause to the animal"
	"Possible health problems that may arise as a result of wearing the collar for a long time. Collars should be developed in such a way that it won't cause any health problems to elephants"
(3) Logistical difficulties	"Economically demanding, logistically difficult to conduct."
	"Difficult task"
	"Initial cost"
	"High cost"
	"It will be very expensive, fixing collars also to animals is also very tough task."
	"How do we identify elephants in the wild that usually go to attack villages to put the collars? How to capture the wild elephants to wear the collars on their neck?"
	"High cost, difficulty in fitting them on elephants"
	"Trying to capture wild elephants"
	"To capture & fix the satellite linked collar on the wild elephants."
	"If a mobile system is included the availability on the phones and rated resources could be scarce in the remote areas where the issue is persistent."
	"To get proper technical knowledge, proper staffing for elephant handling"
	"We can't use collars for every elephant in the heard. Its big challenge for deciding and select Elephant to put a collar."
	"This can be only used on a number of elephants, so figuring out which ones to be used will be a problem."
	"All the farmers here do not have mobile phones like other countries "
	"Elephant behaviours are unique to each area and therefore each area and elephant behaviour should be studies before this can be implemented."
	"Tranquilizing and fixing the shock collars. Monitoring 365 X 24 Hrs."
	"Will require lot of effort, many people and a lot of time"
	"Identification of key problem animals"
	"It will be difficult to put collar for large number of elephants and it would be a costly process"
	"It would be cost-prohibitive to use this on a scale that matters for managing elephants. cannot be deployed on hundreds of individuals over their lifetimes."

Theme	Examples
	"The challenge is to determine the exact location of a virtual electrical fence in a landscape that is completely fragmented. In addition, elephants often need to cross people's crops to move from one block of protected forest to the next. If this path is cut off with a virtual electrical fence, the conflicts will escalate. The underlying issue is not what type of electrical fence could be used, but to design an integrated elephant-friendly landscape."
	"Fixing the collars on all wild elephants"
	"Difficult task to fix collars on wild elephants"
	"Capturing wild elephants to install the collars would require a lot manpower."
	"Key challenge will be the implementation of the method which needs funding and training through workshops."
	"Extensive fieldwork and a dedicated team at the initial stage. Finding the problem elephants."
	"Applying the collars on elephants is certainly difficult/ dangerous"
	"The usual problems of capture and immobilization to fit a collar will exist and the responses of animals in the vicinity may also affect further collaring efforts. Until you start, it is difficult to determine how many elephants you would need to collar to make a consistent impact and the number could be large, if not all."
	"Scaling this up to cover large herds of elephants will be a challenge. For individual elephants, this would be somewhat manageable. cost of maintenance of such a system would be considerably high"
	"Fitting the collars on wild elephants. Even if it is done only on the matriarch, tranquilizing and capturing the matriarch to fit the collars might lead to anti-human feeling in the herd and they might want to harm humans in general."
	"Defining boundaries for virtual fences without severely compromising land available for elephants would be a key challenge especially in areas with no land-use plan. Deciding which individuals and how many individuals from a group should be fitted with a collar to effectively mitigate the conflict would be challenging."
	"Elephant living in a group and you cannot collar all of them but only few. The cost to collar elephant is expensive. The habitat need to be improve with proper land use planning, if they don't have enough room to live then this technique would certainly will not be effective. Combination with all the other mitigation strategies should also be applied."
	"Practicality in implementing in large areas with HEC"
	"Aside from the animal rights issues, there is the problem of installing electric collars on so many animals. Even if one decides to install the collars only on matriarchs, that is still a large number of animals that needs to be collared."
	"Expense of doing it at scale, including all the individuals/the right individuals (that might be leaders) in a group that participate in conflict; Collaring younger animals that are still growing might risk strangulation, meaning collaring them more than occasionally could lead to a high monitoring burden/risk of unconscionable animal welfare costs; Once more than a few elephants are collared, the government might lack the capacity necessary to properly track them and intervene."
	"I think the biggest challenge would be setting criteria of when it would be appropriate to use shock collars, and criteria of when it would be inappropriate to use shock collars. There will definitely be an element of trial and error, but there still be a robust justification of why to conduct the pilot study in a particular location/why you think the pilot study will be most likely to succeed in the location you choose."
	"Most wildlife departments and community organizations do not have the resources or technical capacity to do this."
	"High initial cost, Risk in fixing collars, lack of trained personnel, not enough people with experience to implement"
	"Identifying the problem elephants would be the primary issue for this approach. We are seeing in our tracking data that their movement behaviour are very diverse and identifying problem elephants can be challenging than previously thought since the elephants' resource use and strategy can change year-by-year."

