# Integration of agent-based and GIS-based modelling for geosimulation of human-elephant interactions in the Bunda District, Tanzania

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Abel Ansporthy Mamboleo

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# Abstract

Human-elephant interactions (HEI) are one type of the human-wildlife interactions that cause several adverse impacts to communities near African wildlife reserves. However, HEI is considered to be the most disastrous because of hostility of elephants and sheer size. The adverse impacts of human-elephant interactions include human and elephant deaths and injuries, crop damage and hidden impacts. Crop damage is the most common HEI reported adverse impact. Existing spatial and socio-economic studies provide a clear insight into HEI occurrences but lack precise measurements for each factor to either minimise or eradicate HEI occurrences. The model was developed to recommend the best HEI scenario(s) for either reduction or eradication of HEI occurrences in the Bunda District. A field survey was conducted to collect local opinions on HEI. A total of 130 questionnaires were distributed and collected from 12 villages in the district. Closeness of the villages to protected areas was the main criterion used to select the study area villages. The results from the questionnaires and secondary data were used to develop rule sets for development, calibration and, validation of an agent-based model of HEI for the Bunda District, Tanzania.

Spatial data on the location of hidden impacts and elephant crop damage were collected from 12 villages. Due to the complexity of hidden impacts and elephant crop damage, agricultural officers, wildlife officers, medical experts, and community development officers were consulted for clarification and consultation. The spatial data were used for kernel density estimation and hotspot analysis. Additionally, the spatial analysis was conducted to understand the relationship between HEI occurrences and environmental features. The spatial analysis showed the presence of more HEI incidents near the Grumeti Game Reserve than the Serengeti National Park. In addition, many incidents of HEI occurred within 2000 meters from rivers and protected areas. The results from a spatial analysis were used for model development, calibration and, verification and validation of the model.

The model simulated, tested and evaluated 18 modelling scenarios. Model results from each scenario were analysed for comparative performance, where minimal recorded incidents of crop damage, human deaths, elephant deaths, and hidden impacts were the primary focus. In that case, the selection of the best performing scenario based on the magnitude of the reduction of adverse impact(s). The AGHEI recommends the best scenario that minimised human access to the river, conservation corridors as well as the reduction in elephant population size. However, for each selection of the best scenario(s), there were costs that a model user must incur, as there was no cost -ree scenario. Reduction of any of the adverse impacts may run counter to fiscal, conservation, land and socio-economic policies. Therefore, the model user may select the best scenario within the constraints of these policies.

AGHEI allows conservationists to design, test and prescribe tested actions that can reduce HEI occurrences. This approach is possible in all countries with active elephant ranges worldwide, once modified. This AGHEI is specifically applicable to Bunda District, as it replicates the environment and behaviours of agents specific to Bunda. It serves a specific purpose and not a general-purpose tool. However, implementation of AGHEI to other areas is possible but it requires changes in the densities of elephants and humans in the models, as well as their attributes and the environmental characteristics of new areas. In addition, there must be changes in interaction rules to reflect the HEI dynamics of the areas of interest-specific to local populations. The thesis recommends further studies to investigate the distribution of HEI incidents in villages near Grumeti Game Reserve and Serengeti National Park, to evaluate, environmental legal and socio-economic implications for implementation of AGHEI modelling scenarios.

Keywords: Agent-based Model, Bunda District, Conservation corridor, Geographic Information Systems, Grumeti Game Reserve, Human-elephant Interactions, Human-Wildlife Interactions, Serengeti National Park,

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# List of Acronyms

| | |
|---|---|
| ABCM: | Agent-Based Computational Modelling |
| ABM: | Agent-based Model |
| ABM-LUCC: | Agent-Based Model of Land Use or Cover Change |
| AGHEI: | Agent-based and GIS-based Model of Human-elephant Interactions |
| CA: | Cellular Automata |
| CITES: | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| DAI: | Distributed Artificial Intelligence |
| DGO: | District Game Office |
| DLM: | Digital Landscape Model |
| GGR: | Grumeti Game Reserve |
| GIS: | Geographic Information Systems |
| GPS: | Global Positioning System |
| HEI: | Human-elephant Interactions |
| HWI: | Human-wildlife Interactions |
| IUCN: | International Union for Conservation of Nature |
| KWS: | Kenya Wildlife Services |
| MAS: | Mass Agent System |
| MNRT: | Ministry of Natural Resources and Tourism of Tanzania |
| OOP: | Object-oriented Programming |
| SENAPA: | Serengeti National Park |
| TANAPA: | Tanzania National Parks Authority |
| TAWA: | Tanzania Wildlife Authority |
| TAWIRI: | Tanzania Wildlife Research Institute |
| TENP: | Tsavo East National Park |
| UNDP: | United Nations Development Programme |
| URT: | United Republic of Tanzania |

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# Chapter 1 – Introduction

Human-wildlife interactions (HWI) offer positive and negative impacts to the communities residing near protected areas. The positive impacts include food, the raw material for industries, the basis for tourism and local medicines (Woodroffe et al., 2005). Negative impacts from HWI include human and livestock deaths or injuries, crop raiding, house demolitions, infrastructure damage, and hidden impacts. However, the negatives often outweigh the positive impacts because of their severity and frequency (Desai & Riddle, 2015). The severity and frequency of negative impacts depending on the type of species involved the nature of reserves, socio-economic activities and scarcity of ecological resources in the reserves (Lamarque et al., 2009).

Of all wildlife species, local people that share habitats with African elephants (*Loxodonta africana*) regard them as the most destructive species because of their unselective feeding behaviour and the ability to kill humans (Lamarque et al., 2009). Human-elephant interactions (HEI) cause problems in local communities in countries with large elephant populations. In Tanzania, Bunda is one of the two districts with the highest number of HEI events per year, with more than 500 (Mduma et al., 2010). Likewise, Assam is one of the districts with the highest number of HEI incidents per year in India (Borah & Bhuyan, 2016). Existing mitigation measures between local people and scientists have had little effect in reducing the adverse impacts of HEI (Fernando et al., 2008). Mitigation measures such as chili peppers, farm guarding, setting off fires and whistleblowing have been largely unsuccessful in reducing HEI occurrences (Lamarque et al., 2009; Parker et al., 2007).

Most mitigation measures are only effective under limited circumstances (Desai & Riddle, 2015). In addition, mitigation measures have received inadequate scientific testing (Nelson et al., 2003). Scientific testing usually unveils the durability, reliability, and productivity of any method. However, scientific testing and innovation are expensive in time and resources. The use of computational simulation may help in reducing the costs of both developing, replicating and testing HEI mitigation measures. Such an approach may lead to the innovation of and suggestion of reliable HEI mitigation measures. This thesis uses computation modelling to test and identify different options to either reduce or eradicate the adverse impacts of HEI in the Bunda District. The thesis integrates agent-based modelling (ABM) and geographic information systems (GIS) to form a geosimulation model of human and elephant interactions (AGHEI) that examines HEI occurrences in the Bunda District. The AGHEI investigates patterns of HEI resulting from the large-scale interactions between humans, elephants and the environment. The AGHEI model approach simulates HEI to evaluate the best option(s) for the reduction or elimination of adverse impacts of HEI.

## 1.0 Human Wildlife Interactions

Human-wildlife interactions (HWI) occur everywhere that wildlife and humans come into contact but mostly in communities near protected areas because wildlife use such areas as dispersal areas, migratory corridor, and refugia areas (Desai & Riddle, 2015). Parker et al. (2007) described HWI as “any interaction which results in negative effects on human social, economic or cultural life, on animal conservation or on the environment”. This thesis uses the phrase “human-wildlife interactions” instead of human-wildlife conflict (HWC) as the thesis focuses on HEI.

Due to their usually negative effects, HWI often impedes conservation and sustainable rural development efforts in developing countries (Granados, 2011). HWI impacts are the most debated conservation and development agenda in developing countries (Ladan, 2014). However, the extent and context of negative impacts differ due to the particular animal involved, geography, climate, culture, and environment of each country (Parker et al., 2007). The interactions cause direct and indirect impacts on human, wildlife and human property. Some of the notable impacts are human and elephant deaths, injuries and property damage. Hill (2004) suggested that costs, such as disruption of school attendance for children and the increased risk of contracting diseases during the night while guarding crops, were indirect or hidden impacts. Treves (2007) explained that HWI makes affected people become less sympathetic to wildlife conservation. As an example, rural people in Tanzania preferred removing adjacent wildlife protected areas after being in constant conflict with elephants (Gadd, 2005).

The proximity of people to protected areas and conversion of forests to food and cash crops degrades wildlife habitats and increases the likelihood of HWI (Ladan, 2014). Rahman et al. (2010) identified habitat fragmentation, deforestation, encroachment and unplanned settlement as the main sources of HWI in Bangladesh. Loss of natural wildlife habitats in favour of socio-economic development causes direct and indirect impacts on the movement, distribution, habitat use and preference of wildlife (Mutanga & Adjorlolo, 2008). In addition, impacts of climate change, such as floods, unreliable rainfall patterns, droughts, and increased temperatures, contribute significantly to increased chances of HWI (Ladan, 2014). Rapid increases in local human populations as well as changes in wildlife behaviour, such as unpredictable migratory patterns due to climate change, may intensify HWI occurrences (Mduma et al., 2010).

The nature of protected areas, geography and socio-economic manifestations of the place may determine the type of wildlife species that humans interact with (Graham et al., 2010; Parker et al., 2007; Thouless et al., 2016). Humans interact with herbivores in crop harvesting or ripening seasons while the home ranges of some carnivores extend dramatically in dry seasons because of prey scarcity, thus maximising interaction intensity with humans (Lamarque et al., 2009). Human-omnivore interactions are unpredictable due to their changeable feeding habits, which in some cases is not seasonal (Burton et al., 2013). Interactions between humans and herbivores are the most prominent and devastating because of the nature of the impacts (Treves et al., 2006). For centuries, humans accrued enormous benefits from African herbivores, including meat, manure, milk and ivory (Woodroffe et al., 2005). These herbivores also create serious economic, environmental and socio-cultural losses for humans. As examples, herbivores, including eland, hippopotamus, black rhinoceros, velvet monkeys, and elephants, cause significant agricultural losses for humans through crop raiding (Hill, 2004). Of all herbivores, local people claim that the African elephant is the most destructive and dangerous herbivore (Bandara & Tisdell, 2002). The exceptional feeding behaviour of elephants and the difficulty in controlling this behaviour are some of the reasons for this frustration.

## 1.2 Human-elephant Interactions

Human-elephant interactions (HEI) are a specific type of human-herbivore interactions where crop damage and hidden impacts are the most noticeable manifestations (Lamarque et al., 2009; Madden, 2004; Mduma et al., 2010). HEI can lead to human and elephant deaths or injuries, destruction of elephant habitat, and property and crop damage (Desai & Riddle, 2015). Humans harvest meat, organic fertiliser, ivory and medicines from elephants (Woodroffe et al., 2005). Lee and Graham (2006) stated that HEI was present in pre-colonial Africa. Indeed, coexistence between humans and elephants has a long history with HEI occurring over the entire coevolution of elephants and humans (Ladan, 2014). Lamarque et al. (2009) asserted that humans and elephants have interacted since human species started sharing the same habitat with elephants.

In Africa, about 37 countries reported HEI incidents in 2009 (Mduma et al., 2010; Parker et al., 2007). Granados (2011) stated that crop damage was the most reported impact of HEI in African countries. Guarding frequency, nature of crops, and isolation of the crop field influence elephant crop damage (Songhurst & Coulson, 2014). Some countries also report indirect or hidden impacts as another form of HEI adverse impacts (Barua et al., 2013). Indirect impacts from HEI include fear of injury and deaths and the disruption of normal routines, such as school attendance by children. Indirect impacts also include fear of walking at night, fetching water, collection of firewood and traditional medicines, and suffering from diseases, such as malaria contracted while guarding farms at night (Parker et al., 2007). Hidden impacts, in this thesis, refer to as indirect impacts. Indirect impacts are not obvious and rarely studied and local people barely regard them as problems generated by wildlife. The impacts are regarded hidden because neither conservationists nor villagers talk about them, nor their mitigation measures or means of assessment.

Despite the positive and negative effects of HEI, when the adverse effects exceed the positive, the affected local people become unsupportive of elephants and identify elephants as major pests whose existence threatens their lives and property (Granados, 2011; Ladan, 2014). Inadequate government support and intangible benefits emanating from elephant conservation intensify' negative opinions about elephants (Bandara & Tisdell, 2005; Barua et al., 2013). In addition, the exceptional lifestyle of elephants, such as their capacity to damage both field and stored crops during dry and wet seasons, strengthens negative opinions about elephants and make farmers insecure about their livelihoods (Lamarque et al., 2009). The capacity of elephants to compete with livestock and humans for water, food, and space discourages people from coexisting with elephants (Mduma et al., 2010; Nelson et al., 2003).

Because of their foraging behaviour and propensity to cause damage, people label elephants as agricultural pests and potential killers (Bandara & Tisdell, 2002). Also, uncompensated elephant damage undermines human's efforts and desire to engage in elephant conservation at a time when most conservation and land policies in Africa struggle to balance the needs of humans and elephants (Messmer, 2000). Regular interactions between people and elephants make them less tolerant of elephant damage. In retaliation, local people display aggression towards elephants sometimes resulting in deaths.

As a complex problem, HEI requires conceptual reasoning to develop sophisticated mitigation measures. For many years, scientists and local people have adopted several approaches to solve the problem including killing problem elephants, crop guarding, chili powder spread around the crop perimeter and the placing of hives of stinging bees. However, the majority of methods focus more on halting crop damage than elephant deaths, human deaths, and hidden impacts. Since HEI is both a dynamic problem in both space and time it is important to have a full understanding of both spatial context and underlying mechanisms behind HEI prior to developing and adopting any mitigation measure. To understand a spatial context requires a GIS approach and to understand the dynamics of HEI requires an ABM approach.

## 1.3 Integrating ABM and GIS for Human-elephant Interactions

Most studies have examined HEI in the context of crop damage, elephant deaths, and human deaths rather than hidden impacts (Prasad et al., 2011; Smith & Kasiki, 2000; Wilson et al., 2013). Spatial studies conclude that HEI events usually occur in landscapes that are close to rivers, protected areas and conservation corridors (Kyale et al., 2011; Prasad et al., 2011). The closer farms are to rivers, protected areas or corridors the more the damage to farms is likely (Prasad et al., 2011). Social-economic studies concluded that human and elephant population sizes affect the frequency and magnitude of HEI (Ladan, 2014; Lamarque et al., 2009; Mduma et al., 2010). The larger the human and elephant populations, the more frequent incidents of HEI occur (Lee & Graham, 2006). Existing spatial and socio-economic studies provide a clear insight of factors affecting HEI occurrences but lack precise measurements for each factor to either minimise or eradicate HEI occurrences.

Reduction of responsible factors can possibly reduce or eradicate HEI occurrences (Granados, 2011; Prasad et al., 2011; Wilson et al., 2013). Understanding the precise measurements for each factor is difficult, as it requires long-term experiments and replication of experiments in the study area. For example, experimental farms could be established at several distances from rivers, protected areas and conservation corridors. The farms could be guarded and crop damage incidents routinely measured and recorded, allowing the minimum distance to minimize HEI to be determined. Likewise, there could be other independent experiments investigating precise measurements for either human or elephant population size. In these experiments, humans or elephants in the study area either would be gradually killed or relocated until the HEI occurrences are either reduced or eradicated. If any factor does not minimise HEI occurrences, then scientists would design a separate experiment to include more than one factor at a time until the incidents are either reduced or eradicated.

In reality, such experiments are impractical and unethical. However, it is still important to provide conservation stakeholders need crucial information for designing and adopting appropriate HEI mitigation measures. Considering the importance of the information in eradicating HEI occurrences, this thesis integrates Geographic Information Systems (GIS) and Agent-based Model (ABM) approaches into AGHEI as an alternative approach. GIS provides information about where HEI occurs and what may co-occur with these events. ABM predicts where and when HEI occurs and responses to different mitigation measures. This integration of GIS and ABM aids the understanding of the dynamics of HEI. A lack of published studies integrating GIS and computational modelling to investigate HEI dynamics motivated the undertaking of this study. AGHEI is an abstract laboratory because it enables the identification of the responsible factor(s) and provides for precise measurement(s) of each incident without practically affecting the real world (Wilensky & Rand, 2015). In addition, the AGHEI performs ethical laboratory experiments and practice, as it allows adjustment, calibration of human, and elephant populations in the computer environment without violating any human and elephant ethics.

The AGHEI simulated and evaluated different scenarios of HEI to recommend the best performing scenario for either reducing or eradicating of the adverse impacts of HEI. The AGHEI recommended scenario(s) with either zero or lowest HEI occurrences as the best scenario(s). The model results disclosed how adverse impacts of HEI emerge (McLane et al., 2011) and identified mechanisms and causality behind HEI (Johnston, 2013). The model simulated HEI in the Bunda District, Tanzania. The district has the highest events (More than 500 annual incidences) of HEI in Tanzania (Mduma et al., 2010). The district borders Serengeti National Park and Grumeti Game Reserve. The two protected areas form part of the Serengeti ecosystem, which is one of the few ecosystems in Tanzania with a steady elephant population (TAWIRI & KWS, 2014).

## 1.4 Research Objectives

The main objective of the thesis is to develop a better understanding of HEI in the Bunda District of Tanzania by integrating agent-based modelling (ABM) and geographical information systems (GIS) to develop, run, and validate AGHEI under different modelling scenarios of HEI occurrences. The AGHEI developed, tested, and evaluated different scenarios to recommend the best scenario(s) for reduction and eradication of adverse effects of HEI in the Bunda District.

The objectives of the thesis were to:

- Determine and model the spatial patterns of HEI (hidden impacts, human and elephant deaths, and elephant crop damage) in the Bunda District, in relation to rivers, protected areas and conservation corridors.

- Conceptualise, develop, calibrate, and validate an agent-based model of HEI in the Bunda District by using rule-sets based on questionnaires and literature.

- Create, test, and evaluate modelling scenarios for either reduction or eradication of elephant death, human death, elephant crop damage and hidden impacts.

## 1.5 Research Questions

Specifically, the thesis asked the following questions:-

Do HEI occurrences vary with changes to the human population size?
Do HEI occurrences vary with changes in distance of human residents and farms to the rivers?
Do HEI occurrences vary with changes in distance of human residents and farms to the protected areas?
Do HEI occurrences vary with changes in the elephant population size?
Do HEI occurrences vary with changes in distance of human residents and farms to the conservation corridors?

## 1.6 Description of the Study Area

Tanzania is the union of the Tanzania mainland (formerly Tanganyika) and the Tanzanian islands (Unguja and Pemba). It is the largest country in East Africa and the 31st largest country in the world with an area is 945,166 km2, four times larger than New Zealand. Tanzania lies between latitude 1° and 12° S, and longitude 3° and 4° E, sharing borders with Rwanda and Burundi in the north-west, and the Democratic Republic of Congo in the west. The country also borders Kenya and Uganda in the north, Zambia in the south-west, Malawi and Mozambique in the southeast and the Indian Ocean in the east (see figure 1.6.1). Bunda is among five districts of the Mara region in the northern part of Tanzania. The Mara region borders the second largest freshwater lake in the world, Lake Victoria. Tanzania has 972 protected areas, which occupy about 36% of Tanzania's total area (Mduma et al., 2010).

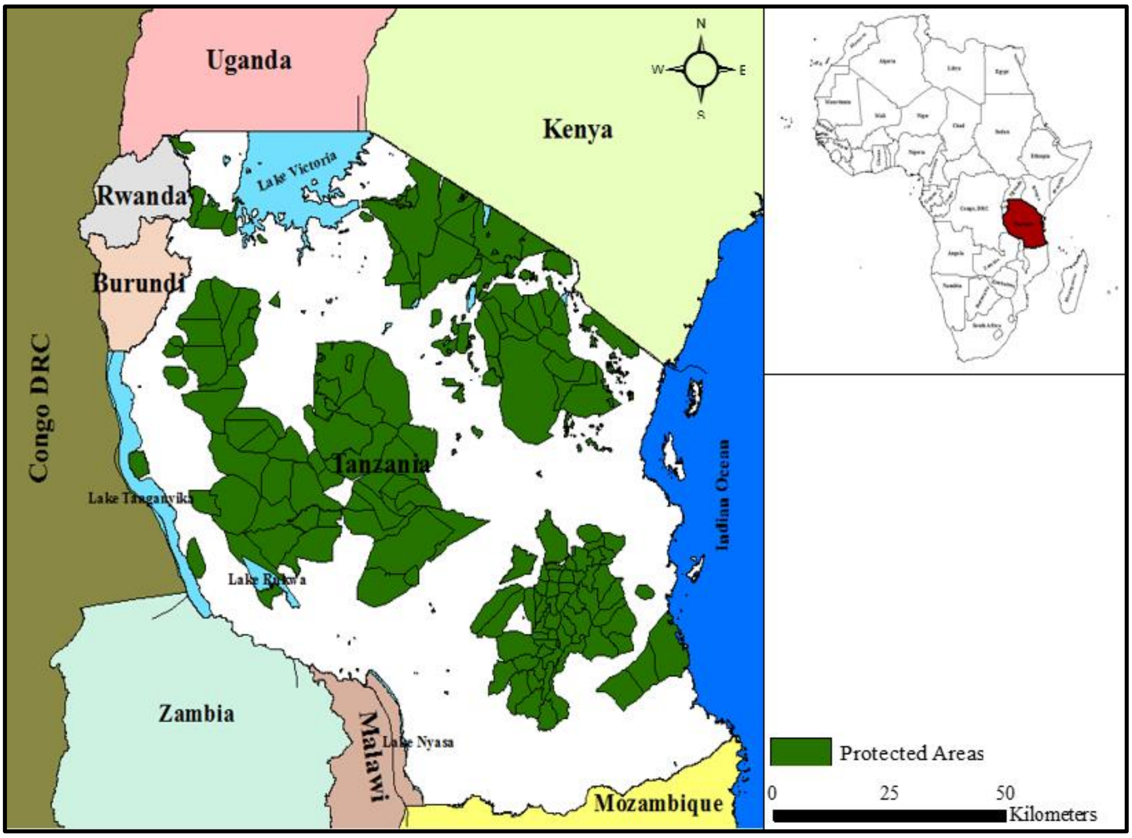

Figure 1.6.1: Location, wildlife protected areas and neighbouring countries of Tanzania.

Tanzania categorises her protected areas into National Parks, Game Reserves, Forest Reserves, Marine Protected Areas, Wetland Reserves, Game Controlled Areas, Ngorongoro Conservation Area, and Community-Based Natural Resource Management Areas. The categorisation centers on their administration, functions, and restrictions (Kideghesho & Mtoni, 2008). Bunda District is in the Serengeti ecosystem, which covers about 30,000 km2 (see figure 1.6.2). It lies between latitude 1°28” and 3017” S, and longitude, 33°50” and 35°20” E. Protected areas in the Serengeti ecosystems include Ikorongo Game Reserve (563 km2), Grumeti Game Reserve (416 km2), Maswa Game Reserve (2,200 km2), Ngorongoro Conservation Area, Serengeti National Park (14, 763 km2) and Kijereshi Game Reserve (km2). There is a strict prohibition on livestock keeping and human settlement in the National Parks and Game Reserves. Ngorongoro Conservation Area allows some human activities while National Parks promote non-consumptive wildlife utilisation (Kideghesho & Mtoni, 2008).

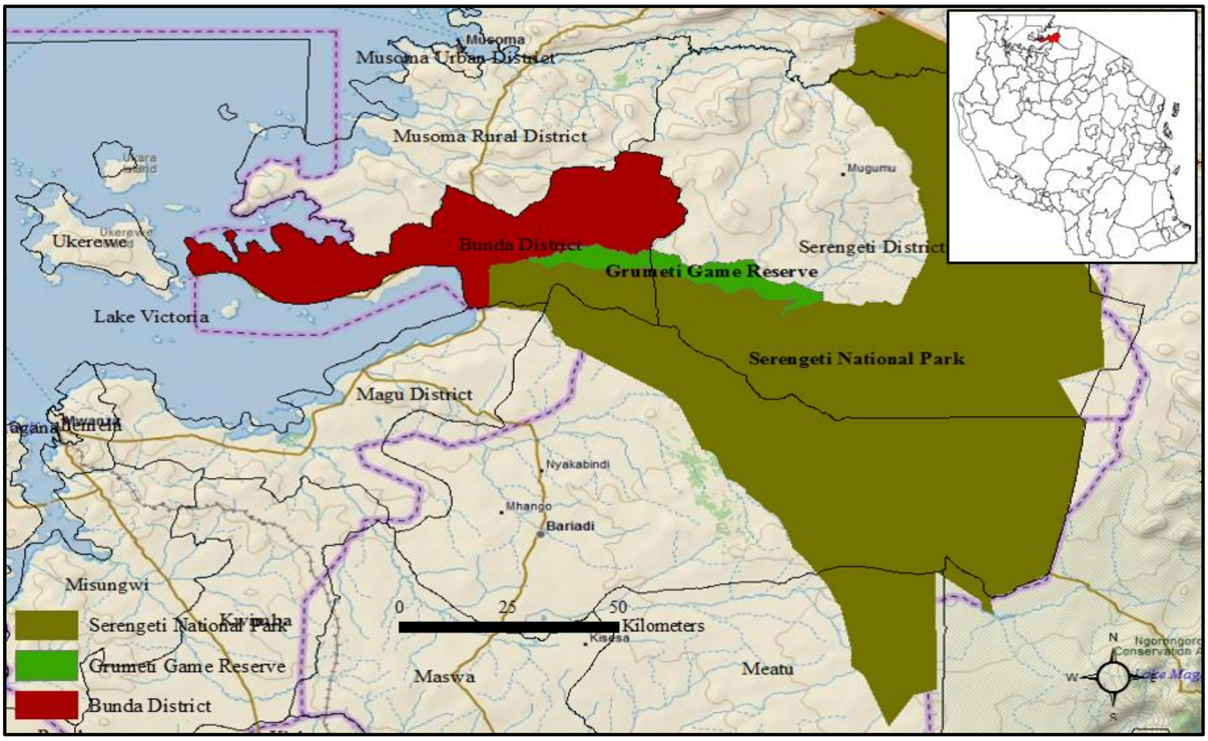

Figure 1.6.2: The Bunda District, Serengeti National Park and Grumeti Game Reserve.

The number of elephants is increasing in the Serengeti ecosystem despite ivory poaching pressure in the country (Mduma et al., 2010). According to Walpole et al. (2004), the earliest aerial count census showed that the Serengeti ecosystem had about 500 elephants in 1961. However, the number increased to more than 2,500 elephants in the 1970s. Because of ivory poaching in the 1980s, the number dropped to 500 elephants by 1986. The Universal Anti-poaching Operation formerly known as "Operation Uhai" and the adoption of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) in the 1990s reduced ivory poaching in Tanzania (Kideghesho & Mtoni, 2008). The elephant population in the Serengeti ecosystem has been increasing for the past 20 years and there were 3,068 elephants in the ecosystem (TAWIRI & KWS, 2014).

## 1.7 Thesis Summary

The thesis is comprised of seven chapters. Chapters 1, 2 and 7 are presented as normal chapters, while chapters 3, 4, 5 and 6 are presented as standalone papers. Since they are standalone papers, there will be content repetitions in some chapters, particularly description of the study areas.

**Chapter 2** summarises the literature that supports the aims of this thesis. It highlights where the knowledge gaps are and describes how this research can address these gaps. It summarises different studies about African elephants, human-wildlife interactions, geographical information systems, and agent-based models.

**Chapter 3** presents the results from field survey about local people's opinions on the incidence, magnitude and mitigation measures on HEI. The findings were used to develop the conceptual frameworks, programming code and verification of AGHEI outlined in Chapter 6.

**Chapter 4** presents a spatial analysis of crop damage patterns. These patterns were used to develop the HEI modelling environment, and for calibration, and validation of the AGHEI as presented in Chapter 6.

**Chapter 5** presents a spatial analysis of hidden impacts.

**Chapter 6** presents AGHEI conceptualisation, development, calibration and validation. It also provides an overview of the modelling scenarios and model experimentation and results on different scenarios. Lastly, the chapter discusses the model findings and suggests the best scenarios from AGHEI.

**Chapter 7** summarises the main findings and presents conclusions and direction for future research. This chapter presents the strengths and weaknesses of the approaches used for collecting the data for development and validation of the AGHEI and describes the importance and effects of the modelling approach. The applicability of the AGHEI approach within and outside the Bunda District is discussed. In addition, suggestions for future similar research are presented.

## 1.8 Statement of the Status and the Structure of Manuscripts

In this thesis, Chapters 3, 4, 5 and 6 have been prepared as manuscripts. Each manuscript contains individual abstract, introduction, methodology, results, and discussion sections. All manuscripts share one overall conclusion section, which is in Chapter 7. The status of all manuscripts is pre-submission as they are still under preparation. Mr. Abel Ansporthy Mamboleo (planning, data collection, analyses, writing), Dr. Crile Doscher (planning of the project and assisting with writing) and Associate Professor Adrian Paterson (planning of the project and assisting with writing) jointly author the manuscripts.

# Chapter 2 – Literature Review

## 2.1 An Overview of African Elephants

African elephants (*Loxodonta africana*) are distributed over 3 million km$^2$ in 37 African countries (WWF, 2004), equivalent to 22% of the African continent (Campos-Arceiz et al., 2012). Savannah or bush elephants (*Loxodonta africana africana*) occupy Southern, Western and Eastern Africa, whereas forest elephants (*Loxodonta africana cyclotis*) live in Central and Western Africa (Thouless et al., 2016). Population trends for African elephants are increasing despite some parts on the continent experiencing declining populations (Blanc et al., 2007). The ivory trade and HEI have been the main threats to the size and structure of elephant populations in Africa (Graham et al., 2010). The African continent hosted nearly 5 million elephants between 1930 and 1940 (WWF, 2004). The population declined significantly during the 1970s and 1980s because of uncontrolled ivory poaching and habitat fragmentation (WWF, 2004).

Africa currently hosts about 470,000 to 690,000 elephants (Campos-Arceiz et al., 2012). Blanc et al. (2007) stated that, in 2006, about half of the African elephant population were present in Tanzania (108,816 elephants) and Botswana (133, 829). As a comparison, Asia hosts about 50,000 elephants, of which 25,000 live in India (Bandara & Tisdell, 2005). The elephant population in Tanzania reached 109,051 individuals in 2009 (Mduma et al., 2010). However, blood ivory poaching in Tanzania reduced elephant populations from 109,051 in 2009 to about 55,000 individuals by 2015 (MNRT, 2015) . Elephant habitat has decreased from about 49% of Tanzania's area (458,351 km2) in 1998 to about 39% (370,000 km$^2$) in 2009 (Mduma et al., 2010). Human activities, including poaching, HEI and habitat degradation pose threats to the existence of African elephants (Graham et al., 2010; WWF, 2004). Uncontrolled human activities result in the loss of elephant habitats and migration corridors (Ladan, 2014). Human activities, such as hunting, livestock keeping and farming in the elephant landscape, interfere with elephant movement and foraging patterns (Graham et al., 2010).

Elephant migration is healthy as it allows an exchange of genetic material (Graham et al., 2010). Restricted movement constricts elephants into small habitats or "ecological islands" and affects population sustainability because the animals become genetically isolated leading to inbreeding depression (Ladan, 2014). The increasing local human populations are another threat to the existence of elephants (Blanc et al., 2007). The African continent is predicted to host about 1.8 billion people over the next 40 years (Le Bell et al., 2011). An increased population enhances demand for land, water, food, energy and industrial raw materials, and increases habitat fragmentation for wild species (Ladan, 2014). Human population growth also escalates resource competition between humans and elephants (Mduma et al., 2010).

### 2.1.1 Ecology of African elephants

Body size and ecological requirements determine the size of the elephant home range (Campos-Arceiz & Blake, 2011). Elephant home ranges typically extend between 5 km2 and 3,120 km2 depending on the availability of food and breeding mates (WWF, 2004). The distribution of food and water may also determine the size of a home range (Shannon et al., 2006). For example, an arid environment dictates the elephants require 12,800 km2 in Namibia and 24,000 km2 in Mali to meet their nutritional requirements (Graham et al., 2010). In that situation, the dry season home range is larger than the wet season range (Shannon et al., 2006). Elephants are adapted for long distance movement, which is crucial for accessing scarce resources (Graham et al., 2010).

Elephants are a generalist mega-herbivore without a natural predator (Cumming et al., 1997). The large body size enables the elephants to ignore most predators but increases the complexity in locating adequate quality and quantity of food (Cumming et al., 1997). As a result, elephants eat what is available to them though they are selective on the parts of the plant they eat (Osborn, 2004). African elephants consume about 500 species of plants (Campos-Arceiz & Blake, 2011). Asian elephants consume nearly 100 plant species (Campos-Arceiz & Blake, 2011). Elephants spend 70% to 90% of their time foraging while drinking about 100 to 400 liters of water per day (Hazarika & Saikia, 2013), and consuming about 100 kg to 300 kg of vegetation in a single day (Osborn, 2004). As a hindgut fermenter, they sometimes increase foraging periods to compensate for decreased food quality (Van de Koppel et al., 2002).

Elephants select plants that offer the highest nutrient level at a certain place and time (Osborn, 2004). The nutrition status of elephants determines the birth rates and sex of their offspring (Osborn, 2004). Male offspring are more costly to raise than female offspring in terms of nutrient investment. Elephant populations under inadequate nutrition may have distorted sex ratios (Gough & Graham, 2006). Elephants prefer grass species because of their high nutrient level, ease of harvest, low fiber content and low toxicity. They avoid bark and wood twigs because of lengthened handling time, lignification and thorns (Osborn, 2004). Elephants also feed on acacia seedpods to supplement their protein intake (Van de Koppel et al., 2002).

Elephants scarcely meet the dietary requirement from eating only grasses in the dry season because the level of protein becomes low in grasses at this time (Van de Koppel et al., 2002). In that situation, elephants often switch to crop-raiding if given the opportunity (Oliveira et al., 2014). Crop raiding is where wild herbivore grazers target human field crops or stored crop products for foraging (Lamarque et al., 2009). Elephants value agricultural crops because of their high nutrients and low chemical and physical defenses (Osborn, 2004). Male elephants are habitual crop raiders because they take more risks to obtain nutrients that will maximise their reproductive success and are regularly found closer to human settlement than females (Hoare, 1999). Furthermore, (Graham et al., 2010) ascertained that the speed of elephant movement is higher in the human-dominated landscape than in protected areas. In short, elephants can adjust their foraging patterns according to circumstance (Hoare, 1999).

### 2.1.2 Human-elephant Interactions

HEI occurs when the basic requirements of elephants overlap with those of humans (Ladan, 2014). Coexistence between humans and elephants has existed since the beginning of humanity (Ladan, 2014) and HEI is therefore at least as old as agriculture (Lamarque et al., 2009). Since the beginning of agriculture, 10,000 years ago, farmers have been in constant conflict with elephants (Oerke, 2006). HEI possess positive and negative consequences (Woodroffe et al., 2005). People obtain positive benefits through direct exploitation of tangible products from elephants, such as trophies and medicines, and intangible products, such as tourism (Lee & Graham, 2006). In addition, humans obtain benefits through exploiting HEI with the conversion of wildlife habitats into agricultural land, human settlements, roads, and railways. Humans obtain negative outcomes in the forms of human deaths, injuries, crop damage and competition for prey (Ladan, 2014).

For many countries, national statistics on HEI are either lacking or incomplete (Messmer, 2000). Such statistics are crucial in highlighting the general overview of HEI, particularly in the developing world (Ladan, 2014). In those countries, the incidents are not only poorly assessed but are also not spatially identified (Mutanga & Adjorlolo, 2008). HEI needs special attention because people regard elephants as the most dangerous herbivore in their environment (Okello et al., 2014), as elephants damage both staple and cash crops (Parker et al., 2003).

When positive and negative factors of elephants are summed, the benefits elephants provide to humans may exceed their conservation costs (Messmer, 2000). Unfortunately, the fate of elephants depends on the tolerance of humans (Treves, 2007). Bandara and Tisdell (2002) suggested that human actions are a major problem in wildlife conservation, including HEI. HEI occurs in all countries with elephants (Ladan, 2014; Lamarque et al., 2009). In Africa, HEI usually occurs in localities close to natural elephant ranges (Le Bell et al., 2011). HEI inflict direct and indirect negative impacts to humans including crop damage, deaths, crop damage, and hidden impacts.

#### 2.1.2.1 Crop Damage

One of the most noticeable negative impacts of HEI is crop damage (Le Bell et al., 2011; Mduma et al., 2010; Vincent R. Nyirenda1, 2012)). Farmers in Africa experience regular crop damage incidents and describe elephants as threats to agriculture and rural development (Parker et al., 2007). Due to negative interactions, many people consider elephants to be vicious killers and uncontrollable agricultural pests (Treves, 2007). In Ghana, elephants cause yearly agricultural crop damage amounting to US$ 450 per farmer (Lamarque et al., 2009), which is equivalent to 34% of the annual household income in Ghana (Brown et al., 2008). The annual cost of elephant crop damage is US$ 60 in Uganda (Lamarque et al., 2009), which is equivalent to 7% of their annual household income (Uganda Bureau of Statistics, 2011). Elephant crop damage costs US$ 510 per farmer Cameroon respectively (Lamarque et al., 2009), which amounts 28% of the annual income of the households bordering protected areas (Tieguhong & Nkamgnia, 2012). Also, 65% of annual crop damage incidents in Mozambique involved elephants (Le Bell et al., 2011).

Elephants are not the most destructive species when compared to other agricultural pests, as species like rodents and starlings that cause significant agricultural crop damage amounting to US$ 4.5 billion in the United States (Peterson et al., 2010). Hill (1997) stated that rodents cause significant agricultural damage to subsistence farmers in Africa. In Asia, every year, rats consume enough food to feed 200 million people per year (Stenseth et al., 2003). Pre-harvest losses caused by rodents in Tanzania are about 15% of the total annual harvest (Meerburg et al., 2008). A worldwide agricultural loss of about 10.1 % on rice, wheat, maize, potatoes, soybeans, cotton and sugar beets due to insects occurred in 2003 (Oliveira et al., 2014). Baboons, pigs, velvet monkeys and birds ranked as the most destructive agricultural pests in Uganda (Hill, 2004).

Elephants are not significant agricultural pests compared to primates, wild pigs, rodents, and insects although elephant crop damage is more localised and severe than those of other pests (Hoare, 2007). In addition, most of the HEI victims are poor subsistence peasants (Lamarque et al., 2009). Crop damage not only reduces food security but also the nutritional status of poor families (Granados, 2011). In the same way, Asian elephants cause significant agricultural damages to farmer incomes in India, where elephants damage approximately 1 million hectares of agricultural crops, and demolish between 10,000 and 15,000 houses, annually (Barua et al., 2013). The annual agricultural damage by elephants in India is worth 3 million US dollars (Barua et al., 2013). However, many countries in Africa including Tanzania, lack statistical data on elephant crop damage due to technical, political and geographical circumstances (Lamarque et al., 2009).

#### 2.1.2.2 Human Deaths

Each year elephants kill and injure people and destroy property (Barua et al., 2013). For example, Indian elephants kill about 200 people in India, annually (Woodroffe et al., 2005). In Kenya, African elephants killed 200 people between 2000 and 2007 (Ladan, 2014). In Tanzania, African elephants kill 40 to 50 people and injure 30 to 40 people, annually (Mduma et al., 2010). Lamarque et al. (2009) reported that human deaths and injuries are less common than elephant crop damage. Despite these figures, elephants cause fewer causalities than some other wildlife species (Lamarque et al., 2009). For example, hippopotami kill more people annually than elephants (Woodroffe et al., 2005). Crocodiles kill about 300 people annually in Mozambique (Lamarque et al., 2009). Rodent-borne diseases infected nearly 14,000 humans and took the lives of about 364 people in northeast Thailand between 1996 and 2001 (Meerburg et al., 2008). Lions killed 35 local people in eight villages within 20 months in Tanzania (Baldus, 2004).

People usually respond to causalities and threats by killing elephants and sometimes by destroying elephant habitat to prevent further destruction (Treves, 2007). 79% of people in Koija, Kenya recommended elephant killing as compensation for human deaths (Okello et al., 2014). 52% of people from the periphery of Bénoué National Park in Cameroon recommended eradication of problem elephants from the park

(Granados, 2011). The retaliation against elephants often takes place without proper recognition and identification of involved elephants (Lamarque et al., 2009). In 2003, pastoralists poisoned all lions in Amboseli Reserve and speared about 27 lions in Nairobi National Park as revenge for killing their livestock (Lamarque et al., 2009). In addition, the government of Uganda killed 106 leopards and 376 lions between 1920 and 1960. In many cases, governments have rewarded local people who have killed carnivores (Treves, 2007). Other countries avoid deliberate eradication of carnivore populations except for exotic carnivores that threaten native ecosystems (Treves & Karanth, 2003).

#### 2.1.2.3 Hidden Impacts

Hidden or indirect impacts also called secondary impacts or "socio-economic opportunity costs" (Hoare, 2007), are usually negative effects on a person's state of "psycho-social wellbeing" resulting from HEI (Barua et al., 2013). The impacts include fear of injury or death, restrictions on human movement, particularly at night, competition for water resources, poor health, and nutritional status, and competition for livestock grazing ground. Indirect impacts also include reduced school attendance for children due to fear of elephants, disruption of family life due to interrupted sleep, interrupted collection of firewood and fruit, and higher chances of being infected by diseases, such as malaria, while guarding crops or property at night (Barua et al., 2013; Parker et al., 2007).Poverty, poor access to basic resources, ethnic and political marginalisation may intensify hidden impacts (Barua et al., 2013). A size of an animal, level of an animal's hostility, the lifestyle of an animal and their biophysical dimensions may further determine the intensity of hidden impacts (Hill, 1997).

The exceptional lifestyle of elephants, which includes the ability to be active for 18 hours, unable to be controlled and great appetite, makes people scared of elephants. Unfortunately, there is no scientific method to quantify the hidden impacts or secondary impacts of HEI into a standard economic scale (Parker et al., 2007).In this case, the indirect impacts of HEI stand to be the main determinants of the people's animosity towards elephants as hidden impacts outweigh other impacts of HEI (Barua et al., 2013). People label elephants as the most dangerous animal species largely because of hidden impacts though they actually cause less damage to life and property than other wildlife species. For instance, it is possible for farmers to tolerate large amounts of agricultural damage from livestock and yet not tolerate comparatively minor crop damage from elephants (Hill, 1997). Furthermore, in some localities in Burkina Faso, people are more tolerant of human deaths caused by crocodiles than those caused by elephants (Lamarque et al., 2009).

### 2.1.3 Mitigation Measures of Human-elephant Interactions

In developing countries, many national conservation policies prevent farmers from taking direct action against problem elephants (Hill, 1997). People often demand the freedom to control problem elephants by themselves (Bandara & Tisdell, 2005). If conservation authorities ignore the needs of rural people or refuse to work with them closely, people continue killing elephants (Madden, 2004). It is possible to train and authorise local people to control problem elephants using legal and ecologically friendly methods. Conservationists generally work in an environment that requires that they recognise, embrace, respect and incorporate attitudes, values, and beliefs of various stakeholders (Messmer, 2000). Conservationists need to be careful when suggesting control measures because each situation of HEI is a unique integration of social, cultural, economic, political, historic, species and geographic complications (Madden, 2004). Conservationists are trained from an ecological perspective with little or no social science and technological training (Bennett et al., 2017) and may have the insufficient practical expertise to end the negative impacts of HEI (Hoare, 1999). The ability to manage HEI becomes more difficult as human social structure and dynamics continue to be overwhelming (Messmer, 2000).

#### 2.1.3.1 Traditional Methods

Delayed support from conservationists leads to the adoption of traditional and farm-based mitigation measures (Sitati et al., 2005). The methods involve self-defense measures taken by people to protect their lives and property (Nelson et al., 2003). People in Asia, as in Africa, use crop guarding, noise, fire, alarms, repellents, fences, ditches, and biological fences, such as cacti, Opuntia and euphorbia, trenches, deterrent, car engine oil, chilli, tobacco dust, fire and play-back calls to defend against

Asian elephants (Fernando et al., 2008; Lamarque et al., 2009). Financial hardship necessitates the adoption of traditional methods (Nelson et al., 2003). These methods are user-friendly, low-cost and more effective at the lower level of the conflict (Fernando et al., 2008). Farmers may use a combination of various traditional methods to increase their effectiveness of controlling problem elephants. A combination of vigilance, chili repellent and simple fencing techniques significantly reduced elephant damage in Kenya, Zimbabwe, and Zambia (Haynes, 1999). However, there is no method that can stand alone as a "universal solution" for controlling elephants; they simply adapt to the techniques (Fernando et al., 2008). Many countries manage HEI without specific policies or legislation (Hoare, 1999). A few countries in Africa have addressed HEI as a single article or a simple clause in their conservation legislation (Lamarque et al., 2009).

Many countries, including Tanzania, use a centralised wildlife damage management system (Mduma et al., 2010). The reason behind such centralisation is that local people cannot control problem elephants by themselves (Lamarque et al., 2009). In these circumstances, the governments authorise special experts or units to kill problem elephants. For example, in Tanzania, only authorised officers can kill problem elephants (URT, 2009). In Namibia, it is mandatory for locals to kill some problem animals, such as primates, but not protected species, such as elephants (Lamarque et al., 2009). Many governments authorise the killing of problem elephants to console the sufferers. For example, the Kenya Wildlife Authority kills about 50 to 120 problems elephants each year in retaliation for human deaths (Lamarque et al., 2009).

The mitigation methods of HEI are neither proactive nor effective (Hoare, 1999). They are generally ineffective because people prescribe particular mitigation measures to a broad range of HEI (Madden, 2004). Also, conservation laws and policies are silent about hidden social and economic impacts resulting from the HEI (Messmer, 2000). Compensation or consolation schemes do not directly integrate hidden impacts into mitigation measures (Madden, 2004) and the schemes seldom translate the hidden impacts into a fair economic scale (Parker et al., 2007). Though it is beyond the scope of this thesis, translating indirect, social and economic as well as nutritional and psychological impacts into the understandable and measurable scale for fair compensation would be very beneficial (Barua et al., 2013).

#### 2.1.3.2 Modern Methods

The innovation of modern methods to mitigate the negative impacts of HEI is crucial. People need effective mitigation measures to reduce the adverse impacts of HEI. Research is not seen as important, in Kenya, local people chased away researchers with machetes after a prolonged study without an outcome that helped people (Treves, 2007). However, scientists have developed and implemented sophisticated technologies to control HEI. For example, image detection systems can detect elephant individuals (Sugumar & Jayaparvathy, 2013). In this approach, a detected image of an elephant is translated into a GSM message that is sent to conservation authorities indicating that the elephant is in close proximity to property. In addition, zoologists in Namibia have successfully controlled the movement of male elephants by emitting a deep vibration call from a female elephant that is in heat (Swietek, 2013).

Ecologists have suggested the deployment of stinging bees (*Apis mallifera adonsonii*) to deter crop-raiding elephants, keeping elephants away from areas by placing beehives. An elephant sidesteps stinging bees to protect its eyes, ears and trunk membranes from bee stings (Ndlovu et al., 2015). Consequently, Ngama et al. (2016) found that elephants avoid both empty and active beehives. Ndlovu et al. (2015) identified that bees auditory and olfactory cues alert elephants to the presence of stinging bees because elephants are proficient in sensing various sound frequencies and use their olfactory system to sense chemicals. In that case, elephants can make a distinction between active and empty beehives, passing swarms and active beehives (Ndlovu et al., 2015). This deterrent method is ecologically friendly, culturally sensitive and economic viable. However, it may sometimes be vulnerable to habituation and the crop food reward may be worth the risk of bee attacks (Ngama et al., 2016).

Innovation and deployment of modern technologies require scientific knowledge on fundamental mechanisms of HEI. Several studies have examined socioeconomic and environmental aspects of HEI. However, scientific information on the configuration and mechanisms of HEI is often unaddressed. Scientific information is crucial when conceptualising, designing, and testing any mitigation measures. Scarce or unreliable information impedes scientific discoveries and testing of promising innovations. This thesis adopted the modelling and simulation approaches to understand, design, test, implement and evaluate different scenarios of HEI. The approach was beneficial as it considered both spatial and dynamic natures of HEI. Since HEI is both a spatial and dynamic problem, in both space and time it is important to have a full understanding of both spatial context and underlying mechanisms behind HEI occurrences. In this thesis, GIS and ABM unveiled the spatial and conceptual understanding of HEI. The two approaches provide answers to the question of where, how and why HEI occurs.

## 2.2 Geographic Information Systems

Geographic Information Systems (GIS) use and store geographically referenced data by linking it with non-geographic features (Llyold, 2010), allowing handling and manipulation of the data for spatial analysis and spatiotemporal modelling (Kainz, 2004). GIS manipulates an object within a geographically referenced space to gain specific knowledge from spatial data. GIS acquires data from aerial photography, paper maps, existing digital data, remote-sensing satellite imagery, and GPS. GIS is a science, a discipline, a technology and an applied problem-solving tool (Longley et al., 2005). GIS is also a data store or application for a database, a toolbox, a technology and a source for spatial information science (Kainz, 2004). In those regards, there are different approaches that people can use to apply GIS. For example, from the application approach GIS can be a tool to answer questions, to support decision making, to store spatial data and information and to make maps.

There are various ways of using GIS as a tool for solving problems. For instance, health experts may use GIS to choose the best location of a hospital. Transport companies may use GIS to select the desired routes for their trucks. Conservationists may use GIS to decide how to manage the protected areas and identify areas with the highest poaching incidents, where to put tourist roads, and where to conduct trophy hunting. Farmers may use GIS to decide on-farm management approaches including the application of fertiliser and pesticides to different parts of the farm. Most decisions that humans make have a geographical component (Longley et al., 2005) and benefit from the use of GIS (Longley et al., 2005).

GIS answers questions about map interpretation, geography, geospatial issues, accuracy and errors (Prasad et al., 2011). GIS provides the ability for measurement, mapping, and analysis of the real world (Longley et al., 2005) as well as analysing patterns in geographical space and extracts knowledge from them (Kainz, 2004). Geoscience follows spatial information theory, which provides the capacity to integrate spatial reasoning, representation of space and human understanding of space. GIS can also simplify the direct integration between geographical information systems and simulation software for agent-based modelling, such as Agent Analyst (Johnston, 2013).

Understanding the spatial patterns of geographical features is important during planning, policy devising, and decision making because many decisions have spatial components (Mutanga & Adjorlolo, 2008). GIS tracks events and entities (Longley et al., 2005). Two important ingredients of geographical data are spatial data (where is it?) and attributes (what is it?) (Einstein, 2001). Spatial data are computer representations of spatial features in the world storing a digital representation of the real world as a Digital Landscape Model (DLM). A database represents various phenomena of the real world (Kainz, 2004). GIS uses vector (points, lines, and polygons) and raster (grid cells) data to model the real world (Einstein, 2001).

Modelling usually creates a smaller, abstracted and generalised representation of the real world (Kainz, 2004). The two approaches of spatial data modelling are analogue map representation and digital database (Goodchild, 2006). Digital or spatial models are gradually replacing analogue models (Kainz, 2004). Analogue models display information on paper, such as a map (Einstein, 2001). Representation depends on the selected spatial data model (Kainz, 2004). Field-based and object-based models are the two fundamental approaches of spatial data modelling. In other words, GIS data are stored as either vector or raster data (Einstein, 2001). Field-based models deal with continuous spatial features, such as temperature, pressure, and elevation, while the object-based model considers discrete objects, such as lakes and buildings (Castle & Crooks, 2006).

There are static and dynamic spatial models. Inputs and outputs of static spatial models belong to the same time, whereas those of dynamic models advance in discrete time steps, each step representing a fixed interval of time (Goodchild, 2006). Geospatial modellers refer to dynamic models as spatiotemporal because of the integration of temporal information. Time intervals can be discrete, such as seconds, minutes, hours, days, months and years, or continuous time intervals, such as “after”, “before” and “events” (Kainz, 2004). Spatio-temporal models outputs can be compared between the real and the modelled world. This creates the possibility of assessing and evaluating human activities in the environment (Goodchild, 2006). The temporal domain is an important component for developing spatiotemporal models (Kainz, 2004). Moreover, dynamic models can be used to predict dynamic situations (Goodchild, 2006).

The geospatial analysis allows the manipulation and transformation of raw spatial data to derive useful information to support decisions making and reveal patterns. According to (Câmara et al., 2004), spatial analysis can be described as an “inductive process”, which examines empirical evidence in the search of patterns that might support new theories, though it can also be deductive as well when testing the existing theories or principles. The branches of spatial analysis are centrographic techniques and pattern analysis. Centrographic techniques measure both central tendencies of location, which include mean, mode, median, and dispersion (range, variance, and standard deviation) of the location of the geographic objects. In comparison, pattern analysis techniques investigate the type of distributions of spatial objects, which are points, lines, and polygons. Spatial analysis occurs in the form of point patterns analysis, surface analysis and areal analysis (Câmara et al., 2004).

Point patterns analysis tests hypotheses about the spatial distribution of a set of points. In the same way, point pattern analysis establishes a relationship between the occurrences of events and characteristics of individuals (Câmara et al., 2004). The two fundamental concepts for studying spatial point behaviour are first-order effects and second-order effects. These are the kinds of processes that are responsible for point patterns or point distribution. First-order effects are associated with the process, intensity and mean number of events per unit area at a certain point (an independently located point). Second-order effects involve interactions of points in the area of study, and spatial dependency is the manifestation of the order. The second-order effect has local representation or neighbourhood patterns. Their patterns cluster and relate to the neighbourhood and not in the global context. In this context, the spatial dependency is an important principle in understanding spatial phenomena. (Câmara et al., 2004) suggest that the concept of spatial dependency originates from the first law of geography, which states, “everything is related to everything else, but near things are more related than distant things”. According to Tobler’s Law “dependency is present in every direction and gets weaker the more that the dispersion in the data localisation increases”(Câmara et al., 2004). As an illustration, the presence of damaged farms near an elephant migratory route suggests that such farms are vulnerable to elephant crop damage.

### 2.2.1 Geographic Information Systems for Wildlife Conservation

The application of GIS for wildlife management has increased in the past two decades (Hazarika & Saikia, 2013). Advancement and flexibility of GIS have enhanced spatiotemporal analysis of patterns for wildlife management (Wilson et al., 2013). GIS enhances the understanding of causal mechanisms and processes of geographically referenced phenomena (Vanleeuwe, 2010). Consequently, GIS provides important tools for solving wildlife management problems (Longley et al., 2005). It simplifies the conservation and management of endangered species by understanding their conservation status, interactions, and movements (Rahman et al., 2010). Ecologists use GIS to solve complex and dynamic geographical problems relating to wildlife management. Kyale et al. (2011) deployed GIS to understand spatial patterns of elephant mortality caused by poaching incidents in Tsavo East National Park (TENP), Kenya. In their study, they found that elephant poaching strongly correlated with land cover, proximity to main rivers, surface water, patrol bases, park gates, park boundaries, and roads. The research findings revealed these environmental features as one of the determinants of poaching incidents in TENP.

It is also possible to apply GIS to investigate wildlife habitat utilisation. Musiega and Kazadi (2004) applied GIS to analyse the wildebeest (*Connochaetes taurinus*) migratory patterns in the Serengeti-Mara ecosystem in East Africa. (Mpanduji et al., 2008) assessed habitat utilisation by African elephants in the Selous-Niassa Wildlife Corridor, which is the transboundary corridor connecting Selous Game Reserve (Tanzania) and Niassa Game Reserve (Mozambique). Scientists have also used GIS to examine the geospatial configuration of HWI. As examples, Mutanga and Adjorlolo (2008) used GIS to study human-eland conflict (*Taurotragus oryx*) near Kamberg Nature Reserve, South Africa. They estimated the proximity of crop damage to environmental features, finding that eland crop damage positively correlated to the distance from water points, but negatively correlated with the distance from forest and roads.

Prasad et al. (2011) used a GIS-based model to predict the patterns of people and Asian elephants in the Western Ghats, India. Rahman et al. (2010) deployed a participatory geospatial technique to sketch routes and migratory corridors of Asian elephants in Sherpur district, Bangladesh. In this study, the researchers used local knowledge to identify, sketch and verify routes, corridors and patterns of HEI in the area. Smith and Kasiki (2000) used GIS to examine the effects of spatially explicit factors on the distribution HEI in the Taita Taveta district in Kenya. Likewise, Sitati et al. (2003) used GIS to predict the spatial aspects of HEI in the TransMara district of Kenya. The prediction model based on land cover and distance from roads. However, most of the geospatial studies of HEI have many features in common. The studies have only explored the spatial configuration of the direct impacts of HEI, particularly crop damage and human deaths. This thesis explored both the direct and indirect impacts of HEI.

In Tanzania, a few studies that have investigated HEI by deploying GIS. Kikoti et al. (2010) analysed elephant use and conflicts in the western Kilimanjaro, Tanzania and Mpanduji et al. (2008) analysed habitat use of elephants in the Selous-Niassa Corridor. In addition, Mmbaga et al. (2017) investigated the concentration of elephant crop damage in the Rombo District, one of the districts with the highest HEI occurrences in Tanzania. In 2004, the Frankfurt Zoological Society funded a study to quantify the impacts of HEI in the Serengeti district (Walpole et al., 2004). Researchers conducted this study on the border of Ikorongo and Grumeti Game Reserves. The researchers used meetings and semi-structured interviews to develop their theories about HEI. Data collection encompassed locating affected farms and villages. Crop damage was the only HEI data collected. Researchers admitted that the nature and extent of the data collected provided inadequate spatial and temporal information.

In this thesis, GIS was deployed to analyse the spatial configuration of HEI in Tanzania's Bunda District, by assessing location, distribution, concentration of HEI in relation to Grumeti Game Reserve (GGR) and the Serengeti National Park (SENAPA). Understanding of distribution, location, and concentration of the hidden impacts may help conservation agencies acquire a geographical outlook of HEI. A concise spatial knowledge about the problem promotes timely and accurate decisions making the process for mitigating the adverse impacts. Geographical and biological components of HEI are important for understanding their distribution, concentration, and proximity to environmental features, as most of the management decisions humans make have a spatial context.

## 2.3 Agent-based Modelling and Simulation

Agent-based modelling and simulation (ABM) is a computational approach for modelling complex systems consisting of agents interacting in an environment (Johnston, 2013). It enables creation, experimentation, and analysis of modelling scenarios composed of autonomous decision-making agents (Wilensky & Rand, 2015). The adoption of ABM is essential because humans live in a complex environment. The world consists of many micro-level interactions that produce events or emergent features (Crooks et al., 2018). As an example, micro-level interactions between humans and elephants produce events, such as human deaths and elephant deaths. In this respect, decisions made by many agents are the immediate cause of the current state of the environment (Tisue, 2014).

ABM creates a simplified environment for experimenting and analysing the interactions between agents and their environment (Gilbert, 2008). A model uses an agent to represent decision-makers in the real world. Agents have all mental components, capabilities, choices, and commitments required to make decisions at the right time (Crooks et al., 2018). Modellers often refer ABM to by different names, including Agent-Based Computational Modelling (ABCM), Agent-Based Social Modelling (ABSS), and Mass Agent System (MAS) (Bousquet & Le Pageb, 2006). In addition, modellers describe ABM as Distributed Artificial Intelligence (DAI) (Bousquet & Le Pageb) and Agent-Based Model of Land Use or Cover Change (ABM-LUCC) (Castella et al., 2005). Modellers describe the simulation of agents as bottom-up modelling or artificial social systems (Axelrod, 1997).

Different authors have described the history of ABM in different ways. For example, Johnston (2013) asserts that the applicability of AMB began 40 years ago, with Stanislaw Ulam's Cellular Automata (CA). The famous "complexity of cooperation" theory of Axelrod (1997) shows that the applicability of ABM began in the 1980s. The author used ABM in the form of complexity theories to study complex problems involving many actors and interactions. Agent-based models may have originated over a hundred years ago when researchers attempted to solve complex social and ecological problems (Heath et al., 2009). However, the history of ABM is not as important as the flexibility and applicability of ABM techniques in solving complex problems.

### 2.3.1 Modelling of Agents and Environment

Johnston (2013) describes agents as both living and non-living entities capable of deciding and carrying out tasks. Agents could include animals, environment, plants, land parcels, cars or humans. Scientists describe the behaviours of agents by simple rules, which agents use to react and interact with other agents and their shared environment (Macal & North, 2010). Consequently, modellers design agents to react in a computational environment by following simple rules (Gilbert, 2008). Interactions may happen between similar agents or between different agents and their associated environment (Heckbert et al., 2010). Such interactions normally result in complex ultimate outcomes of the social or ecological system. ABM captures the interactions between agents and their environment by simulating the complex interaction between them (Tang & Bennett, 2010). The environment is normally an abstract world and neutral interaction ground, with little or no effects on agents. The environment does not decide because it is the medium for interactions but can be affected by agents (Johnston, 2013).

ABM allows a better understanding of the features and processes of complex systems by simulating these processes and systems (Crooks et al., 2018). ABM is an ethical laboratory for carrying out complex experiments as it allows experimentation by killing animals in the computer environment without violating any animal's ethics in the real world (Castle & Crooks, 2006). It is a "way of doing thought experiments" (Axelrod, 1997 and allows respect for human and animal ethics (Gilbert, 2008), because of the ability to perform ethical experiments in a virtual environment, and it saves time and important scarce resources. It provides a modelling environment suited to complex systems for observing emergent, non-linear and adaptive phenomenon (Heckbert et al., 2010). Its flexibility makes integration of ABM to GIS possible.

Unlike theories and mathematical models that are in natural and mathematical languages, computer-programming languages in ABM are more communicative and practical than most mathematically based theories (Gilbert, 2008). Furthermore, the flexibility of computer programs in ABM allows modellers to change major model-parameters or any part of the model without undergoing any significant change in the computer program. In other words, a system in ABM allows individual agents their behaviours and strategies based on the past events while most mathematical models are deterministic, getting the same output from the same inputs unless it's a stochastic system. This is impossible in most mathematical models (Wilensky & Rand, 2015).

Modellers identify agents and their behaviours, specify their rules and identify the context in which the agents interact or live (Crooks et al., 2018). Agents can perform a set of rules multiple times depending on their specifications to obtain possible emergent features (Johnston, 2013). Agents are programmed to interact within a digital environment; such interactions involve the transfer of data from one agent to another. A relationship between agents is specified as reactive, meaning either the agent will only react after being triggered, or as goal-oriented, where it seeks a goal (Castle & Crooks, 2006). Agents act based on their internal state, observations of other agents or the detection of the effects of their actions on other agents (Gilbert, 2008). In this case, the emergent features result from interactions between agents and the environment, and between agent and agent (Heath et al., 2009). Wilensky and Rand (2015) asserted that emergent patterns are subject to deterministic-centralised mindset because people usually underestimate the role of randomness in creating emergence patterns and therefore they ignore randomness as the force for creating emergent patterns. In this study, when interviewees were asked how geese move into v-formations shape when flying, the answers were "it is leader bird in the front and he is followed by his lieutenants" or "it is the mother bird up followed by its children". In reality, there is no leader bird or mother bird leading the flock but these are patterns emerging out of the behaviour of individuals and the adjustment of the behaviour in the interaction with other individuals (Wilensky & Rand, 2015).

In a modelling context, a computer is an experimental laboratory where agents, their behaviours and the environment interact and provide outcomes from simulations. (Castle & Crooks, 2006). An ABM enables a modeller to simulate macro-phenomena resulting from micro-level interactions of heterogeneous agents with a structure of interaction networks affecting the dynamics of the complex system (Heckbert et al., 2010). According to Castle and Crooks (2006), models are computer programs with a simplified digital representation of an aspect of the real world, transforming them to create a new representation. An ABM computational approach also presents several challenges and impediments to modellers. Validation can be difficult and the difficulty increases as the model become more complex. Furthermore, simulating the behaviour of each agent in the model may become time-consuming (Johnston, 2013).

### 2.3.2 ABM and Wildlife Management

With wildlife conservation, researchers have studied various complex ecological issues by using ABM. Biologists have used ABM to understand animal movement patterns and navigation capacity (Tang & Bennett, 2010). Watkins et al., (2011) modelled the decision making of jaguars when moving across various habitats. Agent goals based on the following questions: "What would be the best corridor design policy? One wide corridor? Multiple thin corridors? A series of small islands between the two forests? The authors concluded by saying that a set of five narrow corridors were better than one corridor of the same collective width. Such findings are practical for wildlife management because wildlife species need reliable ecological connectivity to exchange genetic materials and access basic resources. (Scott et al., 2014) modelled the dynamics of the Santa Cruz Island fox, *Urocyon littoralis santacruzae*, in the US. The authors examined how the low population density of the fox correlates to a low fitness level and whether a recessive allele could spread. The expression of allele effects increased with small increases in annual population growth.

ABM is a versatile tool for exploring wildlife behaviour and movement to achieve conservation goals (McLane et al., 2011). ABM approximates reality because it simulates wildlife behaviours and movements in a detailed realistic way (Castle & Crooks, 2006). However, ABM of wildlife movement is difficult because of the mobility and nature of interactions between species (Tang & Bennett, 2010). The movement of wildlife is in response to achieving short-term goals, such as reproduction, foraging and escaping threats (McLane et al., 2011) as well as to achieve long-term goals of avoiding extinction (Ascensão et al., 2013), and reducing detrimental recessive genes through inbreeding (Scott et al., 2014). Movement behaviours of wild animals entail four important dimensions, internal state of the animal, external factors (climatology, hydrology, ecology and psychology), motion and navigation capacity (Tang & Bennett, 2010).

Modellers have tried to model interactions between humans and wildlife. As an illustration, Ascensão et al. (2013) modelled HWI in the form of road effects on population persistence. Results suggested that partial fences are more effective than passage and full fencing in reducing road mortality as well as in increasing genetic diversity. Similarly, Musiani et al. (2010) explored human-wolf interactions in Banff and Kootenay National Parks, in Western Canada. Their study aimed at understanding future scenarios for guiding decision makers in designing management strategies for wolves (*Canis lupus)* (McLane et al., 2011). Their model highlighted that the presence of humans significantly affects the movement and behaviour of wolves in terms of prey hunting, prey consumption and attendance of pups.

Burton et al. (2013) used ABM to evaluate control methods of wild pigs (*Sus scrofa*) in the US. The modellers used ABM to predict the effectiveness of wild pig control measures. Suggested interventions included administration of immune-contraceptive program and lethal control through hunting. Burton et al. (2013) discovered a combination of contraceptives and hunting would be more effective than either approach used alone. However, the researchers could not unfold and predict the extent of damage and interactions between farmers and pigs. This would help in disclosing how much damage occurs where, within which bounds the wild pig damage exists (McLane et al., 2011). The associated adverse impacts wild pigs are more catastrophic in Africa than any other continent because of the social and economic situation (Barua et al., 2013). This conflict remains one of the most challenging conservation issues (Lamarque et al., 2009).

### 2.3.3 Object-oriented Agent-based Programming Paradigms

The basis of agent-based modelling is that everything is an object and it is possible to take any conceptual component in the problem and represent it as an object in a program (Eckel, 2006). A program is written to simulate states and activities of the objects. The main concepts of object-oriented programming (OOP) are classification, encapsulation, abstraction and inheritance (Eckel, 2006; Wang, 2002). Wang (2002) considered agents as objects with certain attitudes due to their adaptability, mobility, autonomy, adaptability, and personality. Agents and objects are similar because both are defined by the concepts of classification, encapsulation, and inheritance. Agents and objects differ, as agents are intelligent and control their own behaviour while objects are not autonomous (Wang, 2002).

Object-oriented programming defines the relationship of objects by a static inheritance (Eckel, 2006), while the agent-based programming approach defines the relationship between agents using complex and dynamic inheritance (Eckel, 2006). The classification approach for objects is static, as objects cannot change the class they belong to (Eckel, 2006), while in an agent-based approach the classification is dynamic and the agent can change the class it belongs to (Wang, 2002). Agents have an ability to learn and can add or eliminate features dynamically (Castle & Crooks, 2006), but objects are incapable of adding and deleting any features as the methods are invoked under the control of other components (Wang, 2002). In short, an agent-based programming approach can be perceived somehow as a higher level than the object-oriented programming approach (Wang, 2002). Agent-based programs can be implemented using object-oriented approaches though they may fail to cover all complexity of an agent-based paradigm (Wang, 2002).

### 2.3.3 Integrating GIS into Computational Models

The integration of ABM and GIS provides opportunities for combining dynamic-object oriented capacities of ABM and spatial modelling abilities of GIS to analyse HEI (Johnston, 2013). The integration allows ABM to be related to the actual geographical location by explicitly incorporation space into the model design (Crooks et al., 2018). The inclusion of space in the model makes it not only dynamic but also realistic (McLane et al., 2011). The integration of GIS into ABM promotes efficiency through reduced computing times, capacity, and through new functionality (Brown et al., 2005). A majority of modellers focuses on roles for, application of, and complex challenges related to the construction of ABM of HWI, though one of the main challenges for ABM development is integrating GIS functionality into ABM (Parker et al., 2003). This is because of the dynamic nature of ABM (Johnston, 2013). The integration of GIS techniques into ABM provides relevant and realistic dynamic models. The real-world environmental representation in ABM has a coordinate system imported from the real world (McLane et al., 2011). In other words, the world is abstracted away and represented into GIS layers, which form the environment for an artificial world for which agent inhabit (Crooks et al., 2018).

Linkage of ABM and GIS started in the 1990s (Johnston, 2013). SWARM was the first simulation software to integrate agent-based modelling with GIS (Castle & Crooks, 2006). The software needed a user to have prior computer programming knowledge to create a functional ABM. Designation and launching of Netlogo simulation software enabled modellers with no prior programming knowledge to integrate GIS and ABM more easily (Wilensky & Rand, 2015). Modellers can develop ABMs by using myriads of simulation software or toolkits (Castle & Crooks, 2006). Such flexibility provides options for selecting a suitable toolkit for the integration of ABM and GIS (Parker et al., 2003). However, Parker questioned the ability of software to share vocabulary and understand the theoretical effects of underlying assumptions, which is possible in traditional mathematical modelling. Parker advised the development of a universal standard ABM framework for implementation in various software environments.

Technological development in graphic modelling in ArcGIS enables GIS users to develop dynamic models (Johnston, 2013). By assigning temporal behaviour as an attribute of an object rather than the environment, ABM allows a relative view of temporal patterns in which it updates objects asynchronously as opposed to updating all at once (Brown et al., 2005). Johnston (2013) suggested, "interacting GIS and ABMs can represent a full range of dynamic models, from cellular automata to agent-based models with reactive agents to richer agent-based models with goal-direct agents that can learn and update their behaviours". Brown et al. (2005) supported the ongoing argument to extend the existing spatial model to the spatiotemporal models because such an extension enriches the model with suitable information on the evolution of pattern, properties, and location of pattern with time.

Dynamic ABM extracts data from a GIS database and sends modelling results back to GIS for visualisation and further analysis. Models read and use real-world spatial data, such as slope, population, and animal movement from a GIS database, and translate the output in GIS format (Parker et al., 2003). Therefore, dynamic models need firm and dynamic integration of GIS into ABM. The two analytical tools require tighter integration in the form of either agent-based centric, GIS-centric or middleware approaches, which can link the existing data with GIS (Johnston, 2013). Such integration enables harmonisation of the changes and updates on the GIS database with the changes in the status of agents and the environment in ABM. Middleware is the best approach as it builds on existing platforms. It involves the development of software to handle a causal relationship between agents within ABM and spatial features within GIS as well as topological and temporal relationship issues in the model (Brown et al., 2005). The most popular GIS and ABM integration software are Agent Analyst, MASON, and Repast (Johnston, 2013).Brown et al. (2005) described how agents have the capability to take actions that may affect spatial features. Agents can change the value of an attribute in a field, such as the value of a raster grid cell. For example, local people near protected areas may implement mitigation measures to reduce food shortage and human deaths, such as erecting fences, thereby changing their environment. Alternatively, humans may convert elephant corridors and habitats into human settlements and agricultural farms. Human actions may affect attributes (elephant abundance) and spatial expression (through cultivation and settlement) of the polygon features representing the natural habitat of an elephant. For example, elephants as agents hold movement rules related to points and attributes in a spatial database. The points move when the elephant moves, and features of the points change as the elephant moves. In this example, elephants as mobile agents may update their own location, shape, and attribute, affecting changes in a spatial database or graphic display. Similarly, elephants can interact with other agents regardless of having associated spatial patterns or not.

The two methods of representing the environment in an ABM are cell-based raster cells or object-oriented vector patches (Tang & Bennett, 2010). However, the choice of environmental representation depends on the goal of a model (Castle & Crooks, 2006). McLane et al. (2011) asserted that for wildlife management, a cell-based spatial representation of the environment is more convenient than a vector approach. The cell-based approach is user-friendly in computing wildlife movements and behaviours. It is also flexible in habitat selection and conforms adequately to several types of data formats including, but not limited to, remote sensing images and digital elevation models (DEMs). Object-oriented patches are a useful approach to representing animal distribution, movement patterns and animal habitat (Brown et al., 2005). Similarly, object-oriented patches represent agents as vectors, raster layers, and networks (Johnston, 2013).ABM allows an extension of GIS to a simulation environment (Castle & Crooks, 2006). Coupling is a measure of how strongly ABM and GIS software are connected to each other or a measure of the degree of independence between ABM and GIS. Coupling provides the linkage of two standalone software programs by data transfer (Crooks et al., 2018). According to Castle and Crooks (2006), the tight coupling means there are units in between software dependent on one another, characterised by direct inter-system communication during program execution. Loose coupling refers to the practical independence of the systems, and data between systems are exchanged in the form of files.

Brown et al. (2005) recommended tight coupling of data and model within ABM and GIS because of efficiency through reduced time and capability through the new functionality. It is a good way of taking full advantage of GIS and ABM to perform multi-scale geographical data in ABM (Minelli et al., 2016). However, the extent of implementation between GIS and simulation software remains technically and conceptually challenging. Castle and Crooks (2006) discovered that GIS fails to clarify the geographic nature of the geographic phenomenon, particular a spatiotemporal updating of spatial data in ABM, because ABM updates temporal behaviours of agents but GIS does not. Moreover, a difference in the model structure makes ABM and GIS hard to merge making communication between ABM and GIS difficult (Crooks et al., 2018).

Many researchers have used either GIS or ABM separately to study interactions of human-wildlife interactions. For example, Mutanga and Adjorlolo (2008) used GIS to analyse human-eland interactions at Kamberg Nature Reserve in South Africa. Similarly, Sitati et al. (2003) used GIS to predict the patterns of HEI. In this context, few researchers have integrated GIS and ABM to study wildlife management. Perez and Dragicevic (2012) integrated an agent-based model and GIS to study the relationships between tree mortality patterns and insect infestations. The study found that elevation, aspect, and infested neighbours have equivalent weight in the dynamic process of forest insect infestation. Musiani et al. (2010) used ABM and GIS to study human-wolf interactions at Banff and Kootenay National Parks, the study revealed that wolf movements and behaviours were infected by the intensity of human presence.

### 2.3.5 Agent Based Modelling and Simulation Software

The construction of agent-based models involves proper knowledge and selection of a relevant modelling toolkit or simulation software. Agent-based software is important because it provides abstractions with which modellers can develop objects (Abar et al., 2017). It also involves a certain feature of virtual programming, which is crucial for serving time, and for simplifying model development (Crooks & Castle, 2012). As an example of agent-based toolkits, Swarm was the earliest developed simulation software (Johnston, 2013). Currently, there are many simulation software programs, including Repast, Netlogo, GRASS GIS, Mason, StarLogo and Agent Analyst (Crooks & Castle, 2012; Johnston, 2013; Wilensky & Rand, 2015).

There are certain criteria for the selection of simulation software (Abar et al., 2017). Castle and Crooks (2006) suggested criteria such as availability of software templates or demonstrations as familiarity with a programming language and the number of agents for modelling. Others are types of model environments available, and compatibility with other software (Johnston, 2013). Programming experience, execution speed, and scalability of the platform are some of important to consider when selecting a simulation platform (Abar et al., 2017). Programming skills are an essential criterion because scientists wishing to use ABM may be discouraged by how difficult is to learn a simulation platform. In addition, scalability of the platform may influence the selection of a particular platform, the platform that can reproduce a variety of patterns observed in the real system, between moderate to high complexity but not a massive number of agents, is a suitable one (see figure 2.3.5.1).

Image Removed for Copyright Compliance

Figure 2.3.5.1 Easy model development versus model scalability (Abar et al., 2017).

In this thesis, Netlogo was used as the simulation software as it is well-designed with many sample prototypes from different disciplines, which were available for modification to fit the requirements of models under construction. The current version, Netlogo 6.0.2, contains many sophisticated capabilities, such as grouped agents (turtle, link, observer and patches), buttons, selectors, a well-designed user interface, monitors and graphs (Abar et al., 2017). Netlogo has a programming language that is simpler to use than Java or Objective-C, which allows a reduction in both programming efforts and time (Abar et al., 2017). It provides a conducive modelling environment as there is a clear separation between the implementing and displaying environment. In a Netlogo environment, a modeller can develop code to set the most preferred type, size and the colour of agents. A graph and parameter controller can easily be added into Netlogo. Netlogo uses a simple but powerful programming language and a well-designed built-in user interface with detailed documentation of model codes (Railsback et al., 2006).

### 2.3.4 Netlogo Simulation Software

Netlogo is a simulation platform for simulating natural and social phenomena. It is designed for research and educational purposes. Uri Wilensky and Mitchel Resnick authored it at MIT Media Laboratory (Tisue, 2014). Netlogo software enables the investigation of emergent features resulting from large-scale interactions of agents. Historically, Netlogo succeeded in previous multi-agent modelling toolkits, including StarLogo. Netlogo is freeware and is a stand-alone application. The current design of Netlogo reflects the earlier environment of StarLogoT. Acceptance of the software is increasing in different disciplines. Netlogo uses its own programming language called Logo, which is simpler to use than the Java programming language. The environment in Netlogo identifies four types of agents, which are turtles, links, observers and patches. The observer is an agent that provides instructions to patches and turtles. Turtles are the primary mobile agent type in Netlogo while patches essentially make up the environment. Moreover, Netlogo classifies turtles into different collections of agents called breeds. Turtles and patches have locations defined by X and Y coordinates in Netlogo. Netlogo serves a myriad of users with different backgrounds in programming skills, from children in educational institutions to experienced computer programmers. For an experienced programmer, Netlogo allows them to add their own extensions.

In this thesis, the deployment of a GIS approach assisted in the preparation of human settlements, crop farms, elephant habitat and locations of the turtles. The locations of (X, Y coordinates) the model environments and agents reflected their respective positions from the study area. In short, GIS was used to prepare the geographical aspects of the model, which was used as the main interaction interface during the simulation. GIS was used to analyse the current state of the distribution and hotspots of hidden impacts and crop damage in the Bunda District. Moreover, GIS was used to analyse the spatial relationships between HEI patterns and geographical features, such as rivers and protected areas. ABM helped in the conceptualisation and execution of the HEI rules. ABM identified the interactions of small patterns resulting in larger patterns for easy observation and analysis. It enhanced the interactions between and within turtles but also between turtles and patches (environment) to achieve the purpose of this thesis. However, the development of the model needed the support of sets rules. These are the logic of concepts specifying the way of interactions between human, elephants, and environment should interact. In this case, local people's opinions were consulted to understand their experiences with elephants. In addition, other information was obtained from secondary information including literature and government reports.

# Chapter 3 – Local Peoples' Opinions on HEI

# Analysing local opinions on incidence, magnitude and mitigation measures of adverse impacts from human-elephant interactions in the Bunda District, Tanzania

## 3.1 Abstract

A survey was conducted to collect local people's opinions on the magnitude, incidence, adverse impacts and mitigation measures for human-elephant interactions (HEI) occurrences in the Bunda District. The survey involved 30 local people from 12 villages. The survey deployed a purposive sampling technique (judgmental or expert sample) to locate participants with consolidated knowledge and experience on HEI occurrences. Crop damage was the main recorded direct impact of HEI while house damage was the least recorded incident in the district. The majority of local people deployed traditional techniques to mitigate the adverse impacts of HEI. A minority of villagers used wounding traps and most reported problem elephants to conservation agencies to reduce the adverse impacts. Locals claimed that elephants are docile as it was possible to approach them as close as 50 meters without any harm. Despite their docility, locals also claim that preventing elephants from causing crop damage may result in human deaths. Locals recorded sighting more than 11 elephants every day in the farming areas.

**Keywords:** Bunda District, Conservation corridor, Crop damage, Elephant death, Grumeti Game Reserve, Hidden Impacts, Human death, Human-elephant Interactions, Local opinions, Serengeti National Park,

## 3.2 Introduction

Human-elephant interaction (HEI) is a type of human-wildlife interactions, which also includes human-carnivore and human-omnivore interactions. The adverse impacts of the interactions include human, wildlife and livestock deaths, crop damage and indirect impacts. Local people regard HEI as the worst case of human-wildlife conflicts due to the aggressive nature of elephants and their long periods of daily eating. Humans have been routinely interacting with African elephants since before the beginning of traditional agriculture (Osborn, 2004). Local people identify elephants as major pests whose existence threatens not only their lives but also their properties. Inadequate government support and they usually intangible benefits people receive from elephants are part of what is intensifying their negative opinions on elephant conservation (Bandara & Tisdell, 2005; Barua et al., 2013). Added to this is the lifestyle of an elephant that brings people into the conflict with human including the ability to forage on different types of plants, their requirement to drink about 300 liters of water in a day and their 18 hours per day of activity adds to this negative perception (Advani, 2014). The ability of elephants to damage both field and stored crops makes farmers feel insecure about their livelihoods (Lamarque et al., 2009). Humans and livestock fatalities, and competition for water, food, and space with livestock discourage local people from coexisting with elephants (Mduma et al., 2010; Nelson et al., 2003). The negative impacts of HEI usually occur in communities residing in proximity to elephant reserves (Leel et al., 2009; Muruthi, 2005). Elephant crop damage is made more severe and localised because the majority of victims are subsistence farmers whose main socio-economic activity is agriculture (Lamarque et al., 2009).

Crop raiding is the most frequently recorded impact of HEI (Desai & Riddle, 2015). Crop raiding incidents are most severe on farms bordering unfenced protected areas, such as national parks and game reserves (Desai & Riddle, 2015; Lamarque et al., 2009). Elephants prefer crops because of their high nutrient value and low chemical and physical defense (Osborn, 2004). In some areas, male elephants are habitual crop raiders who take risks to obtain nutrients to maximise their reproductive success (Hoare, 1999). Elephants prefer plants that offer a high nutrient level and are easy to access (Osborn, 2004). Because the nutrition status of elephants determines birth rates and sex of their offspring, male offspring are more “expensive” than female offspring regarding nutrient investment (Hoare, 1999). Elephants choose grasses due to their high nutrient level, ease of harvest, low fibre content and low toxicity while avoiding bark and wood twigs because of lengthened handling time, lignification and thorns (Osborn, 2004).

Prolonged exposure to adverse impacts makes people hostile towards elephants. In retaliation to these impacts, people respond by killing elephants, in turn becoming a threat to the size and structure of the elephant population in Africa (Graham et al., 2010). In the absence of timely support from conservation authorities, local people usually deploy cheap, traditional and farm-based mitigation measures (Sitati et al., 2005). People in Asia use crop guarding, noise, fire, alarms, repellents, fences, ditches, cactus fences and playback calls to repel problem Indian elephants (Fernando et al. 2008). Lamarque et al. (2009) described that in Africa, people use vigilance, fencing (including biological fences, such as cacti, Opuntia and euphorbia), trenches, chili and tobacco dust, and fire. If these methods fail, local people will use lethal methods to control elephants (Treves, 2007) (Hill, 2004).

Bunda District has a high incidence of HEI, with more than 500 events occurring every year (Mduma et al., 2010). Overall, HEI is poorly understood in the district but knowing the locations, frequencies, and magnitudes of impacts are critical for effective mitigation measures. To better understand the local people's perceptions and understandings of elephant movements and behaviours, a survey with interviews was carried out. The results from this survey informed the development of the rule sets for an agent-based model. The analysis aimed at gauging local people's knowledge and experience on the locations, magnitudes, incidences, adverse impacts, and techniques for minimizing the negative impacts of HEI in the Bunda District. This information was used for computational modelling and assisted conceptualisation, development of programming code and validation.

## 3.3 Material and Methods

### 3.3.1 Description of the Study Area

Bunda is the home of more than 25 ethnic groups. The most dominant and common tribes in the area are Kurya, Ikoma, Jita, Sukuma, Ikizu, Natta, Isenye, Zanaki, Zizaki, Ngoreme and Taturu. The main economic activity within the region is subsistence agriculture, which accounts for about 80% of the people's annual income (Kideghesho & Mtoni, 2008). Farmers normally grow maize, millet, cassava, and sorghum as food crops and cotton as cash crops. Furthermore, people keep sheep, goats, and cattle (Walpole et al., 2004). The majority of inhabitants are peasants, fisherman, livestock keepers, and small-scale traders. Bunda District had the highest human population density in Tanzania of about 200 people per km2, and annual population growth of about 3.0% (URT, 2013). The District is in the western part of the Serengeti ecosystem lying between latitude 1°30" and 2°45" S, and longitude 33°39" and 34°05" E. It is about 3,088 km2. The district has contributed a large part of its land surface to wildlife conservation. Lake Victoria occupies about 200 km2 of the area, and the Serengeti National Park occupies 480 km2. In that case, the Serengeti ecosystem makes up about 40% of the district's surface area (see figure 3.1.1.1).

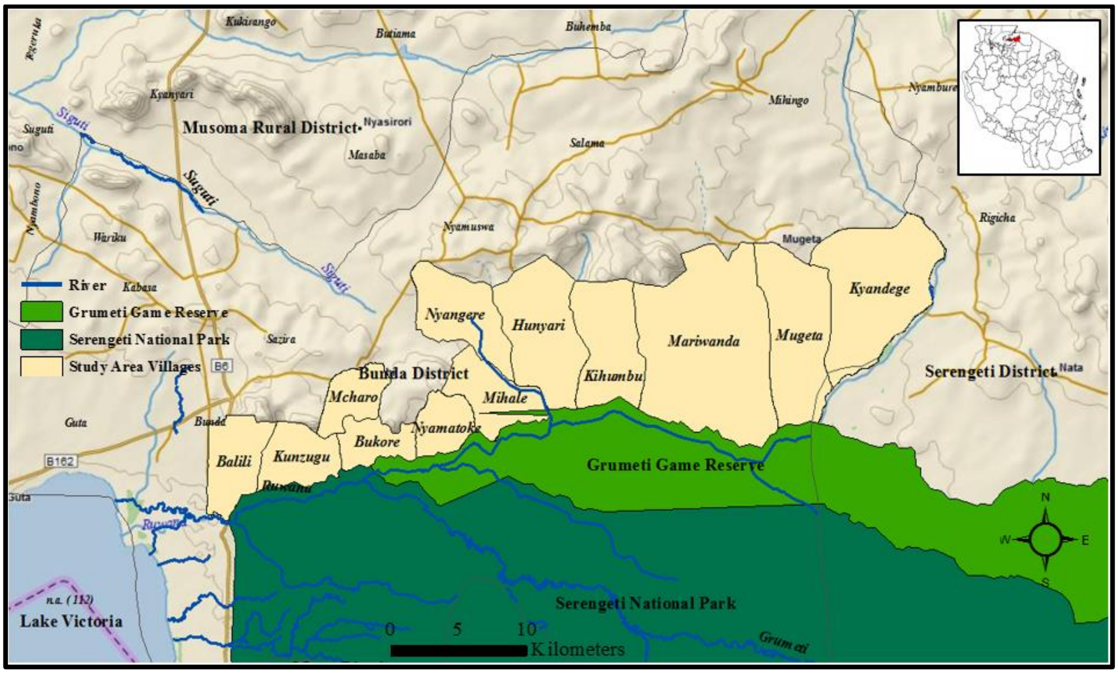

Figure 3.1.1.1: The study area villages bordering Lake Victoria, the Serengeti National Park and Grumeti Game Reserve.

There are wet and dry weather seasons in the area, with rainfall determining the type, length, and timing of the season. The wet season extends from November to May and the dry season from May to October. There is a rainfall gradient, which is relatively low in all areas closer to the boundary of Serengeti National Park and higher rainfall in areas closer to the shore of Lake Victoria. The average rainfall of western Serengeti ranges between 500 and 1200 mm (Kideghesho & Mtoni, 2008).

### 3.3.2 Data Collection

Data were collected over a six month in 2017 in the 12 villages within the Bunda District, Tanzania (see figure 3.1.1.1). Adaptive research techniques were deployed to cope with the cultural diversity and the environment of each community. These techniques enable researchers to use different research techniques to match with a respondent's culture, geographical location and willingness to participate in the study. Research methods included village meetings, interviews, and structured survey questionnaires. This incorporation of different research methods helped in establishing relationships with the communities based on trust, which facilitated a platform for interactive discussion and sharing of HEI experiences. Data collection was aided by local research assistants with the ability to read, write, and speak Swahili fluently, as well as to speak more than one local language and who were from the local communities. Research assistants were responsible for the translation of local languages, security and guiding in the area of study.

A non-probability or purposive (judgmental or expert sample) sampling technique was used for the identification and selection of research participants (Singh, 2014). Application of purposive sampling occurred during village meetings, where adults with undisputed experience of HEI volunteered to participate in the study. Also, door-to-door sampling techniques were used to identify the heads of households with adequate knowledge and expertise on HEI who did not attend the meetings. Participants from 12 villages bordering the Serengeti National Park (SENAPA) and

Grumeti Game Reserve (GGR) were assessed for whether they were head of household, their adequacy of HEI knowledge and closeness of the household to SENAPA and GGR. Based on Yamane's formula for the number of participants needed, 130 people were selected for survey questionnaires and 60 participants for informal interviews (Singh, 2014).

The questionnaires included closed-ended and open-ended questions. The nature of the questions simplified data coding, analysis, and interpretations. Since it was a qualitative study, the open-ended questions provided an unlimited opportunity for participants to answer questions as with as much depth as they could (see Appendix A). The research assistants helped in the dissemination of the structured questionnaires to 130 respondents. Before distributing the questionnaires, participants were fully briefed about nature, aim and time required to respond to the survey during village meetings and also when handing a questionnaire to the respondent (see Appendix B). During coding, each participant was allocated a pseudonym to protect his or her anonymity and a separate coding system was used during analysis.

Furthermore, respondents were asked to complete a consent form and assured that they could withdraw from the study at any time within a six-month period following the interview (see Appendix C). The survey obtained human ethics approval from the Lincoln University Ethics Committee before the circulation of the questionnaires (see Appendix D). 30 minutes were allocated for each participant to understand the survey instrument and 15 minutes to fill in the questionnaire with research assistants. In addition, respondents were given a maximum of seven days to respond to the survey at his/her convenient time. Participation from both adult females and males with adequate experience with HEI was sought.

### 3.3.3 Structure and Description of the Questionnaire

The questionnaire aimed to provide information to develop rule sets for HEI. It consisted of two sections: demographics and HEI impacts (see Appendix A). The demographic section investigated the attributes for creating AGHEI human agents in Chapter 6. The HEI impacts section investigated the rule sets for HEI in the AGHEI.

The questionnaire’s analysis provided the responses with the highest score (percentage) for each question. The study considered the question with the highest score as an attribute or rule for AGHEI behaviours (see Table 3.4.1.1 and Table 3.4.2.1). Questions represented special purposes for attributes of agents, interaction rules, conceptual framework, UML, calibration, verification, and validation of AGHEI.

## 3.4 Results

### 3.4.1 Demographic Characteristics of the Sample

A total of 130 survey questionnaires were collected from twelve villages. Nyangere village produced the largest number of those surveyed while Nyamatoke, Mihale, Kyandege, and Bukore villages produced the lowest number of the respondents. The majority of responses were from married males who were farmers with only primary education (Table 3.4.1.1).

Table 3.4.1.1: The responses from the questionnaires to demographic variable percentage.

| **Variable** | **Responses (%)** | | | | | |
|---|---|---|---|---|---|---|
| | **Male** | **Female** | | | | |
| | 71.5 | 28.5 | - | - | - | - |
| | **Single** | **Married** | **Widow** | **Divorced** | **Other** | |
| | 10.0 | 87.7 | 2.3 | 0 | 0 | - |
| | **Primary** | **Secondary** | **Vocational** | **Higher Education** | **Other** | |
| | 85.4 | 11.5 | 1.5 | 0.0 | 0.8 | - |
| | **Farmer** | **Livestock keeper** | **Business person** | **Public servant** | **Other** | |
| | 90.0 | 3.8 | 0.8 | 5.4 | 0.0 | - |
| | **Migrant** | **Birth** | **Others** | | | |
| | 26.2 | 70.0 | 3.8 | - | - | - |
| | **Corridor** | **Settlement** | **Protected area** | **Others** | | |
| | 1.5 | 96.2 | 2.3 | - | - | - |

### 3.4.2 Local Peoples' Opinions on HEI Occurrences

The majority (70%) of respondents mentioned birth as the main reason for the increased human population in the district (see Table 3.4.1.1). According to their customary rights, respondents (96.2%) described their land as having a designated purposely for settlement or agriculture. The majority of respondents (46.9%) sighted elephants every day on village land. Likewise, (50%) of respondents sighted elephants in both dry and rainy seasons. In village areas, respondents (78.5%) sighted elephants mostly in the farming areas. Moreover, respondents (64.6%) anticipated sighting more elephants near households in the future. In many circumstances, the majority of respondents (83.4%) sighted a group or family of elephants with more than 11 individuals. According to the respondents (54.6%), the minimum distance that the elephant can detect and attack humans was 50 meters (see Table 3.4.2.1).

In addition, a large group (42.3%) stated that when an elephant finds a farmer guarding crops, that the elephant could kill the human. When a farmer finds an elephant damaging crops, the majority (64.6%) stated that the farmer would run away from elephants. According to respondents (82%), human death occurs when people attempt to scare problem elephants away from farms. Most (33.8%) of respondents had never seen people killing elephants, or were unwilling to report so due to fear of government prosecution. The respondents (87.7%) stated that HEI occurrences are increasing. Crop damage was the most common adverse impact of HEI. The largest group of respondents (40%) said that elephants do not damage their houses. Of all respondents (74.6%) agreed on the presence of hidden impacts in the district. The majority (69.2%) mentioned traditional methods, such as farm guarding, are the frequently used mitigation measure for HEI. Table 3.4.2.1 summaries the survey responses.

Table 3.4.2.1: Responses to HEI variables in the percentage.

| Variable | Responses (%) | | | | |
|---|---|---|---|---|---|
| | **Everyday** | **once a week** | **Once a month** | **once in six months** | **No elephant** |
| | 46.9 | 9.2 | 13.8 | 22.3 | 2.3 |
| | **One elephant** | **2-4 elephants** | **5-10 elephants** | **More than 11 elephants** | **Other** |
| | 2.3 | 3.1 | 4.6 | 83.8 | 6.2 |
| | **Farms** | **Settlements** | **Water tap** | **Rivers** | **Other** |
| | 78.5 | 16.2 | 0.0 | 3.1 | 2.3 |
| | **Farms** | **Settlements** | **Water tap** | **Rivers** | **Other** |
| | 26.9 | 64.6 | 2.3 | 2.3 | 0 |
| | **Rain** | **Dry** | **Rain and Dry** | **Other** | - |
| | 31.5 | 14.6 | 50.0 | 3.8 | - |
| | **50 meters** | **51 to 100 meters** | **151 to 200 meters** | **Other** | **-** |
| | 54.6 | 20.8 | 3.1 | 7.7 | - |
| | **Run away** | **Cause injury** | **Kill human** | **Keep eating crops** | **Other** |
| | 14.6 | 8.5 | 32.3 | 42.3 | 2.3 |

## Table 3.4.2.1: continued

| Variable | | Responses (%) | | | |
|---|---|---|---|---|---|
| | **Run away** | **Cause injury** | **Kill elephant** | **Scare it away** | **Faint** |
| | 64.6 | 12.3 | 7.7 | 14.6 | 0.8 |
| | **Complete demolition** | **Slight demolition** | **Other** | - | - |
| | 25.4 | 34.6 | 40.0 | - | - |
| | **Guarding crops** | **Water taps** | **Injuring elephants** | **Killing elephants** | **Other** |
| | 81.5 | 0.8 | 4.6 | 3.1 | 9.2 |
| | **Crop damage** | **Human death** | **Infrastructure damage** | **Others** | **-** |
| | 28.5 | 30.8 | 6.9 | 33.8 | - |
| | **Increase** | **Decrease** | **Neither** | **Other** | **Increase** |
| | 87.7 | 3.8 | 1.5 | 4.6 | 87.7 |
| Are there hidden impacts in the district? | **No** | **Yes** | - | - | - |
| | 24.6 | 74.6 | - | - | - |

### Table 3.4.2.1: continued

| Variable | | Responses (%) | | | |
|---|---|---|---|---|---|
| | **Human death** | **Crop damage** | **Hidden impacts** | **Infrastructure damage** | **Other** |
| | 3.8 | 47.7 | 44.6 | 0.8 | 3.8 |
| | **Traditional methods** | **Snares** | **Guns** | **Report to government** | **Other** |
| | 69.2 | 1.5 | 0.0 | 29.20 | 0 |
| Problem elephants killed by humans last year | | 0 | | | |
| Human affected by hidden impacts last year | | 0 | | | |
| Humans injured by problem elephants last year | | 0 | | | |
| Humans killed by problem elephants last year | | 0 | | | |
| Hectares of crops damaged by elephants last year | | Many | | | |

However, the respondents failed to provide annual statistical data on elephant death, crop damage, human death and hidden impacts. In that situation, this study used secondary data, as outlined below.

### 3.4.3 Secondary Data

In this thesis, secondary data were obtained from government reports and existing literature. Data about the annual incidents on human death, hidden impacts, crop damage, and elephant deaths were missing from the questionnaires. The Bunda District Council provided data on hectares of food and cash crops damaged by elephants over four years (see Table 3.4.3.1).

Table 3.4.3.1: Secondary data on crop damage in Bunda District.

| **Year** | **Crop damage (hectares)** | **Percent (%)** |
|---|---|---|
| 2012 | 70.42 | 3.1 |
| 2013 | 190.2 | 8.4 |
| 2014 | 1772.2 | 78.2 |
| 2015 | 234 | 10.3 |
| Total | 2266.82 | 100.0 |

Source: Bunda District council, 2016

The secondary data on crop damage were used for AGHEI development, calibration, verification and validation (Chapter 6 explains in the detail). The secondary data show that there 2014 had the highest number of hectares damaged by elephants. Crop damage incidents may have been reported more in 2014 compared to other years. It also possible that more farms were cultivated in 2004 than in other years. In addition, statistical data of hidden impacts were missing from the questionnaires and from the Serengeti National Park and Grumeti Game Reserve offices. As a remedy, spatial data from the field survey was used (Chapter 4 explains in detail).

## 3.6 Discussion

Local people suggest that birth rate is the leading cause of rapid human population growth in the Bunda District. This rapid human population growth intensifies the magnitude of HEI because of constant and ongoing competition for necessary resources between humans and elephants in the district. Population growth stimulates a higher demand for food and human settlements. As a way of meeting the increased resource demand, humans encroach into natural elephant ranges for settlement, food, industrial raw materials and construction of areas for the development infrastructure. The human occupation of unprotected elephant habitats usually interferes with foraging behaviours and movement patterns of the animals. The human population density in the district amounts to 200 people per square kilometre (URT, 2013a). Such a high density triggers the demand for basic resources to satisfy the growing human population.

While residents had mixed views about the designation of their areas, the majority of locals viewed their land as being agricultural and settlement land inherited from their ancestors. A small number of locals identified their areas as wildlife corridors. From a legal perspective, URT (1999) recognises conservation corridors as village land. The URT (2009) recognises conservation corridors as an undeclared buffer zone for Serengeti National Park and Grumeti Game Reserve. The presence of wildlife migratory routes and dispersal areas, the proximity of the villages to protected areas and the continuous HEI occurrences may lead to the transfer of villages to other areas

Residents asserted that incidents of elephant damage are increasing every year. The severity of elephant damage is high as most elephant events involve more than 11 individual animals at a particular time and place. In the case of a group size of elephants, local statements correspond to the most recent elephant estimates in the ecosystem, with groups of elephants having between 2 to 26 individuals in the district (TAWIRI & KWS, 2014). Some respondents mentioned having seen 200 to 2000 elephants at a time though it is difficult for anyone to count 2000 (or even 200) elephants from one point at ground level, and this must be viewed with some skepticism. Residents do have an incentive to exaggerate the group size of elephants as it allows the locals to gain the attention of the government and other stakeholders.

The majority of local people claimed to see elephants every day, in both dry and rainy seasons, especially around crop farms. The visitations on the farms coincided with crop damage. A small number of respondents encountered elephants near houses and rivers. A stable elephant population in the Serengeti ecosystem and active migratory corridors in the district may have influenced the daily sightings of elephant activities in the communities. It is important to acknowledge that residents sometimes tend to overstate the extent of HEI incidents when appealing for compensation (Bandara & Tisdell, 2002). In the case of seasonality, elephant activities coincide with local agricultural calendars and climates, causing the pachyderms to be active in both dry and rainy seasons. While many residents claimed to see elephants throughout a particular crop calendar, a minority claimed that elephant activity is only observed when crops are ready to harvest. A few respondents were not sure as they asserted that elephants are unpredictable animals. Resource scarcity due to unpredictable weather makes elephants highly mobile. In the buffer zones, where humans and elephants share undifferentiated landscapes, elephant damage may occur throughout the year (Lenin & Sukumar, 2011).

Local people experienced direct and indirect impacts of elephants. As elsewhere in the world, residents mentioned crop damage as the most noticeable adverse effect of HEI in the district. Other adverse effects included hidden impacts, infrastructural damage, and livestock and elephant deaths. In the case of crop damage, most of the agricultural farms are near conservation areas, which are unguarded and unfenced. Therefore, elephants damage farms quickly and frequently. The pachyderms unselectively damage different types of food and cash crops, fields and stored crops. As generalist feeders, elephants consume different types of crops and various parts of the plants, which makes them highly destructive and unfavourable to local people. In the Bunda District, local people stated that they saw elephants frequently eating several food crops, sorghum, rice, maize, watermelons and pumpkins, and cash crops, sisal, and cotton. In the matter of house damage, local people asserted that elephants do not perpetrate any adverse impacts on houses except when animals occasionally break into the isolated grain stores when foraging seeds in dry seasons.

Residents asserted that human and elephant deaths are rare in the district. Local people had never killed problem elephants, but elephants have killed four people in Kunzugu, Mcharo, Balili and Kyandege villages since 2006. Local people admitted to lacking the motivation for killing problem elephants as the species is highly protected, hard to kill and is the symbol of the ecotourism industry in the country. However, some residents suggested retaliation killing of elephants after human deaths and crop-raiding. This suggests that the majority of residents are cognisant of the socio-economic contribution of elephants. Because of the legal prohibition of elephant killing in Tanzania, elephant deaths may go unnoticed because of fear of prosecution.

Locals reported adverse impacts from HEI. For instance, residents claimed that elephants sometimes restricted their movements to certain areas and certain times. Consequently, hidden impacts severely affected their participation in socio-economic and social activities. Routine guarding of crops threatened the marriages of some local people in Bukore village. One respondent claimed that a wife cheated on her husband while he was guarding crops against elephants. Hidden impacts are the second-largest adverse effects after crop damage, and these are technically difficult to describe and quantify. In a similar manner, locals perpetuate hidden impacts on elephants through the conversion of elephant habitat into agricultural farms, development of infrastructure that affect the habitual movements, feeding patterns and mating behaviours of elephants(Advani, 2014; Ladan, 2014; Lamarque et al., 2009; UNDP, 2014).

Locals deploy traditional methods to control problem elephants. Despite the risk, the techniques are convenient and affordable. Lenin and Sukumar (2011) assert that traditional methods are short-term tactical solutions that usually provide limited success. In the case of effectiveness, local people stated that, in many events, when elephants find residents guarding crops, they often damage crops in their presence without either hurting or killing a villager. A few locals stressed that after making noises and blowing whistles, elephants might move from the crop farm. Ineffectiveness of traditional control techniques does not prevent elephants from becoming habitual crop raiders because they get used to the techniques with time (Desai & Riddle, 2015; Nelson et al., 2003). A few locals used snares to control pest elephants before they approached their farms. The snares injure but seldom kill, and keep the elephants off crop fields. However, the effectiveness of the wire traps remains uncertain, as many residents were hesitant to provide detailed information fearing prosecution. Local people sometimes report HEI to Serengeti National Park, Grumeti Game Reserve and District Game Office for immediate response. Timely response from the conservation agencies becomes relatively difficult due to geographical challenges and logistical problems. However, the Ministry of Natural Resources and Tourism of Tanzania has already completed the construction of the base camp for problem animal control in the Hunyari village.

Local people have innovated and used local knowledge and skills for centuries to address living with elephants. Therefore, for proper prescription of specific mitigation measures to environmental problems, it is important to adopt, learn and if possible improve the existing local knowledge and skills. Locals acquired knowledge and expertise about their environment in the absence of formal education institutions and they understand and conserve natural resources in an informal way. Part of their consolidated knowledge and skills have led to undisputed scientific innovations in the discipline of conservation such as using stinging bees to control problem elephants (Ndlovu et al., 2015). In this study, locals may approach elephants as close as 50 meters without any harm to humans. From a management perspective, local people have demonstrated that neither elephant killing nor traditional techniques can significantly reduce elephant damage. However, science-based methods should replace conventional methods to halt elephant damage in the district.

Responses from the survey and the unstructured interview remain the most valuable and the cornerstone of this thesis and more importantly the development of the AGHEI model. Their responses were used as a foundation for constructing the model's conceptual framework, specific interaction rules, and were used for AGHEI calibration, verification, and validation. All these are explained in detail in chapter six of this thesis. However, the information from the questionnaires was inadequate to supply the rules for the model. In that situation, other information was obtained from the reports and literature.

Some of the data from the questionnaires enabled the development of the model's demographic attributes. The status of the socio-economic activities of respondents was used for developing synthetic human populations and is discussed in Chapter 6. Understanding the reason for increasing the human population in the district enabled the adoption of human birth as the only way for increasing the human population in the model. Knowing the type of land where HEI occurs assisted during the recommendation of the best scenario because the government hardly compensates people who occupy unregistered villages. Understanding the frequency of elephant sightings as well as the season was crucial for determining the model time resolution for AGHEI. The model resolution enabled the setting of an appropriate time step of the dynamics that occurred in the AGHEI. Understanding the area elephants usually visit was crucial for the model environment, model coding, calibration and visual validation of AGHEI. In addition, information about the distance that elephants usually detect the presence of human being was also important for modelling the distance at which elephant should either run or attack human in the AGHEI. Because these are two possibilities are among several factors that determined elephant and human death, crop damage and hidden impacts on the AGHEI.

Finally, yet importantly, it is essential to acknowledge that the quality of survey data is representative, as most of the responses provided similar information with what is already known about HEI. In addition, the survey and informal interview were conducted in the language best understood by the respondents. The respondents were well informed on the aim and objective of the study before participating in the survey. This avoided exaggerations of the responses as they were also informed that the study was not for compensation of property and life loss resulted from HEI. Moreover, the survey was confidential and voluntary, which provided them with an opportunity for free expression. Furthermore, the researcher also participated in the dissemination and collection of the survey. This made it possible to relate what is in the survey and the reality of the study area.

Getting information directly from villagers is useful to get a balanced understanding of the HEI occurrences in the district. Local people who directly interact with elephants have a broader outlook on HEI occurrences than researchers who mostly read about it from literature. Local people's opinions provide technical and scientific knowledge about HEI. In addition, villagers provide contextual knowledge about the whereabouts and history of HEI. However, low levels of participation, perception and attitudes, communication barriers and resistant leaders are some of the obstacles that may hinder local people participated in the research. Local people may offer inadequate participation if they were involved in a similar project in the past, which was unsuccessful. It is hard to for local people to involve in the project with unclear objectives. The political and ethnic ideologies may influence the leaders to discourage villagers to participate in the research.

# Chapter 4 – Spatial Analysis of Crop Damage

## A spatial analysis of elephant crop damage in communities adjacent to Serengeti National Park and Grumeti Game Reserve, Tanzania

### 4.1 Abstract

Crop damage is the most common adverse impact of HEI. The study used GIS approach to analyse the spatial distribution of elephant crop damage and their relationships with geographical features in the Bunda District, Tanzania. Six hotspots and three coldspots were identified. Four hotspots were adjacent to Grumeti Game Reserve and two hotspots near the Serengeti National Park. Of all crop damage incidents, 66% occurred in the village bordering Grumeti Game Reserve, 28% in the villages bordering the Serengeti National Park and 6% in the village the bordered none of the protected areas. Trophy hunting in Grumeti Game Reserve is a possible factor for the presence of the significant hotspots as hunting usually affects the movement and foraging behaviours of certain species. More importantly, unplanned hunting also affects the diversity of key ecological species that are habitat in the habitat manipulation and restoration. In addition, the geographical setting of the study might have contributed to the presence of many concentrations of crop damage incidents near Grumeti Game Reserve. As the majority, nine (75%) villages involved in the study are next to Grumeti Game Reserve and three (25%) villages border the Serengeti National Park. There was also a high concentration of elephant crop damage near rivers and protected areas, which decreased with increased geographical distance from the edge of these features.

**Keywords:** Bunda District, Cold spots, Conservation corridor, Crop damage, Elephant death, GIS, Grumeti Game Reserve, Hot spots, Human-elephant Interactions, Kernel Density, Serengeti National Park, Trophy hunting

## 4.2 Introduction

Crop damage is the most noticeable adverse effect that elephants (Loxodonta africana) have on communities bordering protected areas (Desai & Riddle, 2015). At the local level, African elephants cause substantial and severe impacts to farmers (Parker et al., 2007) by raiding crops, damaging property, and, in some cases, causing death and injury. Elephants raid different types of crops, which make them, locally, the most destructive vertebrate pest (Nelson et al., 2003; Osborn, 2004). Elephants have large appetites and lengthy feeding hours and may remain active for up to 18 hours in a day (Osborn, 2004). Crop damage is a common manifestation in communities surrounding protected areas, which elephants routinely visit for food and water (Lamarque et al., 2009). Other vertebrate species, such as eland, black rhino, baboon, wild boars, red-billed quelea, rodents, and hippos, also cause similar types of crop damage (Meerburg et al., 2008; Peterson et al., 2010).

Several studies have investigated the socio-economic and spatial aspects of elephant crop damage in Asia and Africa using geographic information systems (GIS). A GIS approach is useful for assessing the spatial distribution and concentration of patterns of elephant crop damage. However, technological and financial constraints marginalise some parts of the world from adopting geographic information technology. Knowledge of the geographical configurations of crop damage is essential for decision-making and strategic planning for mitigation measures.

Conservationists deploy a GIS approach to address different wildlife conservation issues. Mutanga and Adjorlolo (2008) assessed eland crop damage by deploying GIS in Kwa-Zulu Natal, South Africa. In a similar study, the prediction of spatial aspects of HEI occurrences was made in an unprotected range of Maasai Mara National Reserve, Kenya (Sitati et al., 2003). However, the spatial examination of elephant crop damage takes place with inadequate or no consideration of the areas of the density of crop damage occurrences (hotspots and coldspots). Because each elephant crop damage incident has spatial characteristics (Goodchild, 2006), a better understanding of its spatial configuration may provide stakeholders with the necessary information required for developing proactive mitigation measures.

To better understand the location, distribution and concentration of crop damage in Bunda District, Tanzania, the location of elephant crop damage incidents (X, Y coordinates) were collected and analysed (Prasad et al., 2011). Such understanding of spatial patterns of crop damage led to the development of a computational model (AGHEI), which is explained in detail in Chapter 6. The geospatial data aided model conceptualisation, development of programming code, and calibration and validation of the model. Bunda District is one of the areas in Tanzania with frequent HEI occurrences (Mduma et al., 2010). A spatial understanding of elephant crop-raiding is lacking, particularly in the communities that border the Serengeti National Park (SENAPA) and Grumeti Game Reserve (GGR). These communities experience numerous events of elephant crop damage. Data were collected from 12 villages, including their surrounding areas bordering the Serengeti National Park and Grumeti Game Reserve in Bunda District (Mduma et al., 2010).

## 4.3 Materials and Methods

### 4.3.1 Data Collection

In Tanzania, a village is a small community in a rural area made up by inhabitants, infrastructure, forests, farms and geographical features, governed by a legally established local authority (URT, 1982, 1999). Collection of spatial data took place in Bukore, Balili, Hunyari, Kihumbu, Kyandege, Kunzugu, Mihale, Mcharo, Mugeta, Mariwanda, Nyamatoke and Nyangere (see figure 4.3.1.1).

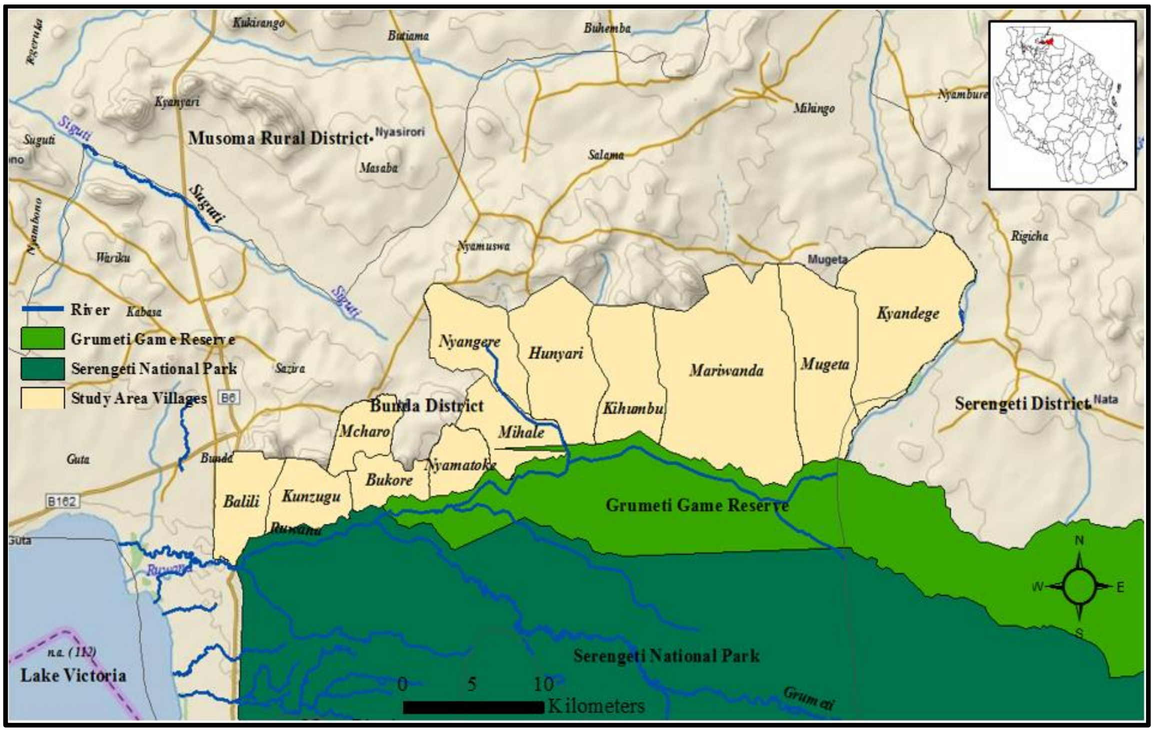

Figure 4.3.1.1: A map of the study area villages and their authorities bordering the Serengeti National Park and Grumeti Game Reserve.

Proximity to protected areas and the high number of incidents of crop damage were the main criteria for the selection of the villages. An adaptive purposive sampling technique was used to identify and record the farms and households that experienced elephant crop damage. Most of the farms with elephant crop damage were visited for identification and documentation of crop damage patterns. Formal village meetings were also used to identify household representatives whose farms had suffered elephant crop damage. Historical patterns of elephant crop damage were identified and collected. This study identified the geographical location of each crop damage incident but not the extent of crop damage. Household representatives, elephant dung, distinctive feeding characteristics of elephants and elephant tracks were the main identification and verification criteria for the presence or absence of elephant crop damage.

Elephant crop damage is the destruction of at least a portion of a crop by elephants. Due to the complex nature of crop damage, experts were consulted for clarification and confirmation of the damage. Experts consisted of wildlife officers, agricultural officers, and community development officers. In addition, villagers and their leaders participated in the identification and description of elephant crop damage for each village before entering an incident into the geodatabase (Wilson et al., 2013). A handheld Garmin GPS receiver recorded the locations (X, Y coordinate) of verified current and previous signs (within the previous year) of elephant crop damage. The data were collected for six months. From the collected information, it was possible to create a crop damage layer in ArcGIS 10.5.

### 4.3.2 Data Preparation and Analysis

A shapefile of the Serengeti National Park, Grumeti Game Reserve, with rivers and administrative villages, was obtained from the Lincoln University GIS server and Serengeti National Park office. The village GIS layer consisted of a set of contiguous polygons representing the areas over which villages had responsibility rather than just the spatial extent of each individual village. A kernel density analysis identified the clusters of elephant crop damage in the district (Gibin et al., 2008). This study uses a 5000 m buffer zone around Serengeti National Park and Grumeti Game Reserve as the bandwidth (Biodiversitya-z, 2015). The Spatial Joint tool combined each village's map and the locations (X, Y coordinate) of crop damage in ArcMap. The resulting map contained a new field with the number of crop damage incidents for each village. The hotspot analysis used the new map to identify villages with a significant concentration of crop damage incidents.

In this study, 'hotspots' are significantly high concentrations of elephant crop damage, and 'coldspots' is a significantly low concentration of crop damage (Harris et al., 2017). The Gedis-Ord G* algorithm was used to identify crop damage hot and cold spots (Getis, 1992). A high Z score and lower P-value indicated significant hotspots. A high negative Z score and small P-value indicated cold spots. Hotspot analysis scrutinises whether high or low values of crop damage incidents were spatially clustered. In addition, proximity analysis assessed the geographical distance for each elephant crop incident to the edge of SENAPA and GGR.

## 4.4 Results

### 4.4.1 Impacts of Environmental Features on Crop Damage

The study recorded 1033 incidents of elephant crop damage from 12 villages for one year. The highest number, 147 (14.23%), of incidents occurred in Mihale village, and the lowest number, 18 (1.74%), of incidents occurred in Nyangere village (see figure 4.4.1).

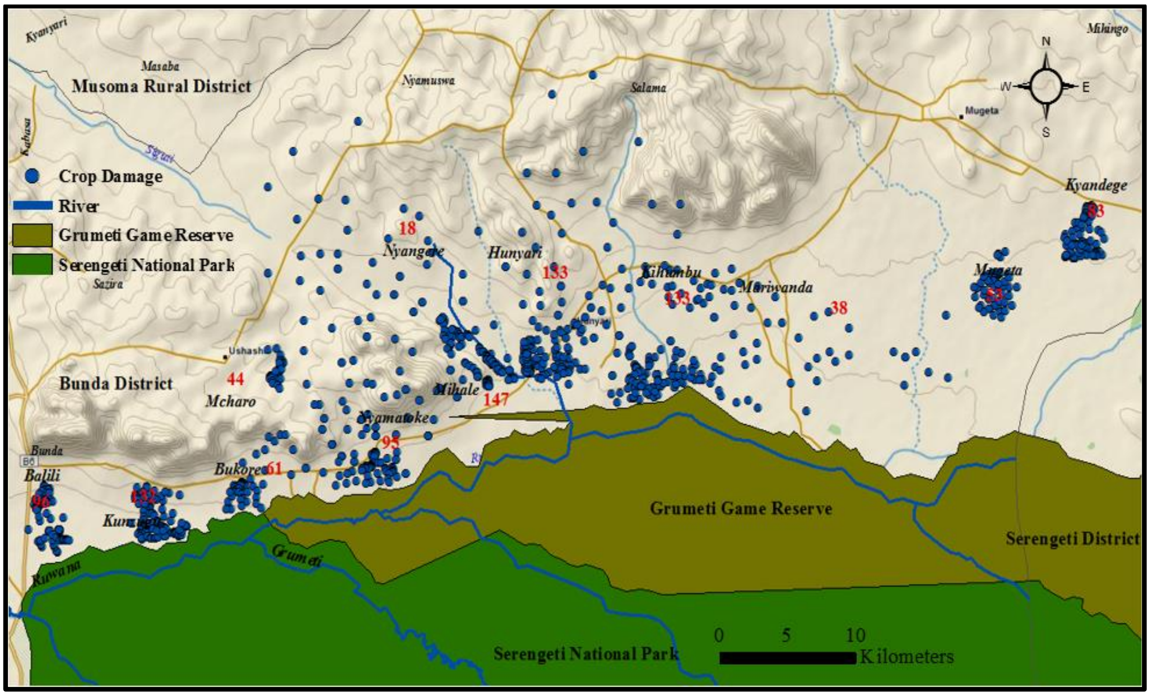

Figure 4.4.1: Crop damage incidents (blue dots).

Based on proximity analysis, the majority of crop damage events (554 or 51.5%) occurred within 2,000 meters of rivers and streams. There were no incidents of crop damage beyond 10,000 meters from the rivers and streams (see figure 4.4.2).

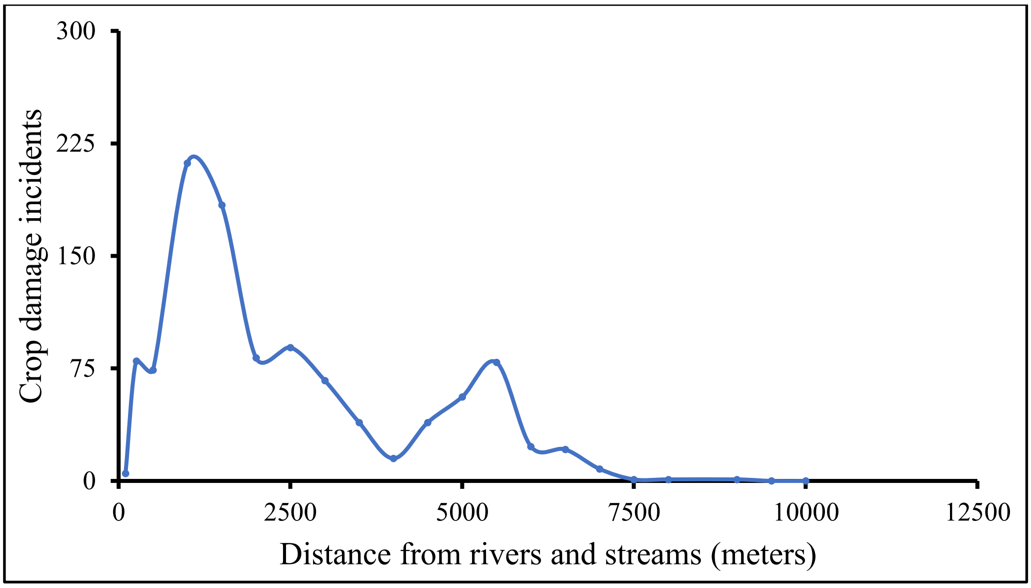

Figure 4.4.2: Crop damage incidents with increasing distance from rivers and streams.

The majority of incidents 574 (53.3%) occurred between 0 and 2,000 meters from the boundary of protected areas (SENAPA and GGR), while, the lowest number of incidents happened between 10,000 and 12,000 meters from the boundaries of the protected areas (Fig. 4.4.3). In comparison, the numbers and proximity of crop damage incidents to rivers and protected areas were similar (see figure 4.4.3 and figure 4.4.4). In other words, the number of incidents recorded at a certain distance from rivers resembled the number of incidents recorded at a similar distance from the boundary of SENAPA and GGR, probably because, SENAPA and GGR used rivers such as Ruwana River, in some parts, as their physical boundaries. The chi-square test at a 0.05 significance level, showed no significant differences between the number of incidents recorded at the certain distance from rivers and the number of incidents recorded at the same distance from the boundary of SENAPA and GGR (n = 6 Value = 30, P= 0.224).

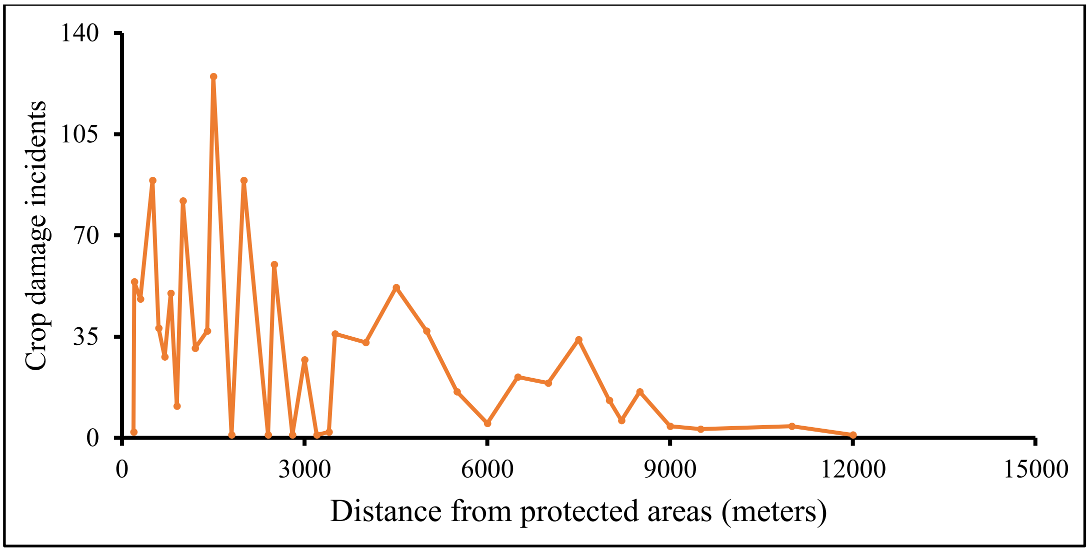

Figure 4.4.3: Crop damage incidents with increasing distance from Serengeti National Park and Grumeti Game Reserve.

## 4.4.2 Kernel Density Analysis

Kernel Density estimated four major concentrations of crop damage in Kunzugu, Mihale, and Kihumbu and Hunyari villages (see figure 4.4.4) (Gibin et al., 2008). The largest concentration of crop damage incidents was between Hunyari and Mihale.