Theme	Examples
	"Coming up with adequate funding for collars and implementation"
	"Rural communities may not have smart phones to receive information"
	"Financial issues, people with specialist technical knowledge"
	"High cost and will require trained people"
(4) Durability and reliable functionality of AGDs	"Prevent damage to the collars in the long-term wear."
	"Long term sustainability of the device, repairing the device, signal errors"
	"Elephants fast learners and intelligent, they will figure out a way to get the collars removed from their necks."
	"Elephants can damage the collar"
	"Technical issues with the device"
	"Network coverage in rural areas (hoping this system would need internet to communicate)"
	"Collars being broken or defects in collars can affect the results"
	"Ensuring all elephants have continuously working collars."
	"Keeping the collars charged. Weather interferences. Updating collars with elephant growth."
	"Natural behaviours/weather/bad maintenance can damage the belt."
	"Replacing batteries,"
	"Elephants might damage it's collar with time."
	"What about the durability of this collar? This will be using a power source like a battery to give an electric shock and sound alarms. So how long will this last? Most of the time troublesome ones are young male elephants, and they tend to fight each other very often. Can that be a problem? Can the collars be damaged and stop working? "
	"Managing and maintained of the collars, Satellite signals will be disrupted by dense forest, cloudy weather and other factors "
	"Poor satellite connection and signal issues"
	"Due to GPS signal loses in rural areas people will get false information about elephants"
	"Collar can be damaged when the elephant goes through the trees and bushes."
	"Should be protected from water."
	"Durability of the collars. Elephants will take off the collar."
	"They'll get used to it"
	"Damage to collar during fights, etc"
	"Battery life "
	"Collars have a battery life, require maintenance (periodic re-collaring), are prone to dysfunction, "
	"Durability and duration. Satellite collars are known to fail often. And the batteries have a life. How would you address these issues?"
	"Chances of elephants removing collars,"
	"Potential malfunctioning of the technology leaving elephants being shocked permanently or inappropriately - both of which might backfire. Elephants are VERY tough on technology, build it very strong & make sure it is fool proof."
	"The collars may malfunction and provide shock at other times or provide a shock of higher intensity than intended. what will happen when the batteries on the collars expire?"
	"Elephants are smart and would certainly find the collar as source of pain and try to destroy it"
	"Durability of the collar, battery life, elephant behaviour could harm the collar, Elephant might find the shock troublesome and try to break the collar"
	"Depending on terrain, canopy cover etc., sufficient GPS linkage might be problematic. Elephants have tough loose skin, so contact points for electric collar might not make consistent connections, all of which might prevent or undo any learned behaviours."

Theme	Examples
	"Sometimes they might be able to remove the collars somehow by damaging them, If signalling systems are damaged or satellite signals or phone signals are low in some areas, then there might be some issues with making people aware about trespassing elephants. "
	"Limited lifetime of collar"
	"I am afraid of collar malfunction, Elephants are clever and will definitely link the electric shocks with the presence of the collar, thus leading to the elephants trying to remove the collar. This will be done in a brute force way with the elephant maybe rubbing it against a tree. This whole process introduces the possibility of malfunction and raises the probability that the elephant will either experience constant noise or constant electrical shocks from the collar. To remove the collar will then be another large stressful event for the elephant as it needs sedating. The possibility of failure with the collar worries me the most."
	"Battery life. the frequency discharging the electric shock and for how long it would discharge shock if animal is not moving from danger zone?"
	"Also, the collar lasts only for a little while."
	"Regulation of the electric charge"
	"Collar failure/signal disable will make harmful to local inhabitants (local people will presume they are protected but these satellite signal disable will cause no warning to them resulting in causality, I think)"
	"Effectiveness of the GPS in tracking elephants in largely forested areas"
	"Durability of the collar – water resistance etc."
	"Risk of elephants receiving shocks continuously"
	"The continuity of proper functioning of the device without any technical failure/ life span of the device? "
	"How the collars are going to be retained by elephants"
	"The satellite collars do not last long. The life span of battery has been always challenging to us. If your collars can have long lasting battery life, then it would be a game changing intervention to minimize HEC."
	"Reliable technological functionality, especially in more remote areas, but in general maintaining satellite connectivity at the right times might be a challenge, Battery life could be an issue; Elephants might (?) recognize the collar is hurting them and try to damage/remove it"
	"In case collars gets removed or detached from elephants' body, elephants take shelters in areas having no satellite connectivity, Satellite linked warning collar may get damaged"
	"Weather resistant collars/ durability of collars"
	"Battery issues and technical issues of the collar"
	"Early warnings might not reach the people properly"
	"Developing a reliable collar"
	"Communication signals might not work in some areas"
	"Durability of the collar, accuracy of collars"
	"How to ensure that all collar work successfully"
	"How the collars may be affected by weather, Chance of collar removing"
	"Satellite connection may break down depending on weather conditions"
	"There is also a chance that the collars would get damaged or could get removed, rainwater could affect the electric components of the collar"
(5) Uncertainties in wild elephants' responses to AGDs	"Training wild elephants to respond to stimuli from the collars "
	"Herd might reject the collar wearing elephant. That's the major drawback because Elephant are socialized animals"
	"If the heard learn that only matriarch is susceptible for these shocks, they will soon adopt against it. Probably make the matriarch wait outside the fenced area while the heard enter without getting shocked?"
	"Feel that elephants could habituate to it"