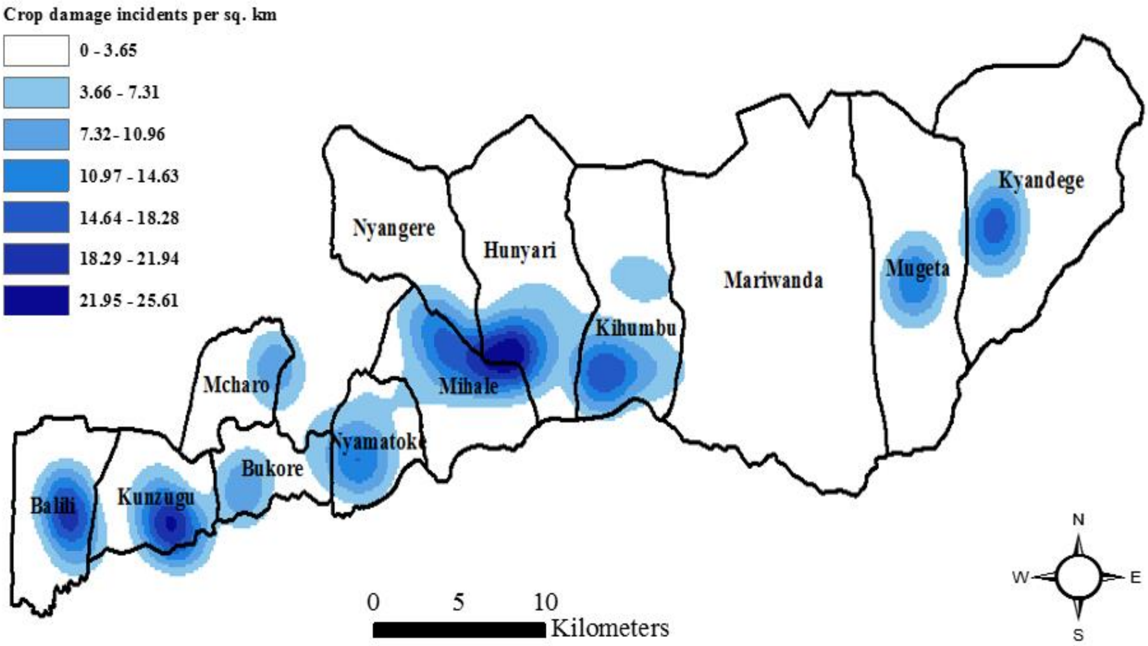

Figure 4.4.4: Crop damage incidents per square kilometre.

### 4.4.3 Hotspot Analysis

A hotspot analysis identified statistically significant hotspots and coldspots of elephant crop damage in the study area. There were significant hotspots of elephant crop damage in Hunyari and Kihumbu villages and a cold spot in Nyangere village. The hotspots bordered Grumeti Game Reserve and SENAPA. The coldspots occurred in the village near GGR particularly in Mariwanda, and in the villages that have no borders onto any of the protected areas, Mcharo and Nyangere villages (see figure 4.4.6). The six villages, which are Balili, Hunyari, Mihale, Nyamatoke, Kihumbu and Kunzugu, had a statistically significant concentration of crop damage incidents (see figure 4.4.6). Bukore, Mugeta and Kyandege had an insignificant concentration of crop damage incidents.

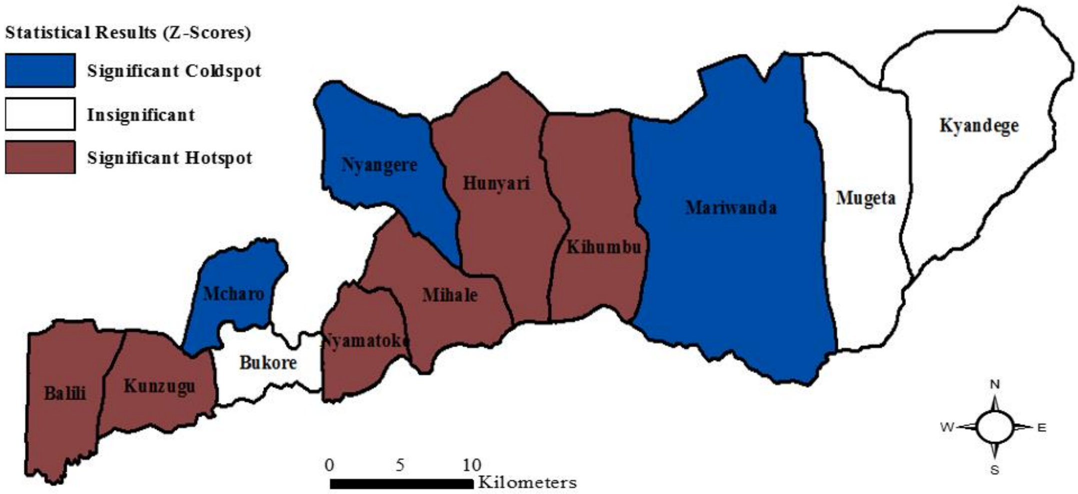

Figure 4.4.6: Statistical test for hotspots and coldspots of elephant crop damage.

## 4.5 Discussion

The degree and frequency of crop damage incidents varied between and within the villages bordering protected areas. For instance, all villages had varying rates of crop damage incidents throughout their administrative areas. Kihumbu, Mihale and Hunyari villages had the highest concentration of elephant crop damage compared to other villages. Crop damage incidents were more common in the villages near protected areas than villages that are more distant. For example, the low crop damage incidents in Nyangere village indicates that crop damage is unlikely to occur in communities disconnected from protected areas. Crop damage was more common in farms near rivers and SENAPA and GGR than farms that were distant from these features. In that context, the findings agree that the boundaries of the protected areas are the focal points of elephant crop damage, certainly for unfenced and unprotected farms (Raihan Sarker & Røskaft, 2014). Likewise, Nyirenda et al. (2012) asserted that protected areas, rivers, human presence and densities, and quality forage might influence the extent of elephant crop damage.

The proximity to water and certain species of forest trees increases the probability of elephant crop damage (Hazarika & Saikia, 2013). Water quality and quantity inside the Serengeti National Park and Grumeti Game Reserve are unreliable. The elevated pH of greater than 10 and high fluctuations of dissolved oxygen (between 1% and 200%) make most of the water in the protected areas undrinkable to elephants (Gereta & Wolanski, 1998). Under these circumstances, elephants and other migratory species will move to unprotected habitats searching for water with satisfactory quality and quantity. The process of migration escalates the probability of elephant encroachment onto crop farms and water infrastructure. According to Nyirenda et al. (2012), elephant crop damage near rivers is more intensive in dry seasons compared to the rainy seasons.

Human population densities and settlements may have caused a clumped spatial distribution of crop damage in certain areas of the district. Bunda District has a human density of nearly 200 people per km2 (URT, 2013a). Despite the high population density, some areas have remained untouched by agricultural and settlement encroachments as populations tend to grow in areas with a suitable level of soil nutrients, moisture content, social services and development infrastructures (Ahmed & Taha, 2016; Linard et al., 2012). In that respect, crop farming becomes possible in the human-dominated landscape. The distribution of the human population coincides positively with the spatial distribution of elephant crop damage in the district. In the district, many residents usually have households surrounded by crop farms. Regardless of human presence, farmlands near conservation areas tend to attract elephant damage because the natural food of elephants usually decreases beyond the boundaries of protected areas (Chen et al., 2015).

Environmental parameters influenced the distribution and concentration of elephant crop damage in the villages. Most of the crop damage occurred between 0 and 2,000 meters from the edge of rivers, Grumeti Game Reserve and Serengeti National Park, and there was no elephant damage recorded beyond 10,000 meters. The elephant is a water-dependent species, spending most of its time near streams and rivers (Nyirenda et al., 2012). In that respect, crop farms that are closer to rivers and borders of conservation areas are more vulnerable to elephant crop damage than those at distant. Harris et al. (2008) asserted that elephants choose foraging near conservation areas and rivers because they prefer moving less, eating well, drinking easily and avoiding human encounters. In short, water availability in the savannah landscape affects the foraging patterns of elephants because animals travel long distances searching for water and food when resource scarcity prevails in the protected landscape (Sitati et al., 2005). In those situations, the proximity of planted crops to rivers and streams is one of the important factors influencing the concentration of elephant crop damage adjacent to rivers and streams.

The adaptive behaviour of elephants reflects a cost-benefit analysis approach. Elephants prefer maximising the benefit from food and water and reproduction while minimising time and energy required to obtain them. Monney et al. (2010) suggested that elephants take into consideration the cost of energy before deciding where to graze and drink and that animals will avoid raiding farms located too far from park boundaries because they are expensive to visit in terms of energy. In respect to external factors, the absence of crop field guards, unfenced protected areas, and the presence of the most preferable natural plants at the edge of the parks, together with increase the susceptibility of neighbouring farms to elephant raiding (Desai & Riddle, 2015; Sitati et al., 2005). The clustering of elephant damage at a particular distance from the edges of conservation areas was similar to the distribution around rivers. The protected area authorities regard rivers, including the Rubana River, as geographical boundaries for SENAPA and GGR. In that respect, the same river is also the physical boundary dividing the anthropogenic and protected landscape into two parts.

Kernel density analysis estimated elephant crop damage in the study area to produce a continuous map for establishing the actual concentration of the damage. The largest concentration of crop damage incidents was between Mihale and Hunyari villages. The villages are next to Grumeti Game Reserve. In addition, there were many concentrations of incidents in villages near GGR compared to SENAPA (Figure 4.4.4). Of all crop damage incidents, 66% occurred in the village bordering GGR, 28% in the villages bordering SENAPA and 6% in the village the bordered none of the protected areas. The geographical setting of the study might have contributed to the presence of many concentrations of crop damage incidents near GGR as the majority, nine (75%) villages involved in the study are next to Grumeti Game Reserve and three (25%) villages border SENAPA (Figure 4.3.1.1)

In addition, concession hunting may determine the largest concentration of crop damage incidents in the villages next to Grumeti Game Reserve. Protected areas in eastern Africa allow trophy hunting for eradicating problem elephants (Burke et al., 2008). In Tanzania, the Wildlife Conservation Act of 2009 allows trophy hunting in game reserves, while prohibiting any hunting activity in the Serengeti National Park (URT, 2009). Hunting usually affects the movement and foraging behaviours of certain species (Burke et al., 2008; Conover, 2010). As an example, frequently hunted agricultural pests that escape concession hunting usually intensify the extent of crop damage (Thurfjell et al., 2012). The Tanzania Wildlife Authority (TAWA) and the District Game Office (DGO) has inadequate resources for managing problem elephants in the district (URT, 2013b). Tanzania National Parks (TANAPA) that manages the SENAPA has more human and logistical resources than TAWA, which may account for the lower incidence outside SENAPA. In that context, geographical challenges and inadequate resources overwhelm the competencies of TAWA to control problem animals outside all national parks.

Understanding the significant crop-raiding hotspots and the influencing factors enhances the ability of conservationists to identify and map the areas with substantial clustering of elephant crop damage events for proactive mitigation measures. Graphical display of hotspots on maps aids policymakers to know where the damage occurs and the reasons for their clustering. In the study, there were six statistically significant hotspots, and three statistically significant coldspots and three insignificant areas (Figure 4.4.6). Four significant hotspots were adjacent to Grumeti Game Reserve. Significant coldspots occurred in the Nyangere and Mariwanda villages only. There were neither statistically significant hotspots nor coldspots near SENAPA.

The presence of many significant hotspots identifies Kihumbu, Mihale, Nyamatoke, Kunzugu, Balili and Hunyari villages as highly predisposed areas to elephant crop-raiding and therefore unsafe for crops farming in the district. In addition, the presence of significant coldspots in Mariwanda and Nyangere suggests that the villages are safe for farming. There were some issues with collecting and identifying evidence of elephant crop damage in the coldspot areas, such as reluctance to participate in the study and inadequate corporation from village governments. More importantly, the geographical setup of some villages, such as Mariwanda and Mugeta were difficult for data collection, the nature of the terrain made some farms in the villages inaccessible for data collection. Such challenges may have influenced the identification of hotspots and coldspots in this study.

The findings of this thesis might apply to other regions with active ranges of African elephants. The elephant stakeholders may use the findings to identify and document elephant distribution outside protected areas. Understanding the habitat utilisation and distribution outside protected areas is one of the major aspects of elephant management. Moreover, conservation authorities may use the findings to identify areas that are vulnerable to elephant crop damage when developing intervention measures. For example, it is likely that the distance from rivers and protected areas will be relevant to other areas in Africa. More importantly, the findings were purposely for AGHEI development, calibration, verification and validation in chapter six. The study provided highlighted the geographical configuration of elephant crop damage in the study area. It provided insights on the way geographical features such as rivers and protected areas need to be a part of AGHEI.

# Chapter 5 – Spatial Analysis of Hidden Impacts

## Analysing geospatial patterns of hidden impacts on humans caused by African elephants (*Loxodonta africana*) in Bunda District, Tanzania

## 5.1 Abstract

Hidden impacts are indirect and largely unreported adverse effects resulting from human-elephant interactions (HEI). Such effects usually go unnoticed and unreported due to the lack of visible damage. Spatial analyses of patterns of HEI have focused on environmental to socio-economic perspectives rather than spatial aspects of hidden patterns. The distribution, proximity to protected areas, kernel density, and hotspots analysis of hidden impacts were analysed in the Bunda District, Tanzanian area with high annual events of HEI. A total of 327 hidden impacts were recorded. The highest number of hidden impacts, 77 (23.53%), was recorded from Kihumbu village and the lowest from Nyangere village, four (0.01%). Abandonment of farms constituted the largest category with 253 (77.4%) hidden impacts while marriage problems formed the lowest category with two events (0.6%). The most hidden impacts occurred between 0 and 2000 meters from the boundaries of protected areas. There was a high number of hidden impacts in villages bordering Grumeti Game Reserve compared to the Serengeti National Park.

**Keywords:** Bunda District, Cold spots, Conservation corridor, Elephant death, GIS, Grumeti Game Reserve, Hidden impacts, Hot spots, Human-elephant Interactions, Kernel Density, Serengeti National Park, Trophy hunting

## 5.2 Introduction

Human-elephant interactions (HEI) are a major conservation challenge (Parker et al., 2007), causing injury and death to both humans and African elephants (Loxodonta africana), as well as destruction of elephant habitat, and human property (Mduma et al., 2010; Rahman et al., 2010). In addition to these more obvious impacts, there are hidden impacts of HEI (Madden, 2004). Such adverse effects usually go unnoticed and unreported due to a lack of visible or obvious damage or interactions (Barua et al., 2013). The impacts include fear of injury or death, restrictions on people's movement (particularly at night), competition for water resources, poor health, and nutrition status, and competition for livestock grazing fields. Elephants reduce school attendance for children due to fear, disrupt families, interrupt sleep and affect the ability to collect firewood and fruit. Guarding of crops or properties at night increases the possibility of suffering from diseases, such as malaria (Barua et al., 2013; Hoare, 2007; Parker et al., 2007). These hidden impacts often outweigh the more obvious interactions, particularly in the number of people affected, and have a significant influence on perceptions of local residents towards elephant conservation (Messmer, 2000). However, the quantification of hidden impacts or secondary impacts of HEI into understandable economic context is particularly challenging (Lamarque et al., 2009).

Under certain circumstances, hidden impacts destabilise local community initiatives and commitment towards sustainable rural development (Parker et al., 2007), especially by undermining efforts dedicated and directed towards poverty reduction (Messmer, 2000). Incidents, such as restrictions on people's movements, marriage problems, psychological problems, malnutrition and inability to collect non-timber forest products (NTFPs) may significantly affect residents. Hidden impacts of HEI complicate community capability, material resources, social resources and typical daily activities (Madden, 2004). The extent and severity of hidden impacts depend on various factors (Lamarque et al., 2009). One of the most significant factors is the ability of people to cope with, recover from the stress, and shock resulting from these impacts (Cooper, 1998; Dimsdale, 2008). Khumalo and Yung (2015) have described the consequences of both stress and shock to people's livelihood and food security.

Besides emotional tension and shock, hidden impacts reduce the willingness of people to coexist with elephants (Osborn, 2004), which causes impediments to sustainable conservation through community-based conservation regimes. Moreover, the stress and shock of hidden impacts create adverse effects on community wellbeing, ability to work, and relationships (Dimsdale, 2008). Ongoing stress causes undesirable health impacts on communities when agencies mismanage elephant-related conflict (Messmer, 2000). Continuous exposure to stressful events may gradually shift humans into a chronic stress state. Consequently, people may experience permanent changes in emotions, physiology, and behaviour (Khumalo & Yung, 2015). Physiological stress complicates their natural immunity and makes them more susceptible to diseases and death (Dimsdale, 2008). African elephants are not the only perpetrators of hidden impacts in Tanzania. Many wild species, such as lions, spotted hyenas, bears and jackals, cause adverse hidden effects to humans in the forms of fear and restricted human movements (Baldus, 2004; Treves, 2007; Woodrofe et al., 2005).

Humans also cause hidden impacts to African elephants (Loxodonta africana), such as through the destruction of elephant habitat by establishing infrastructure, agricultural farms and human settlements within elephant home ranges. Elephants lose their natural habitat and may change their feeding patterns due to resource competition with humans and livestock. Moreover, anthropogenic activities block migratory corridors restricting elephant movements into isolated ecological patches. Restricted movements stimulate inbreeding depression, which usually decreases the biological fitness of the local population (Treves, 2007). In this chapter, the focus is primarily on the elephant-related hidden impacts on humans.

People become intolerant and unsupportive of elephant management when interaction costs are higher than benefits (Treves et al., 2006). Unknown consequences resulting from interactions between humans and elephants are well understood, but a good understanding of their spatial patterns and configurations are lacking. Geographic and scientific components of hidden impacts are crucial in understanding their distribution, concentration, and proximity to environmental features because most of the management decisions humans make have a spatial context. In this study, geographic information systems (GIS) were used to analyze the spatial context of hidden impacts in Tanzania's Bunda District to understand their location, distribution, density, and relationships relative to Grumeti Game Reserve (GGR) and the Serengeti National Park (SENAPA). The understanding of the distribution, location, and concentration of hidden impacts may help relevant authorities and stakeholders acquire a geographical outlook on HEI. Data that are more precise enhanced useful computational modelling and simulation of HEI, by assisting conceptualisation, development of a model code, and model calibration and validation. A concise spatial knowledge of the problem may facilitate a timely and accurate decision-making process for mitigating adverse impacts. The study area was selected based on the high frequency of elephant damage and the proximity of this area to protected areas. Bunda District has the highest incidence (approximately 500 annual events) of human-elephant interactions in Tanzania (Mduma et al., 2010). The District borders Serengeti National Park and Grumeti Game Reserve. The two protected areas form part of the Serengeti ecosystem, one of the few ecosystems in Tanzania with relatively stable elephant populations (TAWIRI & KWS, 2014).

## 5.3 Materials and Methods

### 5.3.1 Data Collection

Data were collected from several villages in the Bunda District (see figure 5.3.1.1). Hidden impacts were observed and recorded at Bukore, Balili, Mcharo, Mihale, Hunyari, Kihumbu, Kunzugu, Kyandege, Mariwanda, Mugeta, Nyamatoke, and Nyangere villages. Hidden impacts of HEI were events that resulted in limited movement of villagers, increased psychological stress, declining health or nutrition status, and children with reduced school attendance. People affected by hidden impacts included those who were highly indebted (as a result of elephant damage), with disrupted family bonds, individuals with interrupted sleep, people who could not collect firewood and fruit, those who suffered diseases while guarding crops or property at night and people who abandoned farming activities because of elephants (Barua et al., 2013; Lamarque et al., 2009; Parker et al., 2007). A purposive sampling technique was adopted to identify and record households and farms that had been affected by hidden impacts (Singh, 2014). Households and farms that claimed to be influenced by hidden impacts were visited. Village meetings were convened to identify the household representative whose family and farms were affected by hidden impacts. Through community meetings, it was possible to describe the types and characteristics of hidden impacts at length to villagers.

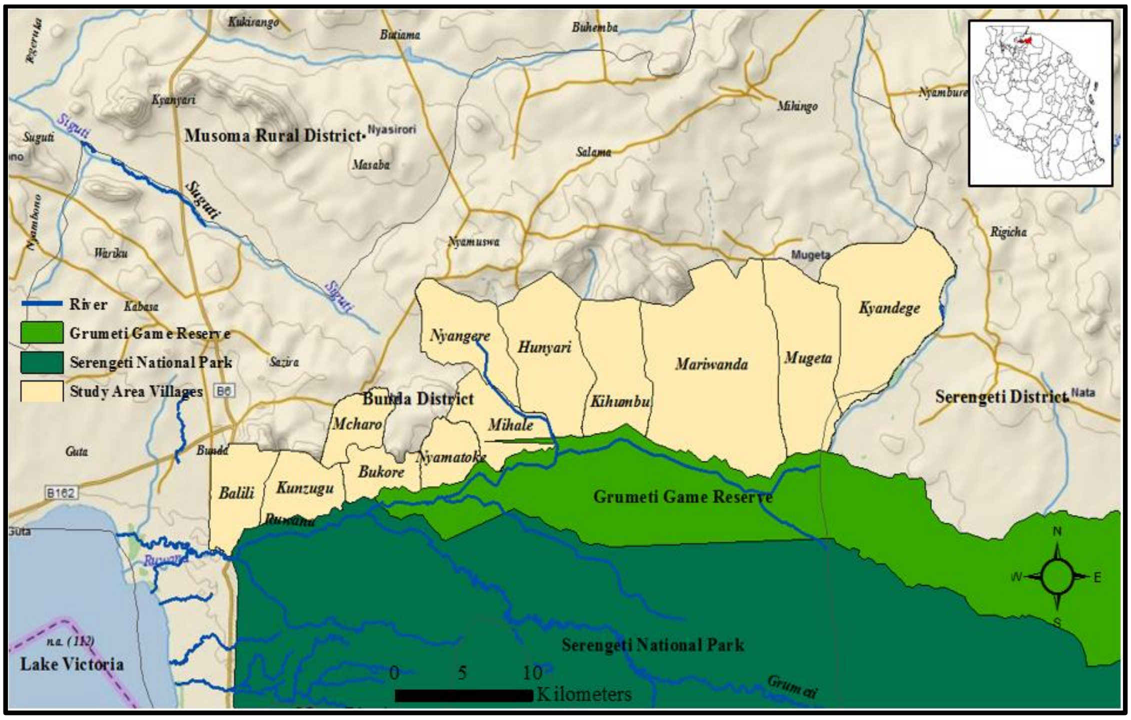

Figure 5.3.1.1: A map of the study area villages and their authorities bordering the Serengeti National Park and Grumeti Game Reserve.

Villagers, particularly village leaders, participated in identification and description of hidden impacts in their village. Because of the complexity and nature of hidden impacts, third party experts (wildlife officers, agricultural officers, medical personnel, village leaders, and community development officers) were also used to clarify and confirm these impacts. Historical and current patterns of hidden impacts were identified and collected over a six-month period. The study only identified the actual location of each incident but not the extent of hidden impacts at each site. All incidents were reviewed and confirmed before they were entered into a databases. Spatial data concerning the locations and types of hidden impact were recorded using a handheld GPS receiver. Impacts related to households were spatially recorded at each respective household, while agricultural patterns were recorded in farms and grazing areas.

### 5.3.1 Data Preparation and Analysis

A shapefile of the Serengeti National Park (SENAPA), Grumeti Game Reserve (GGR) boundaries and villages were obtained directly from the headquarters of Serengeti National Park and the Lincoln University GIS server. Four types of hidden impacts were recorded: "no farming" (NF), "no school attendance" (NS), "restricted movements of adults" (NM) and "marriage problems" (MP). In this study "no farming" refers to farms or households abandoned by local people after several incidents of elephant damage. In the same way, "no school attendance" is defined as the decision of parents and students to not attend school for fear of possible elephant attacks as they travel to school. "Restricted movements of adults" was defined as the decision of adults to reduce their movement away from their households for fear of elephant encounters. "Marriage problems" meant pair bond and family-related problems emanating from HEI, such as the breakup of family relationships after a prolonged absence due to farm guarding.

ArcGIS 10.5 was used to perform geospatial analysis of hidden impacts (Gibin et al., 2008). Kernel Density Analysis was used to identify areas with a concentration of hidden impacts in the study area. For accurate distance measurement between hidden impacts and the edge of the protected areas, all shapefiles were projected into the Arc_1960 UTM Zone 37S coordinate system. A 5,000 m buffer width was used around park boundaries because it conformed to the size of currently recommended buffer zones (conservation corridor as used in this thesis) for SENAPA and GGR. A proximity analytical tool was used to determine the distance of each hidden impact incident to either SENAPA or GGR. After projection, the Near Tool computed the distance for each pattern of hidden impact to the edge of SENAPA and GGR (protected areas).

Hotspot analysis was carried out using the Gedis-Ord G* algorithm for each hidden impact pattern (Getis, 1992). The resulting z-scores and p-values associated with the hotspots provided the probability of clustering of hidden impacts. The hotspot analysis tool assessed each hidden impact in the context of the clustering of that impact. The hotspot analysis used the village shapefile to identify the locations of statistically significant hot spots and cold spots. The analysis used Z scores and P values to identify villages with statistically significant hotspots hidden impacts. The village polygon features, including each village with its surrounding farms and wilderness (12 villages) were combined with incident points using the spatial join tool in ArcMap. The resultant polygons contained a new field with the number of hidden impacts for each village.

## 5.4 Results

### 5.4.1 Impacts of Environmental Features on Hidden Impacts

A total of 327 hidden impact events were observed and recorded from 12 villages over six months. The highest number of incidents (77 (23.53%)) were recorded in Kihumbu village, and the lowest number of incidents (four (0.01%)) were recorded in Nyangere village.

Table: 5.4.1.1 Hidden impacts occurrences in the Bunda District.

| Hidden Impact | Number of Incidents | Percentage (%) |
|---|---|---|
| Marriage Problem (MP) | 2 | 0.6 |
| No Farming (NF) | 253 | 77.4 |
| No School Attendance (NS) | 55 | 16.8 |
| No Walking in the Village (NW) | 17 | 5.2 |
| **Total** | **327** | **100.0** |

"No Farming" had the highest incidence (77.4%), while Marriage Problems (MP) had the lowest 2 (0.6%) incidents (see table: 5.4.1.1).

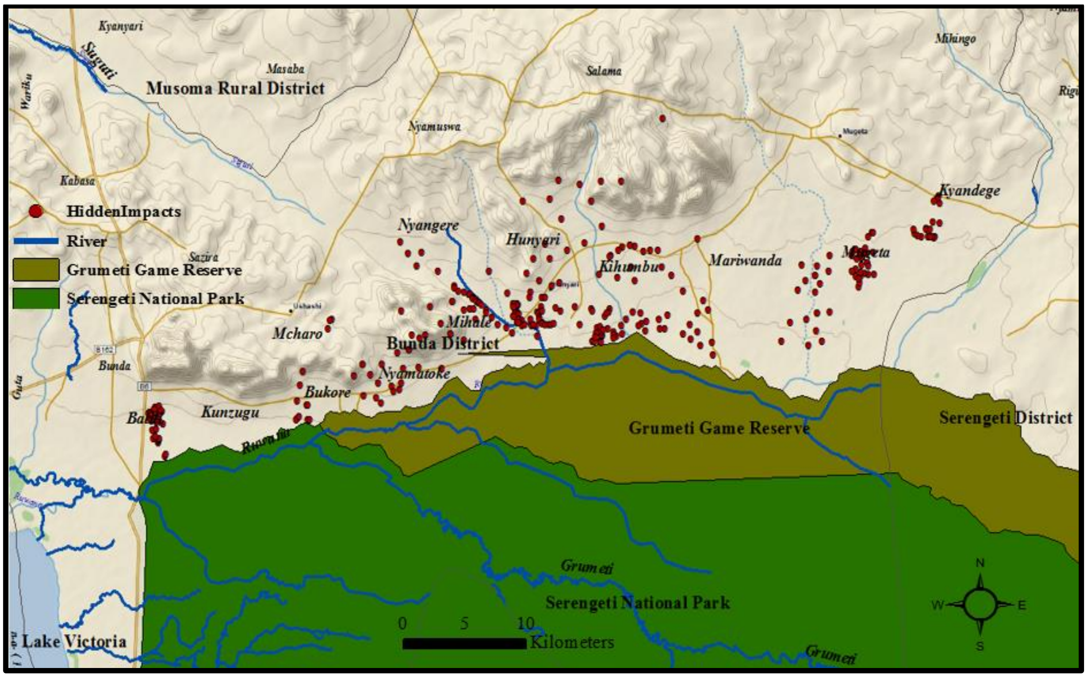

Figure 5.4.1.1: The distribution of hidden impacts (red dots) and their proximity to Serengeti National Park and Grumeti Game Reserve.

In the case of proximity, spatial analysis revealed that the majority (40.3%) of hidden impacts occurred between 0 and 2000 meters from the boundary of Serengeti National Park and Grumeti Game Reserve (see figure 5.4.1.2). Most of the incidents occurred within 5000 meters of the buffer zone.

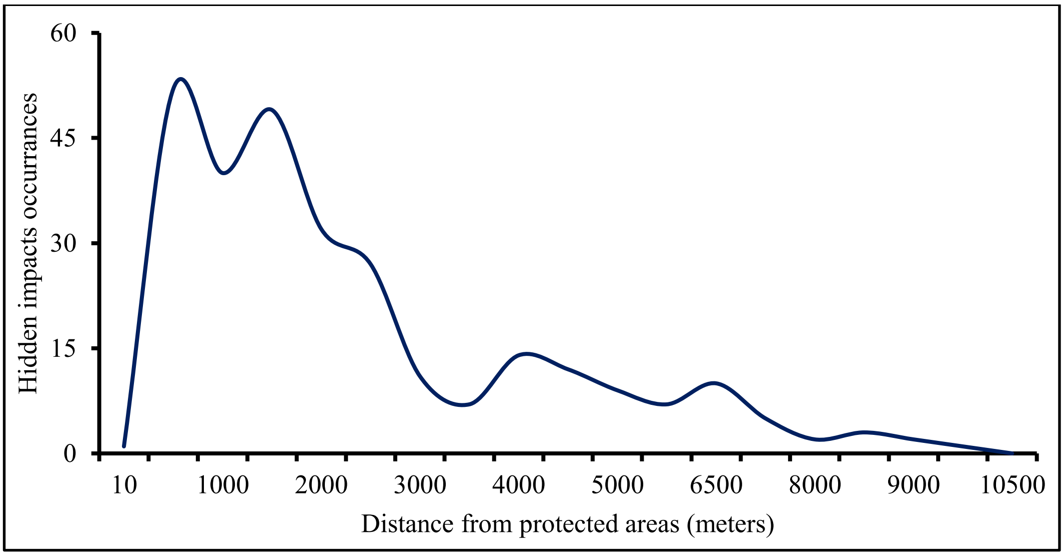

Figure 5.4.1.2: Proximity of hidden impacts from the edge of Serengeti National Park and Grumeti Game Reserve.

In the case of the type of hidden impacts, the identification and recording of "no farming", and " no walking in the village " impacts peaked in areas between 0 and 2000 m from the boundary of protected areas and declined along with increased distance from the areas (see figure 5.4.2). However, "no school attendance" peaked between 4000 and 6000 m from the protected areas. Researchers identified and recorded "marriage problems" between 0 and 2000 m from the edge of protected areas, though there were no "marriage problems" in the areas beyond 2000 m from the boundary of Serengeti National Park and Grumeti Game Reserve.

### 5.4.2 Kernel Density Analysis

Kernel Density Analysis is a technique for generalising the location of incidents to entire areas (Gibin et al., 2008). Kernel Density Analysis identified five major concentrations of hidden impacts in Mugeta, Balili, Hunyari, Mihale, Mariwanda and Kihumbu villages (Gibin et al., 2008). The largest concentrations were in Hunyari, Kihumbu, Mugeta and Balili villages (see figure 5.4.2.1).

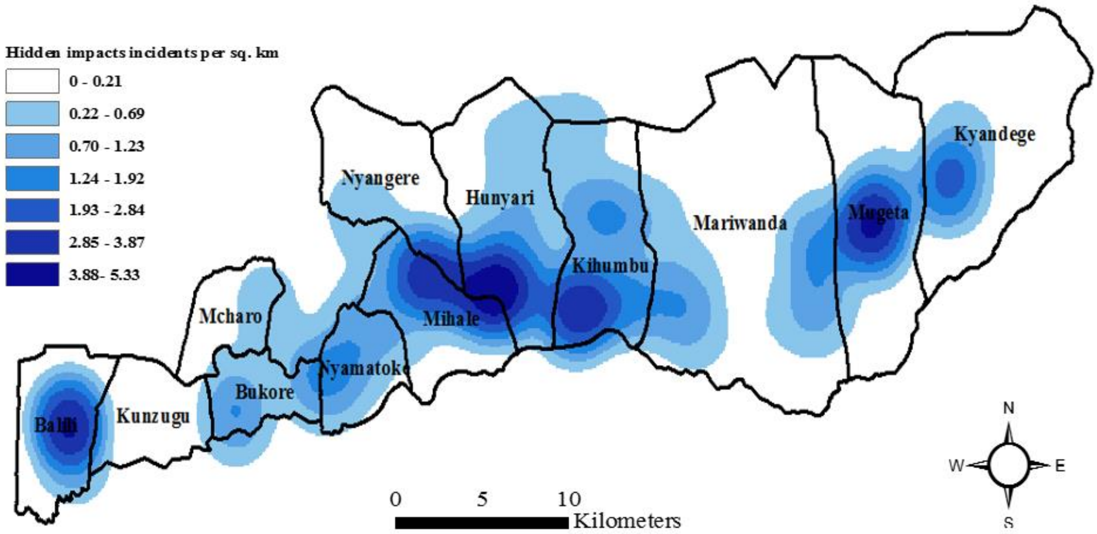

Figure 5.4.2.1: Hidden impacts incidents per square kilometre.

### 5.4.3 Hotspot Analysis

Hotspot analysis identified a significant hotspot of hidden impacts in Kihumbu and Hunyari villages (see figure 5.4.3.1) In the case of location, the hotspot analysis tool indicated that significant hotspot of hidden impacts are located adjacent to Grumeti Game Reserves.

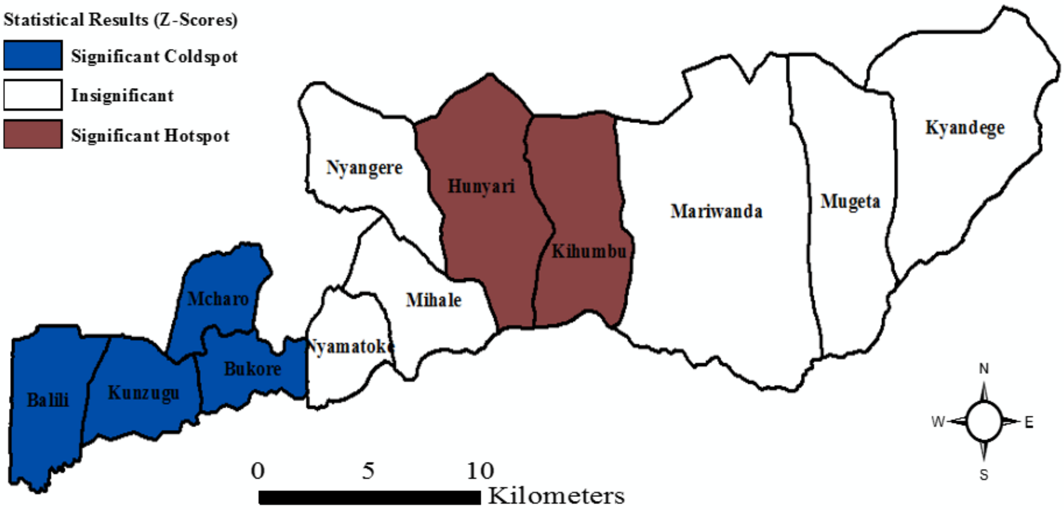

Figure 5.4.3.1: Statistical test results of hotspot and coldspots in the study area.

## 5.5 Discussion

Hidden impacts are complex and require social, economic, medical, environmental and economic knowledge to understand and mitigate them. In this study, we were able to identify and record four types of hidden impacts: delayed school attendance, restricted movement of adults, marriage problems and reduced or abandonment of farming activities. Limited knowledge, time and resources restricted our abilities to identify and record other types of hidden impacts such as psychological impacts and suffering from diseases. Reduction or abandonment of agricultural activities ranked as the most noticeable hidden impact in the district. According to the villagers, people abandoned both their farms and houses to avoid routine agricultural loss from elephants. The majority moved to near villages and communities, while some people moved to other villages with low elephants incidents in the same community to establish new households. In the same way, some people shifted from agriculture to other socio-economic activities, including charcoal burning, fishing, mining, and small businesses. However, it is important to understand that farmers may also abandon their farms because of lack of market skills and information, high transaction costs, poor production, poor transport to the market, uncontrollable diseases and poor farming skills (Khapayi & Celliers, 2016).

In the Bunda District, many communities have one only public primary school (Hartwig & James, 2010). Consequently, children have to walk for several hours to and from school. With elephants present, schoolchildren's safety is at risk. In those situations, parents restrict children's school attendance to avoid possible attacks from elephants. Delayed school attendance by children affects their academic performance and mental development (Hancock et al., 2013). Despite the geographical and technological challenge, if unreported in advance to school administration, no "school attendance" means an unauthorised absence. Analysing the impacts of elephants on school attendance and academic performance is beyond this study. However, it is important to understand that elephant disturbance is not the only factor influencing delayed school attendance in the district. Hancock et al. (2013) found that highly mobile students and pupils, students whose families have low education levels, whose parents have a low-income level and students with low socio-economic index, all had low school attendance level and poor academic achievements.

Elephants also restrict adult movement. With elephants present, it is often difficult for social and economic gatherings to be held. Elephants limit local access to fetching water, firewood, fruits, medicinal plants, vegetable, and mushrooms. Elephants restrict community movements to some locations during different hours of the day. During the night, humans do not leave their houses for fear of elephant attacks. It is not because elephants are more likely to attack at night than a day but it is difficult to avoid elephant encounters at night due to darkness. Restricted movement, generally, for prolonged periods, has physical, psychological and socio-economic impacts on people. Restricted movements caused by elephants may affect an entire household's health by confining them to their home and affecting their physical, mental and social well-being (Boruchovitch & Mednick, 2002). When elephants enter the village area, the collection and preparation of basic human needs become difficult. The absence of indoor plumbing facilities makes the situation more dangerous. Many households have outdoor plumbing services, requiring family members to leave the main dwelling for hygienic issues during night and day. For adults with adequate knowledge of elephant encounters, accessing outdoor plumbing facilities during the night will be the last option due to the maximised possibility of encountering elephants near the house.

Elephants may cause marriage problems for farmers. Villagers reported two cases in Bukore village when men complained about unfaithful wives, which occurred when the men spent time away from homes guarding their cereal farms against elephant damage. Due to numerous elephant incidents in the district, men usually spent most of their time protecting their agricultural fields against elephant invasion. Therefore, husbands and wives experience significant damage to self-image, personal confidence, feelings of abandonment, betrayal of trust and disruption of relationships among family members (Charny & Parnass, 1995). In the case of family support, a husband gradually loses his routine family attention and responsibilities due to extended periods away from home. No cases of wives complaining of the infidelity of husbands while supposedly guarding their crops were recorded, although women only made up a small proportion of respondents.

Hidden impacts mainly affect people residing near protected areas, notably, the majority of individuals residing between 0 and 3000 m from the boundaries of the Serengeti National Park and Grumeti Game Reserve. The proximity of human occupations to protected areas intensifies the frequency and magnitude of hidden impacts (Okello et al., 2014). Many human settlements and activities in the district occur within the buffer zone of the protected areas (Figure 5.4.1.1). These are ecological zones designed purposely for minimising the negative impacts on neighbouring communities and protected wildlife populations (Ebregt & Greve, 2000). Increasing the distance of human settlements from the buffer zone may largely reduce hidden impacts incidents because the increased interface between agricultural areas and elephant habitat magnifies the occurrences of hidden impacts (Desai & Riddle, 2015). Customary and government laws prohibit human occupations and destructive human activities in the buffer zones. Buffer areas usually extend 5000 m from the boundary of protected areas. In the study area, the majority of farms and human residents are within these buffer zones (Desai & Riddle, 2015). Therefore, the reduction or eradication of hidden impacts can be difficult due to the presence of people and anthropogenic activities proximity to protected areas and within conservation corridors. The findings show a significant decrease in the patterns of the adverse effects outside the buffer zone, which supports the need for enforcing the buffer zone for the substantial reduction of the impacts.

Communities neighbouring Grumeti Game Reserve experienced significant hotspots of hidden impacts (Figure 5.4.3.1). Residents bordering Serengeti National Park experienced significant coldspots of hidden impacts (Figure 5.4.3.1). The analysis revealed significant hotspots in Hunyari and Kihumbu villages. Grumeti Game Reserve and Serengeti National Parks vary concerning their management authorities and conservation policies. As an example, tourist hunting is legally allowed in Grumeti Game Reserve and strictly prohibited in Serengeti National Parks. Hunting operations in Grumeti Game Reserve are presumably a contributing factor for the significant hotspot in Kihumbu and Hunyari villages because uncontrolled trophy hunting degrades wildlife habitats (Leisanyane et al., 2013). As it reduces direct and indirect the types and number of keystone species whose importance to the ecosystem's structure, composition and function are disproportionately large relative to their abundance (Nuñez & Dimarco, 2012). Habitat degradation affects the availability of environmental resources for elephants. When habitat loss significantly reduces the quality and size of habitat within their home range, elephants will raid crops and ultimately become habitual crop raiders (Desai & Riddle, 2015).

In this study, a data collected from local villagers and a GIS approach enabled a better understanding of the hidden impacts in a geographic context by recording where the patterns occur, measuring the proximity of hidden impacts to protected areas, measuring their geographic distributions in the study area and also understanding the extent of their concentrations. If properly used, the attained geographical knowledge about hidden impacts may change the way people understand and manage the HEI in the Bunda District. In a similar way, such knowledge is essential for landscape and regional planning towards sustainable conservation. Using local people to identify the types and collect the locations of hidden impacts was crucial because local people understand the severity of hidden impacts better than researchers do.

# Chapter 6 – AGHEI Model

## A computational modelling approach to human-elephant interactions in Bunda District, Tanzania

### 6.1 Abstract

Agent-based model and GIS-based model of human-elephant interactions (AGHEI) simulation model were developed to evaluate and recommend the best management mitigation strategies to either minimise or eliminate human-elephant interactions in the Bunda District, Tanzania. The model estimated the minimum elephant and human population and geographical distances from the edges of protected areas, rivers and conservation areas for the relocation of human settlements. Model results from each scenario were analysed for comparative performance, where minimal recorded incidents of crop damage, human deaths, elephant deaths, and hidden impacts were the primary focus. Selection of the best performing scenario based on the magnitude of the reduction of adverse impact(s). However, for each selection of the best scenario(s), there were costs that a model user must incur, as there was no cost-free scenario. Reduction of any of the adverse impacts may run counter to fiscal, conservation, land and socio-economic policies. Therefore, the model user may select the best scenario within the constraints of these policies. The adoption of the best scenario should not rely solely on the type of adverse impact, tolerance and resilience level of elephants but also the well-being of the affected people. Therefore, the capabilities of people, elephants, and conservationists to accept, tolerate and, ultimately, to recover from a certain level of adverse impacts may determine the selection of the most important scenario.

**Keywords:** Agent-based model, Bunda District, Computational-modelling, Conservation corridor, Crop damage, Elephant death, GIS, Grumeti Game Reserve, Human-elephant Interactions, Model, Serengeti National Park, Trophy hunting, Scenario

## 6.2 Introduction

Like other forms of human-wildlife interactions, human-elephant interactions (HEI) cause several socioeconomic problems for local communities residing in the elephant's natural range. Humans began planting crops in areas that elephants used for foraging, providing a potential appealing food source for elephants. The adverse impacts of HEI include crop and infrastructure damage, human and elephant deaths and a range of hidden effects. The frequency and severity of these impacts are increasing and will continue to do so for the immediate future (Madden, 2004; Thouless et al., 2016). In Africa, people mention elephants as the most dangerous herbivore and the biggest threat to agricultural development. There are a number of impacts resulting from HEI, including human or elephant death or injuries and damage or destruction of food crops (Sitati et al., 2005), as well as a number of indirect or hidden impacts (Barua et al., 2013).

Hidden or secondary impacts, also known as "socio-economic opportunity costs" (Hoare, 2007), refer to the state of "psycho-social wellbeing" stemming from HEI (Barua et al., 2013). Hidden impacts include, but are not limited to, fear of injury or death, restriction on human movement, particularly at night, competition for water resources, poor health, and nutrition status, and competition for livestock grazing ground. Less obvious impacts include reduced school attendance for children due to fear of encountering elephants and increased the contraction of diseases, such as malaria, obtained while guarding crops or property at night (Barua et al., 2013; Parker et al., 2007). In Africa, most of the victims of HEI are poor, subsistence farmers. Adverse impacts of HEI generally outweigh the benefits that elephants provide to humans (Messmer, 2000). Like many problems in wildlife conservation, humans are also largely responsible for the adverse impacts on elephants (Bandara & Tisdell, 2002). Many socio-economic impacts emanating from HEI, such as agricultural losses, fatalities and infrastructural damage, have been quantified (Mutanga & Adjorlolo, 2008). However, scientific interpretations of the fundamental mechanisms behind HEI are either insufficient or lacking.

Agent-based modelling (ABM) and simulation can provide an overview of the contribution of several environmental and anthropogenic determinants of HEI. GIS-based models describe and represent the spatial context of HEI while providing detailed simulation environments of causality, dynamics, and mechanisms behind the interactions Johnston (2013), though it is difficult to add in a temporal component. A computational agent-based modelling approach acts as a virtual laboratory for experimenting and critically analysing complex and vibrant interactions in space and time (Castle, 2006). ABM enables an understanding of how patterns of HEI occur (McLane et al., 2011), as well as the mechanisms and the causality of adverse impacts (Johnston, 2013), while also providing a way to test the effectiveness of different mitigation scenarios.

In this study, ABM was deployed to simulate HEI in the Bunda District, Tanzania. Bunda District experiences high HEI, with more than 500 incidents of HEI occurring every year (Mduma et al., 2010). Model parameters included the size of human and elephant populations, life history information of elephants and humans, and distances to rivers, corridors, and protected areas. The model enabled adjustment, calibration of human, and elephant parameters in a computer environment without violating human, environmental or elephant ethics.

## 6.3 Model Conceptualisation and Implementation

This section describes or formulates the main concepts of the model. The concepts are the abstraction of the HEI in the real world for model users to understand the reality behind the AGHEI. It is the representation of the composition, activities, methods, and properties of the agents in the model. The conceptualisation of the model includes model purpose, and structure and philosophy. The purpose of the model describes the goal of this model. The model structure and philosophy conceptualise the structure and the main concepts such as energy of agents, decision-making and sensitivity of agents, model resolution, simulation, and model stochasticity.

### 6.3.1 Purpose of the Model

The model was developed to simulate HEI in order to evaluate a set of mitigation scenarios, including distances to protected areas, existing conservation corridors, rivers, and their relation to HEI incidents. These models enabled visualisation of interactions and adjustment of the parameter values to obtain the best scenario for either reduction or eradication of HEI events in the Bunda District.

### 6.3.2 Model Structure and Philosophy

The model was subdivided into two main sub-models, one for humans and the other for elephants. The elephant model was further subdivided into sub-models for the movement of elephants, elephant drinking water, elephants damaging crops, elephant deaths and elephants eating natural vegetation. In this model, ‘elephant’ objects were created as primary components, along with humans. Each elephant behaved as a cognitive or conscious agent having mental awareness of its natural environment in which it moves forages and drinks. Elephants were represented as point agents and their behaviours were modelled using complex decision rules, which are outlined in section 6.3.4. Water and food availability determined the movement of elephants. The movements were driven by the level of energy of each individual (internal state).

A shortage of ecological resources (water and food) initialised elephant movements to areas outside their protected areas. Elephant movement and decision-making depended on a number of factors, such as the viability of migratory routes, presence of farm crops, water, internal state (energy level) and corridors. For example, blocked conservation corridors restricted elephant movement to nearby protected areas. Consequently, elephants opted to search for water and food resources in the human landscape, which increased the interaction interface between people and elephants in the model.

The human model was subdivided into sub-models on the movement of humans, drinking water, eating crops, hidden impacts and deaths. The AGHEI represented each human as a conscious agent. Humans behaved as cognitive agents having mental awareness of the environment in which they moved, foraged, drank and guarded farms. A human was represented as a point agent and their behaviours were modelled using complex decision rules, which are outlined in section 6.3.6. Water and food availability determined the movement of elephants. Food and water availability and the presence of elephants in the village area land determined human movement. The movements were driven by the level of human-energy for each individual (internal state).

#### 6.3.2.1 Energy Levels of Agents

Both human and elephant agents maintained and monitored their energy levels. The maximum energy level was set to 100 points and a minimum of 0. In the AGHEI, the energy level is initialised as a random number between 0 and 100. The agents gained energy points after eating food and drinking water. Both humans and elephants lost their energy after performing certain activities. The energy expenditure of all agents varied with the type of activity. When the energy level reached zero the agent died. Energy gain and expenditure varied between and within human and elephant agents. Energy gain and expenditure for elephants and humans are outlined in sections 6.3.4 and 6.3.6 respectively.

#### 6.3.2.2 Decision Making and Adaptation for Agents

Food and water availability, proximity to human activities and human presence influenced behavioural change of elephants. The scarcity of food and water affected elephant movements inside and outside their protected areas. Elephants made decisions based on internal and external conditions. Hunger and thirst, represented by energy state, drove the internal states for elephants. Hunger influenced elephant movement towards quality food sources and thirst influenced elephant movement towards water bodies. External or environmental parameters influenced elephant movement and behaviour. For example, the presence of humans, location of farms and water affected movement towards farms and rivers. Similarly, human adaptation was a result of food and water availability and the presence of elephants in a village. Humans made decisions based on internal and external states. Energy level as the internal state determined the extent of starvation. Low energy level means humans need to eat food and drink water.

#### 6.3.2.3 Objectives of Agents

Each agent has specific objectives to achieve. The AGHEI programmed both human and elephant agents to eat crops, drink water, give birth, move, gain and expend energy and die. However, the model assigned some activities, particularly for a certain agent. For example, AGHEI simulated elephant as the only agent that could eat vegetation and move in the protected areas. In addition, it allowed humans to acquire hidden impacts.

#### 6.3.2.4 Sensing of Model Agents

Elephants recognise other elephants' sex, age, unique identifications and energy levels, as well as external elements, such as protected areas, conservation corridors, farming area, rivers, and humans. A newborn elephant was assumed to behave in the same manner as an adult. Elephants were permanent residents of protected areas and occasional visitors to village land. Similarly, humans recognised genders, human IDs, household IDs, protected areas, conservation corridors, farming areas, rivers, and elephants. Elephants interacted with human agents, farms, rivers, vegetation and other elephants. Humans interacted with other humans, agricultural farms, streams and elephants.

#### 6.3.2.5 Model Stochasticity

The AGHEI is a non-deterministic model due to the uncertainty in its outputs. The model uses a probability concept to model an agent's properties, methods and environment. In addition, AGHEI is non-deterministic because it replicates most of the aspects of HEI. Probabilities were assigned to agent behaviours making them somewhat unpredictable. Due added randomness and unpredictability, several runs of the model were performed to provide a suite of meaningful outputs. Each scenario was run 200 times for each iteration to make meaningful predictions, and creating an average to use as a model output.

#### 6.3.2.6 Model Resolution

The Netlogo simulation platform outputs data at discrete intervals. Every grid cell in the model had 10 m x 10 m resolution. The patch size (grid cell) resolution matched the pixel size of the elevation layer, which was imported into the model at the beginning of a simulation. When moving, an elephant could move into a new grid cell every hour depending on its internal state. The maximum distance covered by wild African elephants was 10 km per day (Rowell, 2014). In this case, elephants could cover up to 10 grid cells every day in the model depending on internal and external states. The maximum distance covered by humans was 8 km per day (Tudor-Locke, 2011). In that case, human managed to cover up to eight grid cells every day.

#### 6.3.2.7 Model Simulation and Observation

For each simulation, the model ran for 8760 time steps, each time step is equivalent to one hour. In each hour, an elephant could move, eat food, die or damage crops depending on its internal state. Similarly, for every time step, a human could move, eat food, drink water, acquire hidden impacts or die. The model provided outputs of the number of people with hidden impacts, human deaths, number of elephant deaths, and hectares of crops damaged by elephants at the end of each run. Because the agent is only active for up to 18 hours a day, a simulated day consisted of 18 time steps rather than 24.

## 6.4 Overview of Elephant Model

Elephant model conceptualise the properties and activities performed by elephant agents in the model. Elephant properties and population are essential for assigning the activities of the elephant in the model. The elephant model is sub-divided into elephant demographic, which describes the way elephant population was acquired and imported into the model, and elephant methods, which outlines and describes the main elephant behaviours and methods in the model.

### 6.4.1 Elephant Demographics

Secondary data determined the location, distribution and demographics of elephants in this model. Elephant census reports were obtained from the Serengeti-Maasai Mara ecosystem. An elephant distribution map of the Serengeti-Mara Ecosystem was obtained from the census report was scanned and loaded into ArcGIS for digitisation and georeferencing (see figure 6.4.1).

Figure 6.4.1: Distribution of elephants in the Serengeti-Mara Ecosystem (TAWIRI & KWS, 2014)

The ground control points for the Serengeti ecosystem were identified using Google Earth and used for georeferencing during digitisation. Digitisation was restricted to the portions of Serengeti National Park and Grumeti Game Reserve located in the Bunda District. These data indicated the presence of 11 groups or families of elephants, one group with a maximum of 27 individuals and 10 groups with approximately nine individuals. The model accommodated 127 elephants in total, which the model regards as elephant carrying capacity, the elephant population changed based on deaths. Demographic features of sex structure and age-structure were collected from the literature for simulation (Lindeque, 1991; Osborn, 2004; TAWIRI & KWS, 2014). Elephant herds consisted of 2 to 27 individuals (TAWIRI & KWS, 2014). Age composition of elephant populations was categorised into young, sub-adult or adult elephants. Young were classified as younger than 5 years; sub-adults were between 6 and 24 years, while adults were older than 24 years (Mduma et al., 2010). Age structure was determined as suggested by (Lindeque, 1991), where young constituted 25%, sub-adults represented 24%, and adult elephants constituted 51% of the elephant population in the model. In this model, the total elephant population consisted of 52 male elephants and 55 female elephants, based on a suggested sex ratio of 1:1 (Kioko et al., 2013). Each elephant had a unique identifier (ElephantID), age, sex and initial location.

### 6.4.2 Elephant Methods

Elephants migrate between protected areas searching for scarce ecological resources, which include water, food and breeding mates. Elephants searched for adequate quantities of food and water to heighten their survival rates. Elephants behaved under an optimal foraging theory approach, where an animal selected patches that maximised its energy efficiency in a cost-benefit scenario (Dumont & David, 2004). Selection of the best grazing patches occurred every hour depending on the internal state (energy) and external state (the quality of the current patches). In short, the time interval of their migration depended on the internal state of the elephant and external state of the environment. Their migratory movements usually pass through natural conservation corridors.

Elephants decided on actions that maximise rather than minimise their energy level. In this context, if there is an accessible conservation corridor, elephants will migrate directly to the nearest protected areas. If human activities and settlements block migratory corridors, and there are edible crops and water in the human landscape, considering that food and water scarcity are their main reasons for the migration, elephants will eat the crops and postpone their migration to other protected areas. However, the success of elephants eating crops depends on the farm guarding intensity. Unguarded farms maximised the magnitude of crop damage incidents. Guarding farms slightly reduces crop damage incidents as it sometimes scares away the elephants from the farm. However, scaring away elephants could lead to human deaths. In AGHEI, scaring off elephants or farm guarding results into either human death, elephant death or crop damage. In addition, elephant death, crop damage and human deaths could lead to hidden impacts in humans (Figure 6.4.2.1).

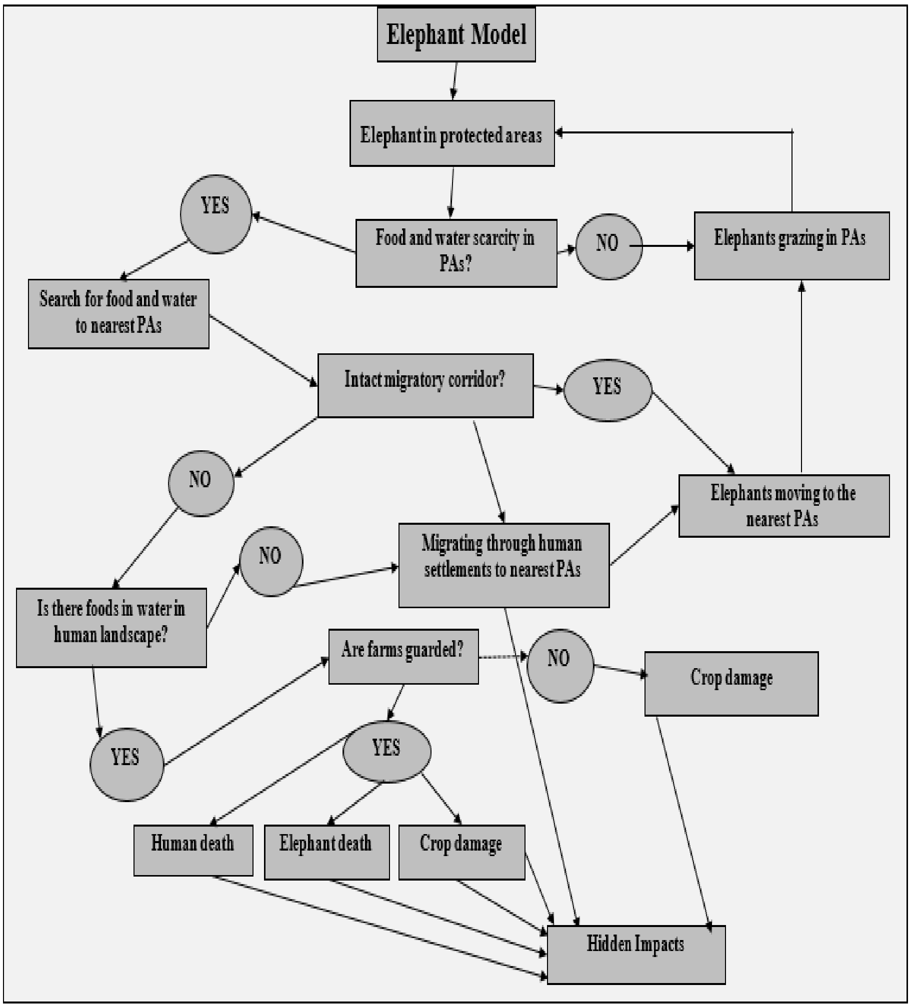

Figure 6.4.2.1: Conceptual framework for elephant movement and behaviours

Each elephant agent carried out specific activities depending on age, location and sex. At any given time, an elephant performed a specific activity depending on the circumstance such as time of the day, level of hunger, environmental and the presence of other agents. Chiyo and Cochrane (2005) found that the crop-raiding age for elephants begins at 10 – 14 years (young elephants), which is the age when male elephants leave herds due to the reproductive competition. In the AGHEI, both male and female (adults and sub-adults) elephants damaged crops, caused hidden impacts and fatal interactions with people. Following model initialisation, elephants assessed the cost of moving into another grid square based on their internal energy state.

Elephants made movement decisions after assessing the eight surrounding grid squares, as well as the current location. Grid cells with the highest ecological resources, or that were farms, were identified as a more suitable destination than those with lower values. If all surrounding grid squares had an equal quality of environmental resources, elephants moved in a random direction at each time step. If all surrounding grid squares were free from human occupation and if crops existed at that location, elephants moved to one and damaged crops. In short, elephant activities (methods) included move-elephants for movement, graze-elephants for eating natural vegetation, drink-elephant for drinking water, give-birth-elephant for giving birth, crop-damage activity for raiding crops and elephant-death for an elephant to die (see figure 6.4.2.2 for a UML class diagram).

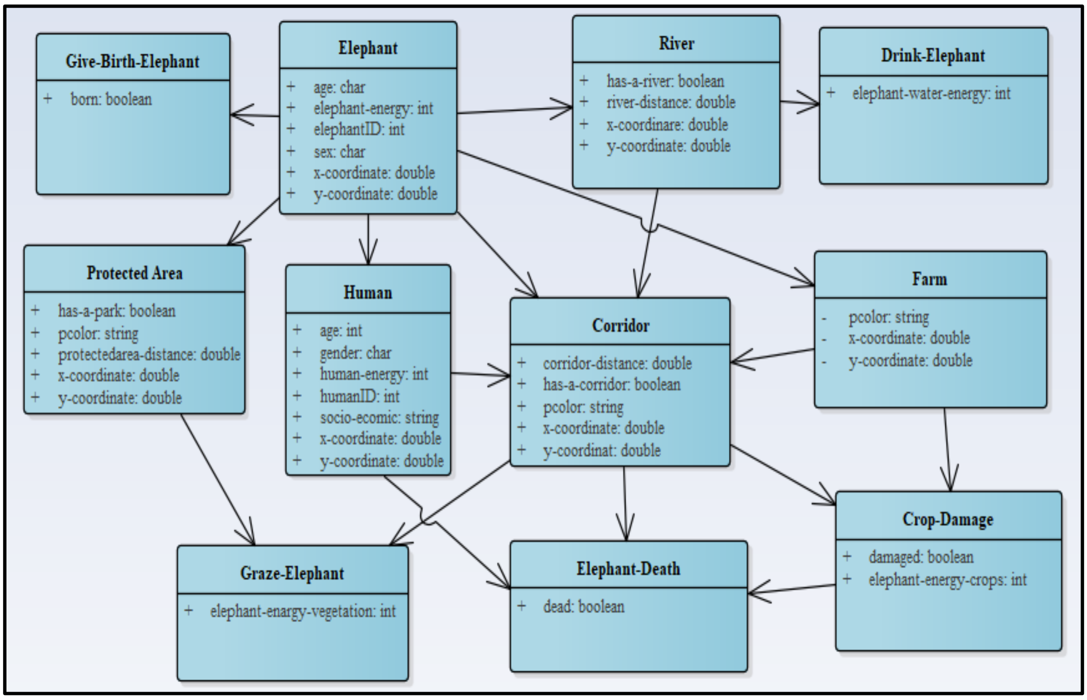

Figure 6.4.2.2: Elephant UML class diagram of model implementation.

#### 6.4.2.1 MOVE-ELEPHANT method

The “fd 1” command was used to move each elephant a step forward, “rt 1” for moving backwards. In this model, one-step represents 10 m to a neighbouring cell. Movement consumed ‘elephant-energy’. The more an elephant moved the more energy is consumed. Since the actual ‘elephant-energy’ consumption for the movement was unknown and probably variable, it was assumed that 1.0 unit of ‘elephant energy’ was consumed per step. Before the beginning of each step, an elephant sensed the direction of movement by locating farms, water, humans and other elephants. Elephants of all ages and sexes performed the movement. However, the direction of the movement depended on the availability of water, food and the type of the agents in the neighborhood.

#### 6.4.2.2 GRAZE-ELEPHANT method

Natural vegetation provides food to elephants in the form of bark, leaves, wood, roots, twigs, fruits, seeds and grasses. Such forms of elephant food are part of the environment and the elephants feed on what is there to increase their energy levels. Vegetation was their primary source of energy, protein and minerals. Elephants of all ages and sexes obtained plants from grasslands, woodlands, forests and wetlands. The AGHEI regarded all-natural food collectively as vegetation. After eating vegetation, the ‘elephant-energy’ level increased. Since food produces more energy than water, the AGHEI assumed that each vegetation intake added 50 points to elephant-energy. The energy points imitate the average digestibility coefficient of the elephant (50%) from vegetation (Clauss et al., 2003).

### 6.4.2.3 DRINK-ELEPHANT method

Elephants require more than 200 litres of water every day (DSWF, 2013). In AGHEI, elephants obtained water from several sources, including streams, rivers and wetlands. The model excluded probabilistic events for getting water from other sources, such as wells and taps, because the spatial data about such sources were unavailable. Since elephants are highly mobile, the AGHEI assumed that 100% of elephants had a chance of obtaining water and no elephants died of dehydration. When elephants drank water, their energy levels (‘elephant-energy’) also increased because elephants also obtain nutrients such as calcium and potassium from water. In that case, elephants received 25 points of ‘elephant-energy’ after drinking water from any source.

### 6.4.2.4 GIVE-BIRTH-ELEPHANT method

Adult female elephants at least 25 years old gave birth to young elephants (Lee et al., 2016). Elephants gave birth when their population size became less than the elephant carrying capacity (127 elephants), and when ecological resources were abundant. Each adult female elephant had an equal chance of giving birth regardless of its current location. Elephant required a large amount of elephant-energy amounting to 20 points for giving birth. This elephant-energy is one off cost on the day of giving birth not every day during pregnancy. Once becoming pregnant, adult female elephants gave birth after 656 days (22 months). Since elephants are monovular (produced only one offspring at a time), female elephants were programmed to give birth to only one calf. In addition, since elephants are precocial (able to walk soon after birth) the young elephant started to walk soon after birth. At birth, the calf was assigned sex, ElephantID, the maximum elephant-energy, age and location. However, AGHEI excluded the death at birth and suckling of the calves.

### 6.4.2.5 CROP-DAMAGE method

Crop raiding incidents occurred mostly in agricultural farms located in either conservation corridors or the vicinity of rivers and protected areas. The farms located outside the corridors experienced less crop damage incidents than those in corridors and rivers. Crops are an opportunistic source of energy, protein, vitamins and minerals for elephants. Consequently, elephants consumed a variety of crops to balance the necessary nutritional requirements of their bodies. However, crop requirements vary according to age, gender, location and energy level of the elephant. In this model, adult, sub-adult and young elephants were usually responsible for crop raids (see figure 6.4.2.5).

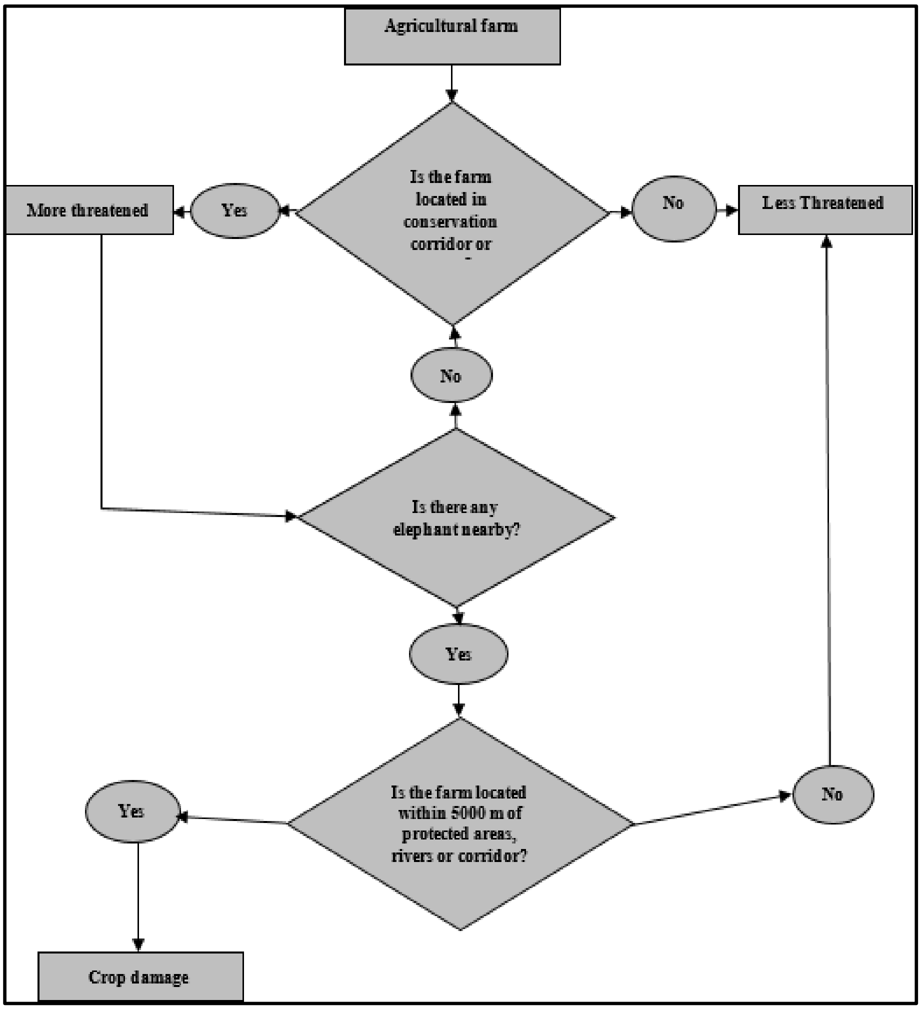

Figure 6.4.2.5: Conceptualisation of crop damage incidents.

The model assumed that after crop consumption, elephant-energy increased by 82 points because energy and nutrients from crops are higher than from natural vegetation (Das et al., 2014).

### 6.4.2.6 ELEPHANT-DEATH method

Elephant deaths in the model excluded natural death, disease-related deaths and poaching-related deaths. Therefore, AGHEI does not take into account such deaths. Elephant death from HEI either occurred after crop damage or as a response to human death (see figure 6.4.2.6).

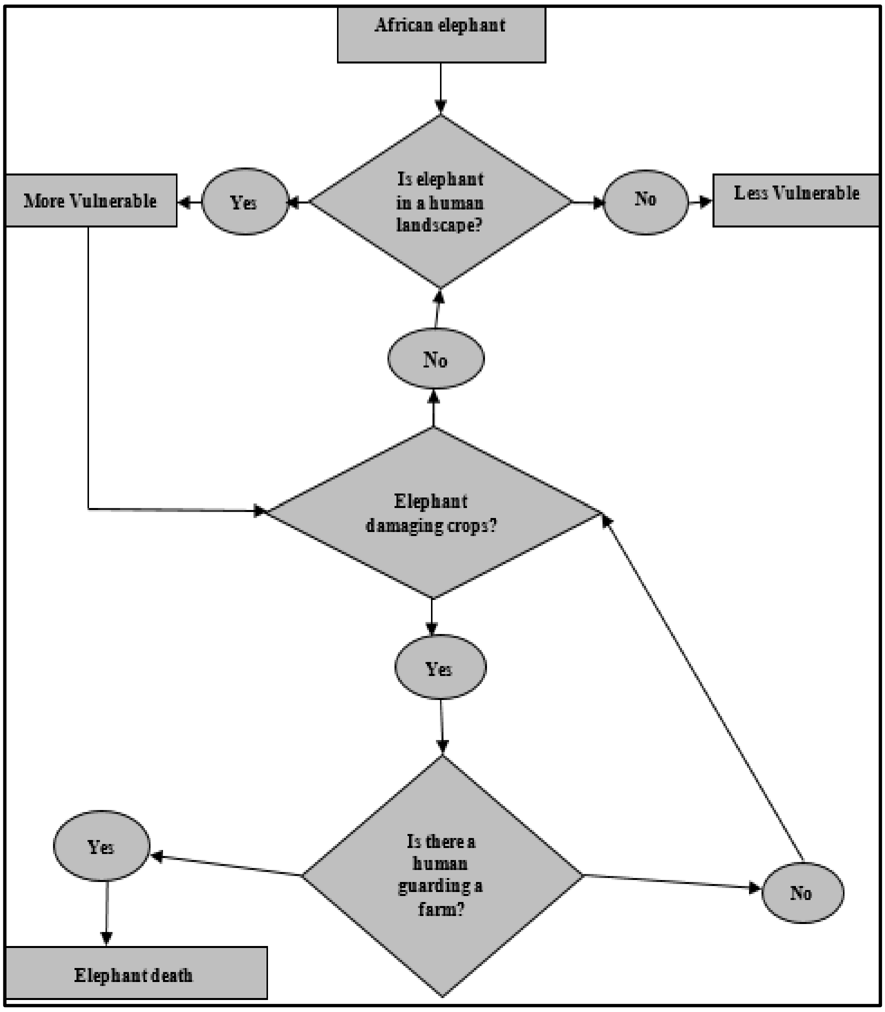

Figure 6.4.2.6: Conceptualisation of elephant death incidents.

Crop damage either occurred in farms located in the corridors and near rivers or outside conservation corridor. Insufficient ecological resources (energy level) influenced the movement of elephants from protected areas to agricultural areas. Humans could also kill elephants when safeguarding a crop farm. Adult and sub-adult elephants were more vulnerable to deaths than young elephants.

## 6.5 Overview of Human Model

Human model conceptualise the properties and activities performed by human agents in the model. Human properties and population are essential for assigning the activities of the human in the model. The human model was subdivided into human demographic, which describes the way the human population was synthesized and imported into the model, and human methods, which describes the main human properties and activities in the model.

### 6.5.1 Human Demographics

Consistent and representative human demographic data are necessary for accurate simulation. The Tanzanian National Bureau of Statistics is responsible for the collection, authorisation and dissemination of population data. Data on individuals (microdata) were unavailable due to confidentiality and ethical issues but the bureau provided general data describing the household structure and summative individual characteristics from the area. However, Useya (2011) recommended synthetic populations for microsimulation. The model used general data from the Tanzanian National Bureau of Statistics to generate a synthetic population. A Monte-Carlo sampling procedure created a synthetic population that possessed demographic attributes closely related to the real population of the Bunda District. The digitisation of actual locations (X, Y coordinates) of buildings from Google Earth images enabled the identification and positioning of human agents in the model.

#### 6.5.1.1 Synthetic Population

The total population of 12 villages understudy is approximately 30661 and spread over 3000 households (Tanzania, 2013). It was impossible for AGHEI to simulate all the people and households within 12 villages. Instead, 600 humans were used in the model, whereby each human represented one household. In this thesis, the household was only used for the creation of human individual not for simulation. In other words, each human agent interacted as an individual human, not as a household. A Monte-Carlo sampling procedure used to create a synthetic generator for creating human agents with age, gender, and socio-economic activity. Human properties particularly ages and genders and socio-economic activity were essential during model development and simulation as they determined what agent could and could not do.

The synthetic generator generated uniformly distributed random number of humans between 0 and 601 in Microsoft Excel. First, the empty list of individuals with age, gender and socio-economic activity was created. The household (house building) was randomly picked for a selection of household representative (human). An individual human was selected randomly to match the age structure of the realistic population in the district (see Table 6.5.1.1). Moreover, the human was selected randomly to match gender and socio-economic activity structures from the survey (see Table 3.4.1.1). Upon completion, the next household was randomly picked up to create the next agent until the number reached 600 (see figure 6.5.1.1). Once the set of human agents was generated, it could be added to the model for simulations.

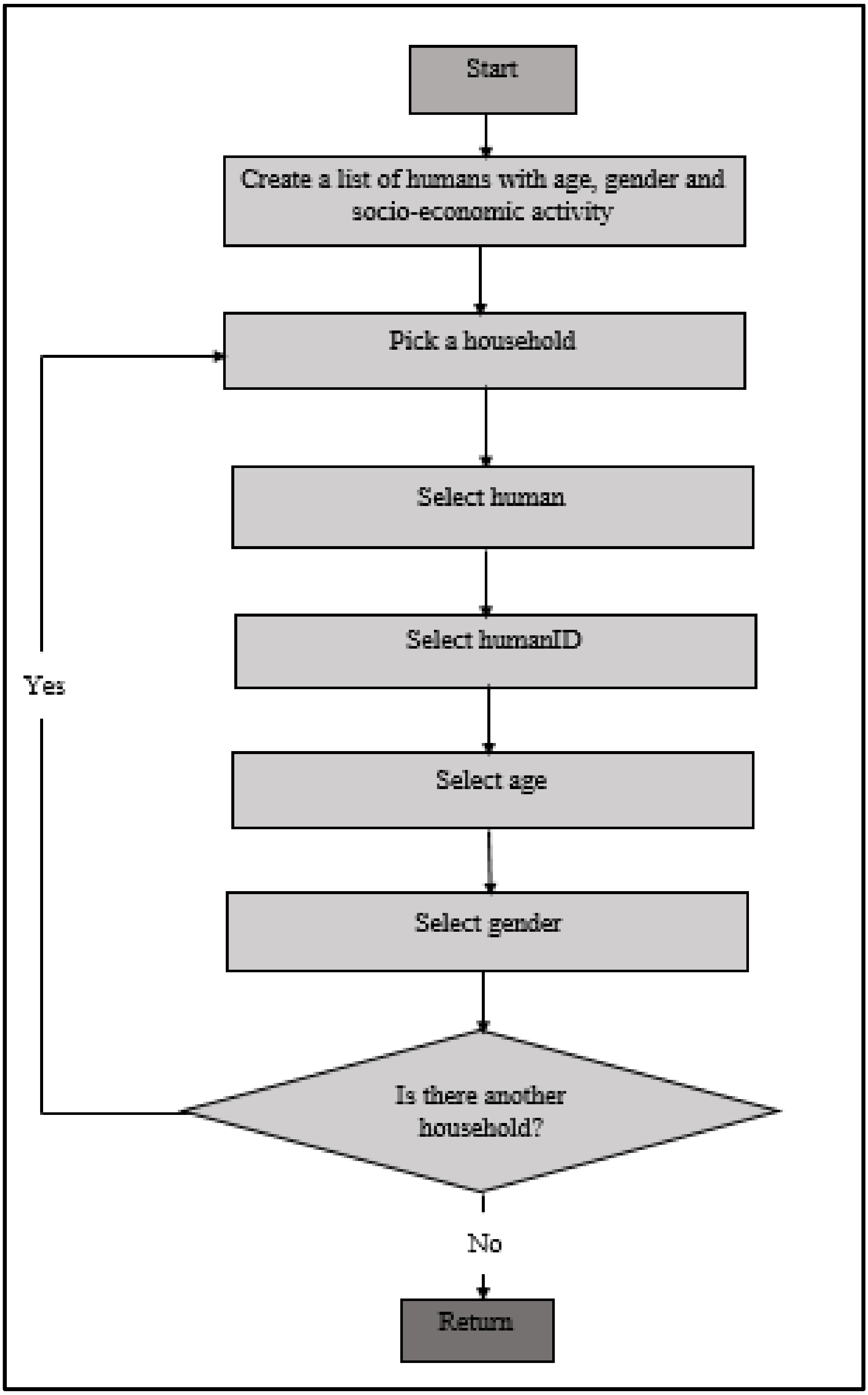

Figure 6.5.1.1: The synthetic generator for generation of human population.

### 6.5.1.2 Human List Creation

The Monte Carlo method generated a statistically realistic population for the Bunda District (see Table 6.5.1.2). This generated a statistically representative population of households for the Bunda District conformed to the statistical indications of the 2012 Population and Housing Census of the United Republic of Tanzania (URT, 2013a).

Table 6.5.1.1: Distribution of the synthetic population by age group in the study area.

| Age (Years) | Percentage | Synthetic population |
|---|---|---|
| 0 - 4 | 15.8 | 96 |
| 5 - 9 | 14.4 | 86 |
| 10 - 14 | 12.6 | 76 |
| 15 - 19 | 10.3 | 61 |
| 20 - 24 | 9.4 | 56 |
| 25 - 29 | 8.0 | 48 |
| 30 - 34 | 6.6 | 40 |
| 35 - 39 | 5.5 | 33 |
| 40 - 44 | 4.1 | 24 |
| 45 - 49 | 3.4 | 20 |
| 50 - 54 | 2.6 | 16 |
| 55 - 59 | 1.7 | 10 |
| 40 - 64 | 1.7 | 10 |
| 65+ | 3.9 | 24 |
| **Total** | **100** | **600** |

#### 6.5.1.3 Spatial Distribution and Location of Human

The synthetic human population was manually distributed over the existing houses in the study areas. A house was regarded as a point and was the initial location for the human agent. The distribution of human population based on proximity (within 10 kilometre) of the house from protected areas, rivers and corridors as criteria. The resultant map was uploaded to ArcGIS as human and consisted of 600 points, each point representing a human agent or household (see figure 6.5.1.4).

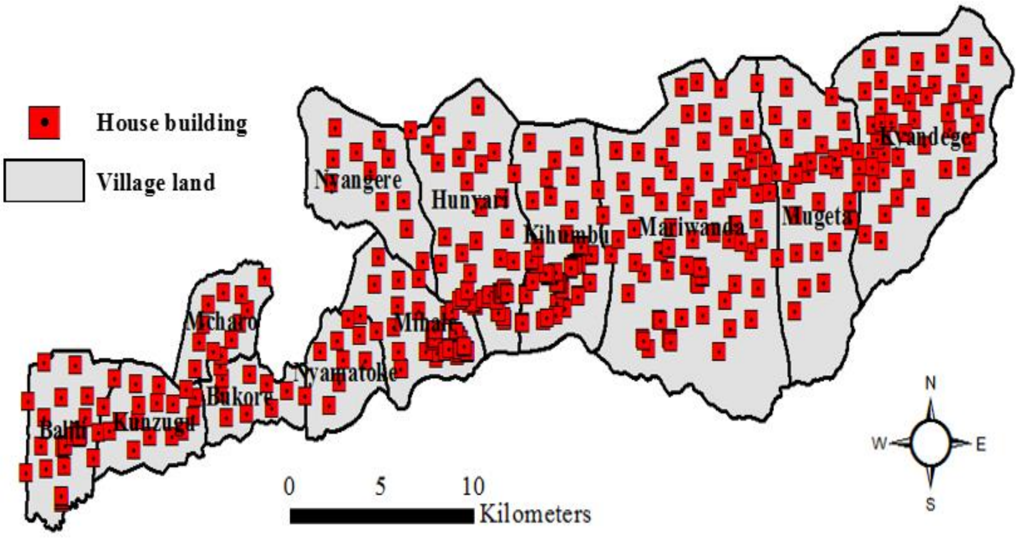

Figure 6.5.1.4: Human population distribution over the house building.

### 6.5.2 Human Methods

The AGHEI assigned specific activities to human agents depending on their properties, such as age, location, socio-economic activities and gender, time of the day, level of hunger, and the presence of other agents. For example, farmers guarded crops and females older than 15 years were capable of giving birth. Following model initialisation, humans assessed the cost of moving into another grid square when moving away from elephants, fetching water and searching for food. Human activities or methods included move-human for human movement, eat-human for eating food, guard-crops-human for guarding crops against elephants, drink-human for drinking water, give-birth-human for giving birth, hidden-impacts for the acquisition of indirect impacts and human-death for human to die (see figure 6.5.2.1).

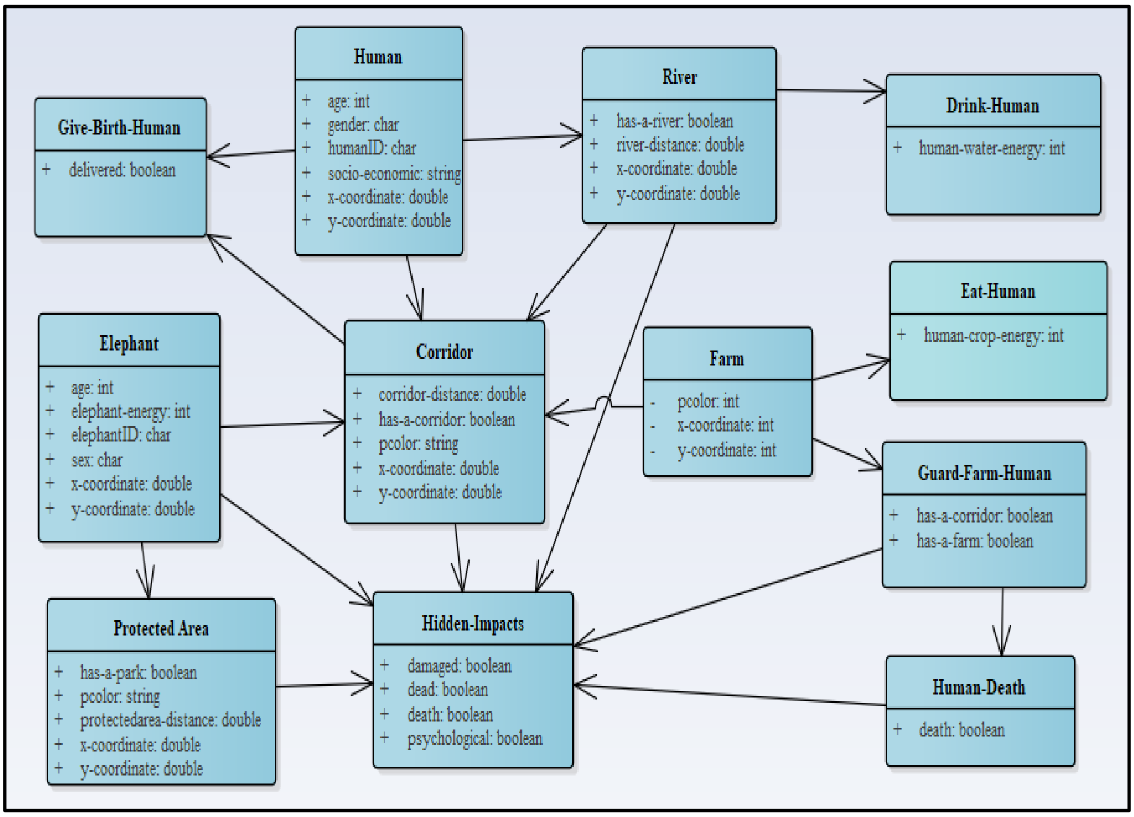

Figure 6.5.2.1: Human UML class diagram of model implementation.

### 6.5.2.1 MOVE-HUMAN method

The Netlogo "fd 1" method was used to move people a step forward and “rt 1” return to one-step in the opposite direction. The movement consumed ‘human-energy’. The more those humans moved, the more ‘human-energy’ was consumed. Each human spent 1.0 energy for each step (10 meters). Before the initiation of each step, people assessed the direction of movement with the primary objective of locating farms, water, elephants and other humans.

#### 6.5.2.2 EAT-HUMAN method

Crops were the primary source of energy, protein, vitamins and minerals for people. People consume a variety of crops to balance the necessary nutritional requirements of their bodies. However, energy demand varied according to age, gender, weight, physical activity level and height of the human. In this model, energy entailed all necessary nutritional requirements that a human needs in a day. When humans consumed crops, their energy levels also increased. Studies estimate that humans obtain 68% of energy from food consumption while the rest is obtained from non-food sources, such as water and minerals (Mishra et al., 2012). In AGHEI, 68% of human-energy (equivalent to 68 points) that came from crops.

#### 6.5.2.2 GUARD-CROPS-HUMAN method

Humans conducted their socio-economic activities through farming and guarding of their farms while avoiding any interruptions from elephants to increase their survival rates. Farmers guarded their farms against elephant invasion. This method was implemented in the farms located in a conservation corridor because these farms are highly vulnerable to elephant crop damage (Desai & Riddle, 2015). If the surrounding grid squares or cells possessed elephants, humans moved either towards or away from elephants. The human-energy level and the content of the grid cell (green for heathy crops and black for bare soil) determined such movements. Based on the survey, in most cases, humans move away from elephants. Less often human either killed elephants or were killed by elephants.

#### 6.5.2.3 DRINK-HUMAN method

People use water for drinking, irrigation, washing and other activities. People need 2 to 3 litres of drinking water every day (CBD, 2010). People obtained water from streams and rivers. The model also excluded probabilistic events for getting water from other sources, such as lakes and wells, as AGHEI does not incorporate these kinds of patches. Since humans are intelligent creatures, AGHEI assumed no person died because of dehydration. After drinking water ‘human-energy’ increased by 20 points as the water was assumed to contain both energy and nutrients for human survival.

### 6.5.2.4 GIVE-BIRTH-HUMAN method

Adult female humans were capable of giving birth. The women were at least 15 years old because women are legally allowed to be married in Tanzania at that age (URT, 1971). Humans give birth when their population size became less than the human carrying capacity (550 humans) for AGHEI. Women gave birth after 6480 hours (9 months) once becoming pregnant. Human spent a large amount of human-energy amounting to 20 points for giving birth. It is one off cost energy on the day of giving birth not every day during pregnancy. The AGHEI simulated women giving birth to only one child. At birth, the AGHEI assigned a child the gender, id, the maximum human-energy, 5 years of age and location. The AGHEI excluded death at birth and costs of early parental care for the child including suckling.

### 6.5.2.5 HIDDEN-IMPACTS method

Barua et al. (2013) described hidden impacts as psychological impacts resulting from injury (nonfatal through to death), disruption of families, livelihoods, poverty, opportunity costs, health and nutritional status and abandoning of school participation for children. People within elephant conservation corridors or near protected areas, and rivers and village land were highly vulnerable to hidden impacts. Hidden impacts occurred due to repetitive observations of negative HEI and crop damage. Hidden impacts affected people aged above four years and of both genders. Farmers became more concerned than other professions. With crop-raiding, farmers become highly indebted, unable to provide their families with food, medication and school fees. Similarly, school-age children were psychologically affected because of human deaths, injuries, malnutrition and poverty caused by elephants (see figure 6.5.2.5).

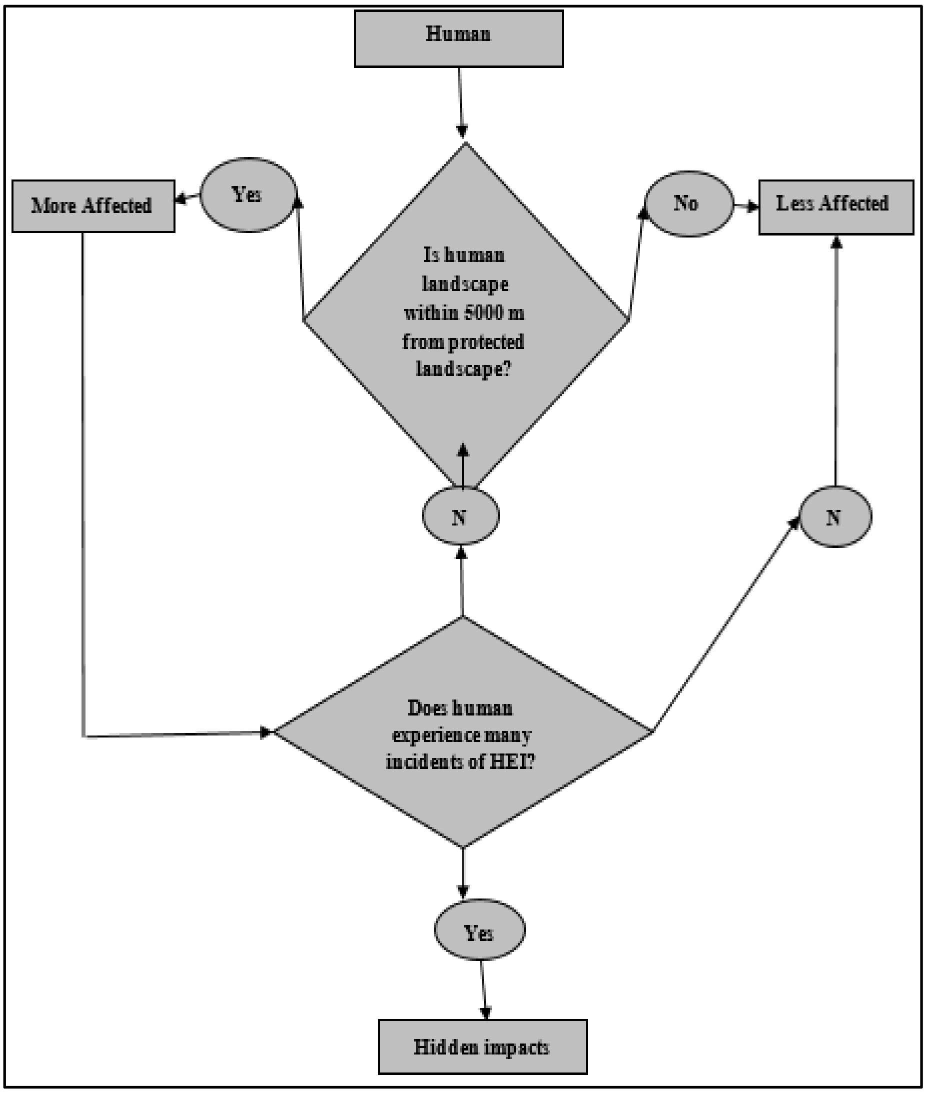

Figure 6.5.2.5: Conceptualisation of hidden impact for hidden impacts.

#### 6.5.2.6 HUMAN-DEATH method

Human death excluded natural death or other forms of human death, such as from disease, robbery and during illegal hunting or poaching. Human deaths occurred after humans attempted to scare elephants away from their crops or stop elephants from attacking people in the villages. Human deaths were rare. In addition, elephants mostly killed humans who were farmers and resided in corridors. Based on the collected data, elephants were able to kill humans above five years of age whose socio-economic activities were agriculture or student (see figure 6.5.2.6).

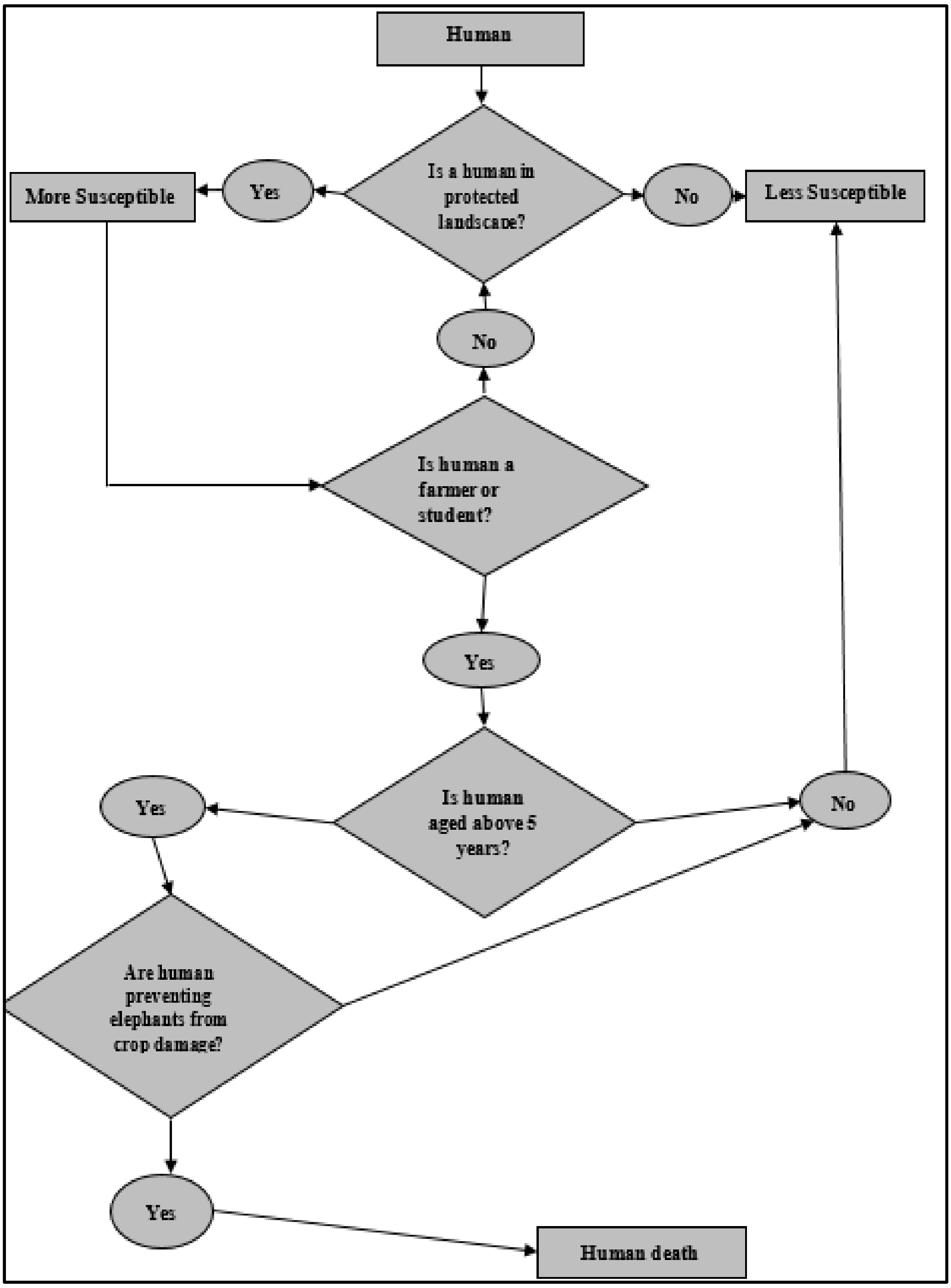

Figure 6.5.2.6: Conceptualisation of human death.

## 6.6 Model Spatial Environment Data

Spatial data layers were constructed to represent the environment. Elevation, rivers, farms, protected areas and corridor spatial data were acquired to characterise the model landscape. A Digital Elevation Model (DEM) was downloaded from the Shuttle Radar Topography Mission (SRTM) (Tan et al., 2015), with a grid cell resolution of 90 meters for the derivation of the slope, elevation and aspect (Farr et al., 2007). The nearest neighbor assignment resampling technique was used to change the DEM cell size from 90 to10 meters (Tan et al., 2015). A shapefile for the farms and rivers were obtained from the Lincoln University GIS server.

Farm objects provided a landscape for people to grow crops, obtain food and interact with elephants, and areas for elephants to interact with crops. Rivers and streams provided areas for humans and elephants to obtain water. Serengeti National Park (SENAPA) provided protected area boundaries, which included the national park and Grumeti Game Reserve (see figure 6.6.1). Protected areas provided the actual landscape for elephants to eat, drink and give birth in the model. The corridor layer was digitised based on descriptions and discussions with wildlife and land experts from Bunda District Council and nearby protected areas (see figure 6.6.1).

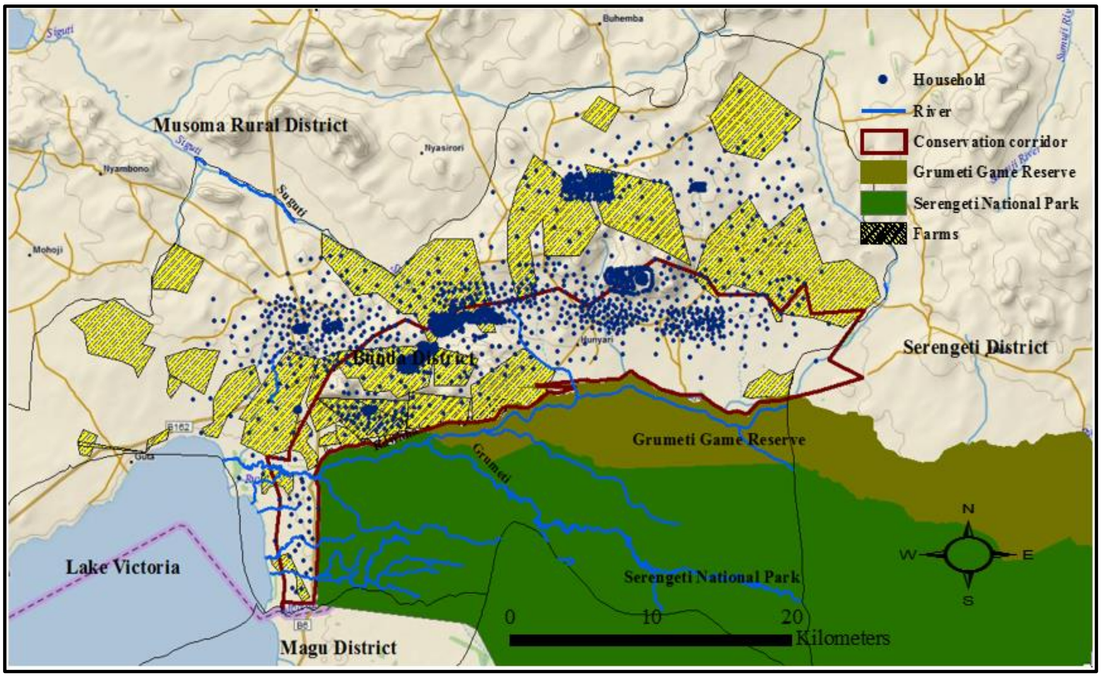

Figure 6.6.1 Spatial modelling environment imported into the AGHEI.

Conservation corridors usually connect natural elephant habitats, but human habitations and agricultural encroachments restrict elephant movement in the migratory corridors. In the model, conservation corridors provided the primary areas where HEI occurred (Parker et al., 2007; Thouless et al., 2016).

### 6.6.1 Model Calibration, Validation and Experimentation

The parameter values used in these models were obtained from a geospatial survey conducted in the study area district from March to October 2017 (chapter four and chapter five). The following parameters were used for the model calibration: 550 individuals, 126 elephants, corridor-distance 0 meters, protectedarea-distance 200 meters and river-distance 252 meters. The above data formed the baseline scenario (section 6.4.2.1). Netlogo provided a graphical user interface (GUI) to observe humans, elephants and their environment in the model. The interface was produced to view agents and programming code if they corresponded to model design, model purposes and model conceptualisation (see figure 6.6.1.1).

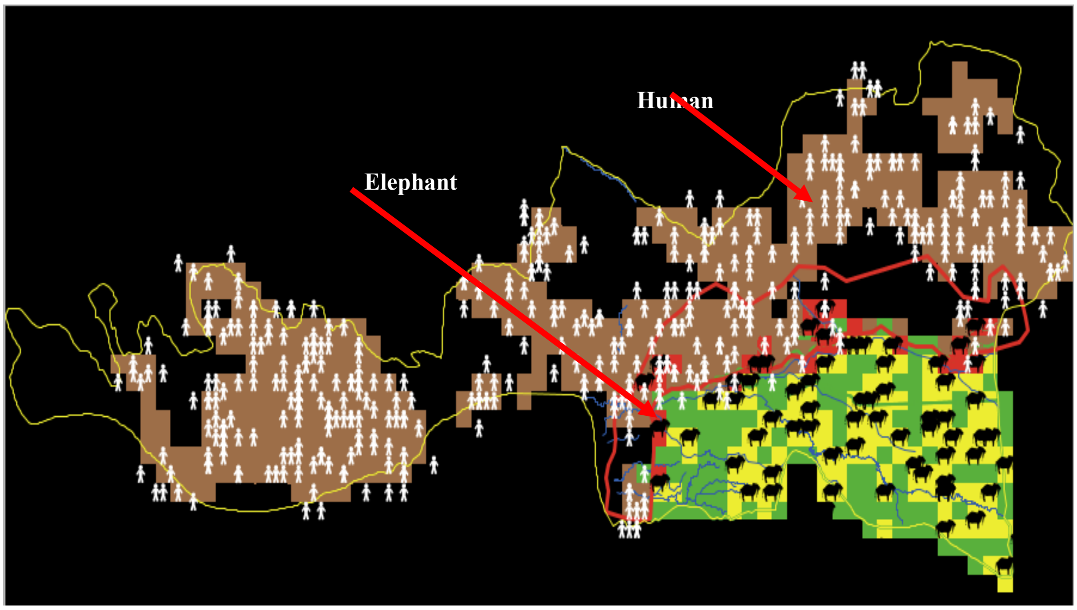

Figure 6.6.1.1: The display of agents on Netlogo simulation environment.

Parameter sensitivity tests were conducted to determine the change in model results in response to changing parameter values. The sensitivity tests determined response of model outputs towards changing of inputs and model-parameter values. It showed the relationship between several model input and output variables. Parameter variability involved river-distance, protectedarea-distance and corridor-distance as input parameters. The main outputs recorded for verification were human and elephant deaths, crop damage and hidden impacts. As an example, parameter sensitivity analysis for river-distance, the river-distance parameter was changed 11 times between 0 and 10000 meters while keeping constant the other model-parameters such as protectedarea-distance (0 m), river-distance (0 m) and corridor-distance (0 m). The outputs were recorded for each river-distance parameter value. Changing a river-distance parameter's values between 1000 to 5000 meters resulted in the different model outputs. In that case, AGHEI tested positive for river-distance parameter value sensitivity (see figure 6.6.1.2).

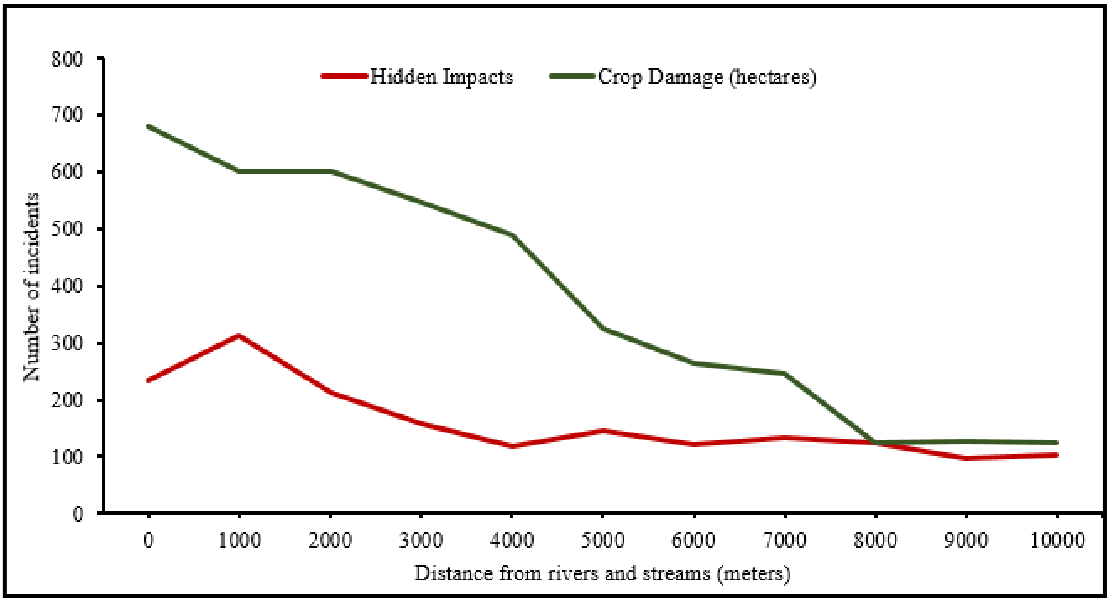

Figure 6.6.1.2: The river-distance parameter sensitivity test on hidden impacts and crop damage.

Moreover, there were comparisons between observed data (survey data) and model outputs to validate the model. Survey data over ten years showed four human deaths in ten years (see Table 6.6.1.1). The model outputs correlate well with the field data.

Table 6.6.1.1: A comparison between field data and model outputs on human deaths.

| Year | Field data | Model outputs |
|---|---|---|
| 2010 | 0 | 1 |
| 2011 | 1 | 1 |
| 2012 | 0 | 0 |
| 2013 | 2 | 0 |
| 2014 | 1 | 1 |
| 2015 | 0 | 1 |
| Total | 4 | 4 |

Source: Field data and AGHEI outputs

In addition, the survey data over ten years showed one elephant death in ten years (see Table 6.6.1.2). The model outputs fit well with the field data.

Table 6.6.1.2: A comparison between field data and model outputs on elephant deaths.

| **Year** | **Field data** | **Model outputs** |
|---|---|---|
| 2006 | 1 | 0 |
| 2007 | 0 | 0 |
| 2008 | 0 | 0 |
| 2009 | 0 | 0 |
| 2010 | 0 | 0 |
| 2011 | 0 | 0 |
| 2012 | 0 | 1 |
| 2013 | 0 | 0 |
| 2014 | 0 | 0 |
| 2015 | 0 | 0 |
| **Total** | **1** | **1** |

Source: Field data and AGHEI outputs

A comparison between field and model outputs on crop damage showed a close resemblance except for an overestimation of 10.52 hectares for four years in AGHEI outputs (see Table 6.6.1.3).

Table 6.6.1.3: A comparison between field data and model outputs on crop damage

| **Year** | **Field data** | **Model outputs** |
|---|---|---|
| 2012 | 71.23 | 680.52 |
| 2013 | 190.21 | 534.20 |
| 2014 | 1772.18 | 582.77 |
| 2015 | 237.56 | 534.20 |
| Total | 2271.18 | 2281.70 |

Source: Field data and AGHEI outputs on hectares of crops damaged by elephants

Comparison between survey data and model outputs on hidden impacts showed a close comparison except for an overestimation of 16 incidents (see Table 6.6.1.4). The AGHEI was unadjusted for hidden impacts because the estimation of the field data was kept constant in all four years of validation. In addition, the documentation of crop HEI incidents in developing countries is difficult (Barua et al., 2013; Treves, 2007), consequently, studies usually underestimate the data as most incidents go unreported (Knight, 2000).

Table 6.6.1.4: A comparison between field data and model outputs on hidden impacts.

| Year | Field data | Model outputs |
|---|---|---|
| 2016 | 328 | 322 |
| 2017 | 328 | 335 |
| 2018 | 328 | 333 |
| 2019 | 328 | 328 |
| **Total** | **1312** | **1328** |

Source: Field data and AGHEI outputs

## 6.8 Model Scenarios and Experimentation

This section provides an overview of the names and the total number of modelling scenarios and sub-scenarios simulated in the AGHEI. It also outlines the number of model parameters and model parameter values used during the simulation for each scenario.

### 6.8.1 Overview of the Scenarios

AGHEI evaluated the effects of 18 scenarios in addition to the baseline scenario. These scenarios were developed to test the effect of changing baseline parameters on reducing HEI, such as elephant and human populations and different distances to areas or features. The baseline scenario represented the current situation of HEI in the Bunda District based on data collected on-site (see chapter X) while the six primary scenarios included elephant-effects (ES), human-effects (HS), environmental-effects (EES), elephant-environmental-effects (EES), human-environment-effects (HES) and human-elephant-environmental-effects (HEES) scenarios. The elephant-effects scenario (ES) examined the effect of varying elephant populations while human-effects scenario (HES) analysed the effect of varying the human population pressure on HEI. The environment-effects scenario investigated the effect of varying environmental biophysical features (distances to rivers, protected areas and corridors). The elephant-environmental-effects scenario assessed the combined impacts of changes to elephant populations and environmental factors while the human-environment-effects scenario examined the joint contribution of varying human populations and environmental factors. Lastly, the human-elephant-environment effects scenario assessed the combined impacts of the optimal human, elephant and environmental factors based on the previous scenario and their impact of the incidence of HEI. The ES, HES, EES, and HEES scenarios were each subdivided into four independent sub-scenarios: River sub-scenario, Corridor sub-scenario, Protectedarea sub-scenario and River_Protectedarea_Corridor sub-scenario. These sub-scenarios evaluated specific geographical impacts of the feature on HEI occurrences. Parameter values for each scenario are summarised in (see Table 6.8.1).

Table 6.8.1: Model parameter values and names for different modelling scenarios.

| Scenario | Protected area distance (meters) | River distance (meters) | Corridor distance (meters) | Human population | Elephant Population |
|---|---|---|---|---|---|
| Baseline (BS) | 200 | 256 | 0 | 550 | 127 |
| Elephant (ES) | 200 | 256 | 0 | 550 | 14 - 127 |
| Human (HS) | 200 | 256 | 0 | 50 -550 | 127 |
| ENS-River | 200 | 0 - 10000 | 0 | 550 | 127 |
| ENS-Corridor | 200 | 256 | 0 - 10000 | 550 | 127 |
| ENS-Protectedarea | 0 – 10000 | 256 | 0 | 550 | 127 |
| ENS-River_Protect_Corridor | 0 – 10000 | 0 - 10000 | 0 - 10000 | 550 | 127 |
| HES-River | 200 | 0 - 10000 | 0 | 50 | 127 |
| HES-Corridor | 200 | 256 | 0 - 10000 | 50 | 127 |
| HES-Protectedarea | 0 – 10000 | 256 | 0 | 50 | 127 |
| HES-River_Protect_Corridor | 0 – 10000 | 0 - 10000 | 0 - 10000 | 50 | 127 |
| EES-River | 200 | 0 - 10000 | 0 | 550 | 14 |
| EES-Corridor | 200 | 256 | 0 - 10000 | 550 | 14 |
| EES-Protectedarea | 0 – 10000 | 256 | 0 | 550 | 14 |
| EES-River_Protect_Corridor | 0 – 10000 | 0 - 10000 | 0 - 10000 | 550 | 14 |
| HEES-River | 200 | 0 - 10000 | 0 | 50 | 14 |
| HEES-Corridor | 200 | 256 | 0 - 10000 | 50 | 14 |
| HEES-Protectedarea | 0 – 10000 | 256 | 0 | 50 | 14 |
| HEES-River_Protect_Corridor | 0 – 10000 | 0 - 10000 | 0 - 10000 | 50 | 14 |

### 6.8.2 Model experimentation

The model was implemented in the Logo programming language using the Netlogo 6.0.1 Integrated Development Environment (IDE) (Wilensky & Rand, 2015). Each model simulation ran for 8760 time steps, with each step representing one hour of real-world time. The model outputs were used to compare emerging outcomes from each scenario. For proper moderation of landscape stochasticity and also the variability of model outputs, parameter combinations and values, for each scenario were run 200 times to obtain a mean value for each output. After a year, (8670 iterations) the total number of human deaths, elephant deaths, total number hectares of crop damage and the total number of people with hidden impacts were recorded for each model.

The calibration of model settings and their associated sets of parameter values was extremely exhaustive and susceptible to several errors. Therefore, the Netlogo BehaviourSpace tool was used to perform automatic systematic model experimentation. This tool ran the model 200 times for each simulation run, systematically varying the parameter values of protectedarea-distance, river-distance, corridor distance, human populations and elephant populations. Several runs of the model regulated environmental stochasticity and variability of model outputs. The model recorded outputs for each possible combination of the model setting and parameter values. This enabled the examination of relationships between various model parameters and the behaviours for selection of the best scenario.

Model results with the total number of human deaths, the total number of elephant deaths, a total number of acreages of crop damage and a total number of people with hidden impacts were exported for statistical and graphical analysis. The data analysis was performed using an ANOVA single factor analysis in Microsoft Excel. Each scenario was individually analysed for the extent of hidden impacts, human deaths, elephant deaths and crop damage against main model variables.

## 6.9 Results and Discussion

A spatially explicit and non-deterministic agent-based model was developed to evaluate the relative performance of different modelling scenarios for reducing or eradicating adverse impacts emanating from HEI in the Bunda District (Table 6.9.1). The AGHEI simulated the adverse impacts of human and environmental factors and specifically the magnitude and frequency of crop damage, human deaths, hidden impacts and elephant deaths. Human population, elephant population, river, wildlife corridor and wildlife protected areas were the main model variables. Hidden impacts were the most difficult incidents to minimise as only four out of the 18 scenarios managed to significantly reduce hidden impacts. In all four successful scenarios, either rivers, humans or both were the main variables. With respect to variables, human residents and farms should be located further from rivers to minimise hidden impacts. The model describes hidden impacts as multidimensional as many factors influencing their incidence and severity.

Table 6.9.1: Model results from various modelling scenarios below summarises the model outputs based on visual observation of the graph(s) from each scenario, where reduced means there was a noticeable reduction of either incidents from one extreme of the variable to another and eradicated means a zero incident.

| **Scenario** | **Main variables** | **ANOVA: Single Factor Statistical Results** (*p-values*) **at significance level of 0.05** | | | |
|---|---|---|---|---|---|
| | | **Hidden impacts** | **Human death** | **Elephant deaths** | **Crop damage** |
| Elephant effects | Elephants | Insignificant and not reduced | **Significant and reduced** | **Significant and reduced** | **Significant and reduced** |
| Human effects | Human | **Significant and reduced** | Significant but not reduced | Significant but not reduced | Significant but not reduced |
| ENS-River | River | Significant but not reduced | **Significant and reduced** | Significant but not reduced | **Significant and reduced** |
| ENS-Corridor | Corridor | Significant but not reduced | Significant but not reduced | Significant but not reduced | Significant but not reduced |
| ENS-Protectedarea | Protected areas | Significant but not reduced | Significant but not reduced | **Significant and reduced** | Significant but not reduced |
| ENS-River_Protect_Corridor | River, corridor and protected areas | **Significant and reduced** | **Significant and reduced** | Significant but not reduced | **Significant and reduced** |
| HES-River | River and human | Significant but not reduced | **Significant and reduced** | Significant but not reduced | **Significant and reduced** |
| HES-Corridor | Corridor and human | Significant but not reduced | **Significant and reduced** | Significant but not reduced | Significant but not reduced |
| HES-Protectedarea | Protected areas and human | Significant but not reduced | **Significant and reduced** | Significant but not reduced | Significant but not reduced |
| HES-River_Protect_Corridor | River, corridor, protected areas and human | **Significant and reduced** | Insignificant but eradicated | Significant but not reduced | Significant but not reduced |
| EES-River | River and elephant | Significant but not reduced | **Significant and reduced** | Significant but not reduced | **Significant and reduced** |
| EES-Corridor | Corridor and elephant | Significant but not reduced | **Significant and reduced** | **Significant and reduced** | Significant but not reduced |
| EES-Protectedarea | Protected areas and elephant | Significant but not reduced | **Significant and reduced** | **Significant and reduced** | Significant but not reduced |
| EES-River_Protect_Corridor | River, corridor, protected areas and elephant | **Significant and reduced** | **Significant and reduced** | Significant but not reduced | **Significant and reduced** |
| HEES-River | River, human and elephant | Significant but not reduced | Insignificant but eradicated | **Significant and reduced** | **Significant and reduced** |
| HEES-Corridor | Corridor, human and elephant | Significant but not reduced | **Significant and reduced** | Significant but not reduced | Significant but not reduced |
| HEES-Protectedarea | Protected areas, human and elephant | Significant but not reduced | **Insignificant eradicated** | Insignificant and not reduced | **Significant but not reduced** |
| HEES-River_Protect_Corridor | River, corridor, protected areas, human and elephant | **Significant and reduced** | **Insignificant but eradicated** | **Insignificant but eradicated** | **Significant and reduced** |

Moreover, all modelling scenarios suggested that hidden impacts were impossible to eradicate, as none of the scenarios produced zero incidents. It is also important to note that people acquire hidden impacts indirectly; occurrences of such impacts do not depend only on the size of an elephant population but also on the size of the human population, geographic location of human settlements and an individual's previous experiences with elephants. As an example, the human-effects scenario indicated that a slight decrease in the human population decreases the hidden impacts at a higher rate in the model (see figure 6.9.1.1).

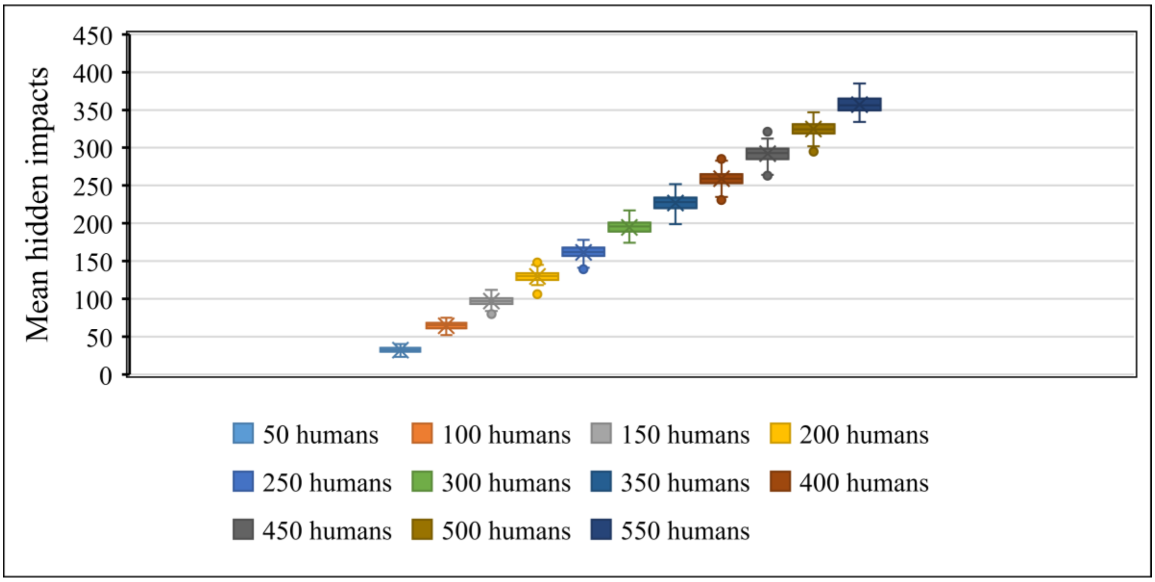

Figure 6.9.1.1: The effect of human-effects scenario on mean hidden impacts.

Human deaths were the easiest incidents to reduce as 15 out of 18 scenarios minimised human fatalities in the model. Reduction in the human population significantly reduced human deaths in the human-effect scenario (see figure 6.9.1.1). This suggests that population size is one of the main factors influencing human deaths. It was likely to reduce human deaths without affecting the human population as evidenced in ENS-River_Protect_Corridor scenario (see figure 6.9.1.2) and elephant effects scenarios (see figure 6.9.1.3), which largely reduced human deaths.

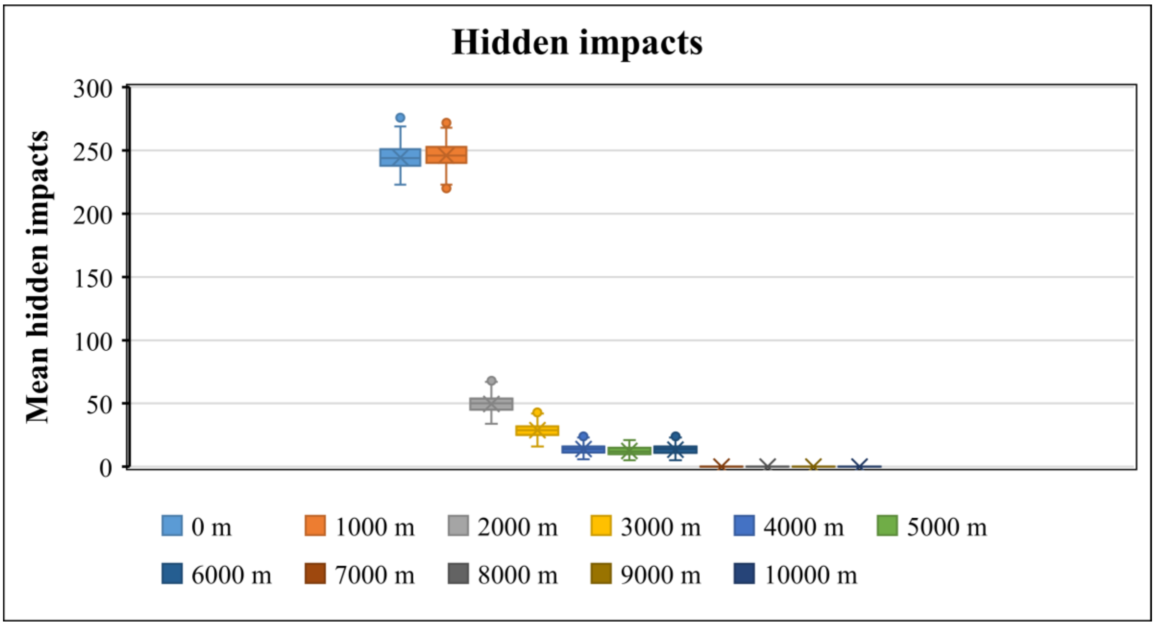

Figure 6.9.1.2: The effect of ENS-River_Protect_Corridor on mean hidden impacts.

The AGHEI suggests that human deaths can be minimised by reducing the elephant population and moving human settlements further away (6000 meters) from rivers, conservation corridors and protected areas. It was difficult to minimise human deaths without reducing the human population size. Human-environmental effects and human-elephant-environmental effects scenarios show zero incidences of human deaths after incorporating human, elephant and environment as model variables. In short, AGHEI has more options to select from for either reducing or eliminating human death than other incidents.

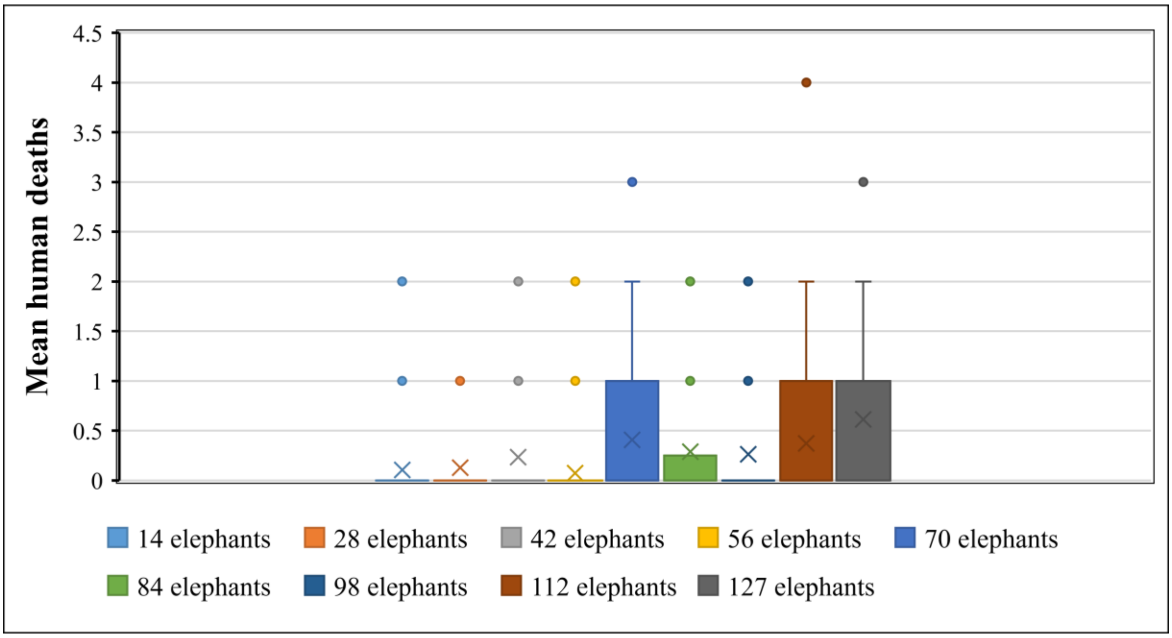

Figure 6.9.1.3: The effect of varying the elephant population (elephant effects scenario) on mean human deaths.

The AGHEI reveals that elephant death is one of the difficult incidents to reduce; only six scenarios minimised elephant fatalities. In those scenarios, the elephant population was one of the main variables. The model suggests reducing elephant population size as one of the options to minimise elephant deaths (see figure 6.9.1.3). Conversely, the adjustment of human population size insignificantly reduced elephant deaths in the model (see figure 6.9.1.1). In short, it was likely to reduce elephant deaths without adjusting the human population size, though eradication of elephant deaths was unlikely without reducing human population size. For instance, The of ENS-River_Protect_Corridor scenario reduced elephant deaths, without affecting human population size (see figure 6.9.1.2).

The AGHEI produced eight modelling scenarios that minimised crop damage. The majority of those scenarios included river distances or elephant population as one of their main variables. Results suggest that most of the crop damage incidents occur within 1000 meters from rivers. Adjustment of the human population size insignificantly reduced elephant crop damage (see figure 6.9.1.1). According to the AGHEI, human population size is not the only the contributing factor to crop damage. Implementation of human-environmental effects and human-elephant environmental-effects scenarios that included human factors in simulation minimised crop damage. The elephant-effects scenario shows that elephant crop damage may be reduced without affecting the human population size (see figure 6.9.1.3). It also suggests that it is likely to decrease elephant crop damage without moving agricultural farms away from rivers. Likewise, it is possible to reduce crop damage without adjusting the elephant population size by adopting the environmental and human-environmental effects scenarios. However, it was impossible to eradicate all crop damage incidents in the model by adopting any scenario.