Theme	Examples
	"They will find a way to adopt that shock "
	" Maybe the elephant will adapt to the electric shock and need to develop a system to increase or variable the electric shock where necessary. Behavioural changes due to frequent electric shock. As we know, many elephants' habitats and migrating routings are within the human areas."
	"Variable sensitivity to shock from elephant to elephant"
	"It is possible that some elephants will continue to raid crops and risk the shock, such as bull elephants (esp in musth). The shock could also cause aggressive behaviour so this also should be monitored so no one is in the vicinity and in danger."
	"Elephants are extremely smart animals and if you only tracked the matriarch it's likely this elephant may learn to avoid human-dominated landscapes, but this may not be the case for the rest of the group, who may still incur while the matriarch forages elsewhere."
	"However, collar will be attached to one elephant of the herds. I don't know how rest of the member will react to this."
	"Habituating to the shock collar, Chances of elephant panicking and acting aggressively in response to the shock,"
	"Terrifying of the elephants leading to human elephant conflict"
	"habituation"
	"Elephants are absolute genius. They quickly adopt or decode. We can only put on lone tuskers or matriarch. So other elephants of the herd can still cause sufficient damage."
	"Elephants are intelligent and somewhat unpredictable from our perspective as a different species. Individuals varying greatly in their behaviours and reactions ('personalities') and the consequence of receiving one or several electric shocks with only locational and auditory, but no visual, cues is really unpredictable. Captive animals may not offer much insight, so field tests are probably required from the start."
	"May aggravate the animal to cause more destruction."
	"Elephants can be acclimatized to the electric shock if they are frequently subjected to this, If the electric shock is given only to the leader of the herd or few, then the other members might enter the villages and do the damage. "
	"Over the long term it could have unpredictable behaviour results. Imagine a herd of elephants moving towards a border. The matriarch receives a shock and starts moving away. Would that behaviour challenge his/her ability to lead the herd? Would it lead to internal conflicts in the herd?"
	"Behavioural and thinking patterns difference between captured and wild elephants. "
	"Elephants are intelligent animals and the collar on the matriarch might lead to change in behaviour of the herd towards her. Also, once the collared elephant realizes that the shock is not really painful and bearing through it helps the herd in fetching food, the method might prove ineffective compared to electrical fencing wherein the entire herd gets the electrical shock."
	"Based on my experiences, most of wild elephant do tolerate things more than captive elephant, so the voltage that use for wild elephant maybe need to be adjusted. Also, I'm not sure whether wild elephant will show similar result to captive or not. Anyway, please also be careful, if the shock or noise from collar will stimuli the aggressive of the wild elephant."
	"It assumes that matriarch or habitual troublemakers will drive other elephants away from the danger. In reality this won't happen. The other non-collared animals will cause HEC, probably to a lesser extent? There is a possibility of HEC to be aggravated since electric fences are not existing, at least when pilot study is underway with proposed method."
	"The boundaries then might also have to have electric fences or something which the elephant takes as the reason of shock so he will keep avoiding it after the collar stops working"
	"Elephants could also learn to get around the barrier effect over time."
	"A word of caution in that elephants are vastly intelligent animals and may not be as acquiescent as cattle and sheep. The drive to find food and water currently means that some individuals, even mature females, will tolerate the pain of an electric fence to reach it."
	"Every Elephant can react in different way. Outcome cannot be generalized."

Theme	Examples
	"One will also cause disturbance in the social dynamics of the animals, because the other elephants will not understand why the collared matriarch is refusing to go into a certain area. They can't understand that the collared matriarch is receiving electric shocks from the collar."
	"How will the other elephants react to the elephant wearing the collar, Difference in how individual elephants will respond to it."
	"In case the elephant breaches the virtual fence, there should be a backup mechanism to mitigate the conflict which would arise then."
	"Elephants will eventually learn to circumvent it , they have done it every method used by humans"
	"There is a risk of elephant's behaviour being influenced/hampered by shocking from installed in her/his neck collars that even can provoke more damage to human lives/property,"
	"Some elephants (a minority) might get habituated"
	"The key challenges are the tremendous plasticity in elephant behaviour and their ability to adapt. As with other management techniques, I imagine that for some individual elephants the collars might work but perhaps not for all. Some elephants could potentially become more aggressive and go on a rampage after being shocked."
	"The time taken for elephants to learn the process"
	"Elephants could get aggressive as it disturbs their natural behaviour"
	"Since there is no physical barrier, if the elephant panics after the shock it might not be able to figure out the direction in which it should move"
	"If elephants walk forward ignoring the stimuli it will be difficult to be safe from the elephant"
	"This method might not be effective if the elephant gets used to the shock and sound"
	"Issues with sensitivity of elephants"