According to the AGHEI, changing human or elephant factors can only reduce but not eliminate HEI occurrences. In comparison, the elephant effects scenario reduced all adverse impacts except hidden impacts whereas the human effects scenario reduced only hidden impacts. It was also possible to reduce or eliminate human deaths without affecting elephant population size by adopting the HES-River-Protect-Corridor scenario (see figure 6.9.1.4), but it was unlikely to eradicate any of the incidents without reducing human population size (see figure 6.9.1.1).

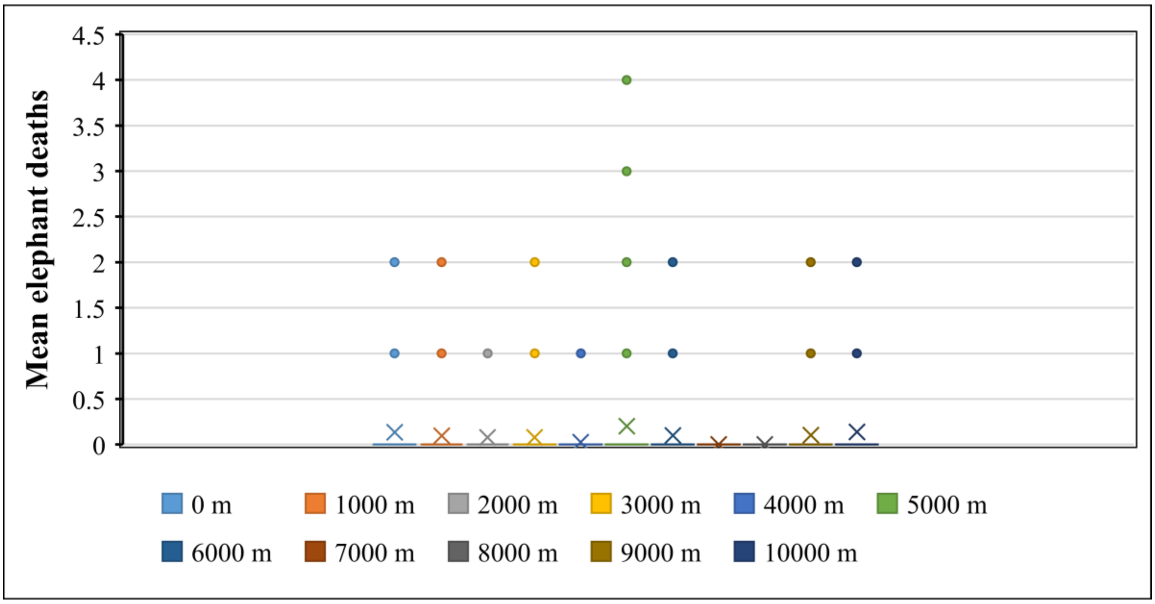

Figure 6.9.1.4: The effect of the HES-River-Protect-Corridor scenario on mean elephant deaths.

In reality, the AGHEI shows that HEI results from a combination of many factors beyond just human and elephant. According to Graham et al. (2010), geographical factors are another determinant of HEI. As an illustration, implementation of the HES-River-Protect-Corridor scenario suggested that distancing human settlements from rivers, corridors and protected areas could reduce all incidents, except elephant deaths (see figure 6.9.1.4). In short, many conservation-related problems are caused by a human component (Bandara & Tisdell, 2002). Implementation of the HES-River-Protect-Corridor scenario by moving human settlements and activities away from environmental features (river, protected areas or corridor) eradicated human deaths (see figure 6.9.1.4). The scenario also managed to reduce hidden impacts but failed to reduce elephant deaths.

The elephant scenario is capable of reducing all incidents except hidden impacts (see figure 6.9.1.3). This scenario demonstrates how the elephant population size influences HEI occurrences. To ascertain the impacts of elephants and environment features on HEI, the elephant-environmental effects scenario was implemented and reduced all incidents, except elephant deaths (see figure 6.9.1.5).

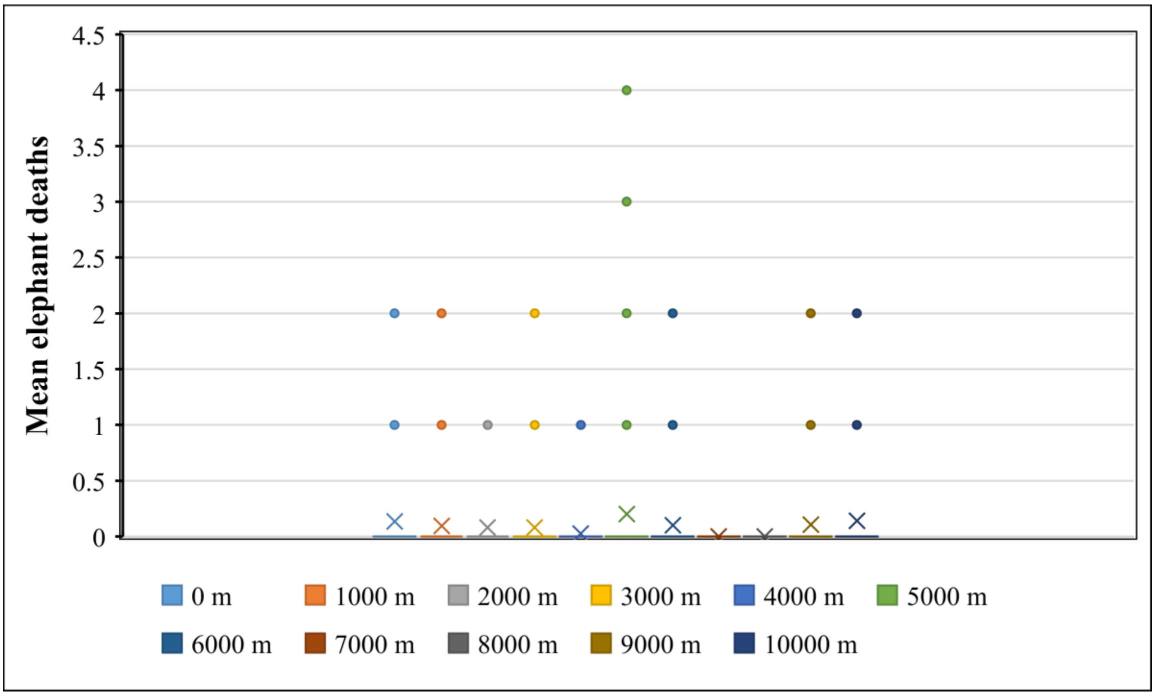

Figure 6.9.1.5: The effect of the EES-River-Protect-Corridor scenario on elephant deaths.

According to the results, the elephant-environmental effects scenario is suitable for reducing human deaths, hidden impacts and crop damage but not elephant deaths. The human-environmental effects, elephant effects, human effects and elephant-environment effects scenarios were ineffective at either reducing or eradicating all HEI occurrences in the model. The various scenarios are useful in reducing or eradicating a particular incident. The collective impacts of human, elephant and environment features on HEI was investigated by implementing the human-elephant-environmental scenario. According to the scenario, it was unlikely to reduce or eradicate all the impacts by just adjusting human and elephant populations with one of the environmental features (river, protected areas or corridor). Nevertheless, moving farms and settlement from rivers eradicated human deaths. In that manner, the performance of the rivers sub-scenario was better than corridors or protected areas sub scenarios. The adjustment of human and elephant populations with all environmental features (rivers, protected areas and corridors) reduced hidden impacts and eliminated human and elephant deaths in the model. In the HEES-River-Protect-Corridor scenario, the total disappearance of most hidden impacts and elephant crop damage occurred after 8000 meters from rivers, corridor and protected areas (see figure 6.9.1.6).

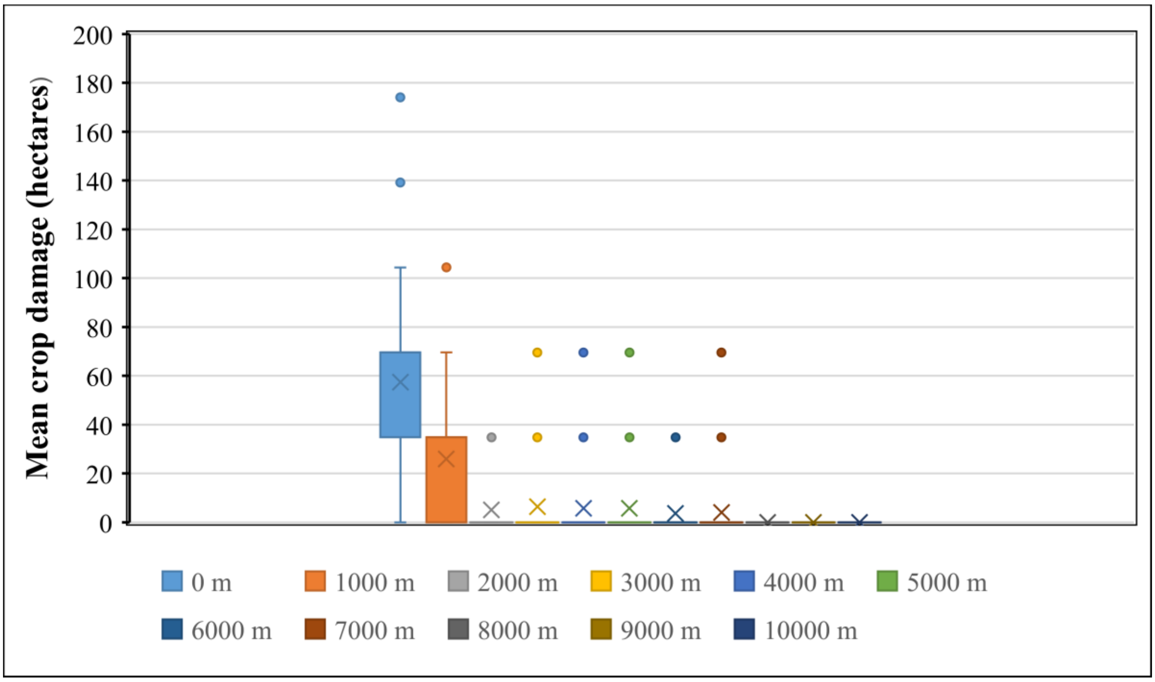

Figure 6.9.1.6: The effect of the HEES-River_Protected area_Corridor on crop damage.

A noticeable reduction of incidents in the human-elephant-environmental effects scenario happened beyond 5000 meters from edges of protected areas (see figure 6.9.1.6). Areas up to 5000 meters from protected areas are usually considered a buffer zone, where governmental and customary laws regulate resource utilisation (Biodiversitya-z, 2015). Strategic resource management of buffer zones usually aims at enhancing positive impacts while minimising negative ones on neighbouring communities and sustainable conservation (Ebregt & Greve, 2000). Environmentally destructive activities, such as farming, deforestation, infrastructure development and livestock keeping, are highly discouraged within a buffer zone. Governments encourage ecologically friendly activities, such as reforestation, collection of non-timber forest products and ecotourism activities, and regard them as an integral part of sustainable rural development policy and environmental conservation programs. The magnitude of human and wildlife interactions in a buffer zone is high because of their proximity to core wildlife reserves. For people to coexist with wildlife in a buffer zone, adoption of the highest degree of tolerance for the problem is required. As an alternative, people should relocate their settlements and socio-economic activities away and use a buffer zone as an area for ecological friendly activities, such as worshipping activities, environmental conservation and tourism.

### 6.9.1 Comparative Performance and Selection of the Best Scenario

Selection of the best performing scenario based on the magnitude of the reduction of adverse impact(s) stemming from HEI. However, it is important to understand that, for each selection of the best scenario(s), there are costs that a governing body must incur for successful implementation. It is beyond the scope of this study to estimate the cost for each scenario. On that note, this study analysed several options as much as possible to describe each possible scenario. However, there was no cost-free scenario.

If the aim is to eradicate elephant and human deaths and reduce hidden impacts and crop damage, then the human-elephant-environmental-effects scenario (HEES-River-Protect-Corridor) is the best scenario. This scenario recorded the lowest incidence of human death, people with hidden impacts, elephant death and the number of hectares of crops damaged by elephants. The scenario eradicated human deaths and elephant deaths beyond 0 meters from protected areas and rivers. Moreover, it significantly reduced the number of people with hidden impacts and crop damage with the total disappearance of the HEI occurrences occurred beyond 7000 meters from the rivers, corridors and protected areas. The elephant effects and elephant-environmental effects scenarios (HEES-River-Protect-Corridor) were the next best-performing scenarios, reducing three out of four incidents.

Despite the effectiveness in eradicating and reducing incidents, the governing body should also consider in advance the fiscal, conservation, land and socio-economic policies before the adoption of the suggested scenarios as they may seriously challenge the implementation of the human-elephant-environmental effects scenario. The problem is that this scenario requires a substantial reduction of the elephant population, which may contradict conservation policies, laws and international conservation agreements. The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) recognises African elephants as an endangered species in Tanzania. Similarly, in some parts of the country, the incidents of commercial ivory poaching have reduced elephant populations close to local extinction. In those situations, reduction or translocation of elephant population could be ecologically, financially and legally impractical.

As a substitute to the elephant-related scenario, the human-environmental effects scenario is a good choice as it eliminated human deaths and reduced hidden impacts but not elephant deaths and crop damage. Since the primary focus of many conservation organisations is to maintain a healthy elephant population while protecting the welfare of people this can also be an improper choice as elephant death and crop damage are still present. Based on priorities and policies, if the model user prioritises the reduction of HEI occurrences without affecting the integrity of humans and elephants, the environmental effects scenario (ENS-River-Protect-Corridor) is the best choice. It reduces all incidents except elephant deaths. Implementation of this scenario requires moving of farms and settlements to beyond 7000 meters from rivers, corridors and protected areas (see figure 6.9.1.2). For that reason, depending on the land ownership of the area, compensation for land and property before moving people to other locations may be required. It may also depend on people's willingness to move. This scenario also will not reduce elephant deaths.

The model user may choose to reduce elephant and human deaths only without affecting elephant and human population sizes. In that case, the environmental effects scenario (ENS-Protectedarea) would be the most effective choice. This scenario recommends distancing human settlement to 10000 meters from the edge of protected areas. However, the scenario does not end the hidden impacts and crop damage incidents. Alternately, the user may decide to reduce crop damage and human deaths only without affecting elephant and human population sizes. In that case, the environmental effects scenario (ENS-River) is the best choice. The scenario recommends locating human settlements more than 8000 meters from rivers and streams.

In short, the adoption of the best scenario should not rely solely on the type of adverse impact, tolerance and resilience level of elephants but also the well-being of the affected people. The capabilities of people, elephants and conservationists to accept, tolerate and ultimately to recover from a certain level of adverse impacts may determine the selection of the most important scenario. Making decisions about total eradication or reduction of adverse impacts is situational. The scenarios with the lowest incidents are highly recommended as the best scenarios. In addition, AGHEI recommends that, before selecting the best scenario, consideration of financial policies, conservation policies and social policies and legal framework is undertaken. Legal and policy dimensions may complicate the implementation of the best scenario when not taken into consideration. Finally, the human-elephant-environmental-effects (HEES-River-Protect-Corridor) would be recommended as the best scenario for the total eradication of negative impacts and environmental effects (ENS-River-Protect-Corridor) scenario as the best for substantial reduction of HEI occurrences with minimal impacts on the integrity of elephants and humans (see figure 6.9.1.2).

# Chapter 7 - Conclusion

## 7.1 Conclusion

The purpose of this research was to suggest the best option to either minimise or reduce adverse impacts of HEI in the Bunda District by determining the current extent of hidden impacts, human and elephant deaths, and elephant crop damage in relation to rivers, protected areas and conservation corridors. Additionally, a survey was conducted to identify local opinions on HEI occurrences in the district. The results from the spatial study and questionnaire were used to conceptualise, develop, calibrate and validate the AGHEI model. The model evaluated 18 modelling scenarios and recommended the HEES-River-Protect-Corridor based on the magnitude of the reduction of adverse impact(s) stemming from HEI. However, there are other potential criteria which should also be considered before the adoption of this scenario, including fiscal, conservation, land and socio-economic policies. The other criteria may seriously challenge the implementation of the human-elephant-environmental effects scenario.

Embracing local knowledge to develop effective mitigation measures of human-elephant interactions (HEI) is essential. Local people, as the main interacting party, may provide essential facts for a clear understanding of HEI occurrences. In the Bunda District, crop damage is the most common impact of HEI, but hidden impacts may also play a large role. The frequency and magnitude of the HEI occurrences are increasing alongside the increasing human population. Traditional mitigation measures become ineffective and they result in elephants becoming habitual crop raiders. Such methods are not only dangerous to humans and elephants but also lack scientific testing. Introduction of effective mitigation measures is important for saving lives and property. However, scientific tests of the methodologies are required to design, test and recommend the best mitigation measures of HEI.

In this thesis, GIS and computer-based modelling have indicated where, why and how HEI occur. GIS provided geographical knowledge about location, distribution and concentration of hidden impacts in the Bunda District. Four types of hidden impacts were identified. Abandonment of agricultural farms and houses was the primary hidden impact in the District. Most of the hidden impacts occurred within buffer zones, where conservation laws promote environmentally friendly activities, especially in the areas that bordered Grumeti Game Reserve. There was a lower level of hidden impacts in communities bordering the Serengeti National Park than Grumeti Game Reserve, possibly due to tourist hunting, as poorly executed trophy hunting activities usually affect the quality and quantity of the environmental resource (Burke et al., 2008). Graphical presentation of the patterns of hidden impacts provides the conservation stakeholders insights into their impact, existence and severity. However, a comprehensive study to understand the spatial characteristics of other types of hidden implications, such as medical and economic, in the communities bordering Serengeti National Park and Grumeti Game Reserve is highly recommended.

A spatial approach advances understanding of the geographical configuration of direct and indirect adverse impacts of HEI. Previous spatial studies focused more on direct than indirect impacts. The findings of this spatial study became critical for not only AGHEI development and validation, but also for understanding the current situation of HEI in the Bunda District and, by extension, other parts of the elephant range. Understanding the spatial configuration of HEI helps conservation stakeholders envisage the context of spatial relationships of the human landscape in the Bunda District. The study exposed the spatial characteristics underpinning HEI, such as frequency and magnitude of HEI near protected areas and rivers. In particular, the study revealed a high incidence of crop damage and hidden impacts near rivers and protected areas. It provided insightful information, such as where humans live and cultivate, where HEI occurs and how elephants use the areas outside the protected areas. As a result, conservationists may use the resultant maps to identify the elephant distribution and habitat utilization in the district. It is also possible to use the maps to identify, design and delimit elephant migratory routes. The government may use the maps for the identification of safe areas for relocating human settlements and agricultural farms. In short, the geospatial study serves as a powerful communication tool and activates discussions about HEI, elephant management plans, conservation policies and socio-economic development. The study primarily develops and validates AGHEI based on available spatial data. Consequently, AGHEI clearly describes geospatial configuration behind the elephant and human fatalities grounded in HEI dynamics, space and time.

Like many spatial studies, this one was influenced by data quality, quantity and geographical errors. The collection and analysis of spatial data were carried out in 12 administrative villages. The selection of participating villages in this thesis was based on their proximity to SENAPA and GGR not on either frequency or magnitude of HEI. Such selection introduced some geographical issues. The Tanzania government defines village boundaries for administrative not conservation purposes. It was crucial to consider both geographical location and the magnitude of HEI for each participating village. In addition, time constraints, the willingness of participants to participate in the study, expertise on identifying HEI patterns and geographical challenges of the study area may have affected the quality and quantity of the geospatial data used for conclusion. As an example, HEI rectification experts on HEI patterns, particularly medical staff, needed some time to verify hidden impacts due to their complexity. Moreover, some villagers needed incentives to participate in the surveys. Such challenges hindered the availability of reliable data used for spatial analysis. It is important to acknowledge that HEI happened in the margins of protected areas. Therefore, regional and landscape planning is essential to eradicate HEI incidents near protected areas. Prior to the comprehensive regional planning, the assessment of the spatial configuration of HEI incidents is important, as it may disclose the spatial characteristics of the incidents in the human and elephant landscape. There are myriads of ways to analyse the expressions of HEI patterns in the landscape. GIS efficiently connects the damage patterns directly to the regional landscape but ABM provides the dynamic nature of the incidents.

The AGHEI remains important for providing geographical and scientific details about HEI occurrences. With a model like AGHEI, mitigation measures can be tested before their adoption. It is obvious that some HEI intervention measures, such as elephant culling, may jeopardise the integrity of elephant populations. The modelling analyses suggested that the HEES-River-Protect-Corridor was the best scenario for the total eradication of HEI occurrences and that the ENS-River-Protect-Corridor was the best scenario for reduction of HEI occurrences with the fewest impacts to humans and elephants. Since different environmental conservation agencies use different criteria and priorities to decide on HEI interventions, AGHEI provides several options that the government can choose from to reduce one or multiple types of adverse impacts. Such flexibility makes the modelling approach user-friendly and multipurpose. In addition, the model substantially reduces the costs and time of carrying out similar field experiments. It is not practical to implement the model in other areas unless significant adaptations are made to local conditions. Decisions made by elephants and humans depend on a myriad of factors that are area-specific, including psychology, preferences, culture, geography and irrational behaviours of individual agents, which are too difficult to measure for humans and elephants. This AGHEI is specifically applicable to Bunda District, as it replicates the environment and behaviours of agents specific to Bunda. The AGHEI serves a specific purpose and not a general-purpose tool. Implementation of the best-recommended scenarios from AGHEI to areas inside or outside Tanzania should exercise extreme caution as such areas may have local factors that affect HEI in very different ways. However, this AGHEI still serves as the learning platform for conservation stakeholders to understand HEI occurrences better by interacting with it and modifying the specifications to fit their local areas. It can at least form a null hypothesis for expectations around HEI.

The implementation of AGHEI to other areas is possible but it requires changes in the densities of elephants and humans in the models, as well as their attributes and the environmental characteristics of new areas. In addition, there must be changes in interaction rules to reflect the HEI dynamics of the areas of interest-specific to local populations. The magnitude of HEI, culture, experience, conservation policies and laws, poverty level and species of elephants determine the interaction rules. Humans from different areas may have different experiences and responses toward elephants and so different species and subspecies of elephants may react differently to humans. Moreover, before adopting the AGHEI to other areas, adapting the environmental components and set up to reflect the area of interest is essential. Environmental components, such as farms, protected areas, households, rivers and conservation corridor used in AGHEI, differ hugely compared to other areas. Other areas may have more or less similar environmental components to the Bunda District. Since such components are the backbone of the interaction interface, it is important to assure that the environmental setup and ingredients are in the right order. Furthermore, it is also necessary to consider the purpose of the model. The AGHEI aims at controlling four adverse impacts of HEI and any change in this purpose may affect the components and setup and interaction rules. It may also affect the number and type of agents involved. Lastly, but also importantly, the availability of reliable data for calibration, validation and verification of the suggested model is crucial. The validation and verification of AGHEI hinged on the specific data from the Bunda District.

It is essential to note that this model could have been more effective had it been possible to incorporate the detailed dynamics of indirect or hidden impacts. The AGHEI has modelled and simulated hidden impacts as a single output. In reality, there are many types of hidden impacts including suffering from disease, marriage problems, psychological problems, debts and restricted movements. It was not possible to model each of them as an individual impact due to insufficient coverage of data for development and validation. With adequate data on hidden impacts, the model would be able to highlight the extent and severity of each category of the hidden impacts in the district. Such detailed data are lacking because its collection requires a lot of time and a team of experts from different professionals including medical, financial, conservation, agricultural and psychology experts. In that case, this thesis recommends a comprehensive study to identify and quantify hidden impacts in the district. This model could be redeveloped to make it flexible and portable for users from different protected areas with active elephant ranges to apply it without any modification on the configuration of the AGHEI. This would make its application possible locally and internationally. It would also assist both African and Asian elephants. Its application would also be possible to other problem animals in the world including wild pigs, eland, lions, wild dogs and primates.

AGHEI opens a new chapter for both elephant management and HEI mitigation measures. It allows conservationists to design, test and prescribe tested actions that can reduce HEI occurrences. Application of this approach is possible to all countries with active elephant ranges worldwide once modified. Implementation of any modelling scenarios necessitates concerted action and coordinated commitments. It is therefore essential for conservation organisations to seek the political and public will to make a modelling approach work. A successful outcome only happens when the government and public stakeholders speak in the same language. Stakeholders must be willing to recognise and understand HEI occurrences as complex problems. More importantly, stakeholders must also agree on the positive and negative impacts of the suggested mitigation measure. Implementation of the mitigation measures can also be very demanding as most of them necessitate both parties to sacrifice property and/or other resources. Locals may have to sacrifice their property and social justice while the government may sacrifice financial resources and elephant lives. Governments and local communities must be aware of the cost and benefit for each recommended mitigation measures. In addition, the reformation of the legal and policy framework is inevitable before implementation. The reformation will provide a smooth implementation of the agreed mitigation measures between the government and the public.

## 7.2 Future Research Directions

It would be useful to further identify and explore other types of HEI hidden impacts, especially regarding the socio-economic impact on the district. Such studies would require a long-term investment in time, expertise and financial resources. Conducting research on hidden impacts is complicated because it requires a multidisciplinary research team, including medical experts, conservationists, financial experts, community development experts, economists, veterinarians, psychologists and valuers, and adequate time to cover all types of the impacts occurring in the district. It would also be useful for a research team to conduct a similar study in another district with similar HEI incidents for comparative reasons. It is equally important for the study to investigate the type and extent of the hidden impacts that affect elephants.

There should be a study to investigate the distribution of HEI incidents in villages near Grumeti Game Reserve and Serengeti National Park. The study ascertained many hotspots of both hidden impacts and elephant crop damage in the communities neighbouring the game reserve. However, the study failed to conclusively record the distribution and configuration of the incidents. As the location where the hidden impacts are recorded may be different from where the HEI occurred. For example, a human might encounter an elephant and manifest hidden impacts at their home rather than where the encounter occurred. The precise identification, measurement and conclusions from such a study could assist with the future improvement of AGHEI. Also, tracking elephant movement in the Bunda District or nearby districts would give us a better idea of where elephants actually visit and how quickly they move. It would also identify elephant habitat utilisation and population demographics. This is crucial information for model development, calibration and, verification and validation.

There should be further studies to evaluate, environmental legal and socio-economic implications of AGHEI modelling scenarios. This thesis recommends scenarios depending on a user’s environmental and socio-economic policies. However, detailed analysis of policy implications is lacking because it was not the objective of this thesis. A policy-based study should analyse the practicability of the modelling scenarios based on local, regional and international socio-economic policies and laws. A clear description of cost-benefit analysis for each modelling scenario will enable the model used to have a proper understanding of a particular scenario before implementation.

Since AGHEI is computer-based, its coding implementation is always tedious particularly to persons unfamiliar with programming. It is necessary to recommend that, for smooth adoption of AGHEI model with a simplified implementation, it is important to develop an AGHEI agent library for Python that is specific for HEI. Python is a general-purpose language, which is easy to learn for people with little background in object-oriented languages. The library would automatically handle specific activities, such as elephant movement, grazing, drinking, giving birth, damaging crops and migration. The methods included in the library would also output elephant and human deaths, hidden impacts and crop damage and could extend model outputs by including livestock deaths, human and elephant injuries, and the number of elephants and humans with hidden impacts. The potential users of the AGHEI library would include conservationists, computer scientists, social scientists, computer-based modellers, students, policy analysts and mathematicians. Ideally, the AGHEI will be lodged in a web application allowing elephant stakeholders to easily and freely access the application, providing help in designing replicable experiments, which are usually impossible for HEI studies.

Studies are required to model and simulate other forms of human-wildlife interactions including human-carnivore interactions, human-omnivore interactions and human-herbivore interactions. For example, understanding how to manage serial human killing species, such as lions, cause fear and kill livestock and people would be important contributions to addressing the negative impacts. Since their movements are dynamic in both space and time, al modelling of their activities could be used to predict and suggest appropriate mitigation measures. Similarly, the modelling approach can be used to understand the migration patterns of vertebrates and invertebrates between ecosystems, to model wildlife-vehicle collisions to reduce or eradicate road kills as well as the construction of tourism structures and infrastructure in and around wildlife habitats. Additionally, many geospatial studies focus entirely on elephants and carnivores with inadequate consideration of the migration behaviours of other species. This pinpoints out a knowledge gap on the dispersal and movement patterns of species such as dugong, giraffe, hedgehog and other secretive species.

Lastly, the thesis recommends implementing AGHEI in different simulation platforms to compare the model outputs, such as SWARM and Repast. Such platforms have better modelling capability and functionality than Netlogo, although they require extensive coding experience. Implementation of AGHEI in SWARM and Repast may be useful to countercheck the consistency and accuracy of the model. In addition, such platforms may increase the model execution speed that will obviously decrease simulation. Moreover, since the elephant is not the only problem animal, the thesis recommends modification of AGHEI to study other forms of human-wildlife interactions including human-primates, human-carnivores and human-avian interactions.

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# Appendix A Questionnaire

A PhD student from Lincoln University, in the Faculty of Environment Design and Society, conducts this survey. Your answers will facilitate the design, development, validation and implementation of AGHEI model. The model will provide a better understanding of human-elephant interactions and ultimately recommend the best ways to reduce the adverse impacts from the interactions. Your questionnaire is confidential. Please! Complete this questionnaire at a suitable time.

## SECTION A: PERSONAL INFORMATION

1. Your sex

☐ a. Male ☐ b. Female

2. Your marital status

☐ a. Single ☐ b. Married ☐ c. Widow
☐ d. Divorced ☐ e. Other……………….. (Please specify)

3. Your highest education level

☐ a. Primary school ☐ b. Secondary school ☐ c. Vocational
☐ d. Higher education ☐ e. Other……………………….. (Please specify)

4. Your occupation

☐ a. Farmer ☐ b. Livestock keeper ☐ c. Businessperson
☐ d. Public servant ☐ e. Other……… (Please specify)

5. What contributes to increased human population in your village?

☐ a. Migrant ☐ b. Birth
☐ c. Other……………………….. (Please specify)

6. Which of the following statements best describes the area where you are?

☐ a. Conservation corridor
☐ b. Settlement
☐ c. Protected area
☐ d. Other……………..…………… (Please specify)

## SECTION B: HUMAN-ELEPHANT INTERACTIONS

7. How many times did you see elephants in your village last year?

☐ a. Everyday
☐ b. Once a week
☐ c. Once a month
☐ d. Once in six month
☐ e. No elephant
☐ f. Other……………..……………(Please specify)

8. How many elephants were per group?

☐ a. One elephant
☐ b. 2 – 4 elephants
☐ c. 5 – 10 elephants
☐ d. More than 11
☐ e. Other…………..……………(Please specify)

9. What of the following areas, did elephants frequently visit in the village?

☐ a. Farms
☐ b. Settlement
☐ c. Water taps
☐ d. Rivers
☐ e. Other…………..……………(Please specify)

10. In the future, what areas will most often be visited elephants in your village?

☐ a. Farms
☐ b. Settlement
☐ c. Water taps
☐ d. Rivers
☐ f. Other…………….……(Please specify)

11. What season (s) of the year did you most often see elephants in your village?

☐ a. Rain
☐ b. Dry
☐ c. Rain and dry
☐ d. Other…………….……(Please specify)

12. In your experience, what is the minimum distance elephants can tolerate human's presence?

☐ a. 0 - 50 meters
☐ b. 51 - 100 meters
☐ c. 101 - 150 meters
☐ d. 151 - 200 meters
☐ e. Other…………….…………………….(Please specify)

13. What happens when an elephant finds a villager guarding crops?

☐ a. Elephant runs away
☐ b. Elephant injures human
☐ c. Elephant kills human
☐ d. Elephant damages crops
☐ e. Other…………….…………………… (Please specify)

14. What happens when a villager finds an elephants damaging crops?

☐ a. Human runs away
☐ b. Human injures an elephant
☐ c. Human kills an elephant
☐ d. Human scares away an elephant
☐ e. Human faints for fear
☐ f. Other…………………………………(Please specify)

15. How much damage did elephant cause to your houses last year?

☐ a. Complete demolition
☐ b. Slight demotion
☐ c. No impact
☐ d. Other…………………………………(Please specify)

16. In your experience, why do problem elephants kill villagers in your village?

☐ a. After preventing an elephant from crop damage
☐ b. After preventing an elephant from drinking water
☐ c. After injuring one of the family members
☐ d. After killing one of the family members
☐ e. Other…………………………………(Please specify)

17. In your opinion, what is the trend of HEI occurrences in your village?

☐ a. Increase
☐ b. Decrease
☐ c. Neither
☐ d. Other………………………………(Please specify)

18. In your experience, why villagers kill problem elephants in your village?

☐ a. After damaging crops
☐ b. After killing a villager
☐ c. After damaging infrastructure
☐ d. After injuring a villager
☐ e. Other……………………………(Please specify)

19. Are there hidden impacts in the village?

☐ a. No
☐ b. Yes

20. What is the most common adverse impact of HEI?

☐ a. Human death
☐ b. Crop damage
☐ c. Hidden impacts
☐ d. Infrastructure damage
☐ e. Other…………….………………(Please specify)

21. In your experience, how do you control a problem elephants in your village?

☐ a. Traditional method
☐ b. Snares
☐ c. Guns
☐ d. Reporting to TANAPA and District Game Office
☐ e. Other………….……………………………(Please specify)

22. How many problem elephants did villagers injure last year? _________________

23. How many problem elephants did villagers kill last year? ______________

24. How many villagers acquired hidden impacts last year in your village? _________

25. How many villagers did problem elephants injure last year? ____________

26. How many villagers did problem elephants kill last year? ____________

27. How many hectares of crops did problem elephants damage last year? ____________

# Appendix B Research Information Sheet

**Lincoln University**

***Faculty, Department or Research Centre:* *Faculty of Environment Design and Society, Department Environmental Mamagement***

**Research Information Sheet**

**You are invited to participate as a subject in a project entitled - The use of computer technology to study the way humans and elephants interact in Bunda district.** I am a PhD Student from Lincoln University (New Zealand) doing this project for my thesis. The project aims at develop a computer model that will provide a better understanding of the way human and elephants interact in Bunda district. Your responses will help me to formulate this model. I would like you to participate in my project because you have experience with elephants and the effect they can have on your livelihood. In this project, participants are asked to participate in a survey by filling in a questionnaire, each participant will have time to read it first and 7 days to complete the questionnaire. The completed questionnaire will personally be handled back to a researcher.

- Participant's identity will not be made public, or made known to any person other than me, my supervisors at Lincoln University and the Human Ethics Committee, without your consent.

- To ensure anonymity, participants may at any time withdraw from participation, including withdrawal of any information provided by contacting me physically or calling me before 2nd September 2016, through the contacts provided below.

- Data from withdrawn participants will not be used for this research and their questionnaires will be destroyed.

- Participants with impaired vision will be able to use a person whom they trust to read and fill out the questionnaire for them.

- Results of this study will be published as PhD Thesis at Lincoln University.

- As per Tanzania regulations, the results will also be passed to the Tanzania Wildlife Research Institute Authority (TAWIRI), the body that advises the government of Tanzania on wildlife related issues.

- Results of the project may be published as academic journal articles, presented at conferences and a research summary will be made available to all participating villages, but you are assured of your anonymity in this investigation at all times.

- I wish to reassure you that your involvement in this research, the information you provide and any decision you make about your participation is completely confidential to the researcher and the university and will not be shared with any other party.
- Your acceptance, withdrawal, or refusal to participate will also remain confidential.

The project is being carried out by:

Mr. Abel Ansport Mamboleo Mwakaleja

In case you have any problem in completing a survey, please don't hesitate to call +255 719 923 200 for clarifications and help.

Phone: +255 719 923 200 in Tanzania
Phone: +64 02108426541 in New Zealand
Email: abel.mamboleo@linconuniac.nz
Email: ebbo54@yahoo.com

The project has been reviewed and approved by the Lincoln University Human Ethics Committee. Abel will be pleased to discuss any concerns you have about participation in the project.

*Name of Supervisor/Head of Department/Faculty Dean or Director*

Dr. Crile Doscher (Faculty of Departmental of Environment Design and Society, Department of Environmental Mamagement) and Associate Professor Adrian Paterson (Faculty of Agriculture and Life Science, Department of Ecology).

# Appendix C Consent Form for Questionnaire

## Consent Form for Questionnaire

***Name of Project:*** Integration of Agent-Based and GIS-Based Modeling for Geosimulation of Human-Elephants Interactions in Bunda District, Tanzania. I have read and understood the description of the above-named project. On this basis, I agree to participate as a subject in the project, and I consent to publication of the results of the project with the understanding that anonymity will be preserved. I understand that at any time prior to 2nd September 2016, I may withdraw from the project and this includes being able to withdraw any information I have provided. I understand that I participate in filling this questionnaire voluntarily. I provide consent to complete the questionnaire.

Name: ------------------------------------------------------------------

Signed: ------------------------------------------- Date: ------------------------------------------------

# Appendix D Research Permits

**HALMASHAURI YA MJI WA BUNDA**

*(Barua zote zitumwe kwa Mkurugenzi wa Mji)*

**MKOA WA MARA**

Simu Na. + 255 (028) 2621264
Nakushi Na:+225(028)2621055
Email:td.bunda@mara.go.tz

Ofisi ya Mkurugenzi wa Mji
Halmashauri ya Mji wa Bunda
S.L.P 219,
**BUNDA**

**Unapojibu tafadhali taja:**
Kumb.Na.HMB/PF/M:30/7/25

24 Mei, 2016.

Ndg.Abel Mamboleo
**BUNDA.**

**YAH: RUHUSA YA KUFANYA UTAFITI HALMASHAURI YA MJI WA BUNDA**

Husikeni na mada tajwa hapo juu. Aidha rejea barua yako ya tarehe 18/05//2016 ihusuyo mada tajwa hapo juu.

Napenda kukujulisha kuwa umeruhusiwa kufanya utafiti katika vijiji vya Balili,Kunzugu,Bukore,Nyamatoke,Mihale na Mcharo

Kwa barua hii unatakiwa kuripoti kwa watendaji wa Kata husika ili wakupe ushirikiano kwa watendaji wa vijiji.

Nakutakia kazi njema.

P. Z. Kafuku
**Kny:MKURUGENZI WA MJI**
**HALMASHAURI YA MJI**
**BUNDA.**

MKURUGENZI
HALMASHAURI YA MJI
BUNDA.

**Nakala:** Watendaji wa Kata, - KUNZUGU
Kijiji cha Balili
Kijiji cha kunzugu
Kijiji cha Bukore
Kijiji Nyamatoke
Kijiji Mihale
Kijiji Mcharo
**BUNDA** - mpokeeni na mpeni ushirikiano.

HALMASHAURI YA WILAYA YA BUNDA
(Barua zote zitumwe kwa Mkurugenzi Mtendaji (W))

Simu No. +255 (0) 28 262 1055
Fax No. +255 (0) 28 262 1264
E-Mail: halmashauri_bunda@gmail.com
Unapojibu tafadhali taja:
Kumb. No. HB/T:10/98/177

Ofisi ya Mkurugenzi Mtendaji (W),
S. L P. 126,
BUNDA

18/05/2016

Mtendaji wa Kijiji,
Mariwanda, Nyangere, Kihumbu, Hunyari, Mugeta,
Kyandege,Balili, Kunzugu, Bukore, Nyamatoke, Mihale na Mcharo .

**YAH: KUMTAMBULISHA NDUGU ABEL MAMBOLEO KATIKA OFISI YAKO**

Husika na kichwa cha habari hapo juu

Napenda kumtambulisha kwako Ndugu Abel Mamboleo anayefanya utafiti juu ya Migogoro iliyopo kati ya Tembo na Binadamu katika Wilaya ya Bunda. Baada ya utafiti huu tunategemea matokeo yake yatakuwa chachu ya kupata ufumbuzi wa migongano hiyo.

Hivyo, kwa barua hii naomba umpe ushirikiano wa kutosha ili aweze kufanikisha zoezi hili muhimu kwa ustawi wa Wanyamapori na nchi yetu kwa ujumla.

Nakutakia kazi njema,

Marwa P. Kitende

Kny; Mkurugenzi Mtendaji (W)

Kny. MKURUGENZI MTENDAJI (W)
BUNDA

Nakala:

Mkurugennzi Mtendaji
Halmashauri ya Mji wa Bunda - Kwa taarifa

Abeli Mamboleo - Ripoti kwa Afisa Mtendaji wa Kijiji Husika

THE UNITED REPUBLIC OF TANZANIA

**MINISTRY OF NATURAL RESOURCES AND TOURISM**

MALIASILI DAR ES SALAAM.
PHONE:+255-2123686, 25522 2866408,
2866376
Telex: 42741 MALIASILI.
Fax: +255-2123686
Email: dw@mnrt.go.tz
Email :ps@mnrt.go.tz

Mpingo House,
40 Julius Nyerere Road,
15472- DAR ES SALAAM.

**Ref. No.CHA. 403/563/091B/83**

23/03/ 2016

Director General,
Tanzania Wildlife Research Institute,
P.O. Box 661,
**ARUSHA.**

**RE: PERMIT TO CONDUCT WILDLIFE RESEARCH**

Free permit for Abel Ansporthy Mamboleo to conduct wildlife research titled "***Integration of agent-based and GIS based geosimulation of human-elephant conflict***" in Grument Ikorongo Game Reserves has been granted for the period of 5th February, 2016 to 4th February, 2017.

Before the exercise, he is required to report to the management of the reserve for notification and any necessary assistance. Likewise compliance with Wildlife Conservation Act. 5 of 2009 are crucial.

Alex Choya
**For: PERMANENT SECRETARY**

**Copy:**

: Manager,
Ikorongo /Grumet Game Reserve,
P.O. Box 32,
**MUGUMU.**

: Abel Ansporthy Mamboleo

**TANZANIA NATIONAL PARKS**
OFFICE OF THE DIRECTOR GENERAL
P.O. BOX 3134, ARUSHA - TANZANIA

Ref. No. TNP/HQ/C.10/13 Date 22/02/2016

Director General,
Tanzania Wildlife Research Institute,
P.O Box 661
**ARUSHA**

**REF: INTRODUCTORY LETTER FOR RESEARCH SCIENTIST**

This is in response to your letter Ref. No. TWRI/RG/22/VOL.47/88/107 dated 5th February, 2016 regarding the subject above.

I am pleased to inform you that permission is hereby granted to the Tanzanian research scientist Abel Ansporthy Mamboleo to enter and work in Serengeti National Park from 5th February, 2016 to 4th February, 2017 to conduct a project titled ***"Integration of agent-based and GIS Based geosimulation of human-elephant conflict in Bunda District"***

The research scientists is required to abide by all park rules and regulation and should report to the Chief Park Wardens of Serengeti National Park before engaging in the research activities in the park.

Yours sincerely,
**TANZANIA NATIONAL PARKS**

I.A. Lejora
For: **DIRECTOR GENERAL**
Copy: Chief Park Warden, Tarangire, Lake Manyara and Serengeti National Parks.

TAWIRI
Tanzania Wildlife Research Institute
Head Office P.O. Box 661, Arusha, Tanzania
Tel.: +255 (0) 27 254 9571 / 254 8240; Fax + 255 (0) 27 254 8240
E-mail: info@tawiri.or.tz
Website: www.tawiri.or.tz

Our Ref: TWRI/RG/22/VOL.49/88/27

Your Ref:

Date: 21st April, 2016

DED,
Bunda District,
**MARA.**

Dear Sir/Madam,

**RE: INTRODUCTORY LETTER FOR ABEL MAMBOLEO.**

Please refer to the heading above.

The above mentioned research scientist is registered by TAWIRI to conduct a project titled, "*Intergration of agent-based and GIS based geosimulation of human-elephant conflict in Bunda District*".

We are requesting for all necessary assistance to him in order to work in Mariwanda, Nyangere, Kihumbu, Hunyari, Mugeta, Kyandege, Balili, Kanzungu, Bukore, Nyamatoke, Mihale, Mcharo and Sugute Villages for the period of 5th February, 2016 to 4th February, 2017.

Yours sincerely,
**TANZANIA WILDLIFE RESEARCH INSTITUTE**

Dr. Victor Kakengi
**FOR: DIRECTOR GENERAL**

TAWIRI is responsible for the co-ordination of all wildlife research in Tanzania

Njiro W.R.C.
P.O. Box 661
**ARUSHA**

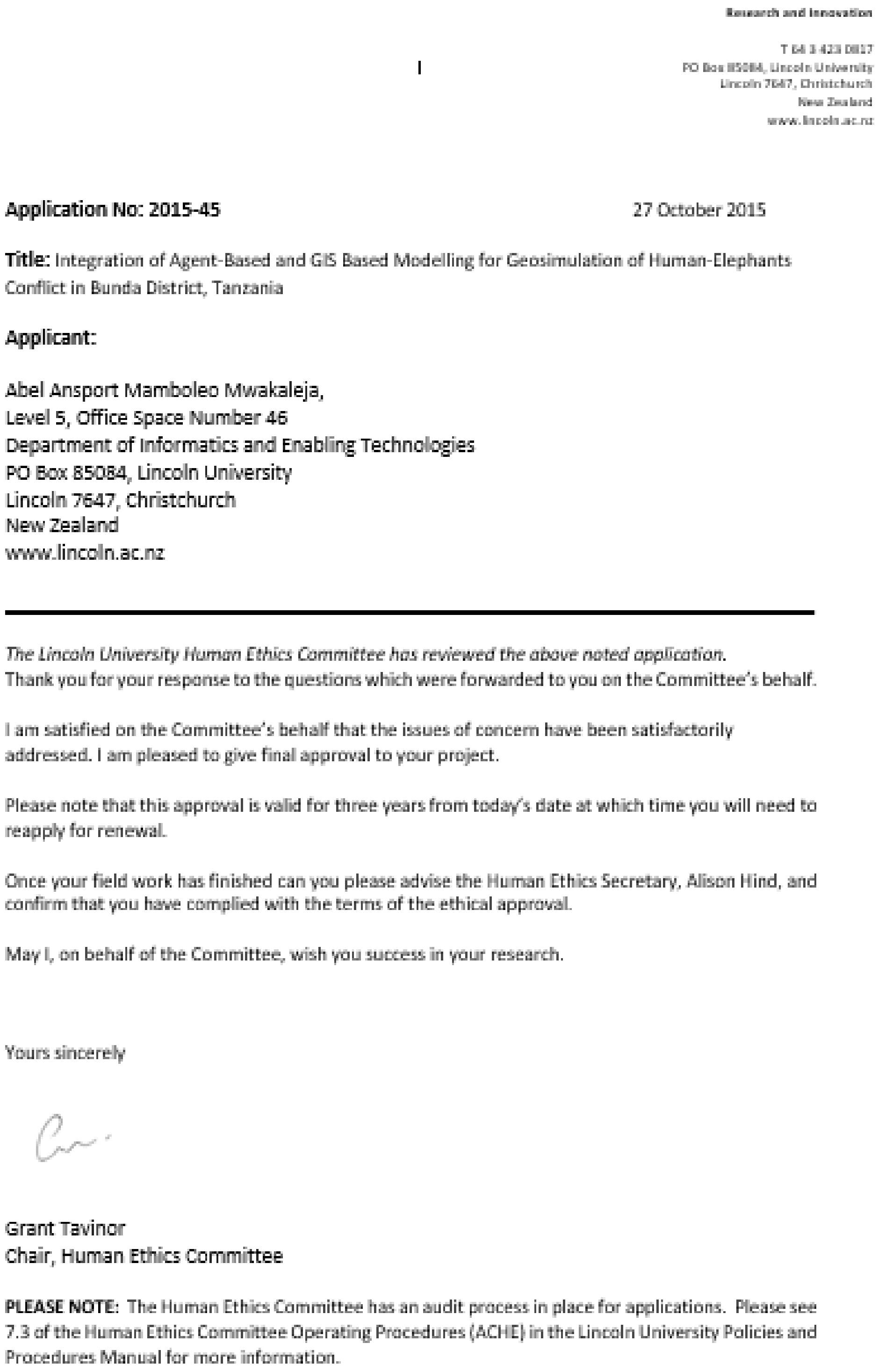
Gombe W.R.C.
P.O. Box 1053
**KIGOMA**

Kingupira W.R.C.
P.O. Box 16
**UTETE-RUFIJI**

Mahale W.R.C.
P.O. Box 1053
**KIGOMA**

Tabora R.S.
P.O. Box 62
**TABORA**

Serengeti W.R.C.
P.O. Box 661
**ARUSHA**



**Research and Innovation**

T 64 3 423 0817
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

**Application No: 2015-45** 27 October 2015

**Title:** Integration of Agent-Based and GIS Based Modelling for Geosimulation of Human-Elephants Conflict in Bunda District, Tanzania

**Applicant:**

Abel Ansport Mamboleo Mwakaleja,
Level 5, Office Space Number 46
Department of Informatics and Enabling Technologies
PO Box 85084, Lincoln University
Lincoln 7647, Christchurch
New Zealand
www.lincoln.ac.nz

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*The Lincoln University Human Ethics Committee has reviewed the above noted application.*
Thank you for your response to the questions which were forwarded to you on the Committee's behalf.

I am satisfied on the Committee's behalf that the issues of concern have been satisfactorily addressed. I am pleased to give final approval to your project.

Please note that this approval is valid for three years from today's date at which time you will need to reapply for renewal.

Once your field work has finished can you please advise the Human Ethics Secretary, Alison Hind, and confirm that you have complied with the terms of the ethical approval.

May I, on behalf of the Committee, wish you success in your research.

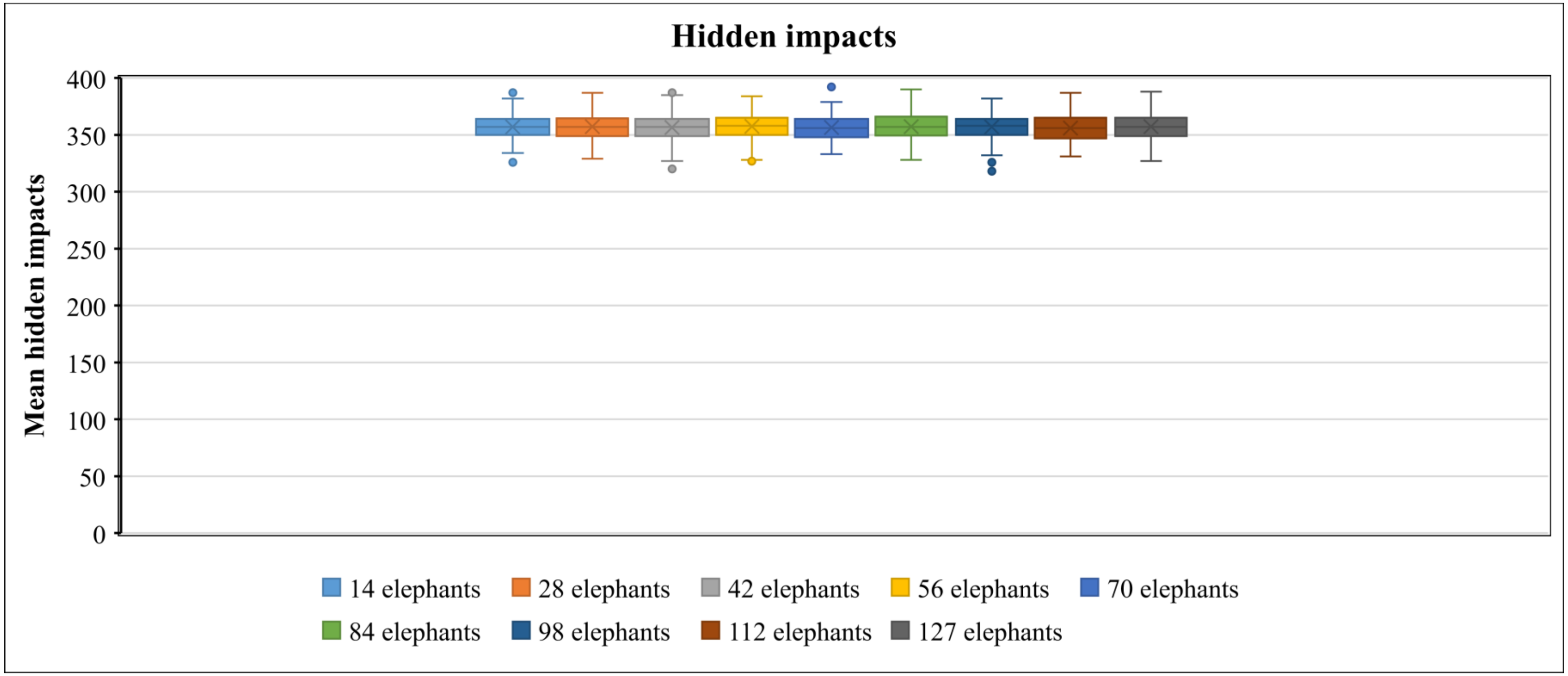
Yours sincerely

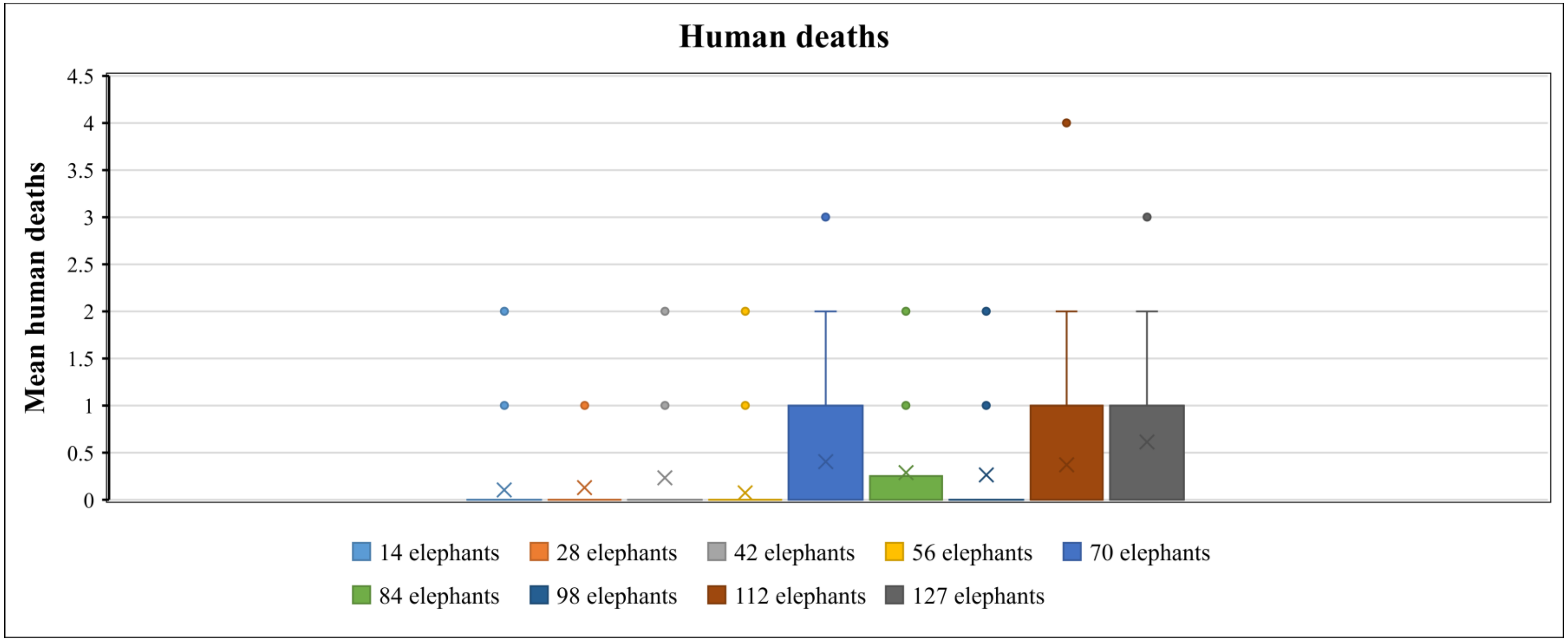
Grant Tavinor
Chair, Human Ethics Committee

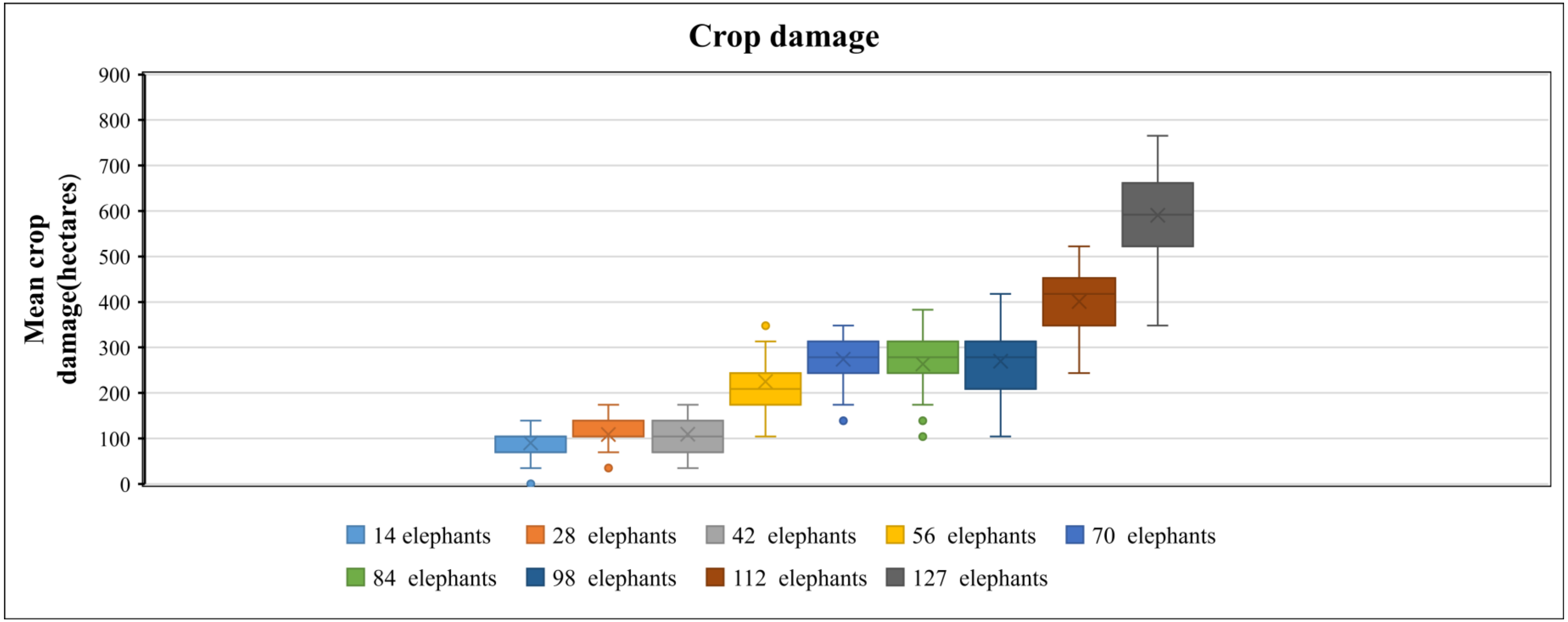
**PLEASE NOTE:** The Human Ethics Committee has an audit process in place for applications. Please see 7.3 of the Human Ethics Committee Operating Procedures (ACHE) in the Lincoln University Policies and Procedures Manual for more information.

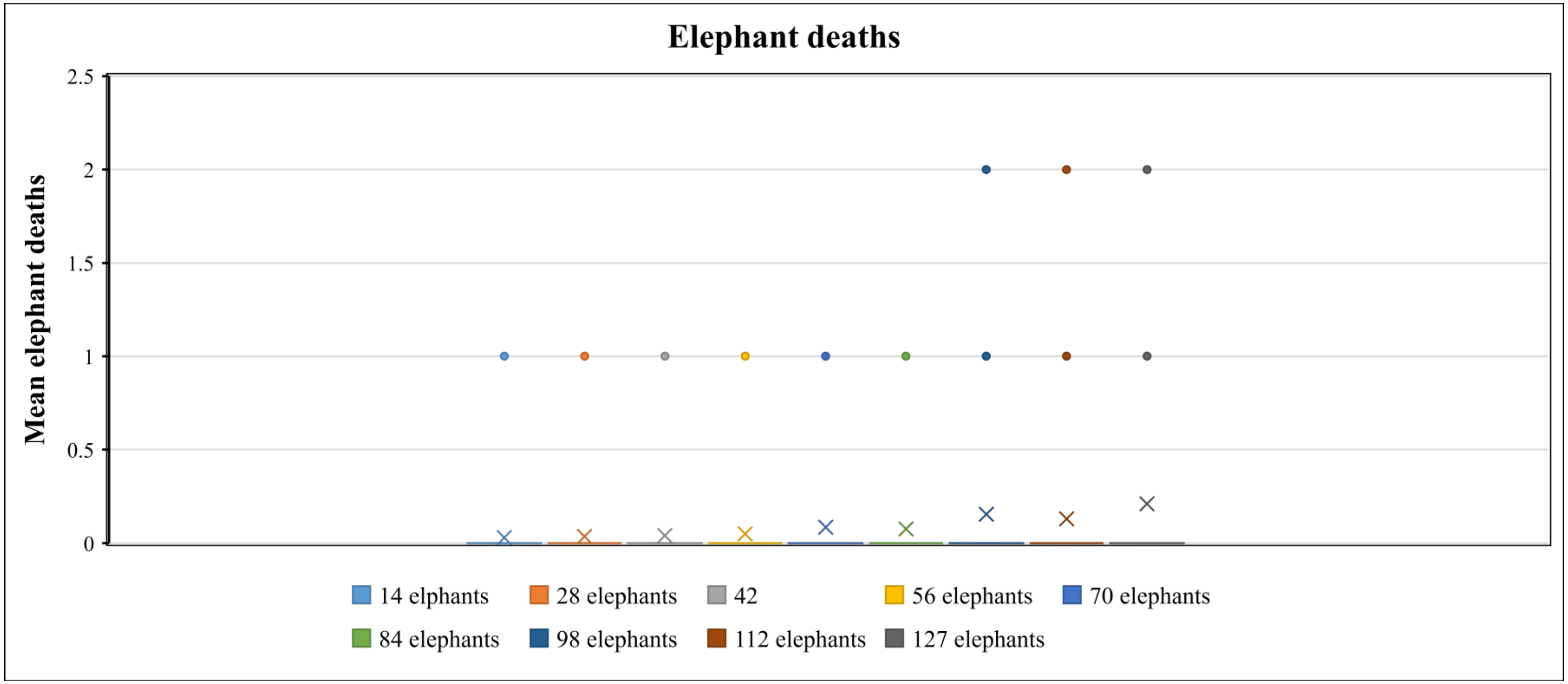
# Appendix D Model Results from Modelling Scenarios

## Elephant-effect scenario

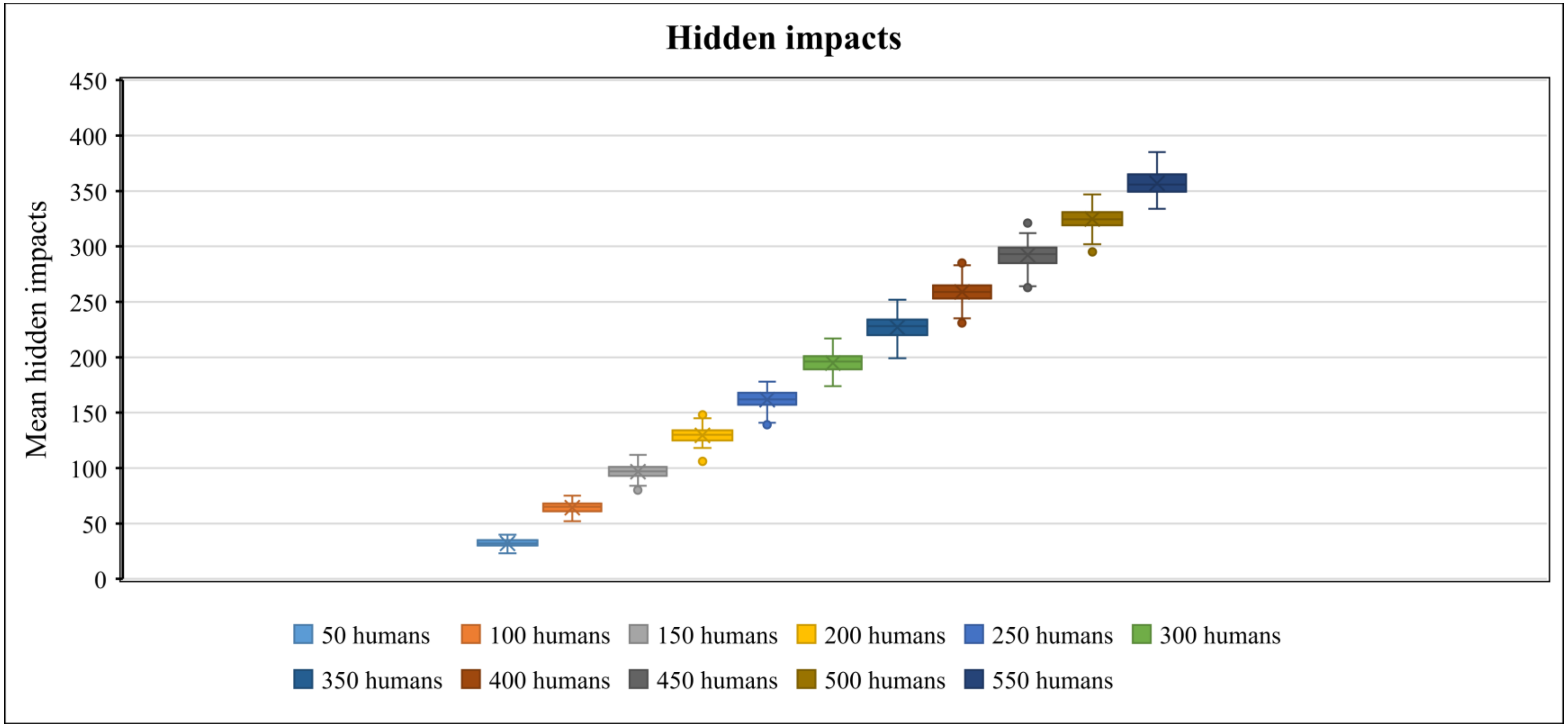


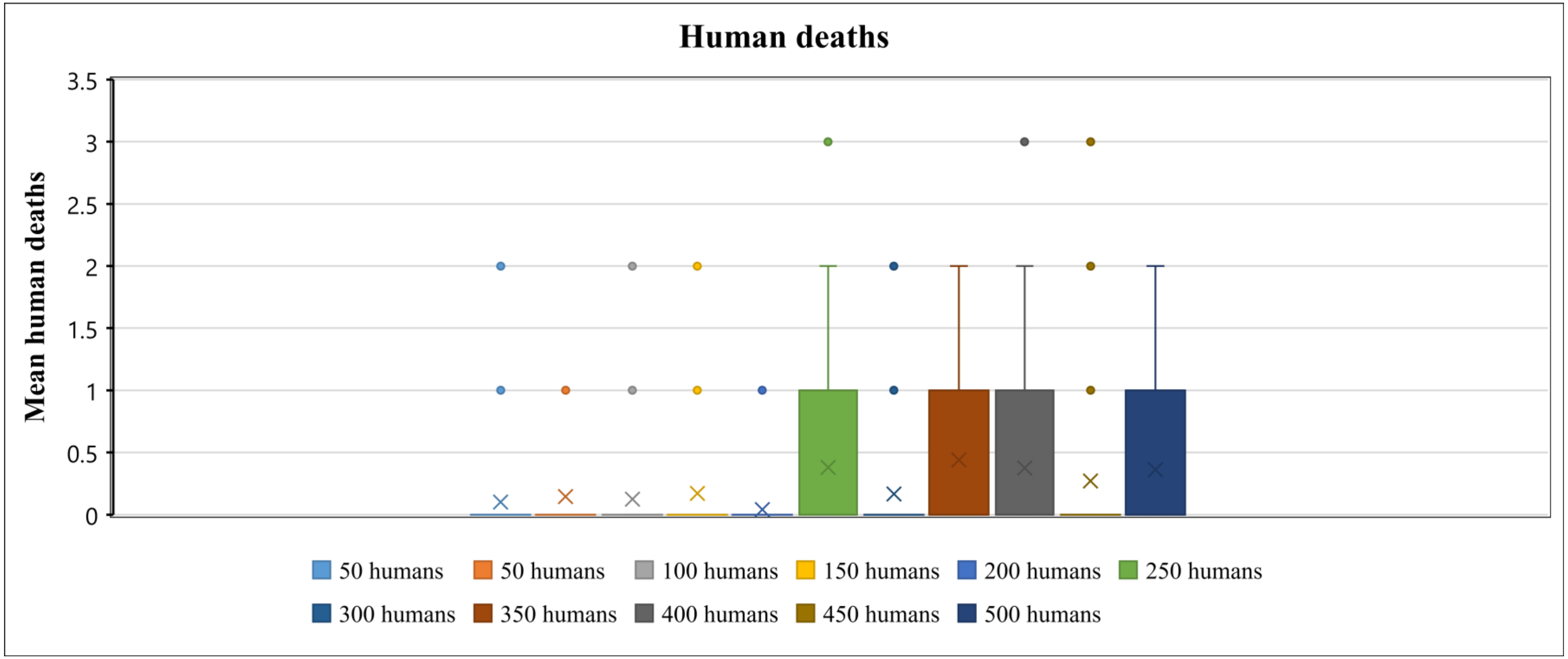

Human deaths
Mean human deaths
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
14 elephants
28 elephants
42 elephants
56 elephants
70 elephants
84 elephants
98 elephants
112 elephants
127 elephants

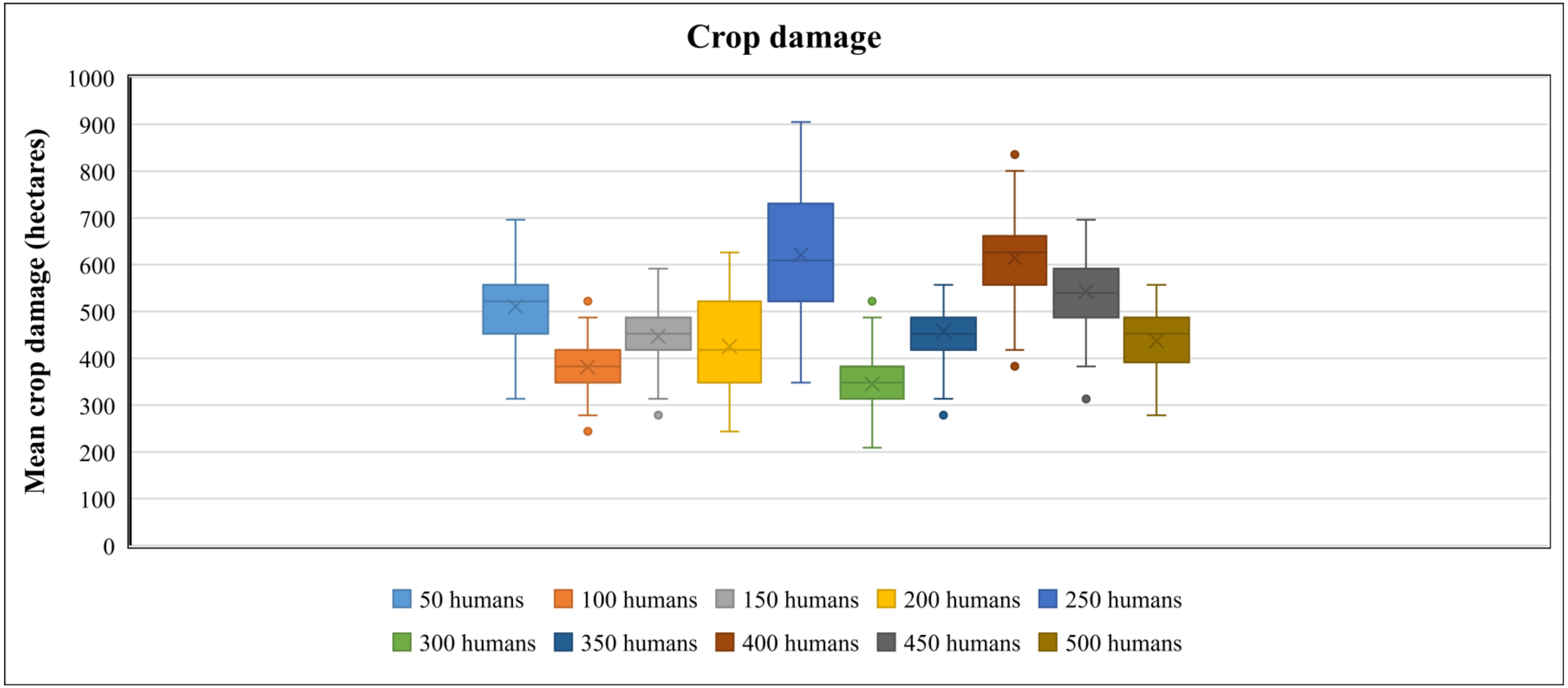

Crop damage
Mean crop damage(hectares)
900
800
700
600
500
400
300
200
100
0
14 elephants
28 elephants
42 elephants
56 elephants
70 elephants
84 elephants
98 elephants
112 elephants
127 elephants

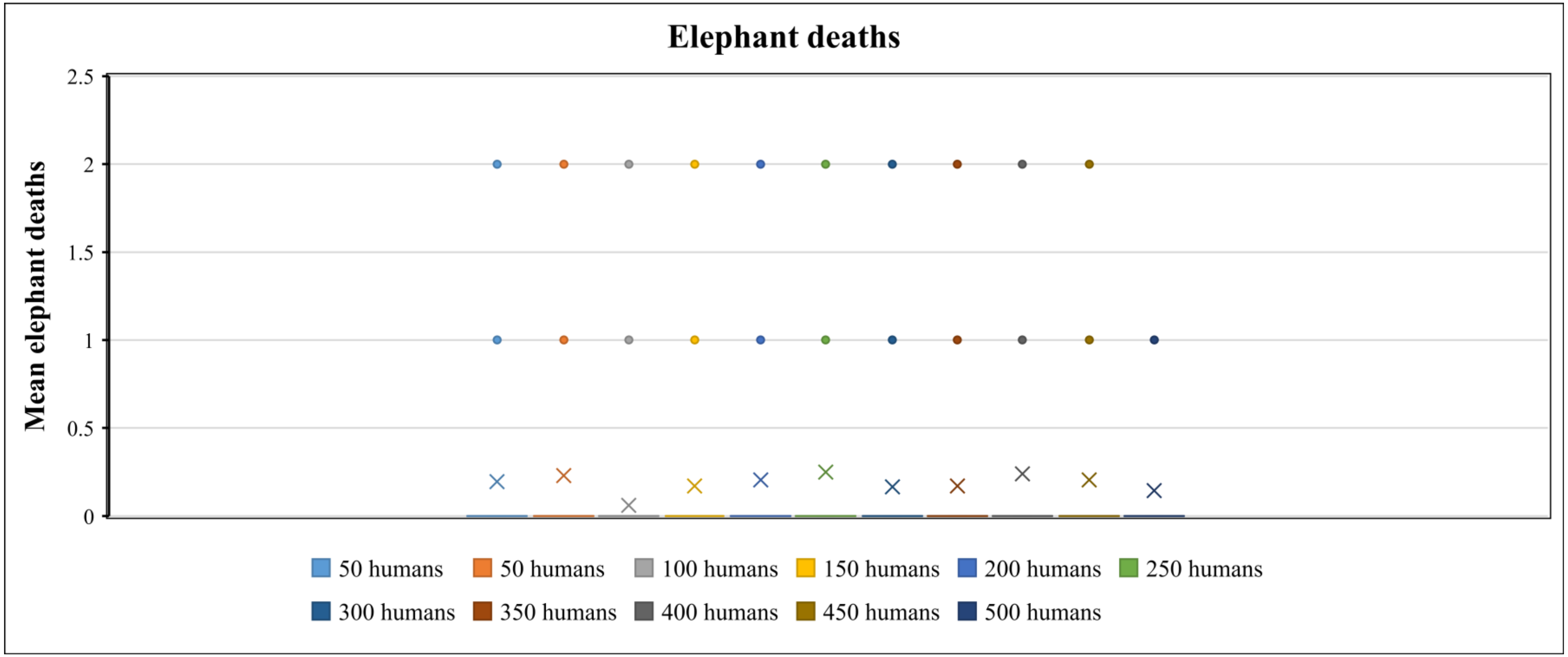

Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
14 elphants
28 elephants
42
56 elephants
70 elephants
84 elephants
98 elephants
112 elephants
127 elephants

# Human-effect scenario




Human deaths
Mean human deaths
3.5
3
2.5
2
1.5
1
0.5
0
50 humans
50 humans
100 humans
150 humans
200 humans
250 humans
300 humans
350 humans
400 humans
450 humans
500 humans

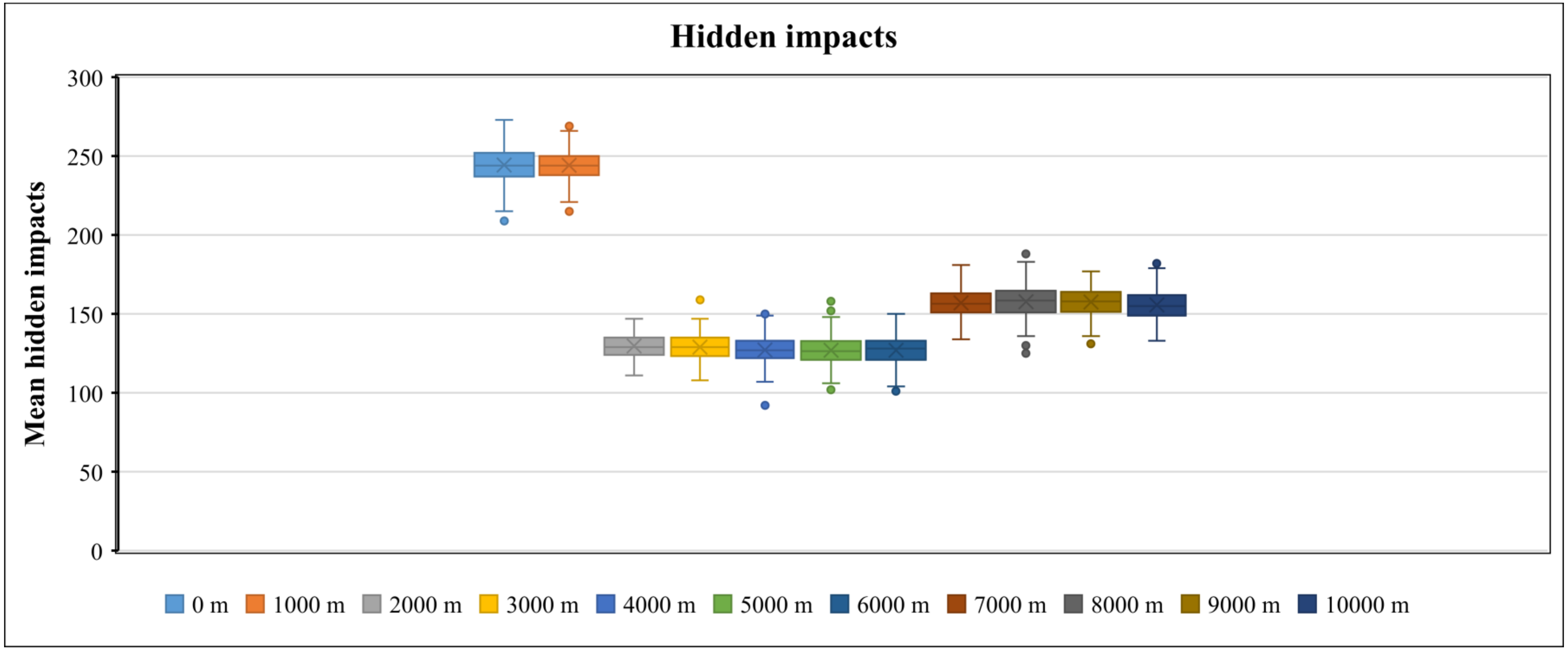

Crop damage
Mean crop damage (hectares)
1000
900
800
700
600
500
400
300
200
100
0
50 humans
100 humans
150 humans
200 humans
250 humans
300 humans
350 humans
400 humans
450 humans
500 humans

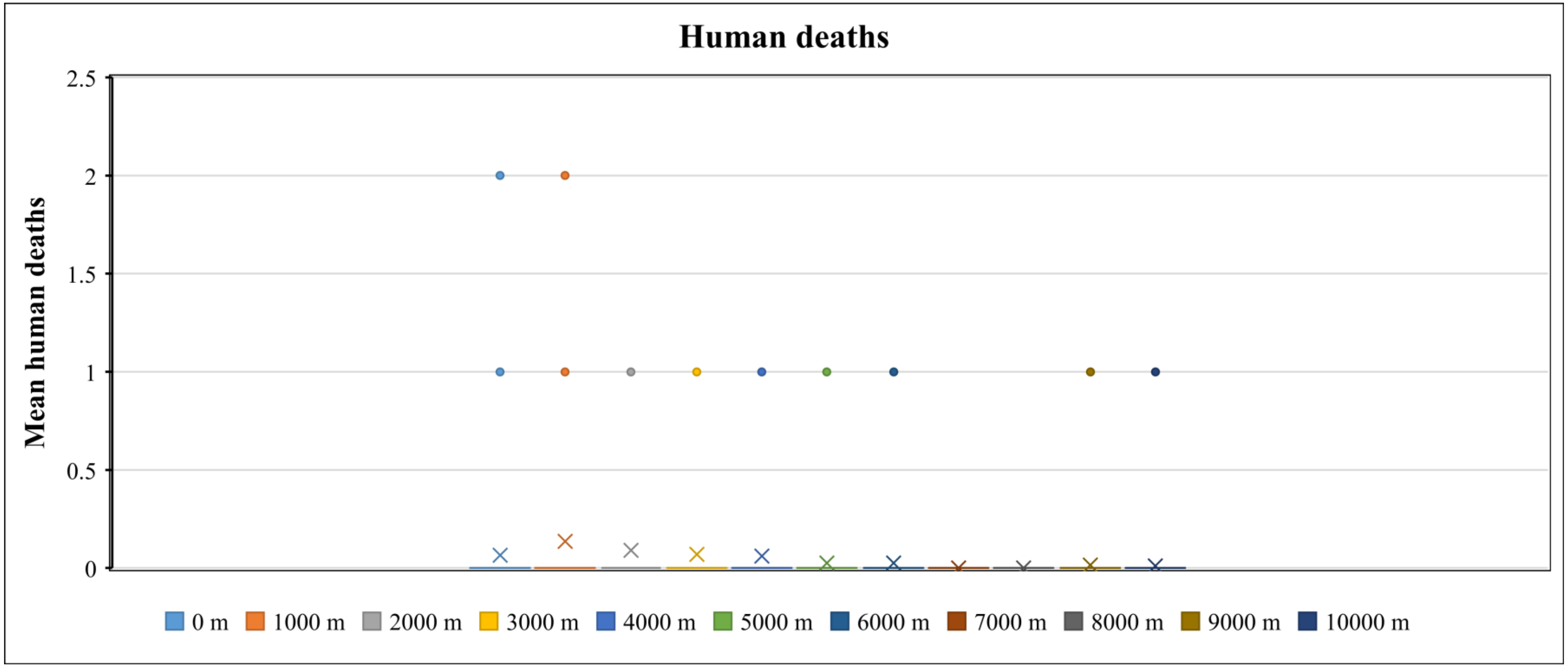


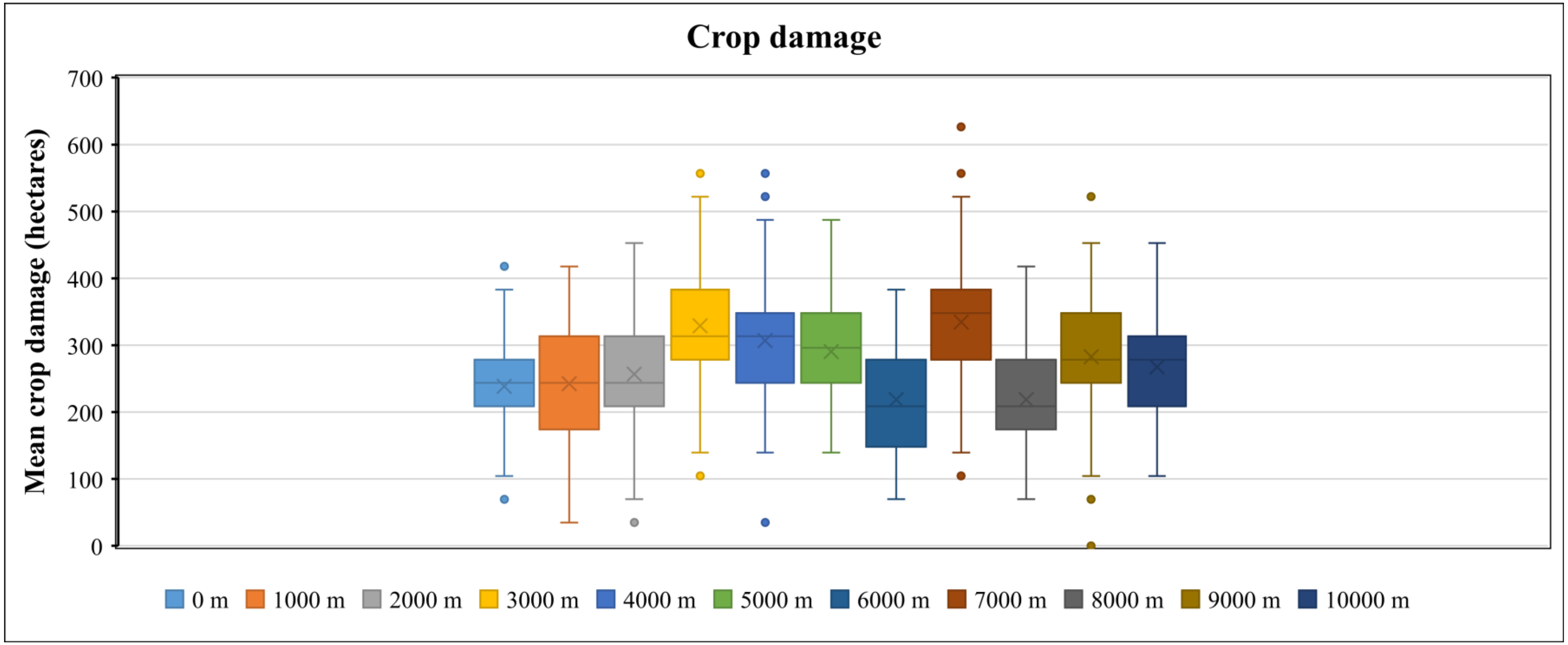
Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
50 humans
50 humans
100 humans
150 humans
200 humans
250 humans
300 humans
350 humans
400 humans
450 humans
500 humans

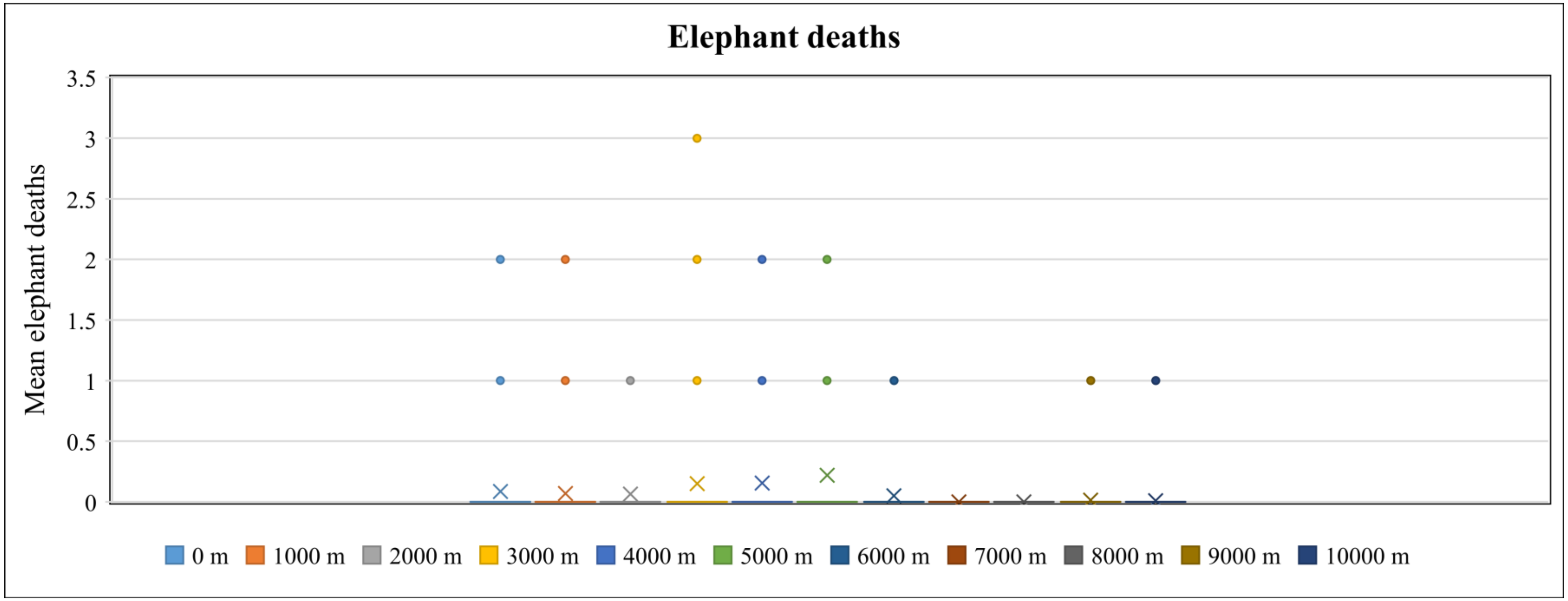
# Environmental effects-scenario

# Corridor (ENS_Corridor)

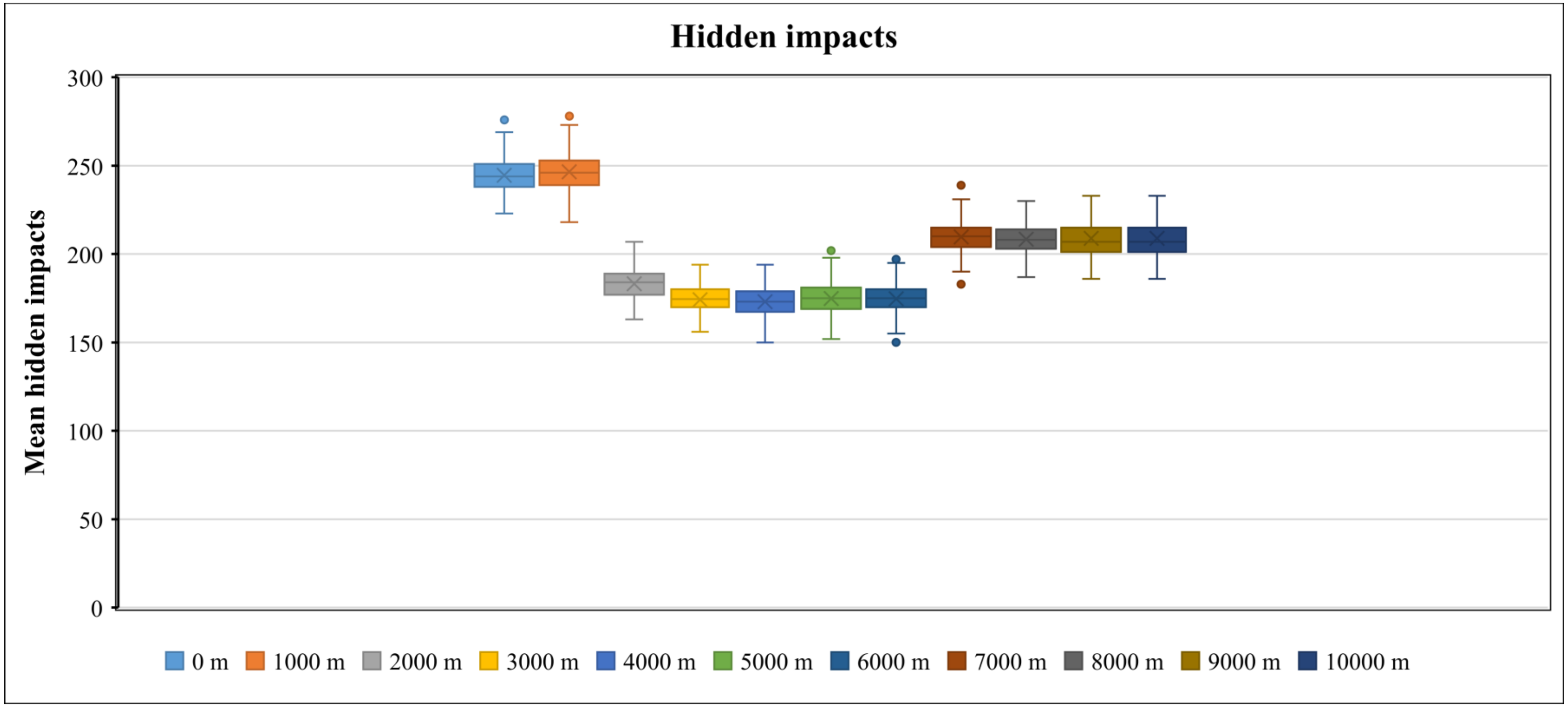


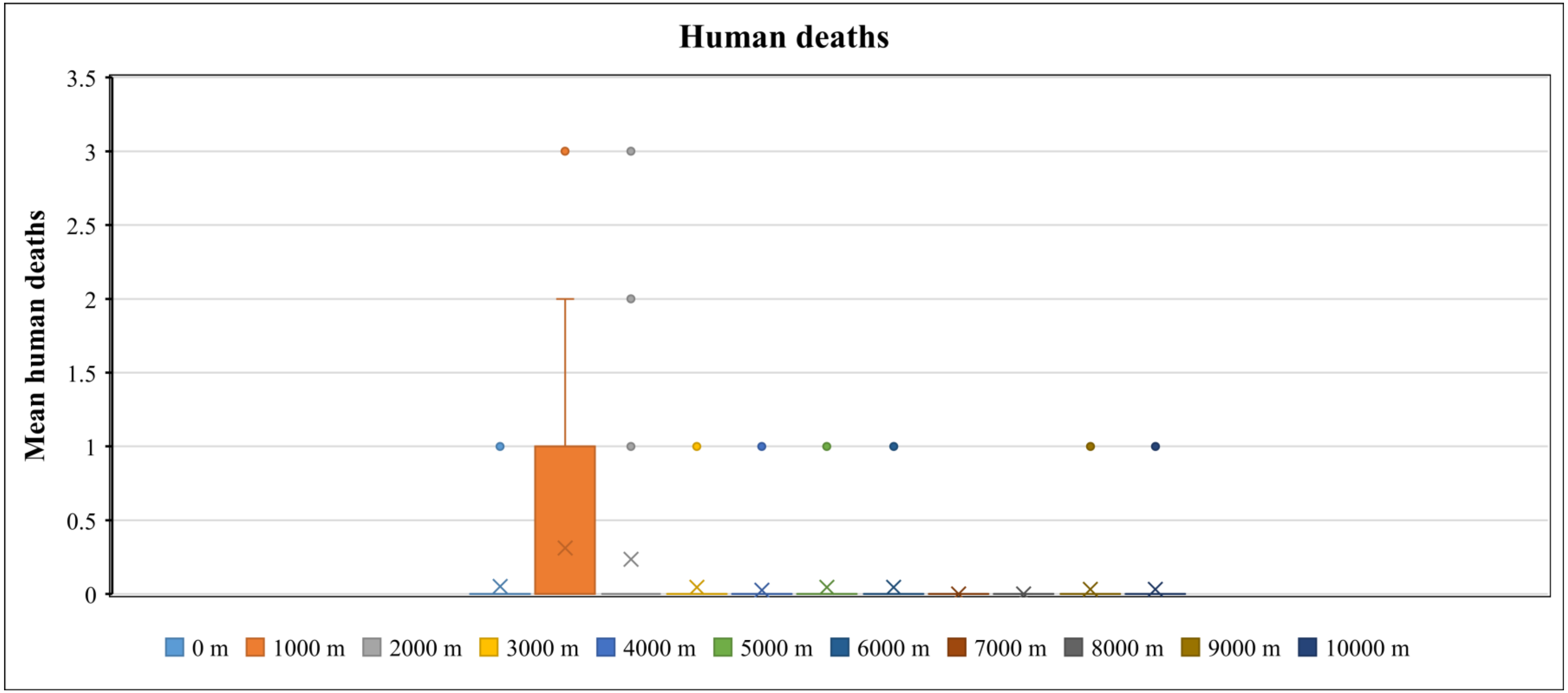

Human deaths
Mean human deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

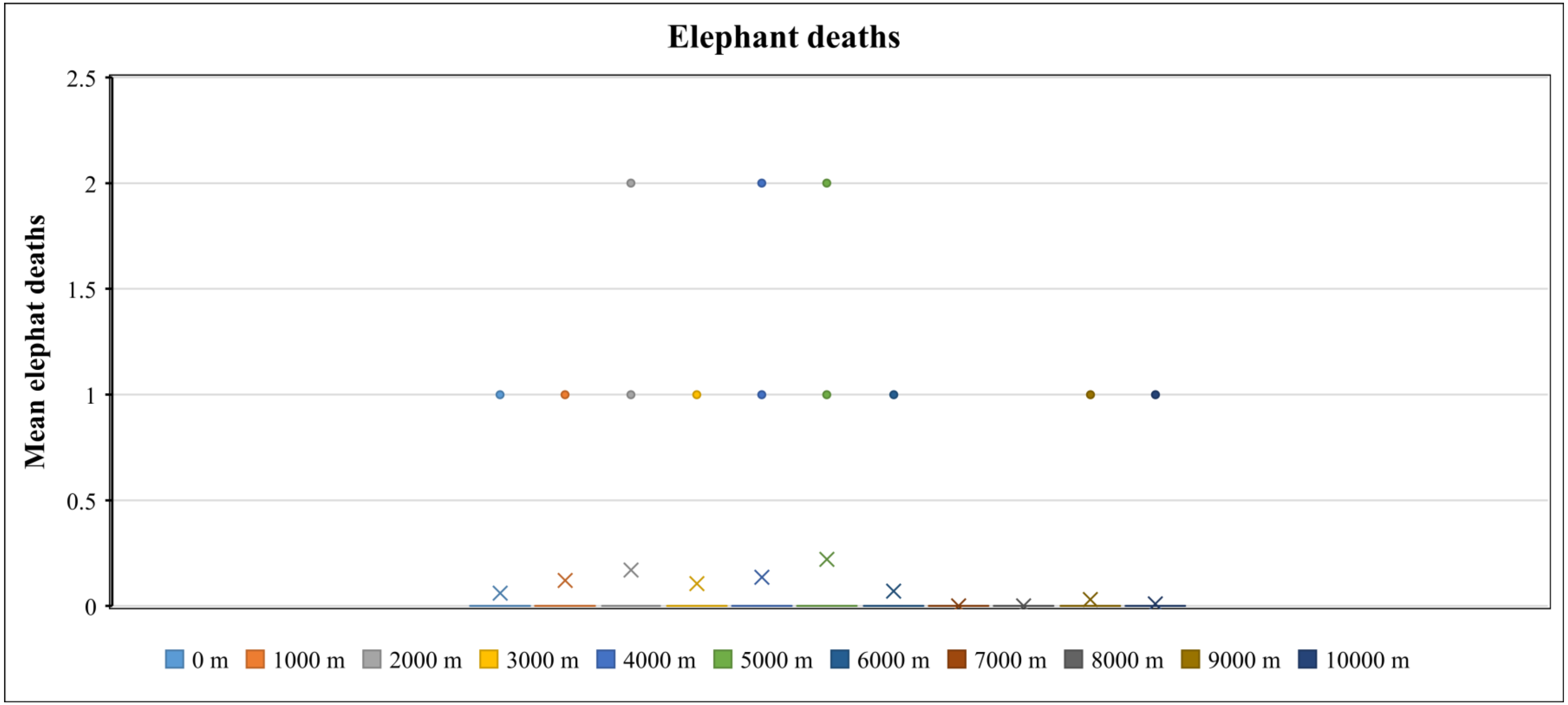

Crop damage
Mean crop damage (hectares)
700
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

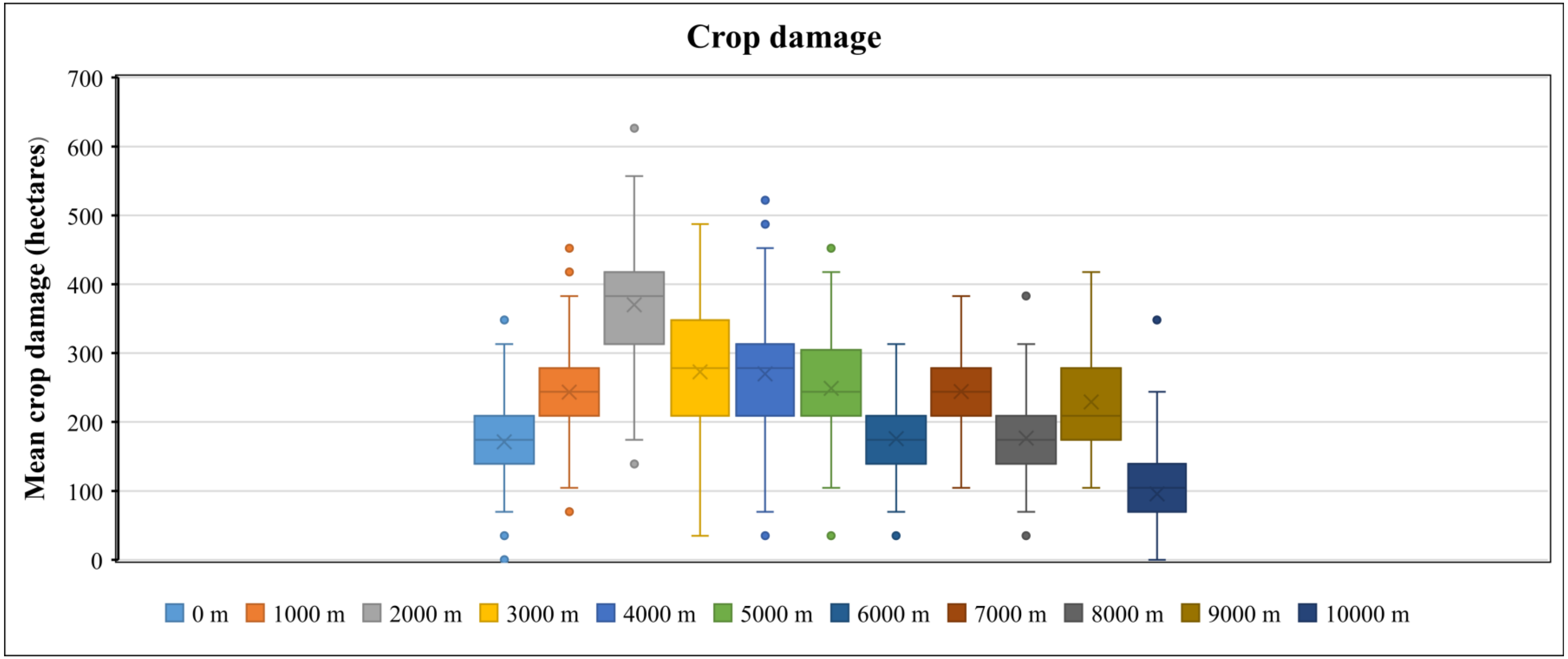

Elephant deaths
Mean elephant deaths
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# Protectedareas (ENS_ Protectedareas)

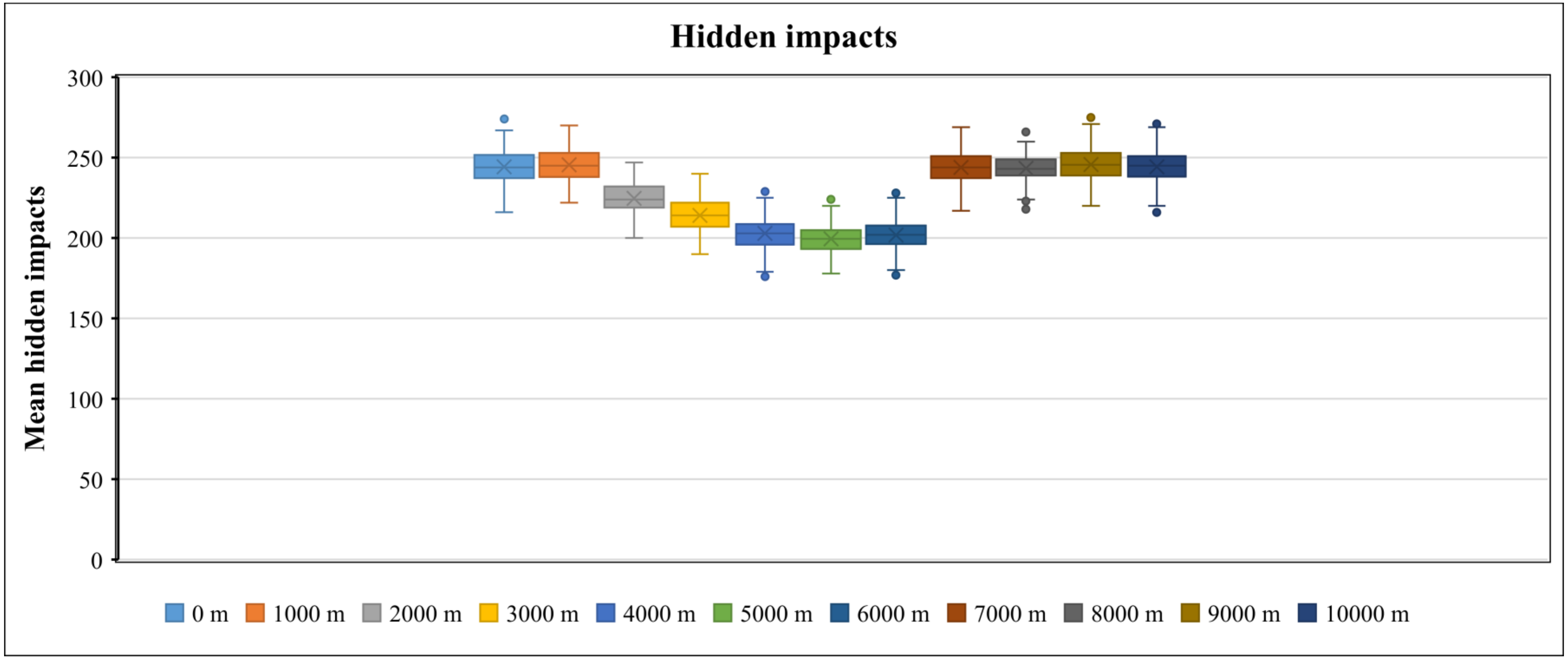


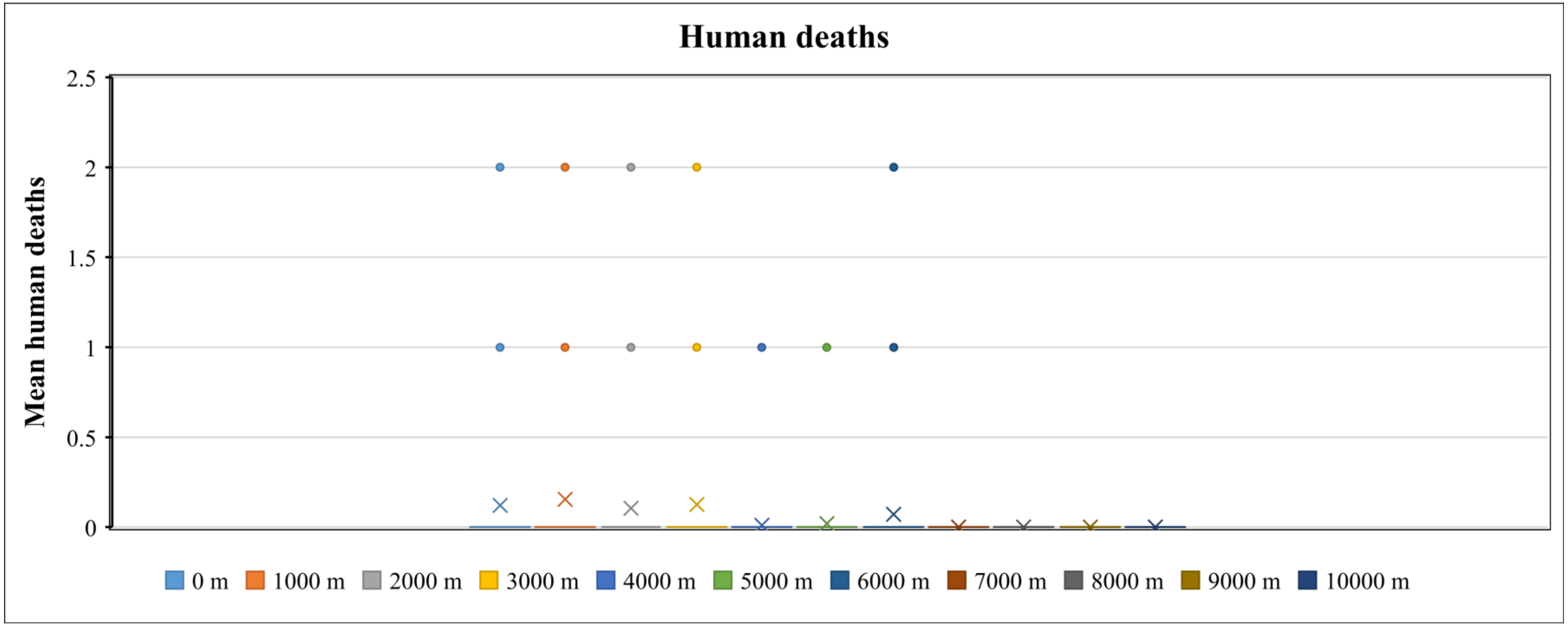

Human deaths
Mean human deaths
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m


Elephant deaths
Mean elephat deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m


Crop damage
Mean crop damage (hectares)
700
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# River (ENS_River)




Human deaths
Mean human deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
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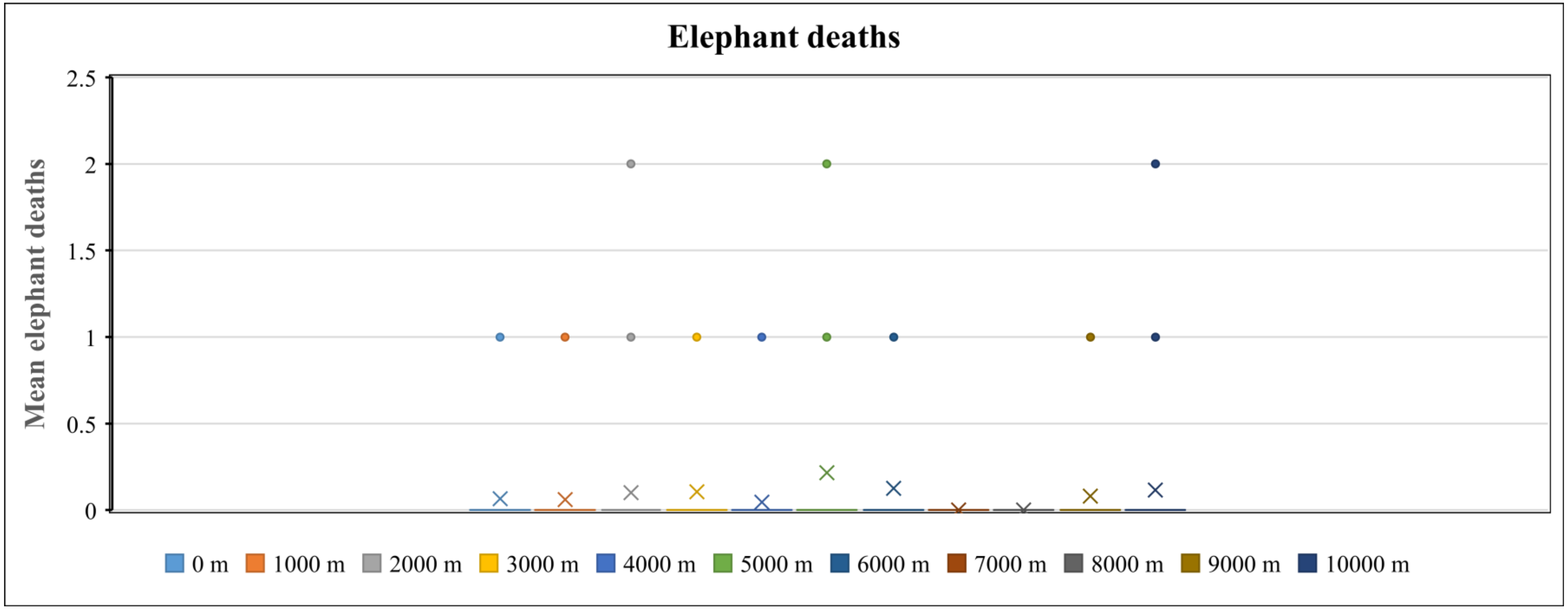
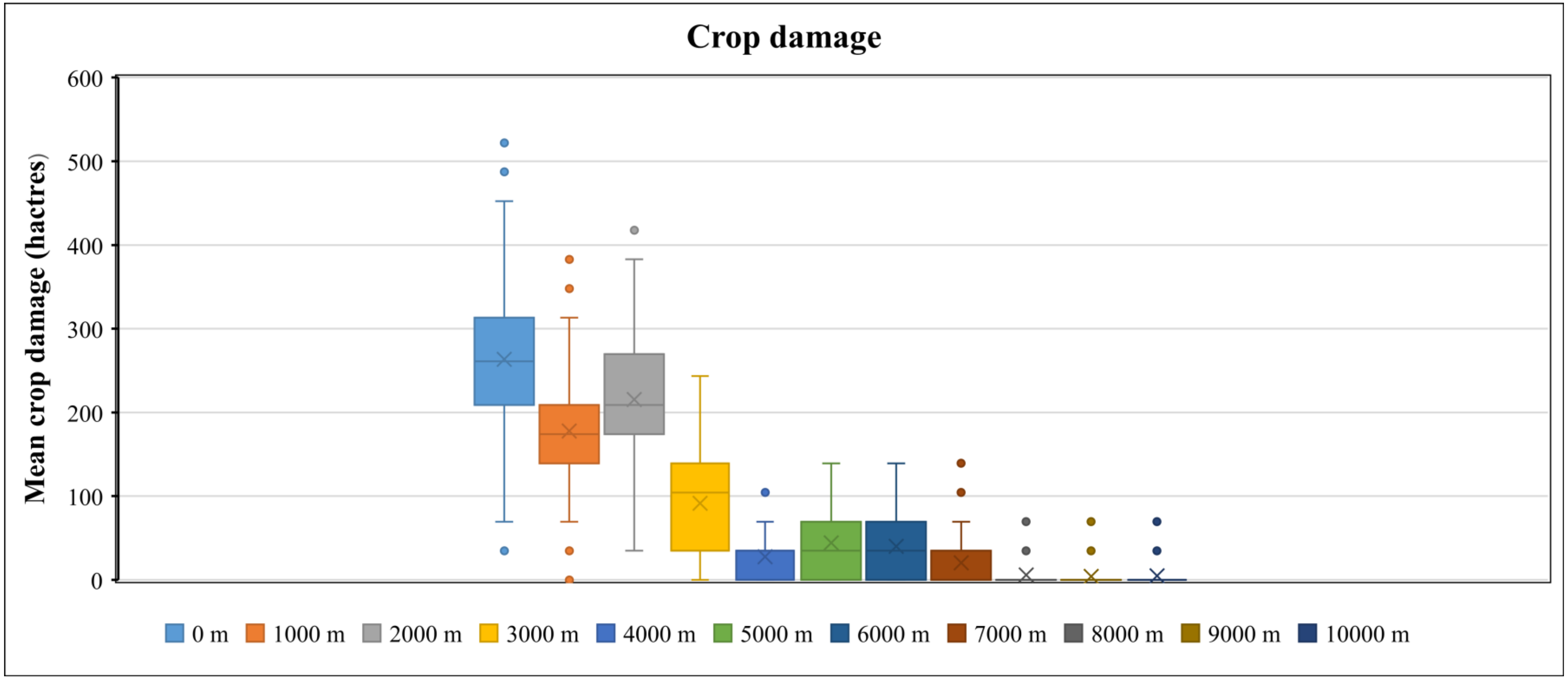
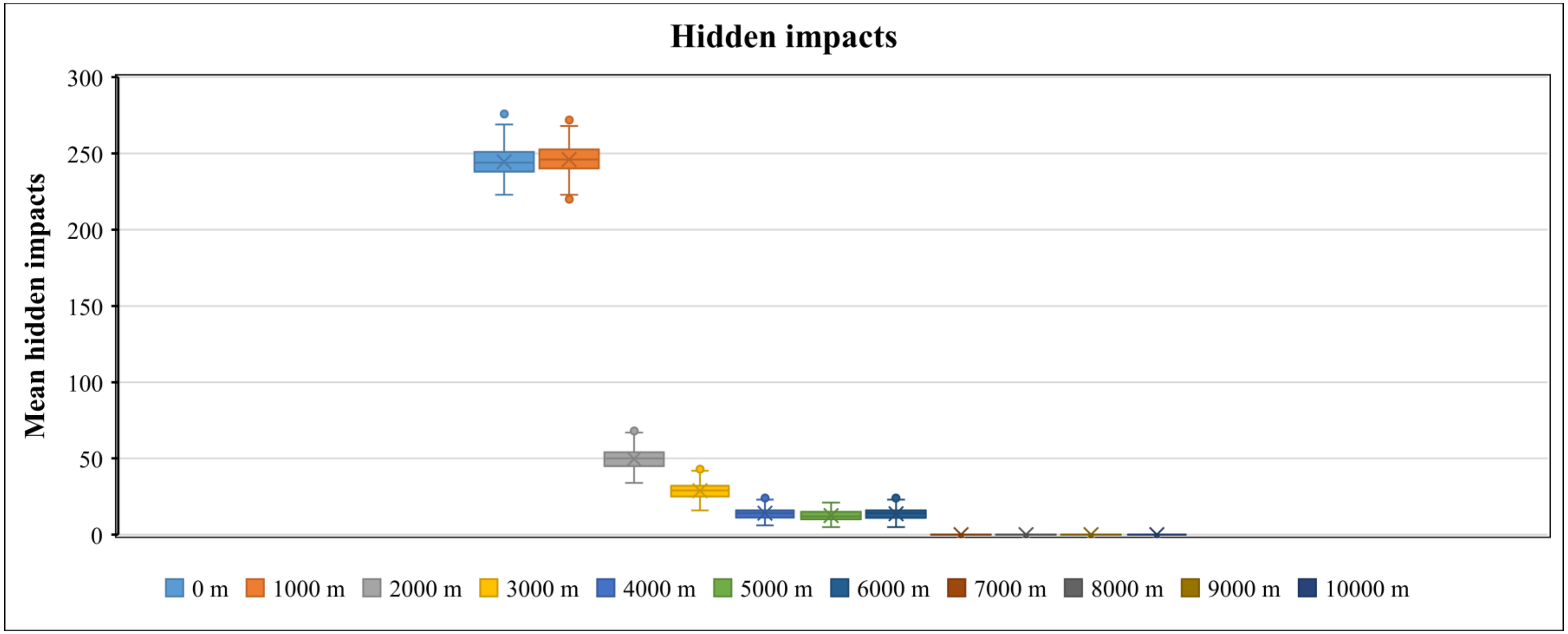
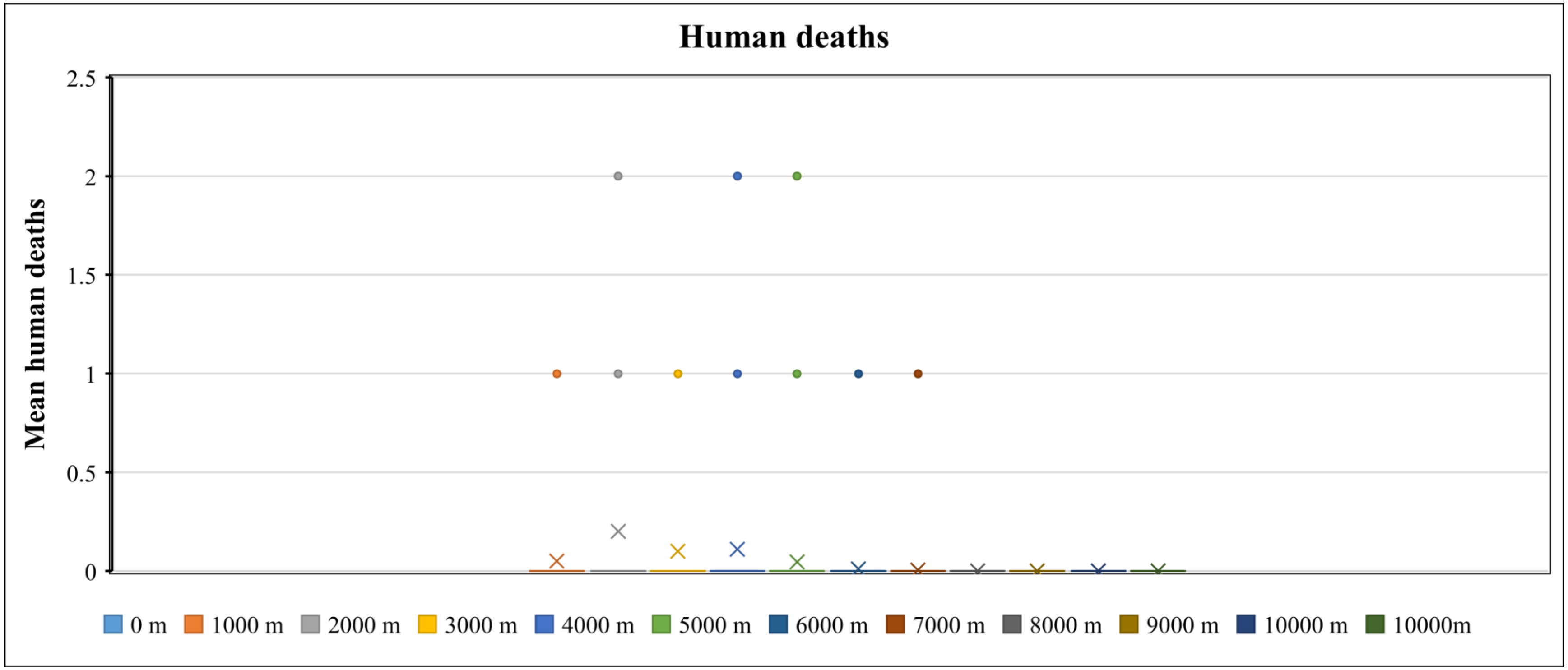
7000 m
8000 m
9000 m
10000 m

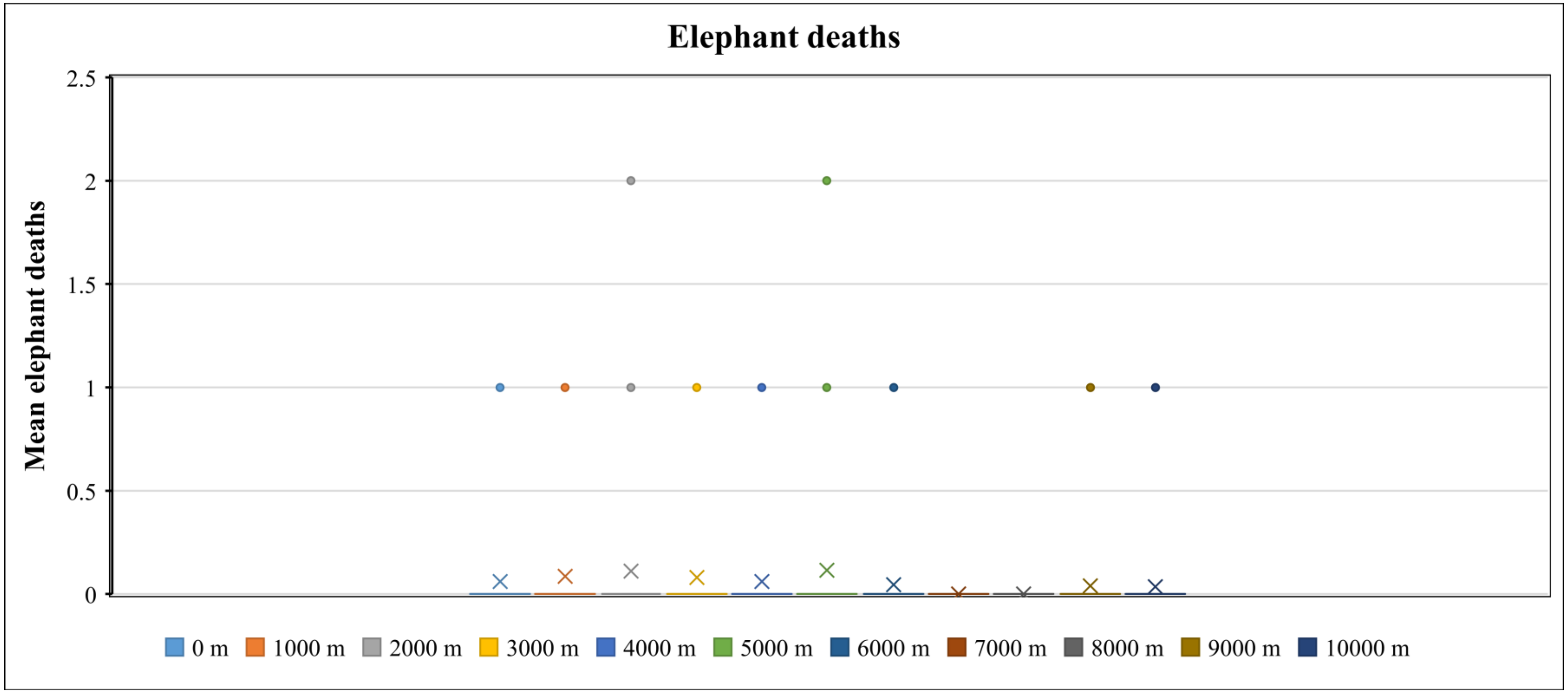

Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

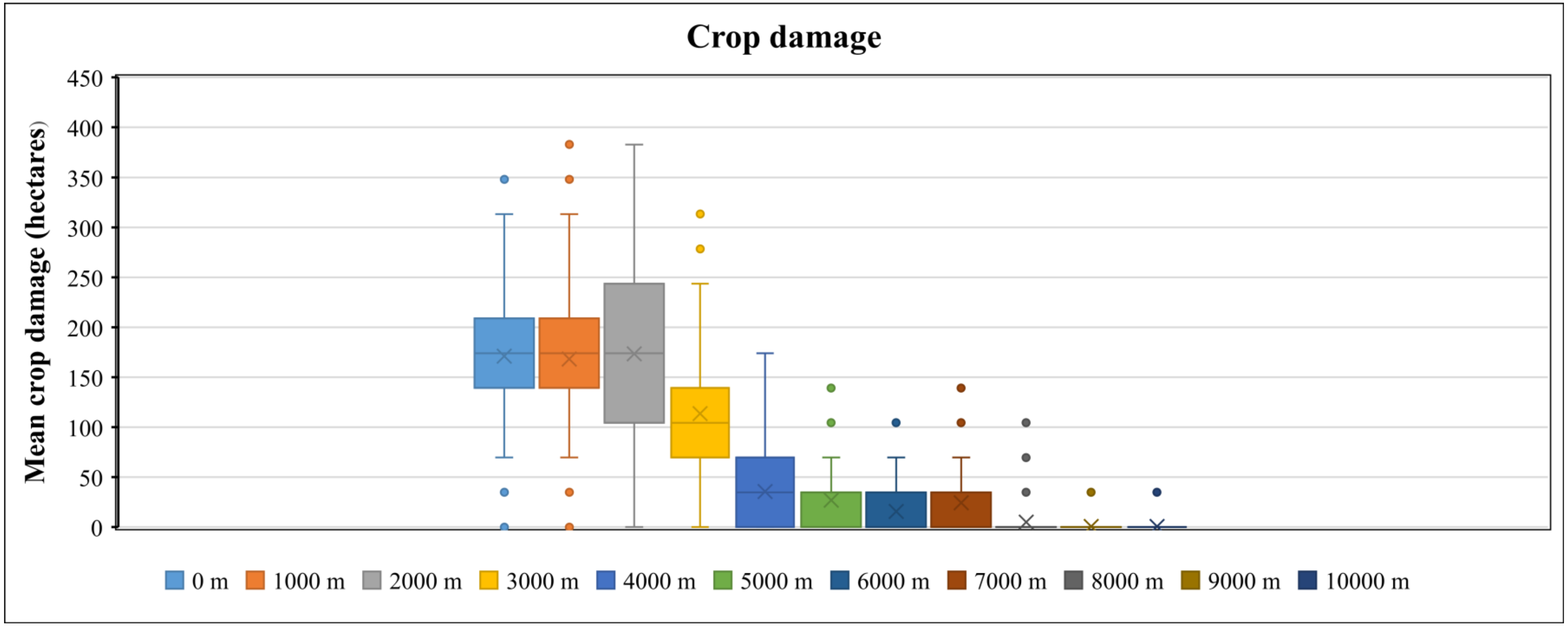

Crop damage
Mean crop damage (hactres)
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# ENS_ Environment_River_Corridor_Protectedarea



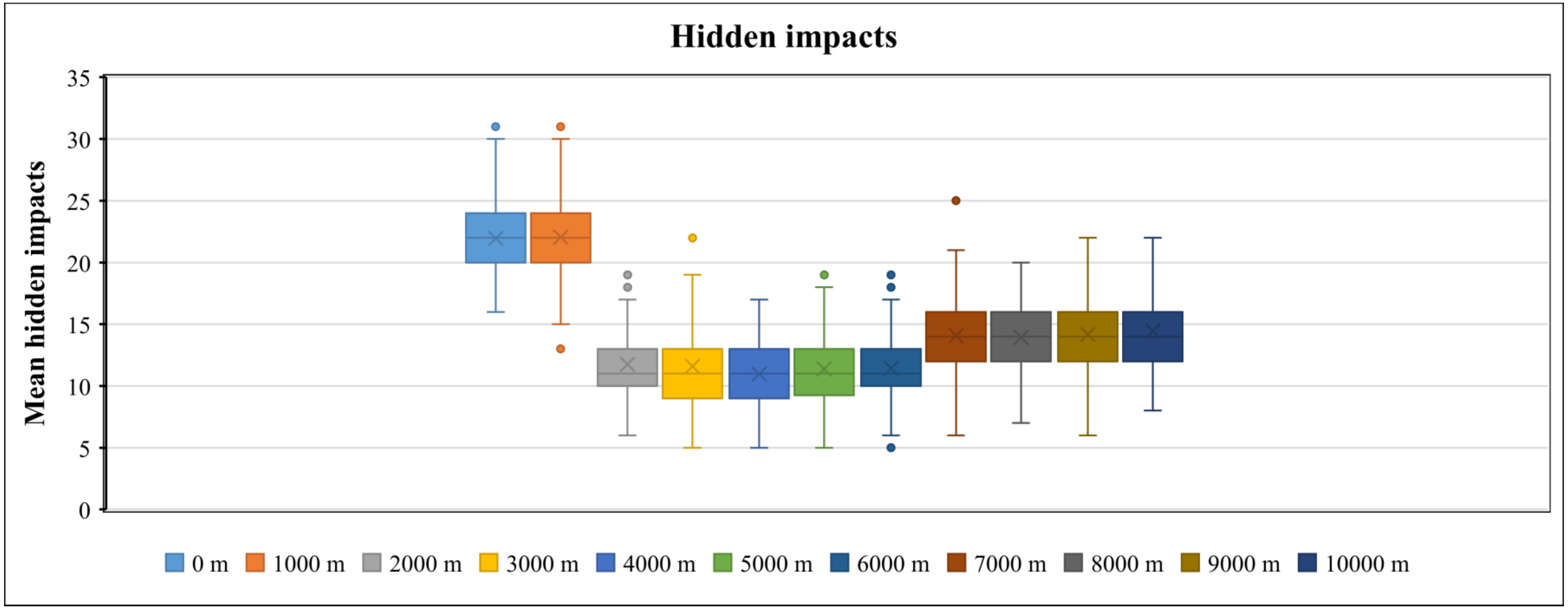

Human deaths
Mean human deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m
10000m

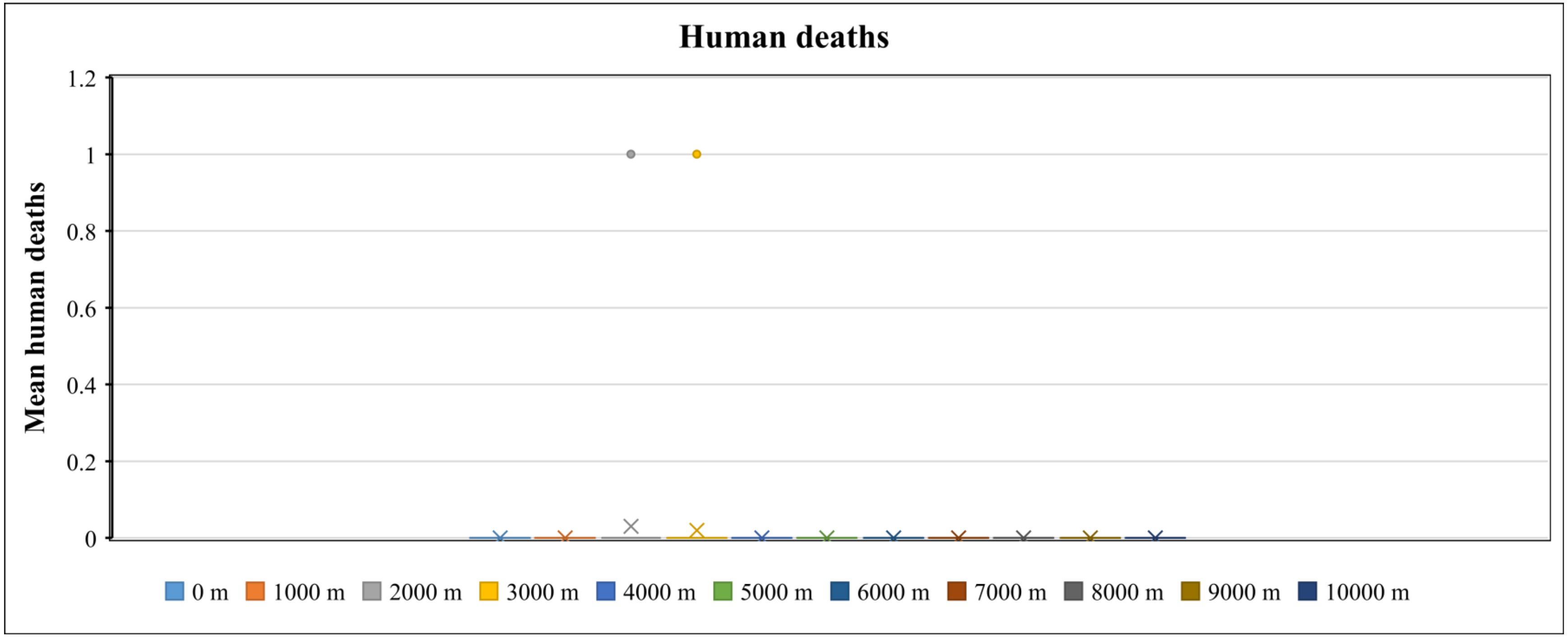

Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

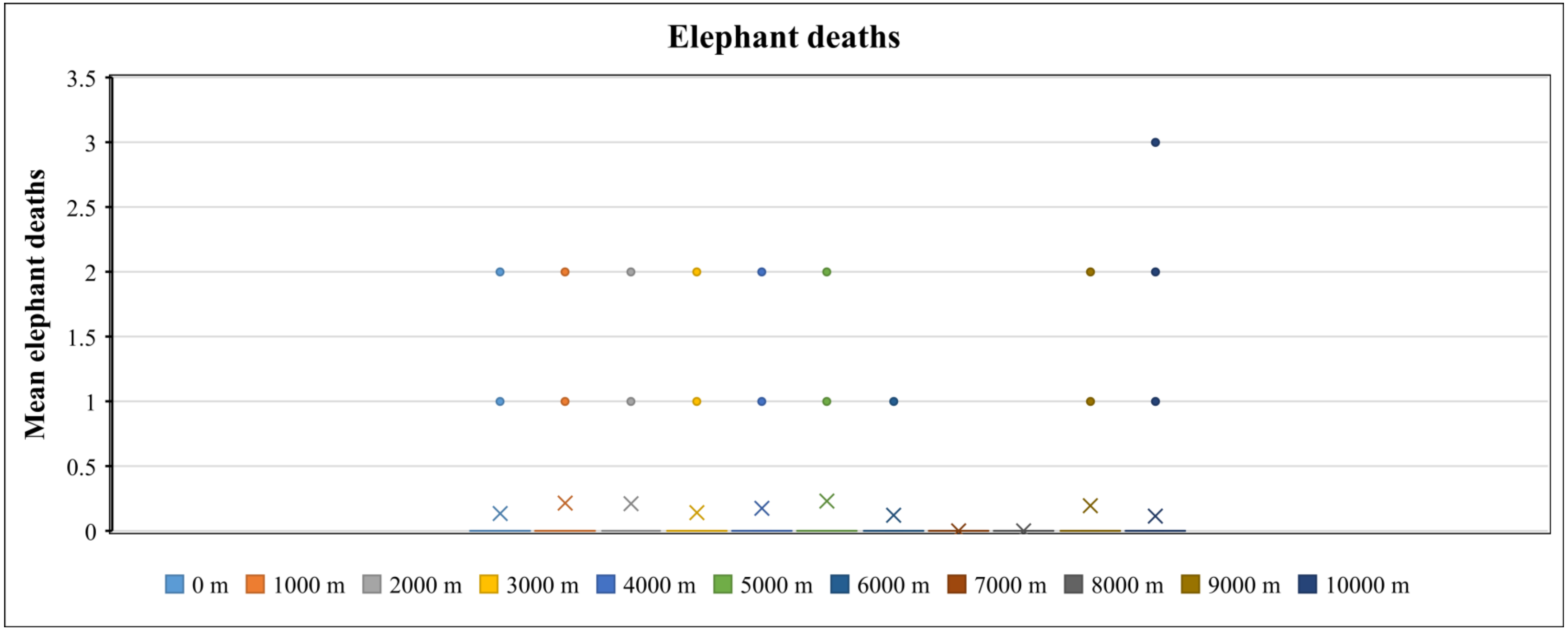

Crop damage
Mean crop damage (hectares)
450
400
350
300
250
200
150
100
50
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

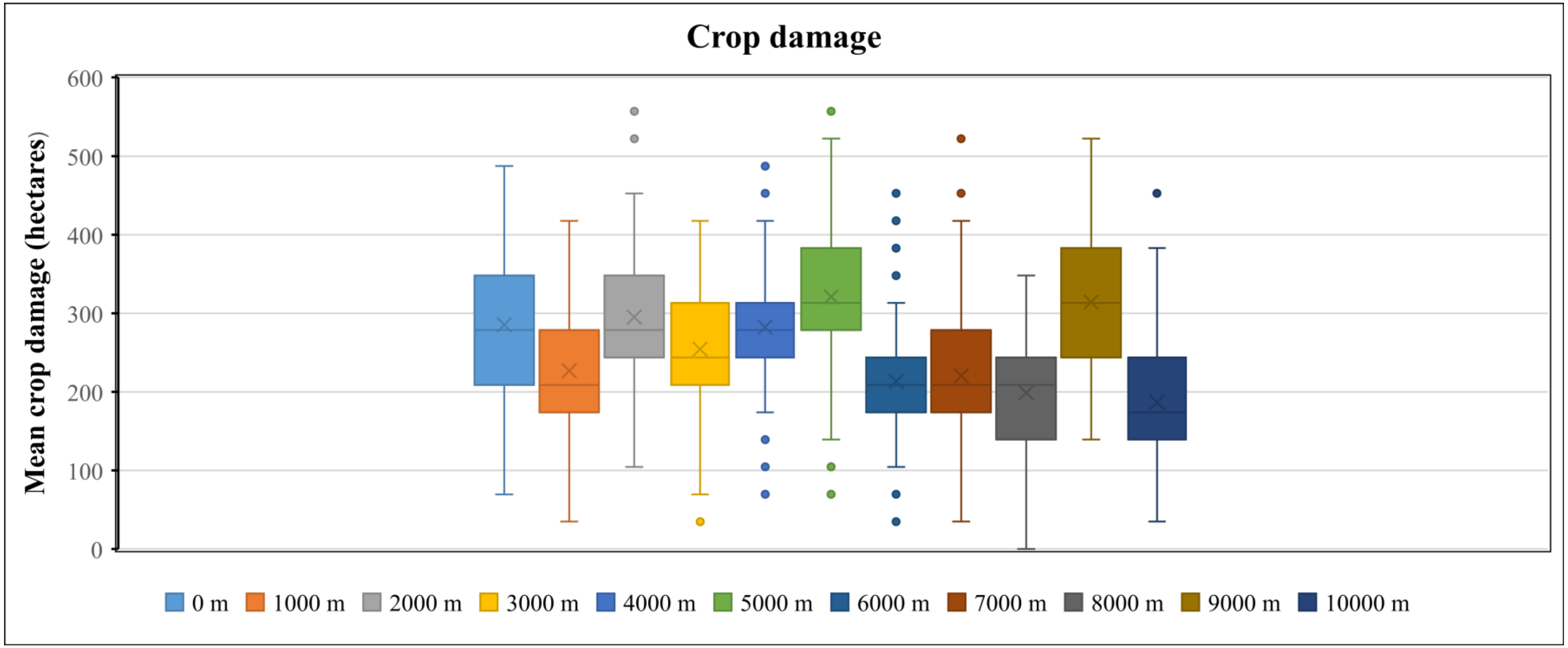
# Human-environmental scenario

## HES-Corridor

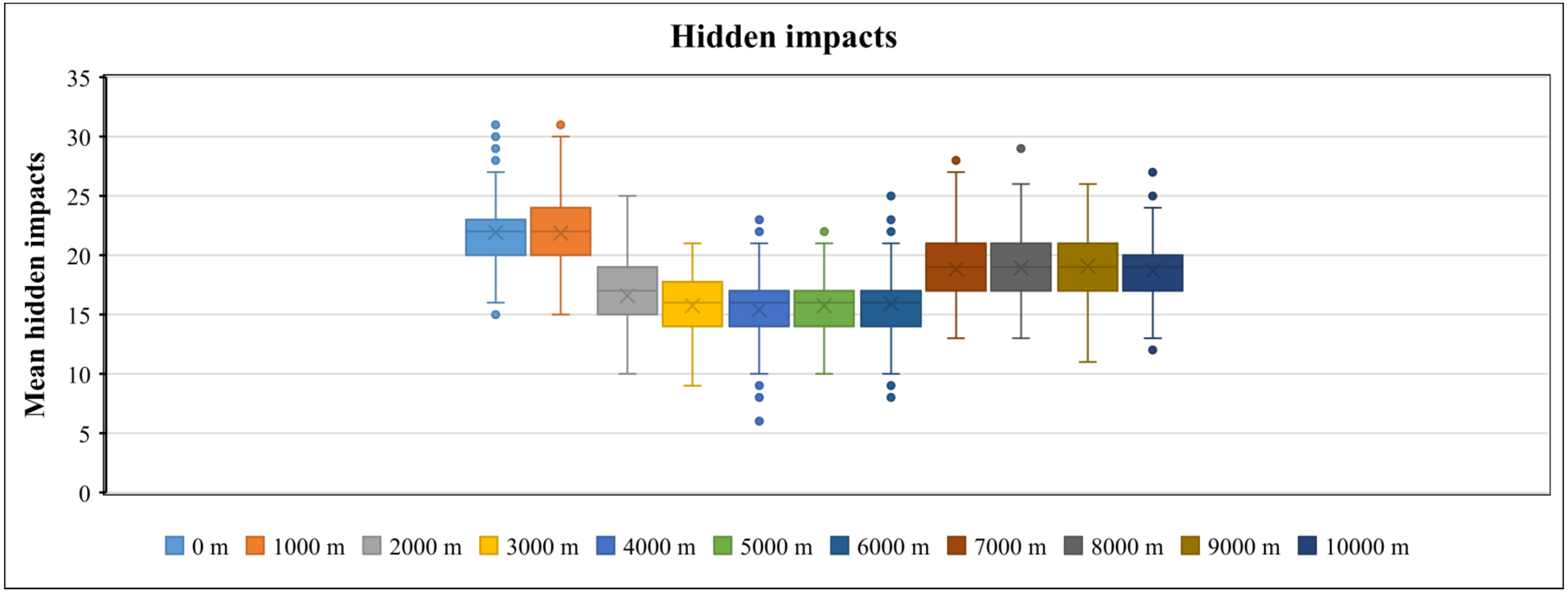


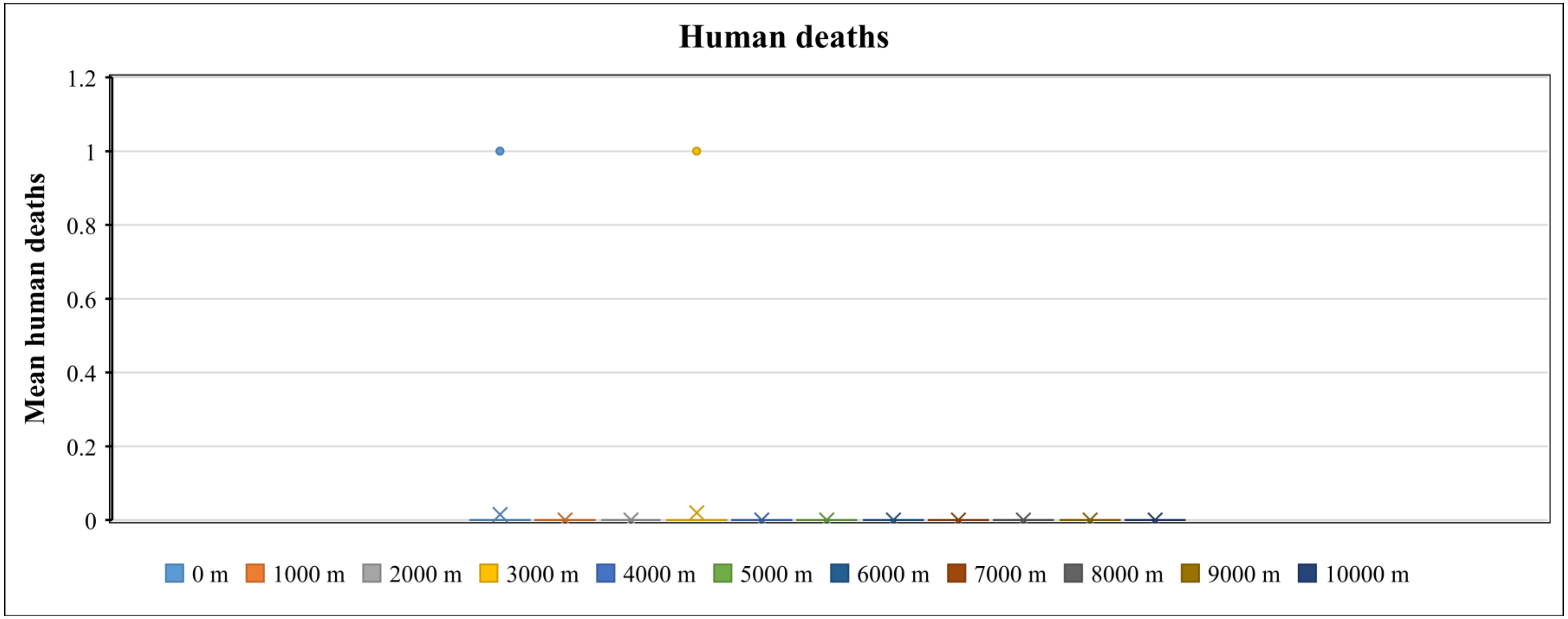

Human deaths
Mean human deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

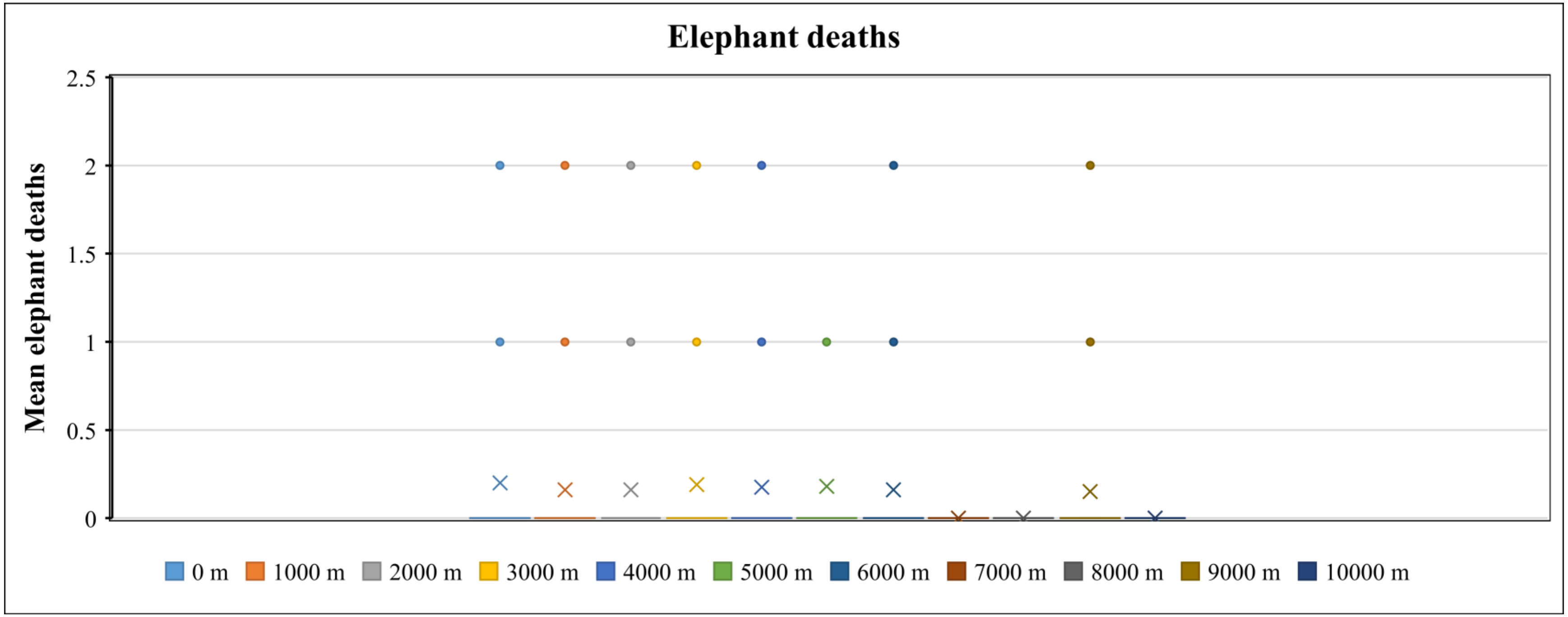

Elephant deaths
Mean elephant deaths
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m


Crop damage
Mean crop damage (hectares)
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HES-Protectedarea




Human deaths
Mean human deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m


Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
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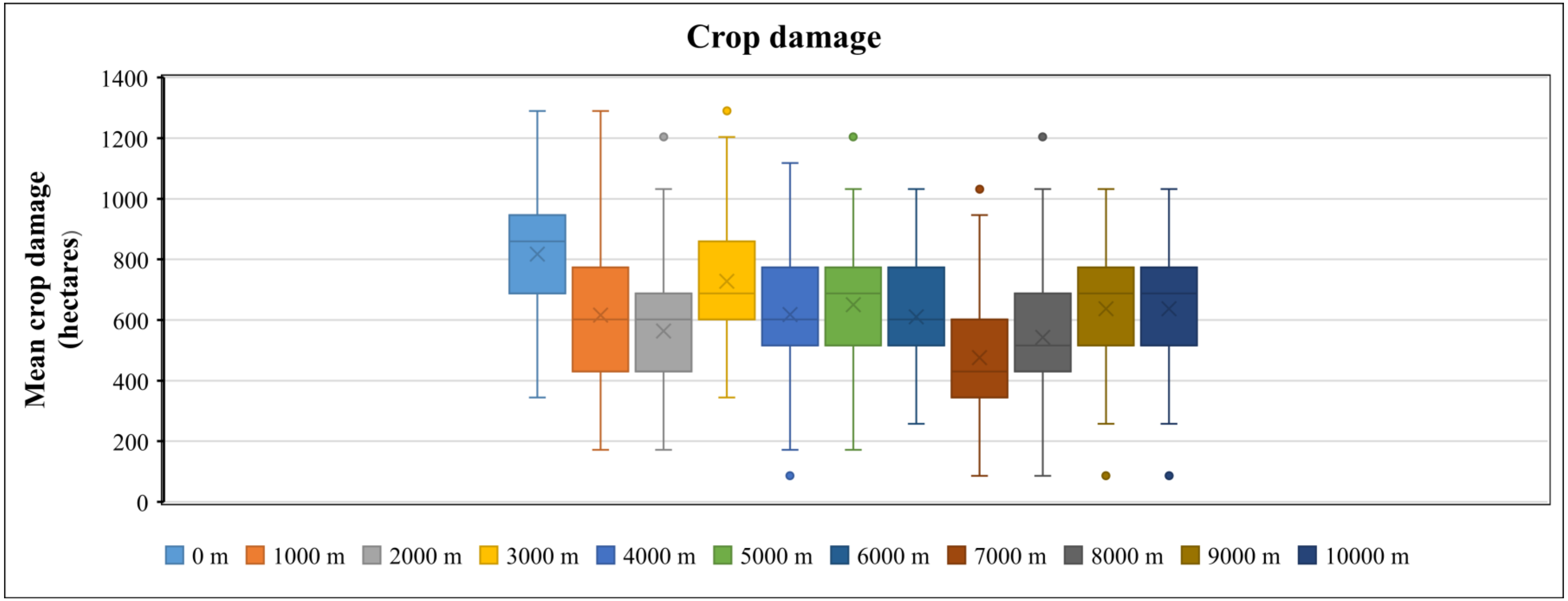
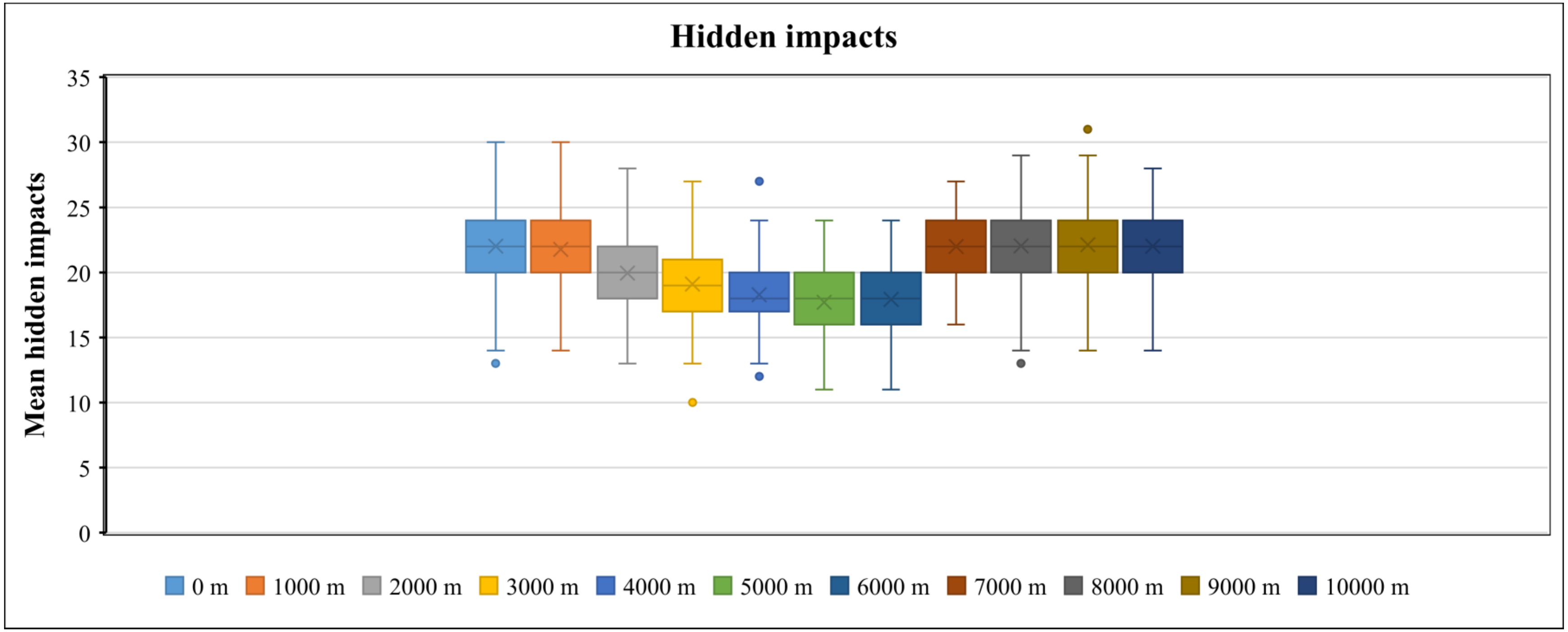
7000 m
8000 m
9000 m
10000 m


Crop damage
Mean crop damage (hectares)
1400
1200
1000
800
600
400
200
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HES-River


Hidden impacts
Mean hidden impacts
35
30
25
20
15
10
5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
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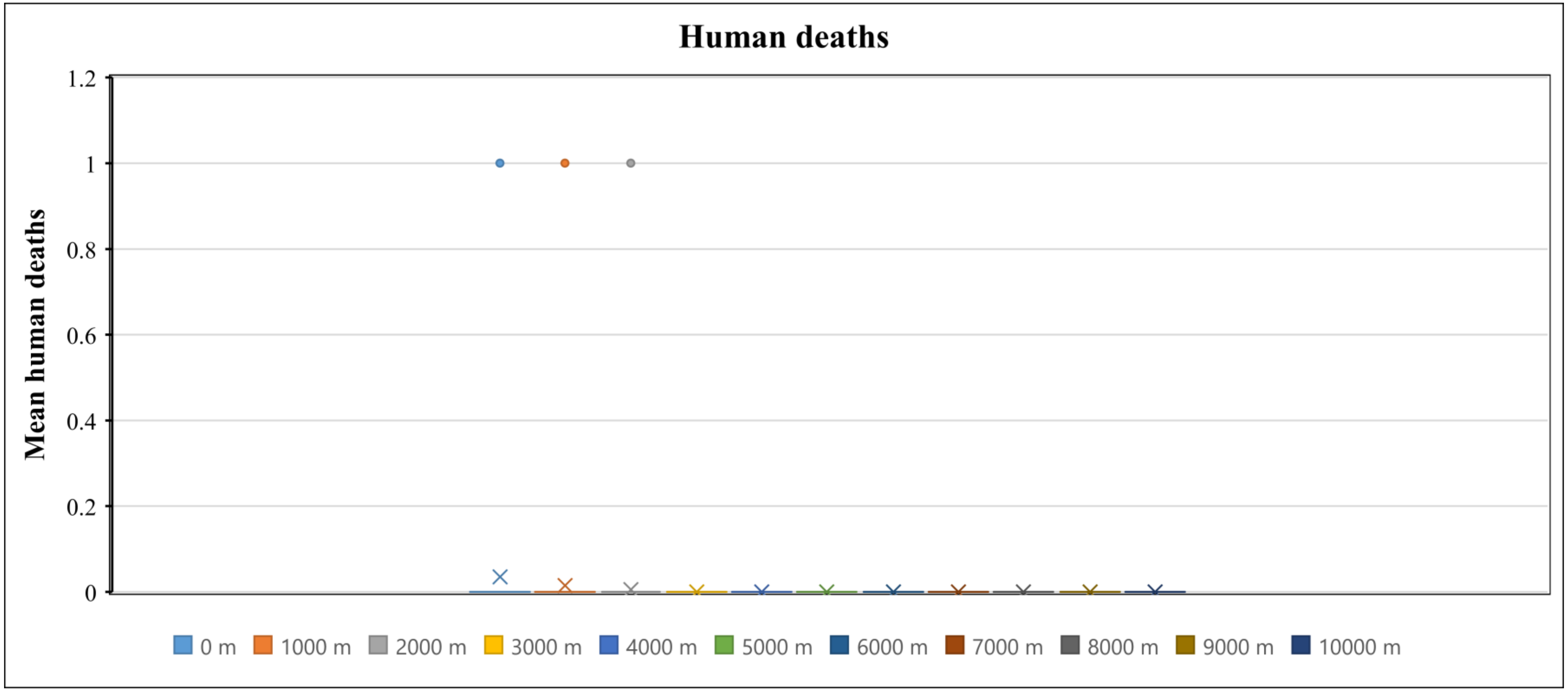
7000 m
8000 m
9000 m
10000 m


Human deaths
Mean human deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
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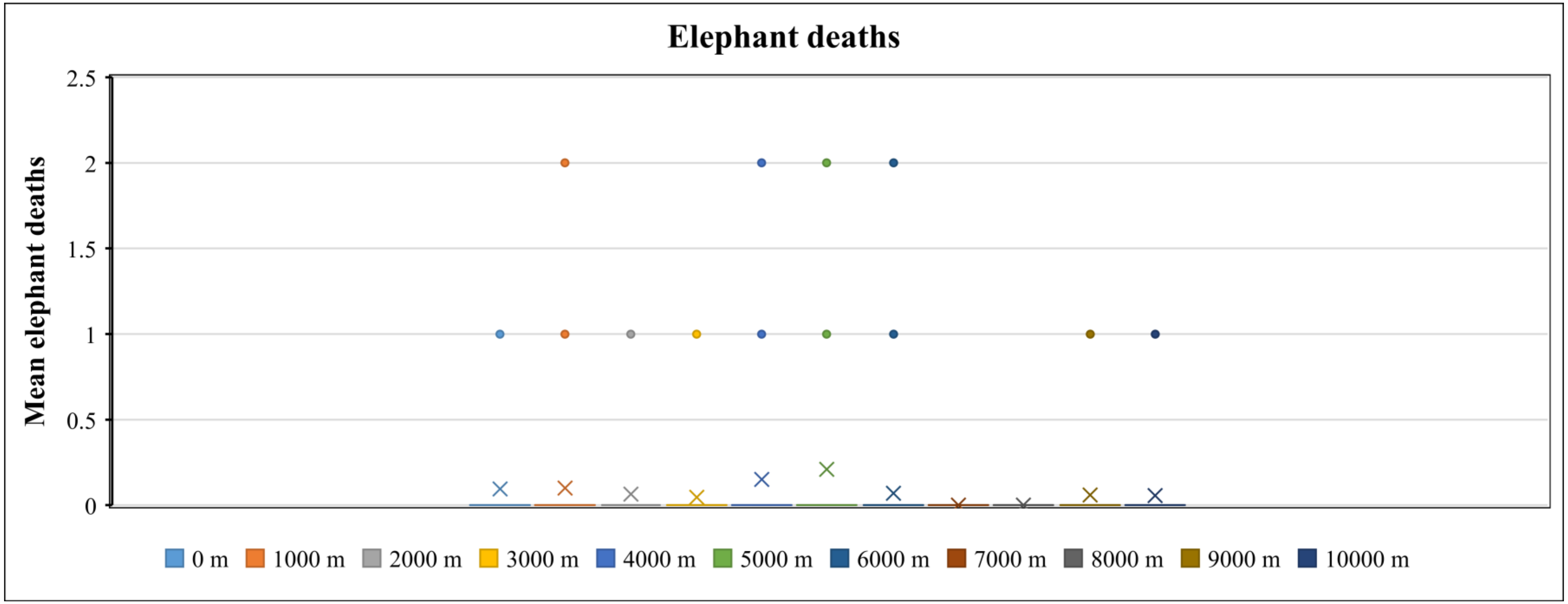
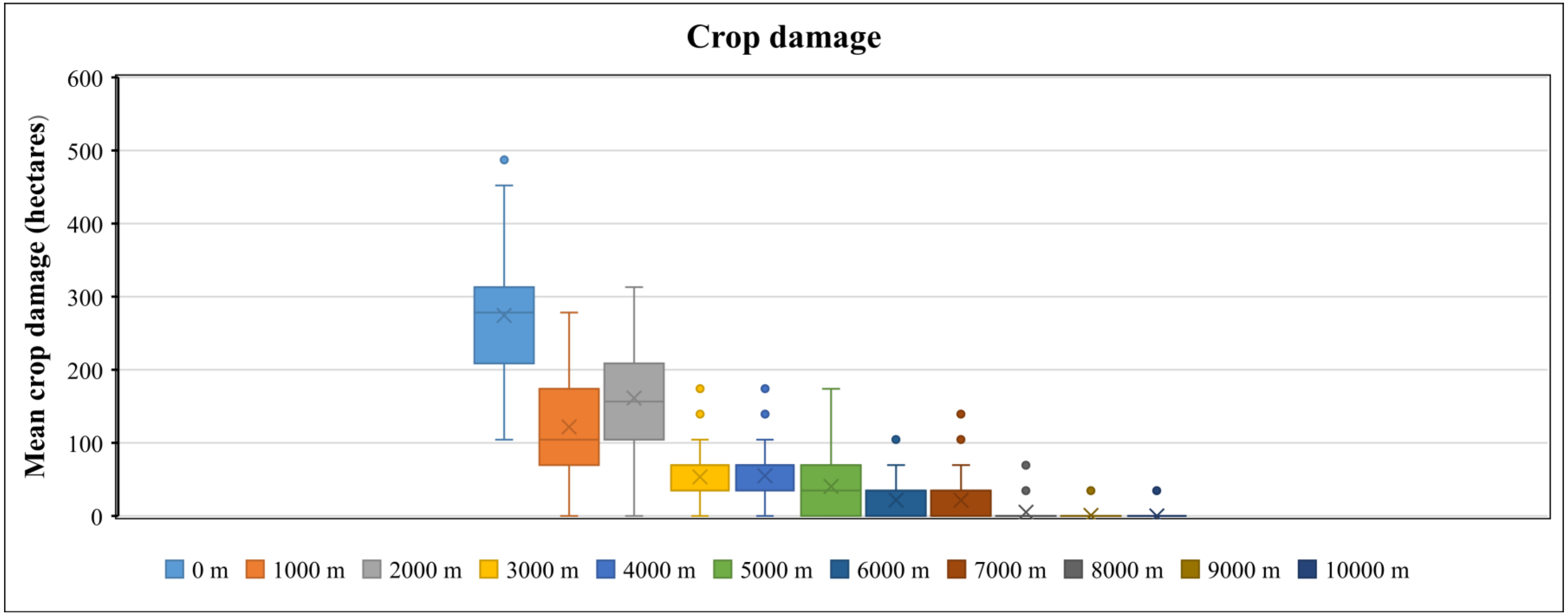
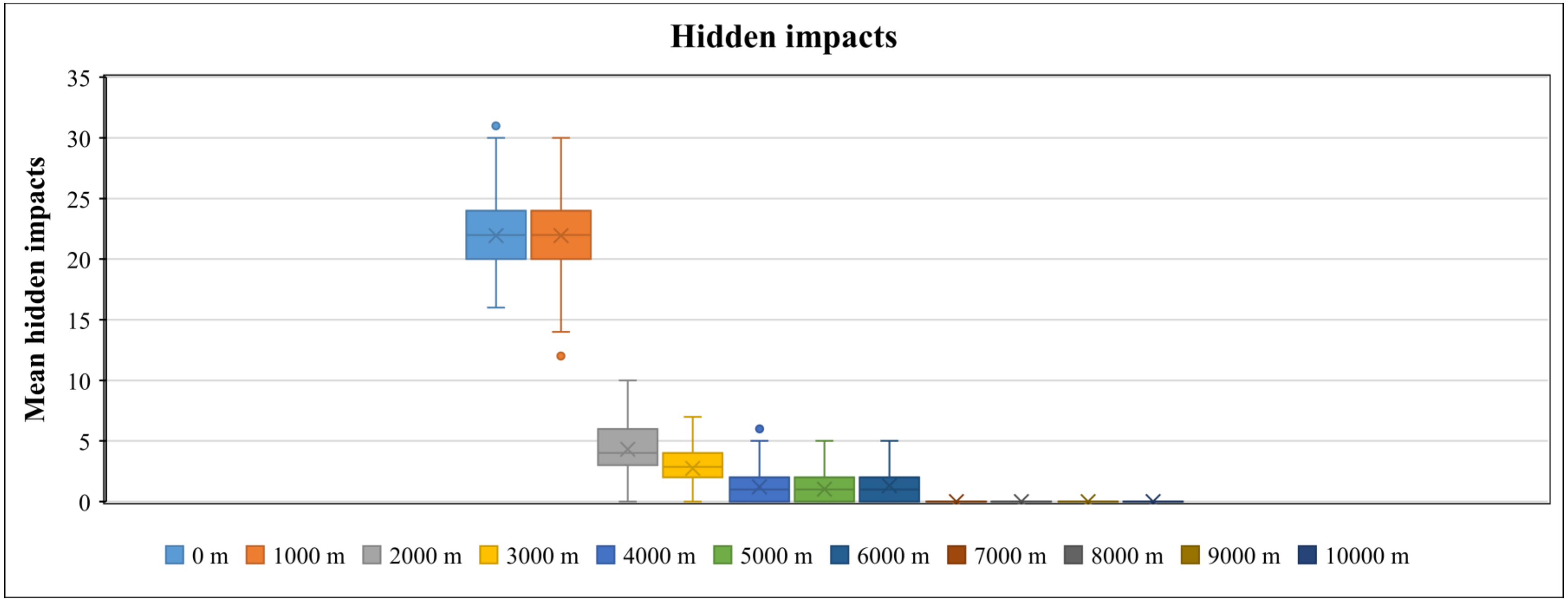
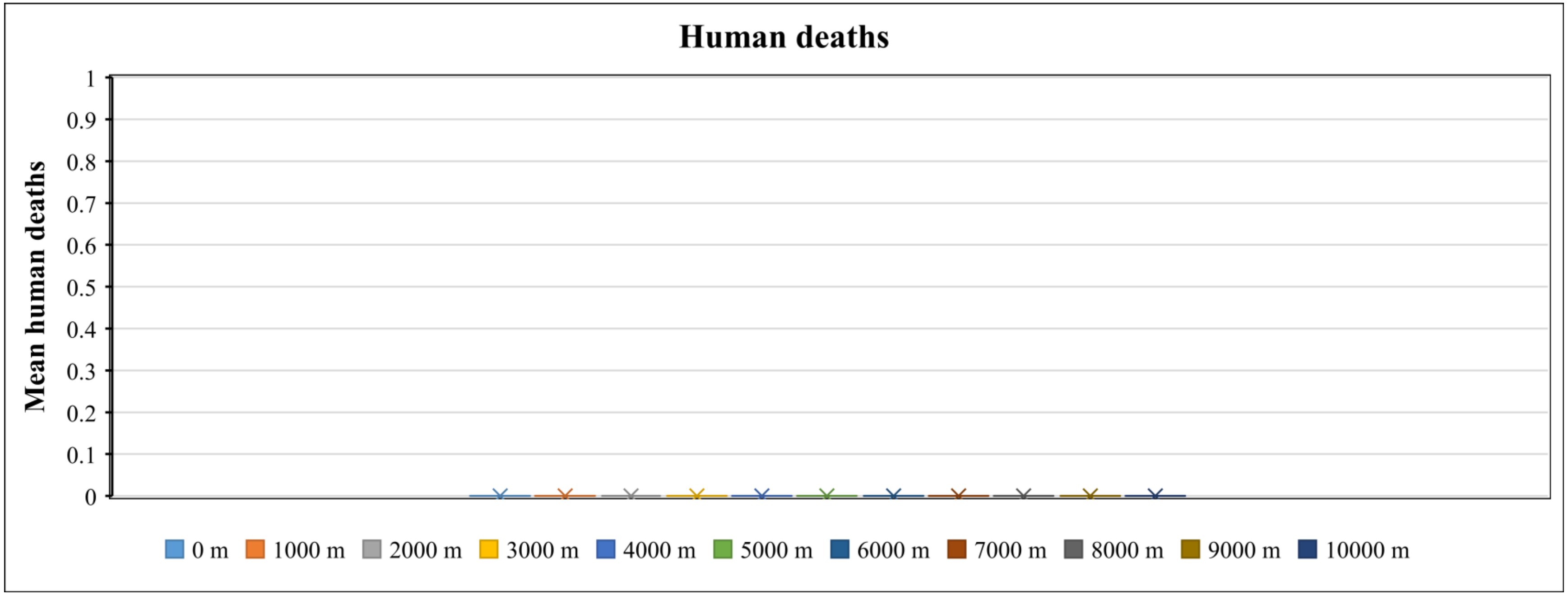
7000 m
8000 m
9000 m
10000 m

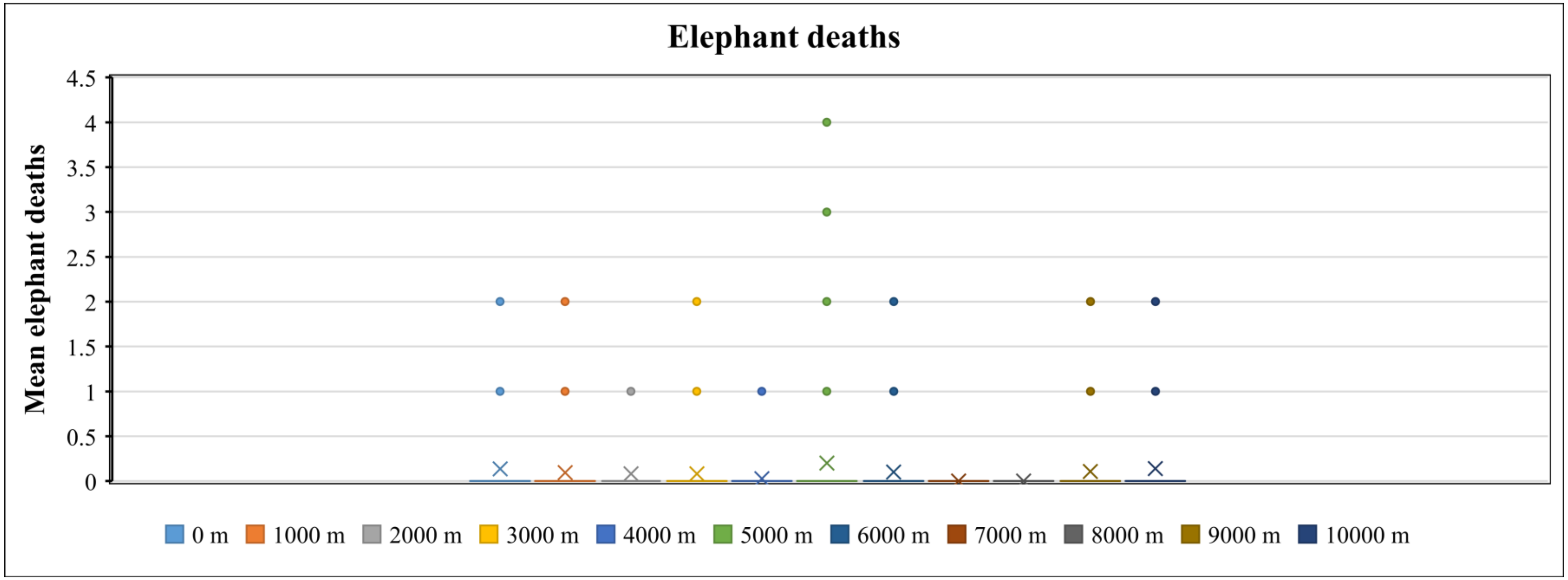

Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

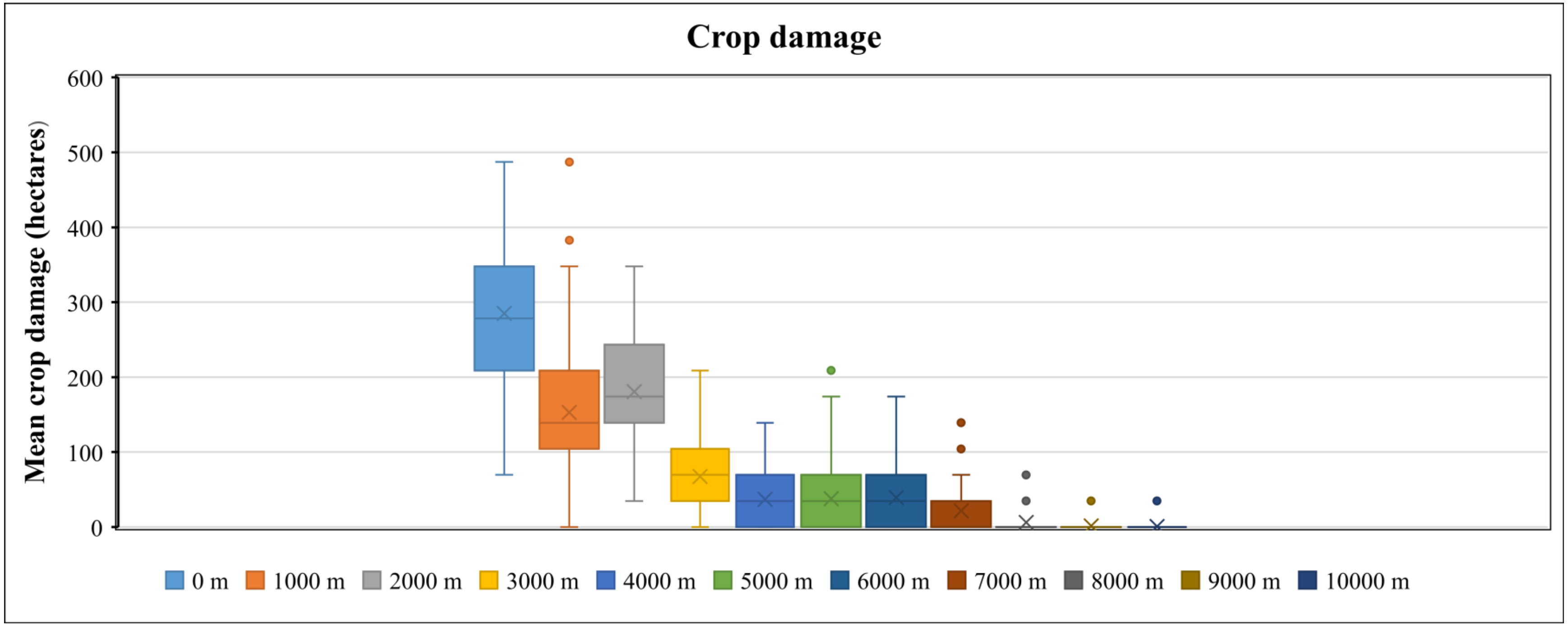

Crop damage
Mean crop damage (hectares)
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HES-River_Protect_Corridor



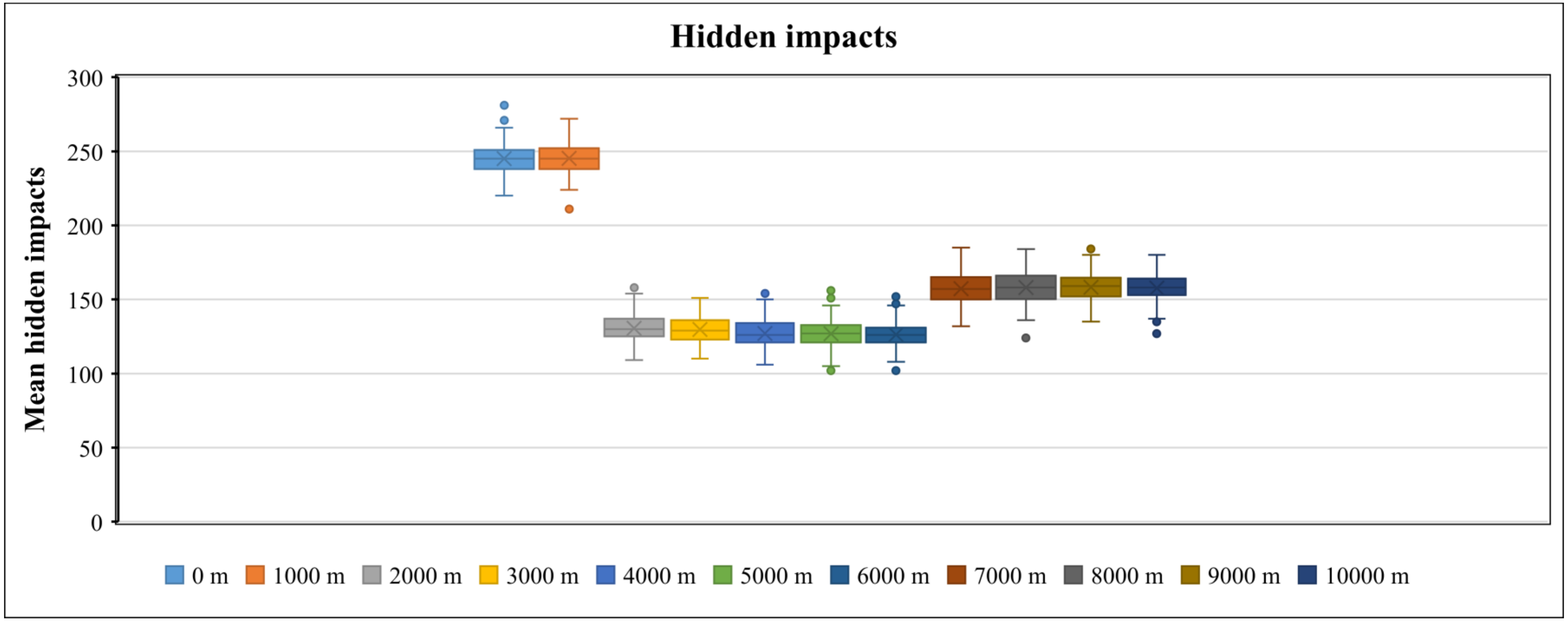

Human deaths
Mean human deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

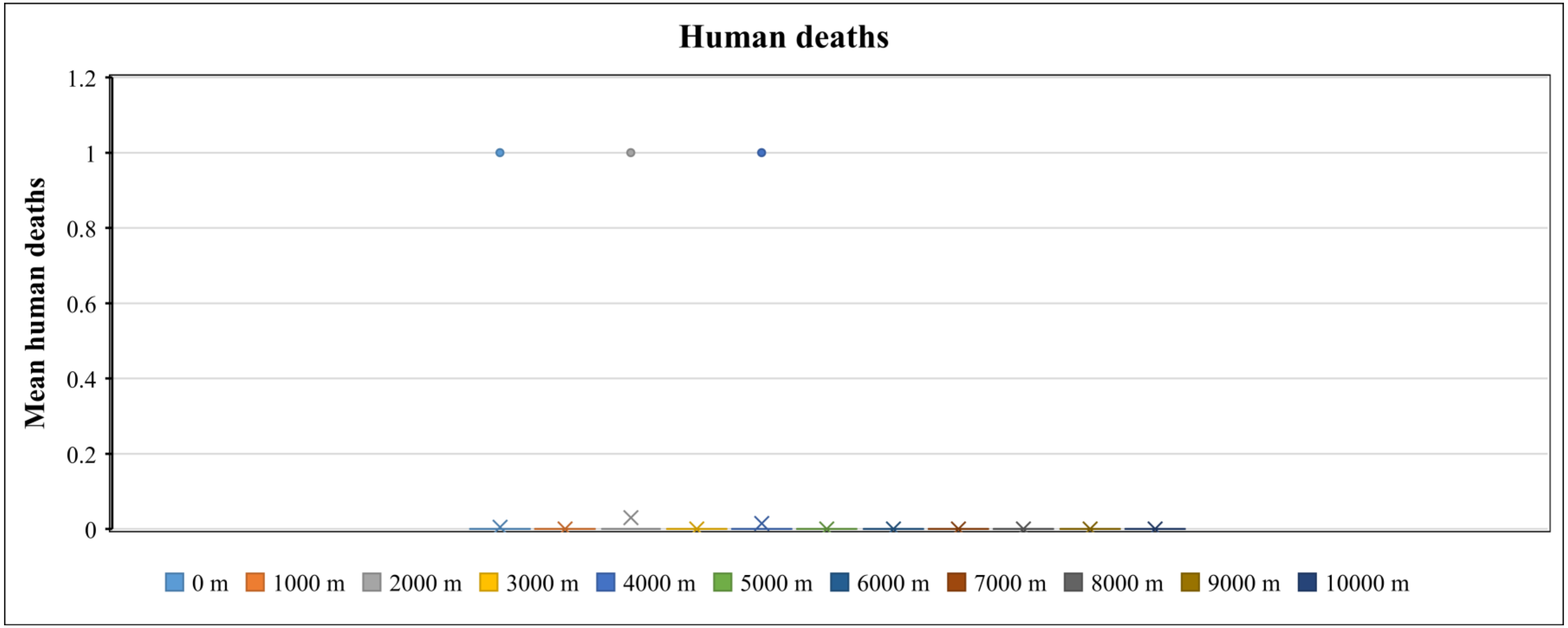

Elephant deaths
Mean elephant deaths
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

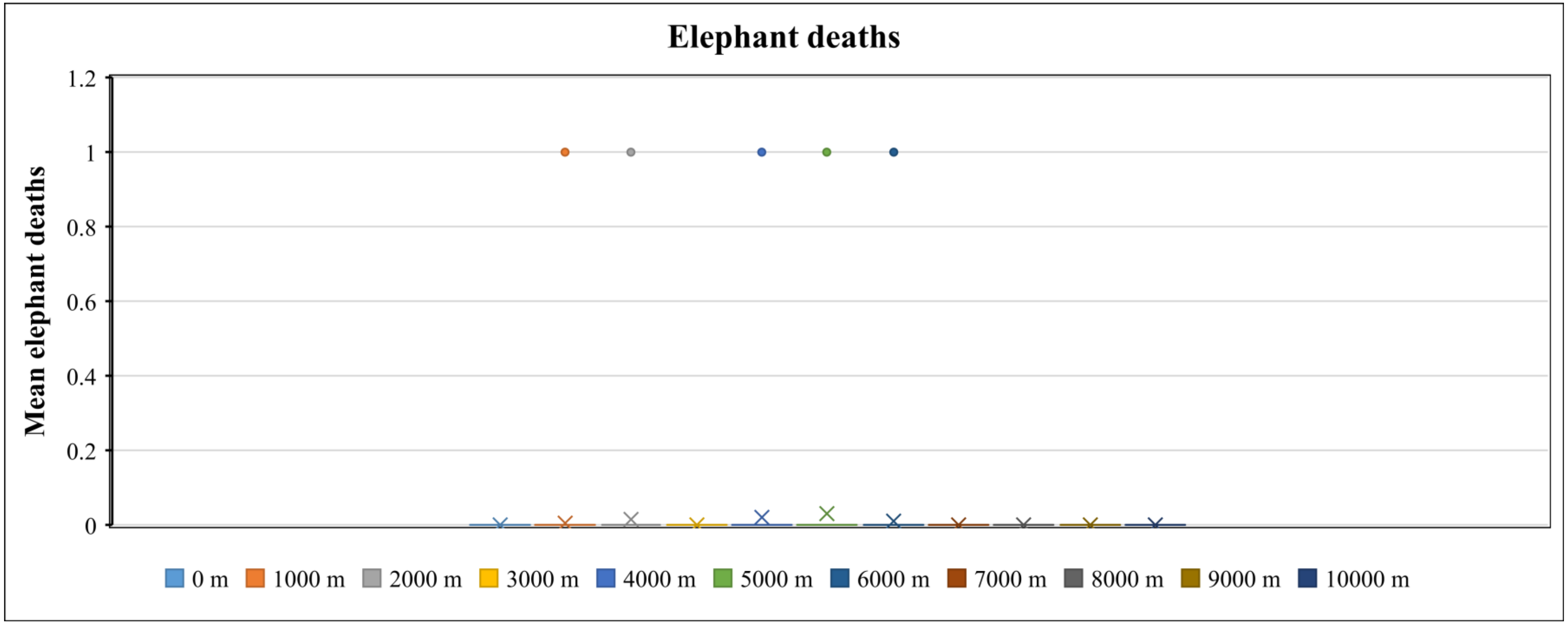

Crop damage
Mean crop damage (hectares)
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

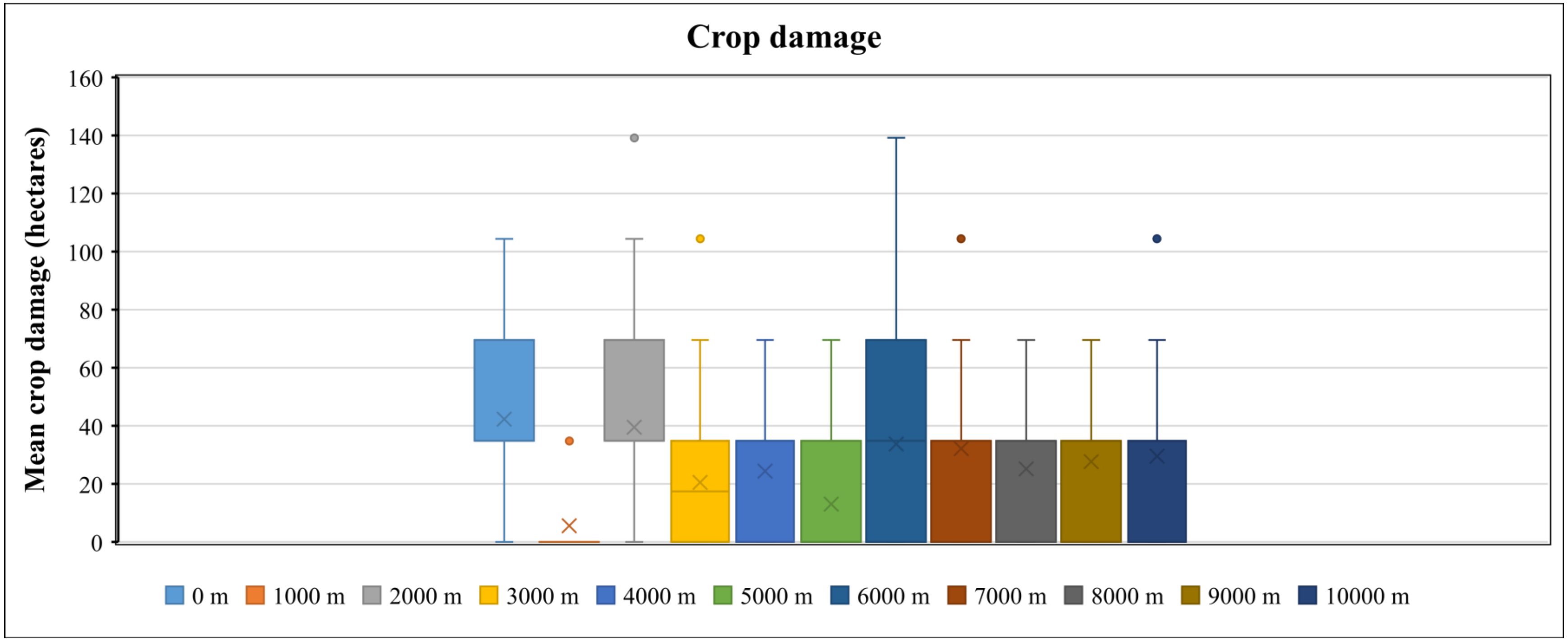
# Elephant-environment Scenario

## EES_Corridor

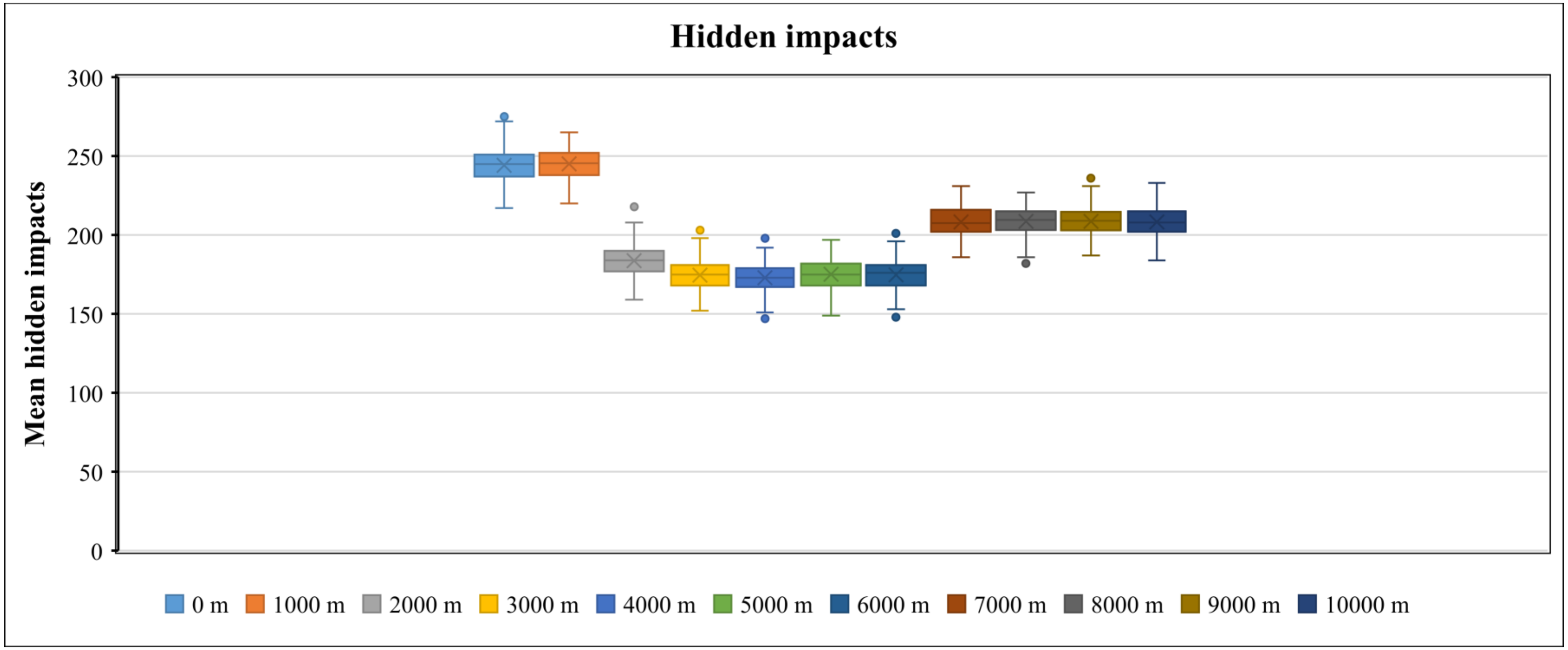


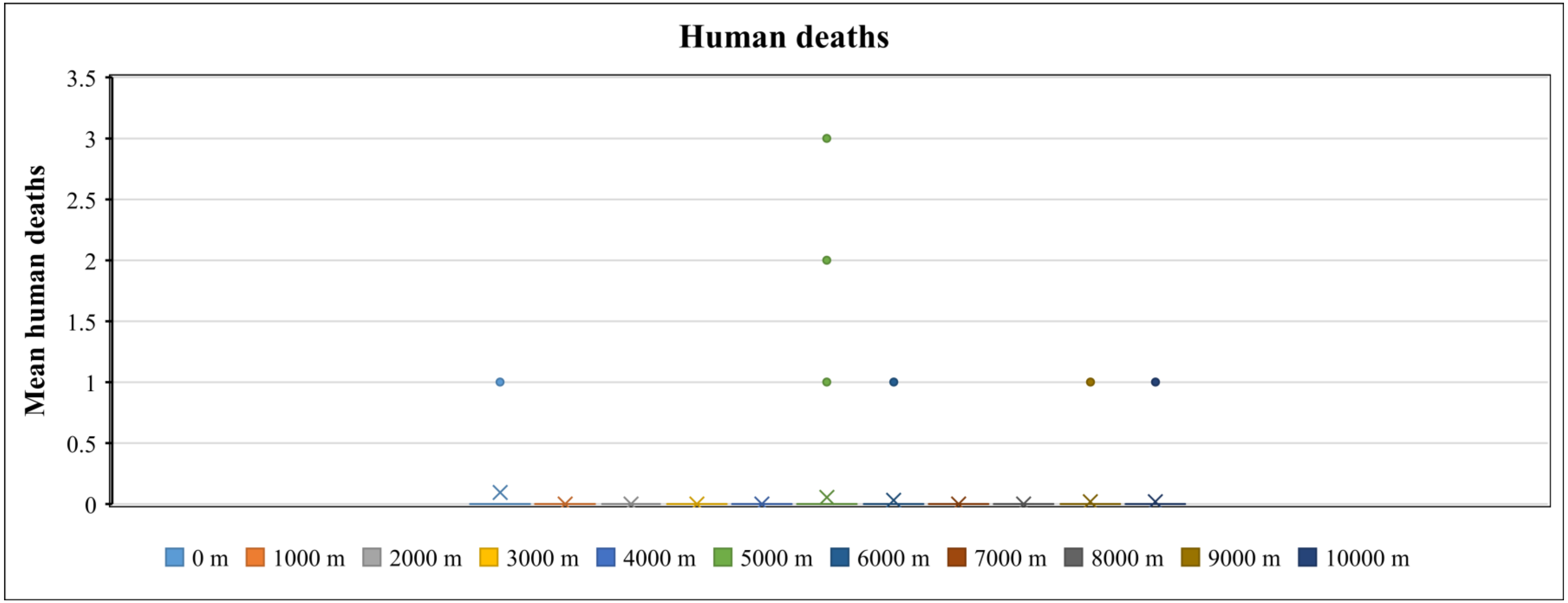

Human deaths
Mean human deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

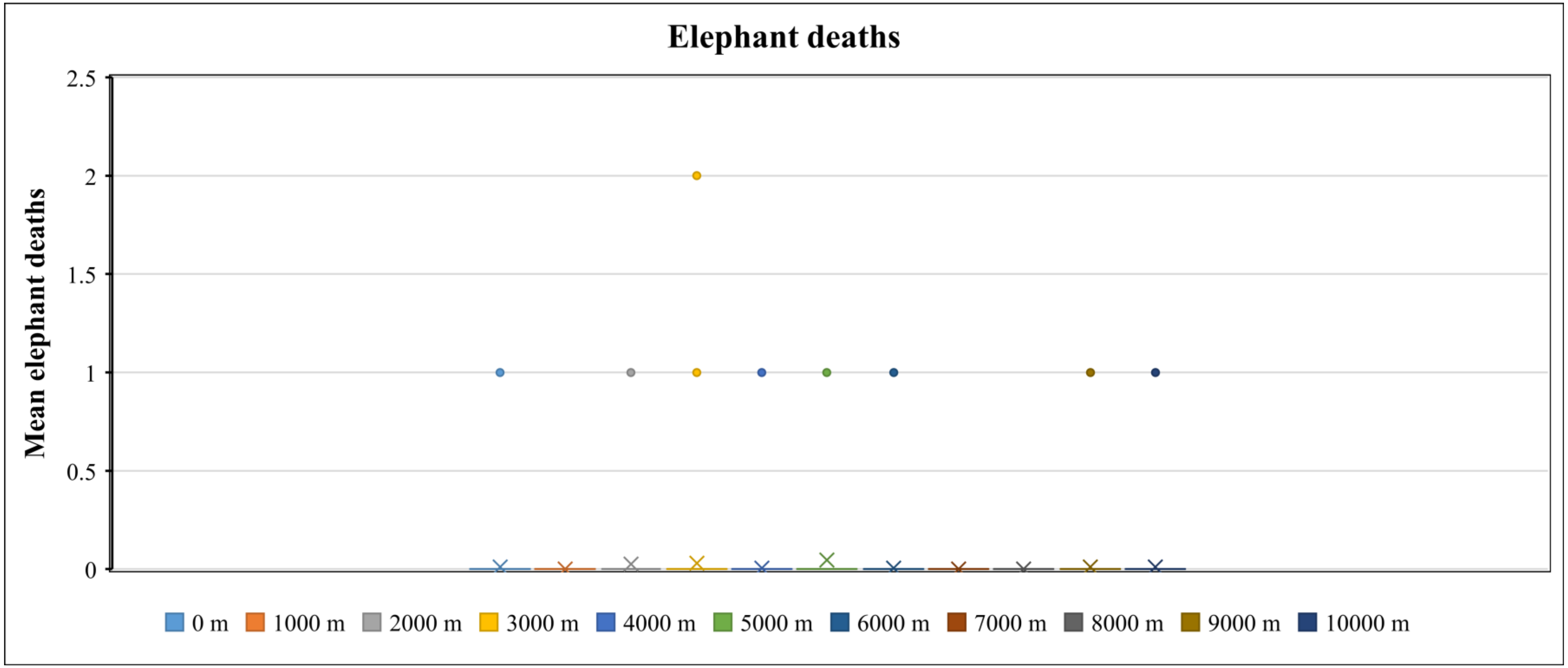

Elephant deaths
Mean elephant deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

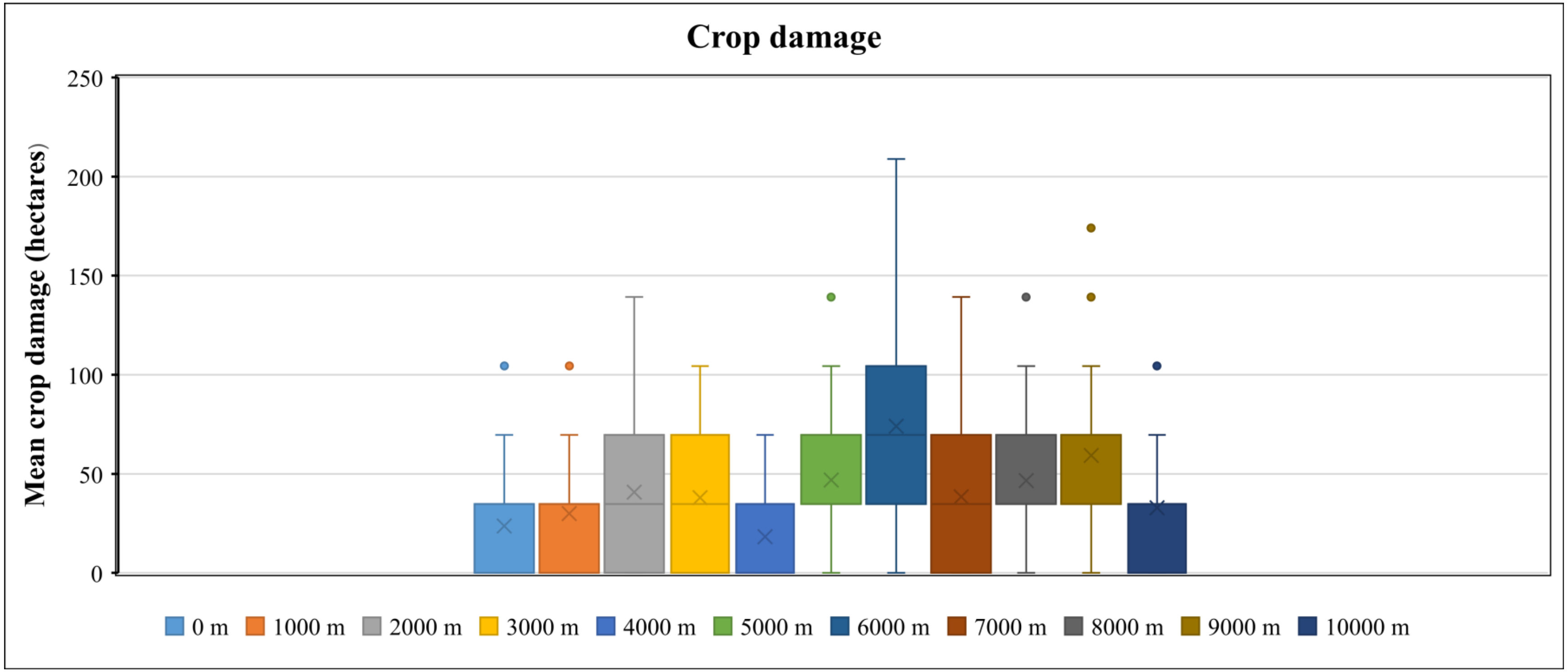

Crop damage
Mean crop damage (hectares)
0
20
40
60
80
100
120
140
160
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# EES_Protectedarea

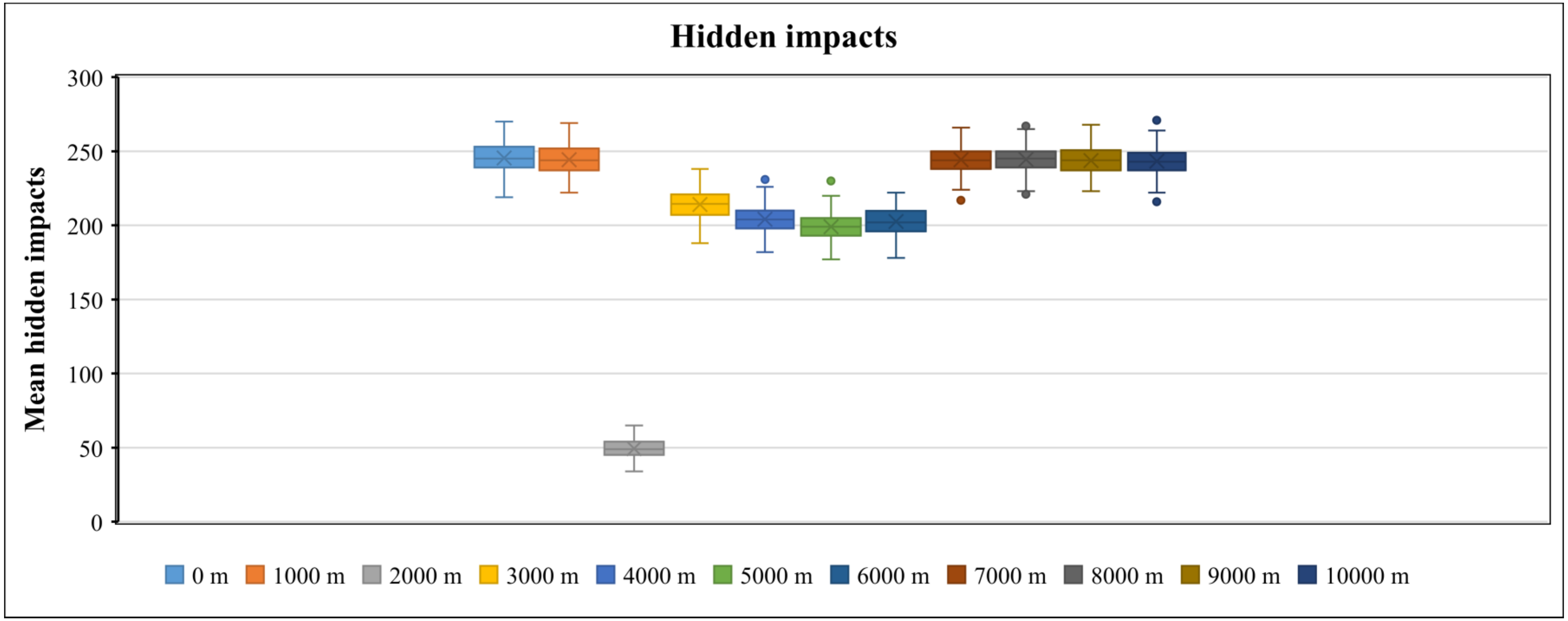


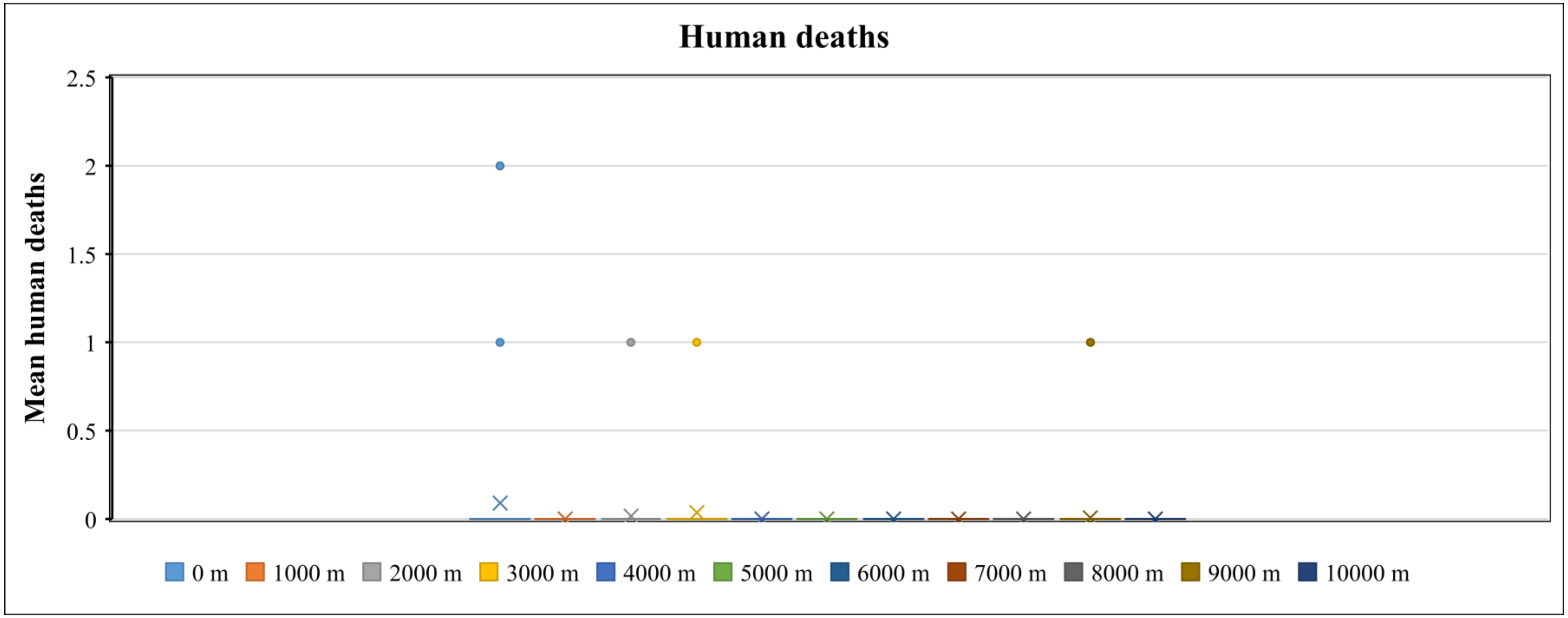

Human deaths
Mean human deaths
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

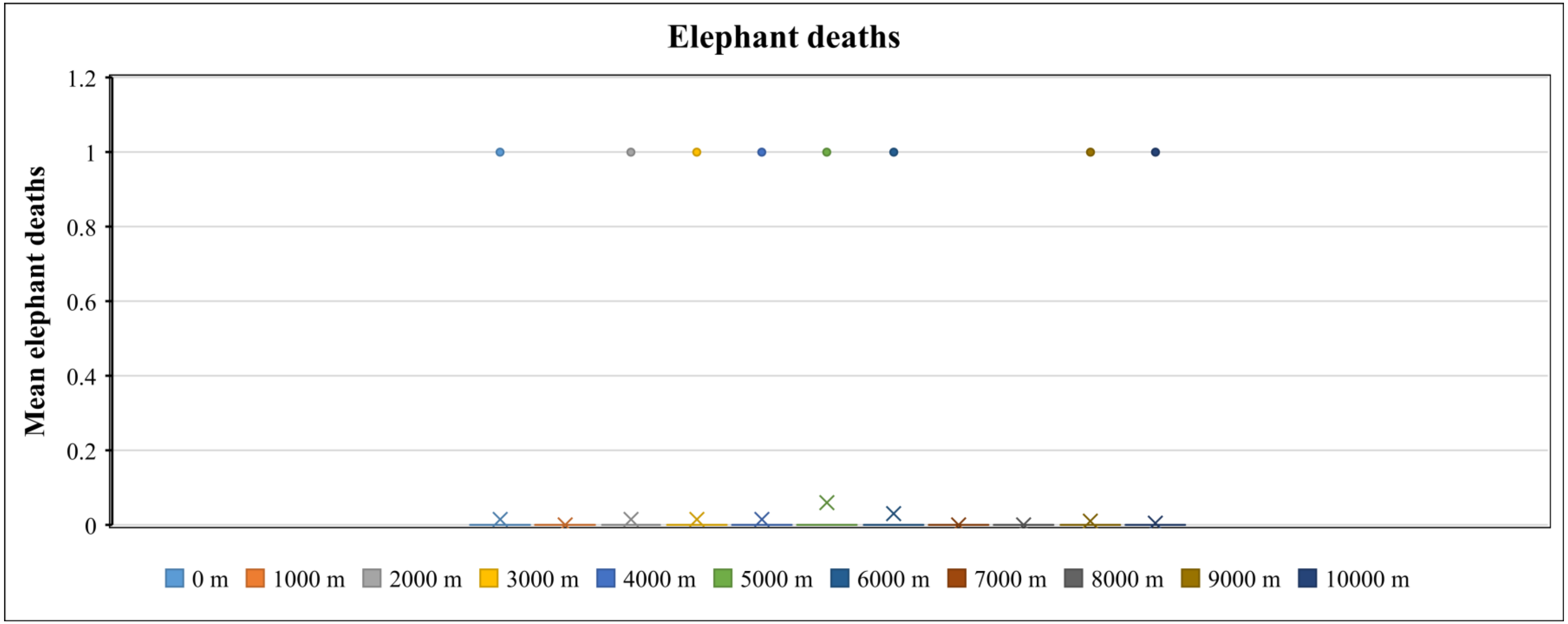

Elephant deaths
Mean elephant deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

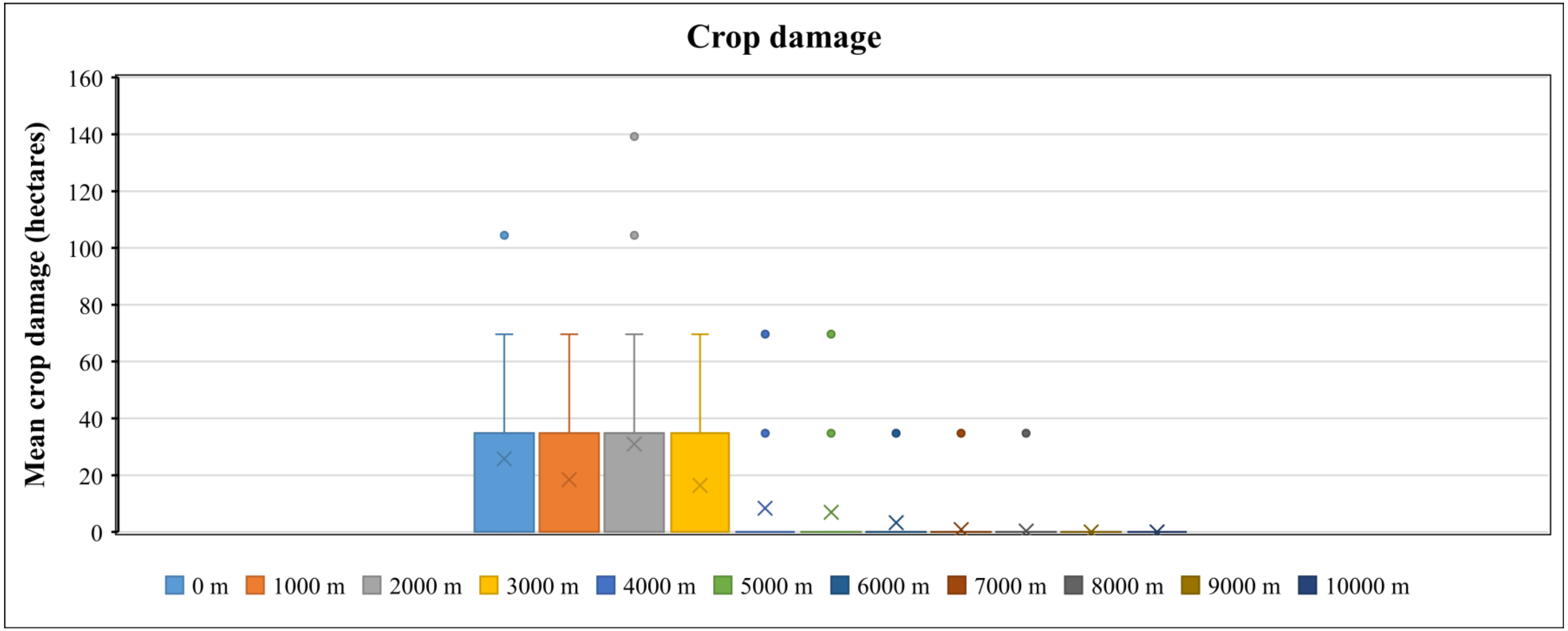

Crop damage
Mean crop damage (hectares)
250
200
150
100
50
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# EES_River

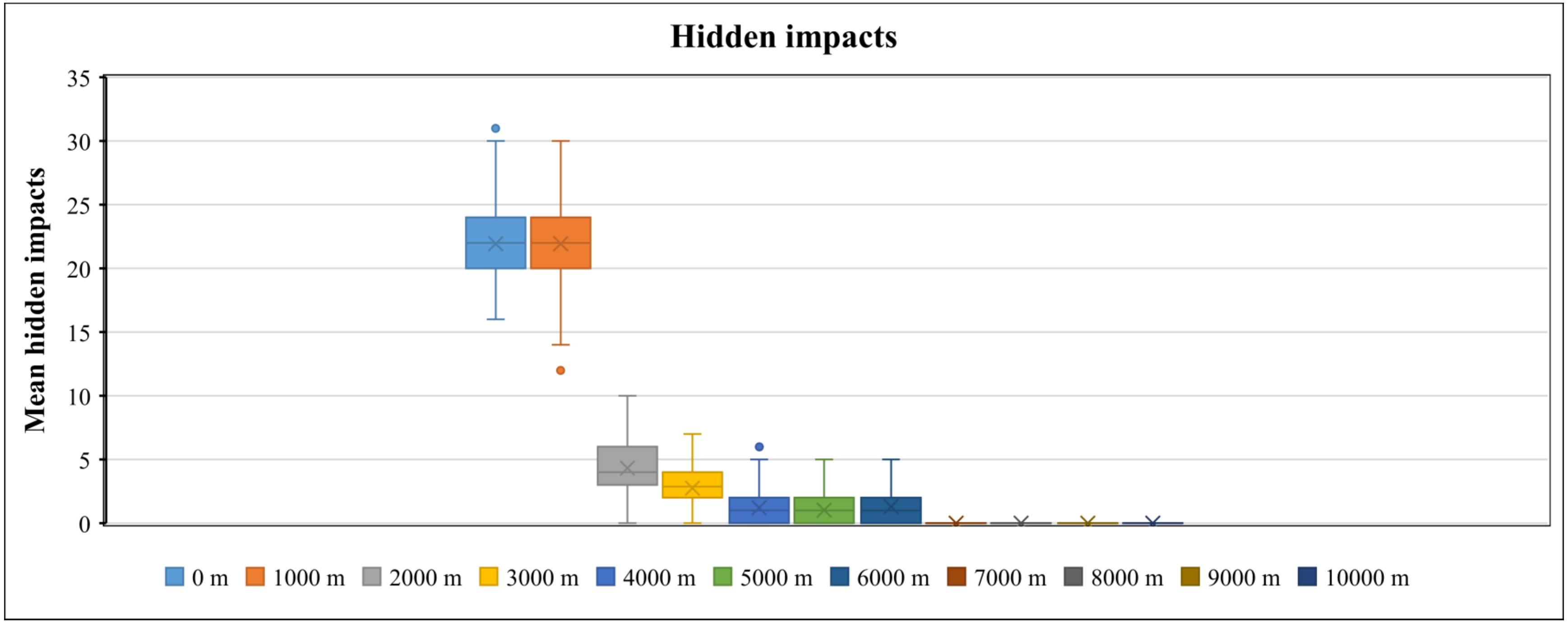

Hidden impacts
Mean hidden impacts
300
250
200
150
100
50
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

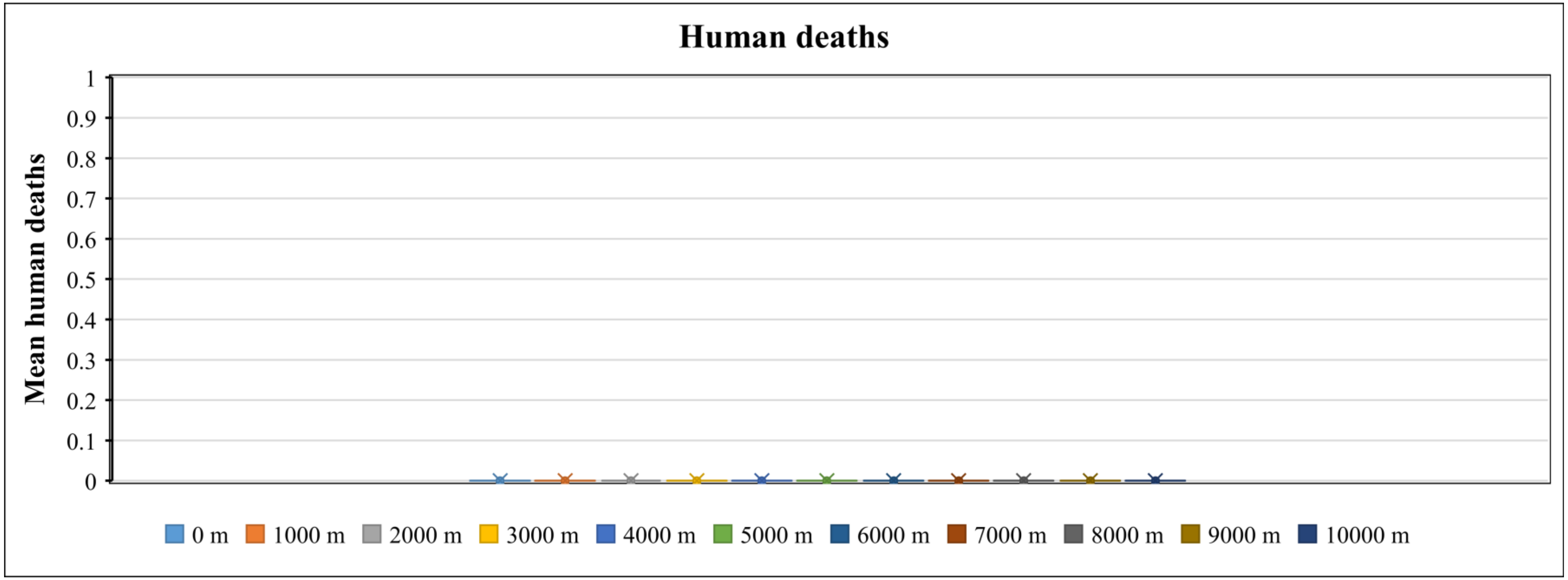

Human deaths
Mean human deaths
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

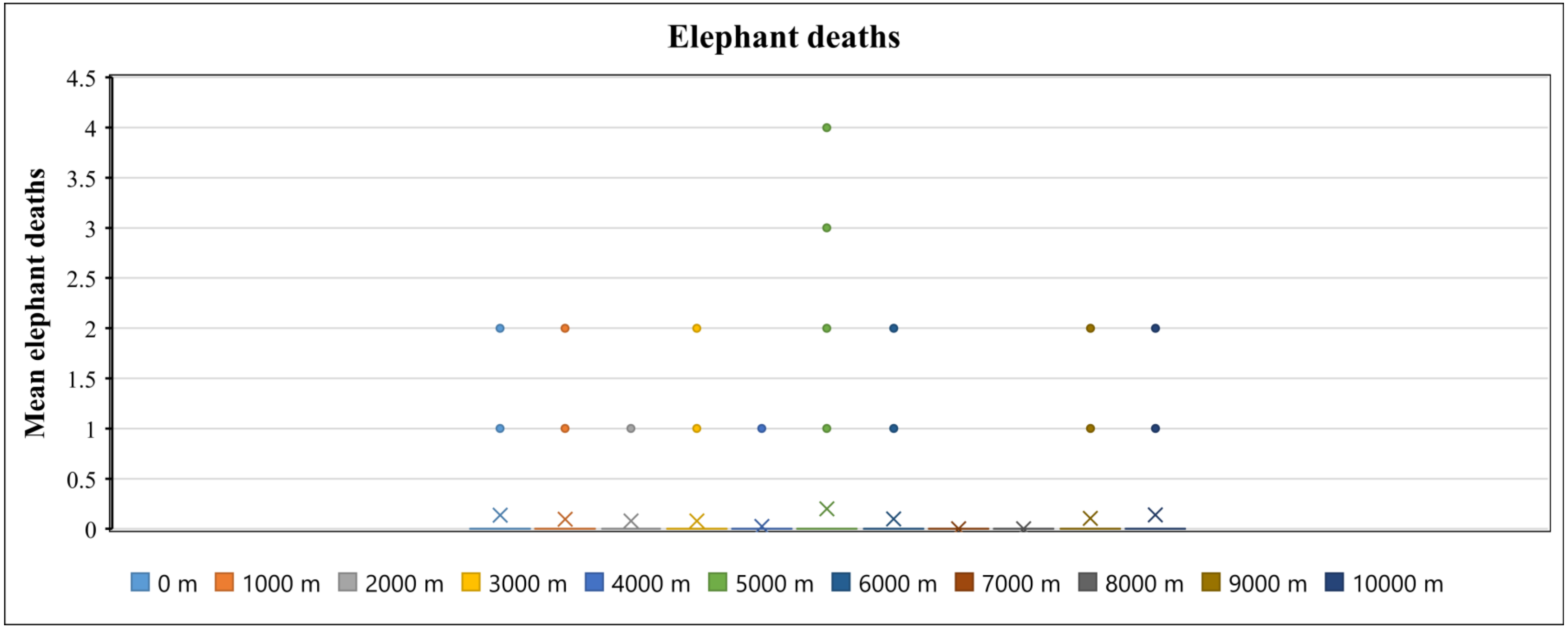

Elephant deaths
Mean elephant deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

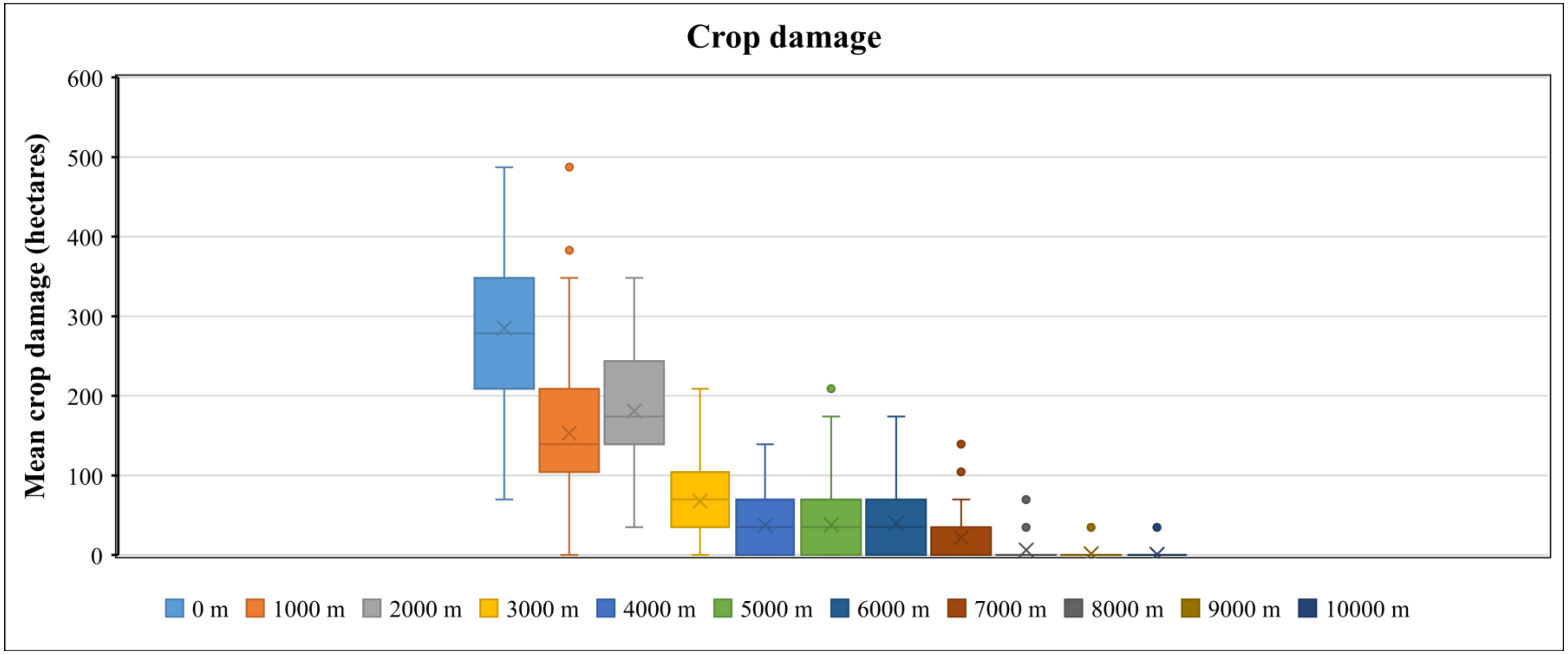

Crop damage
Mean crop damage (hectares)
160
140
120
100
80
60
40
20
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# EES_River_Protect_Corridor

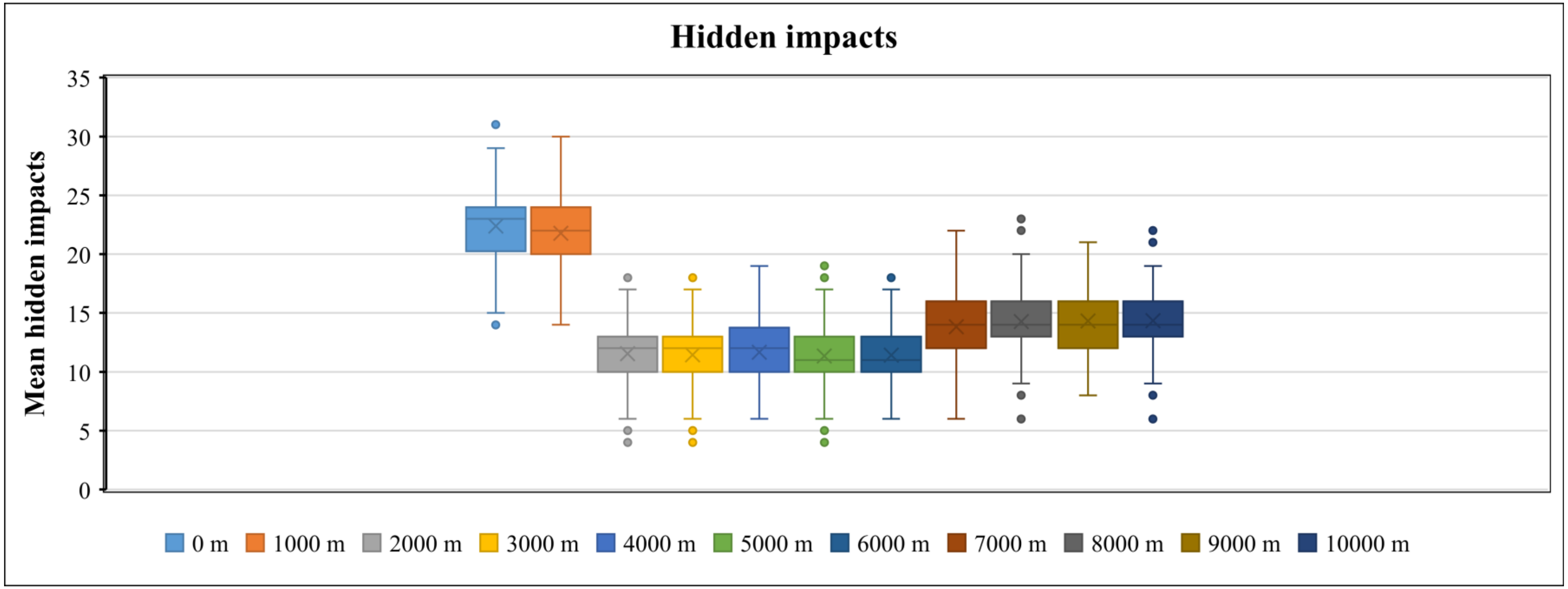


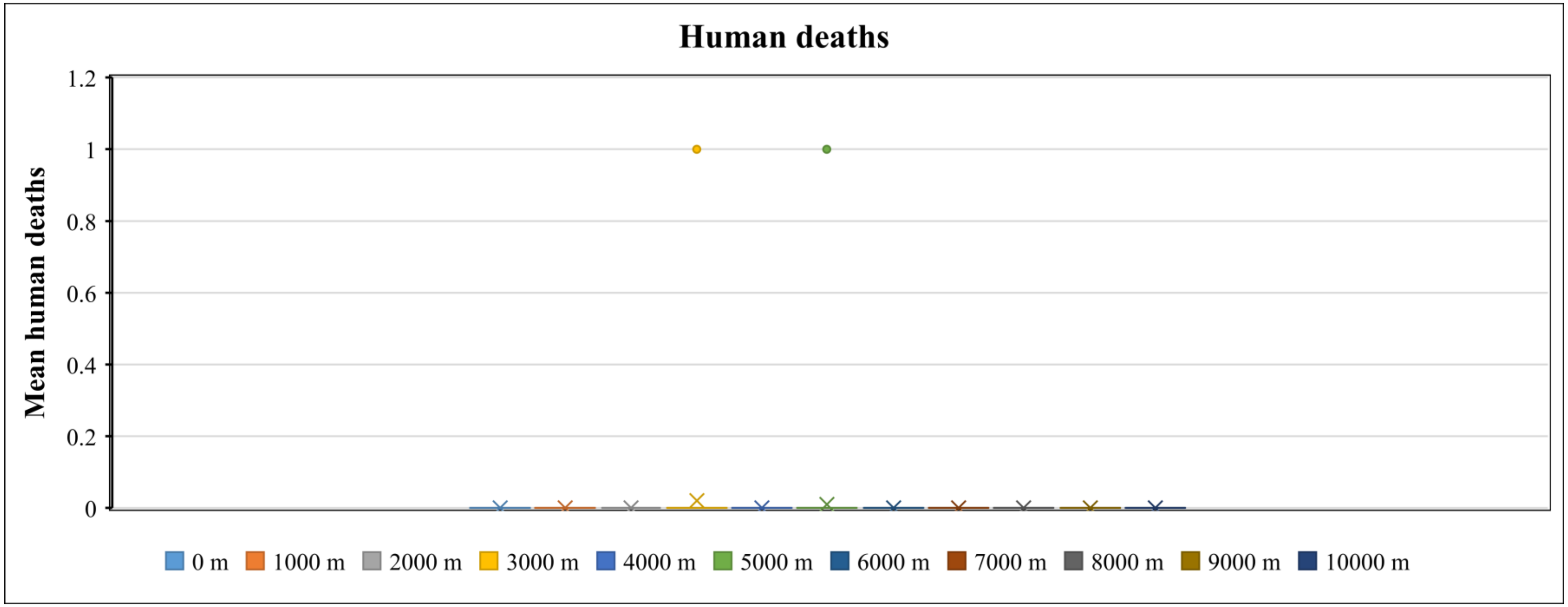

Human deaths
Mean human deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

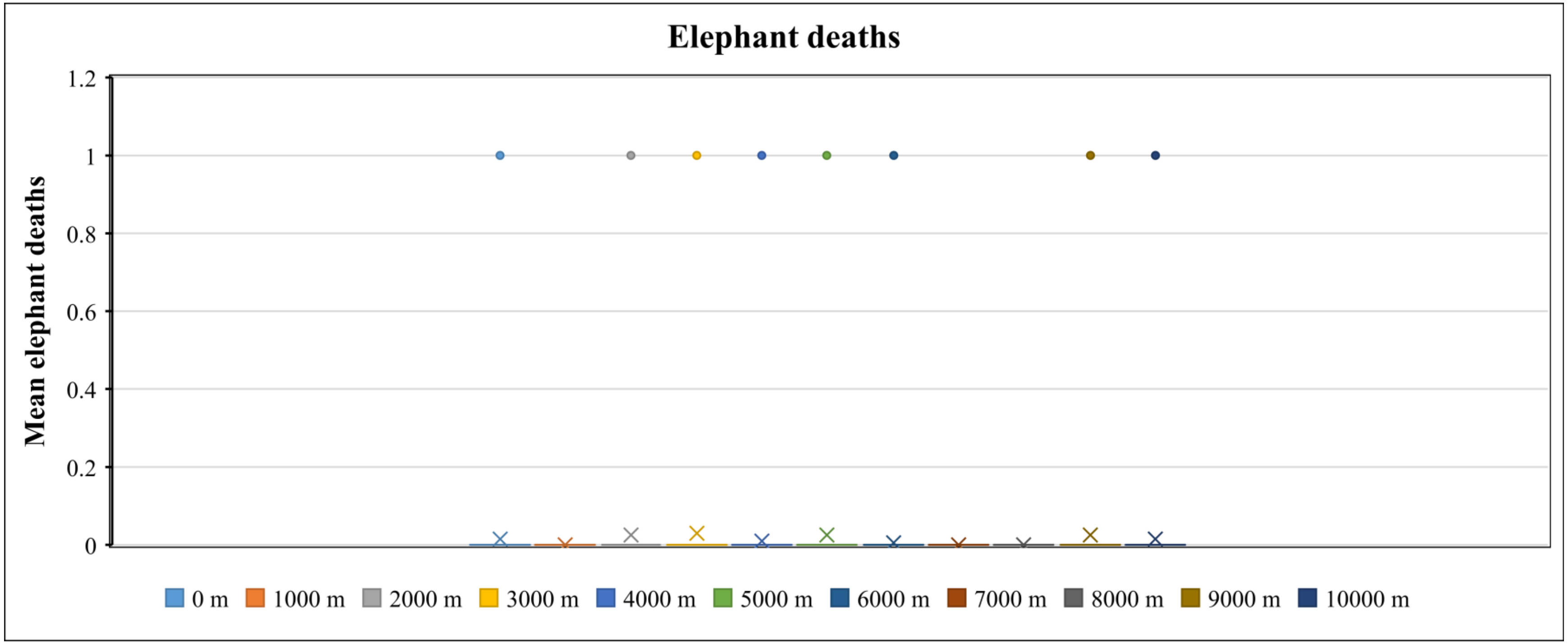

Elephant deaths
Mean elephant deaths
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

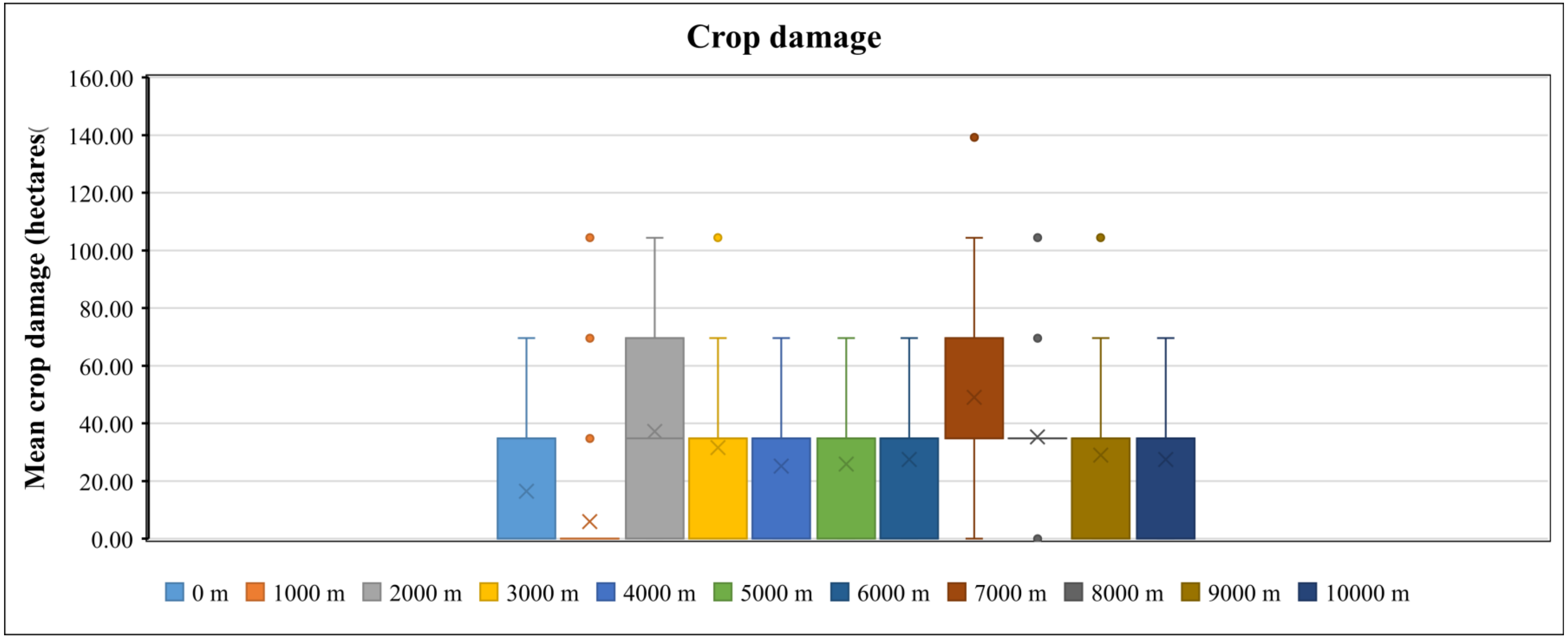

Crop damage
Mean crop damage (hectares)
600
500
400
300
200
100
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# Human-elephant-environment Scenario
# HEES-Corridor

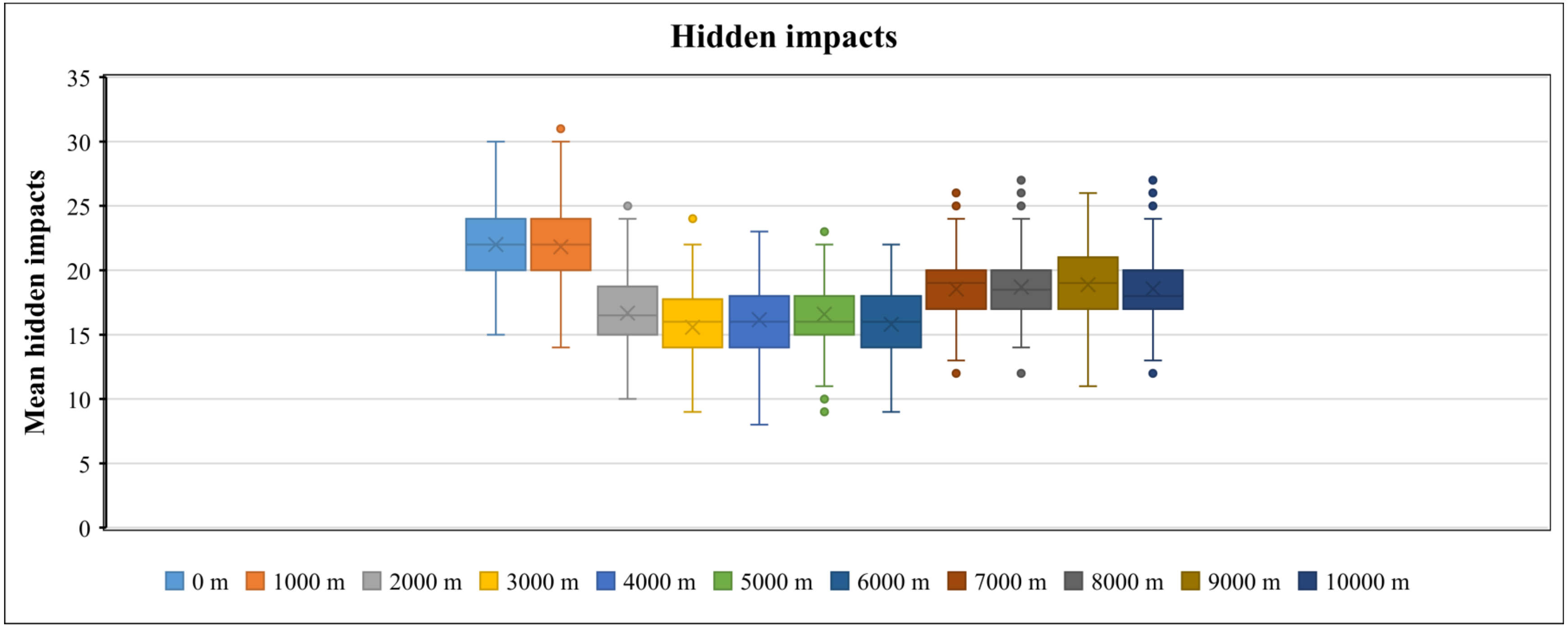


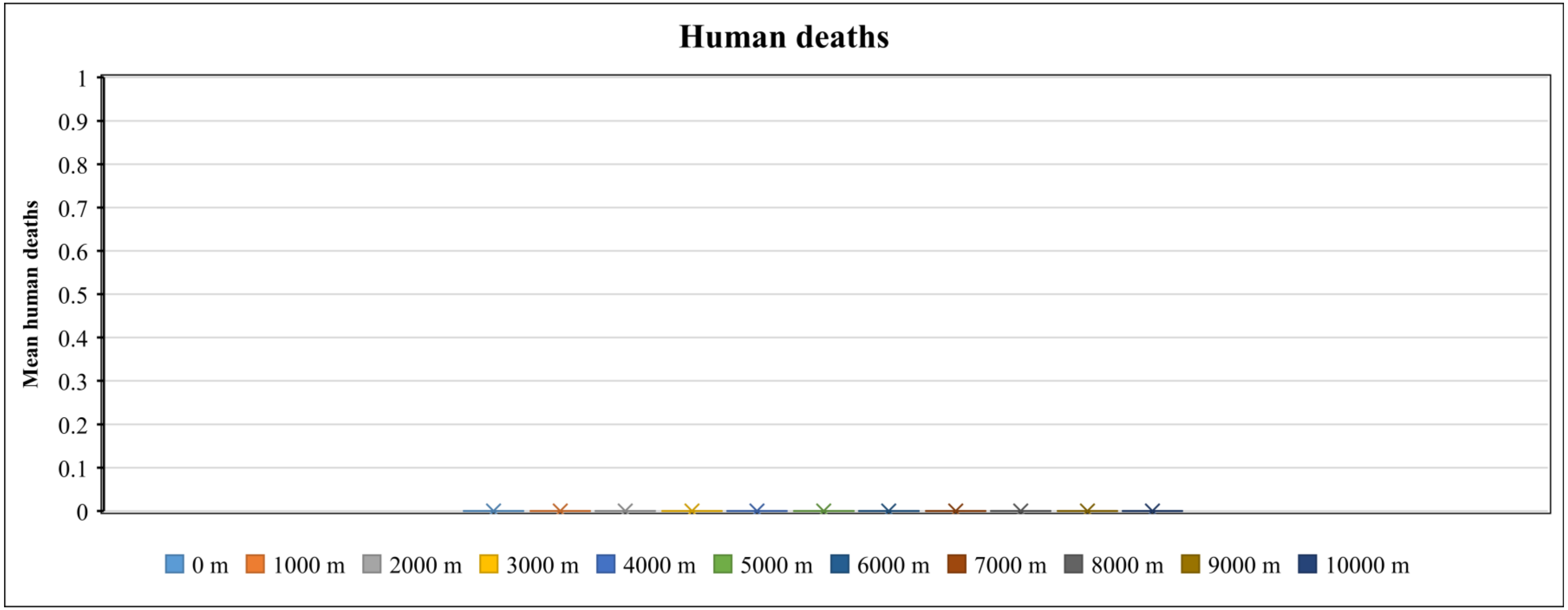

Human deaths
Mean human deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

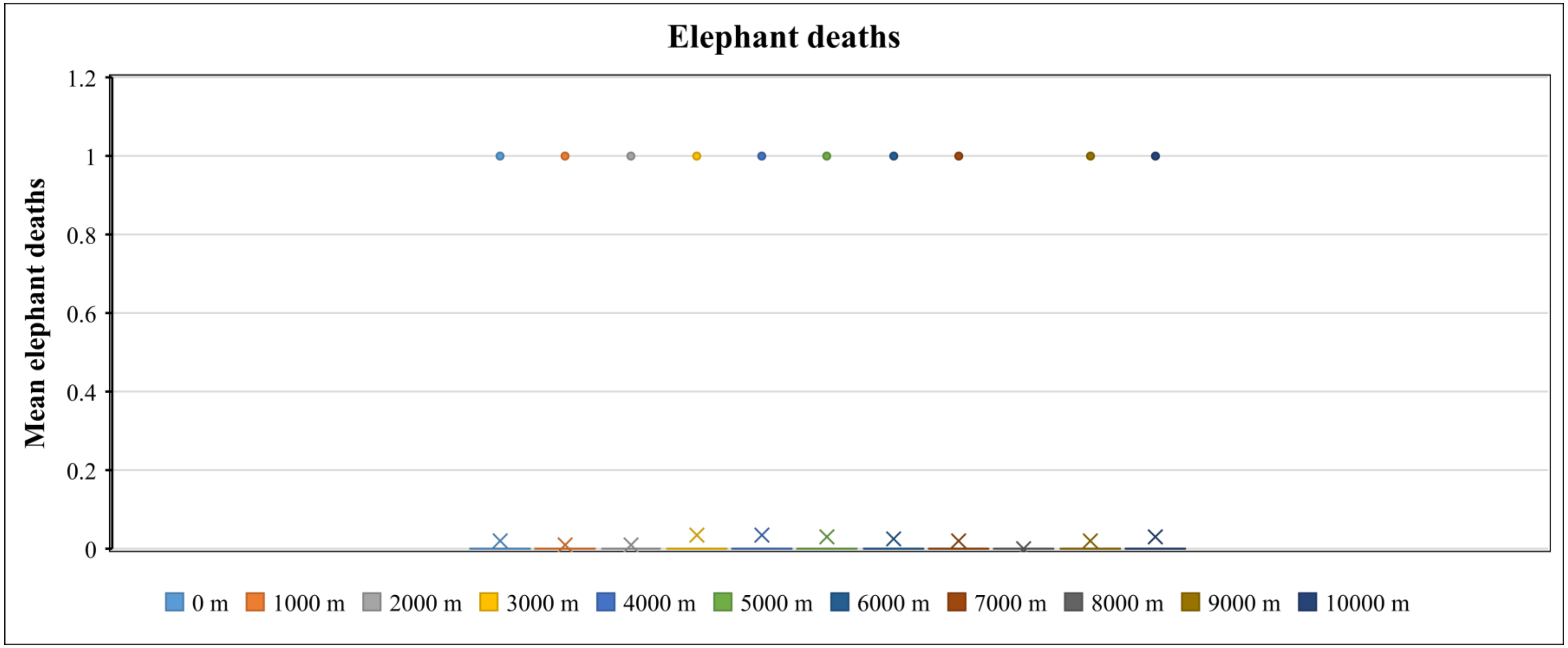

Elephant deaths
Mean elephant deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

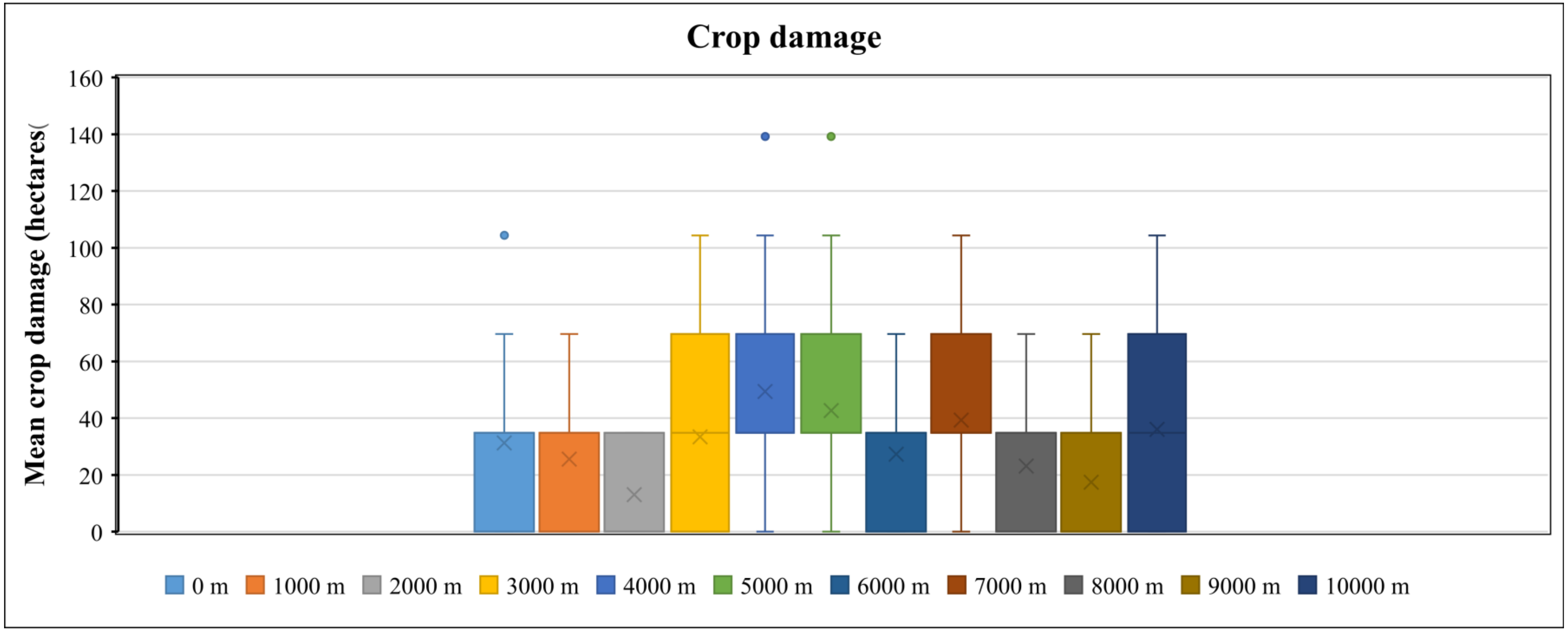

Crop damage
Mean crop damage (hectares(
160.00
140.00
120.00
100.00
80.00
60.00
40.00
20.00
0.00
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HEES-Protectedarea

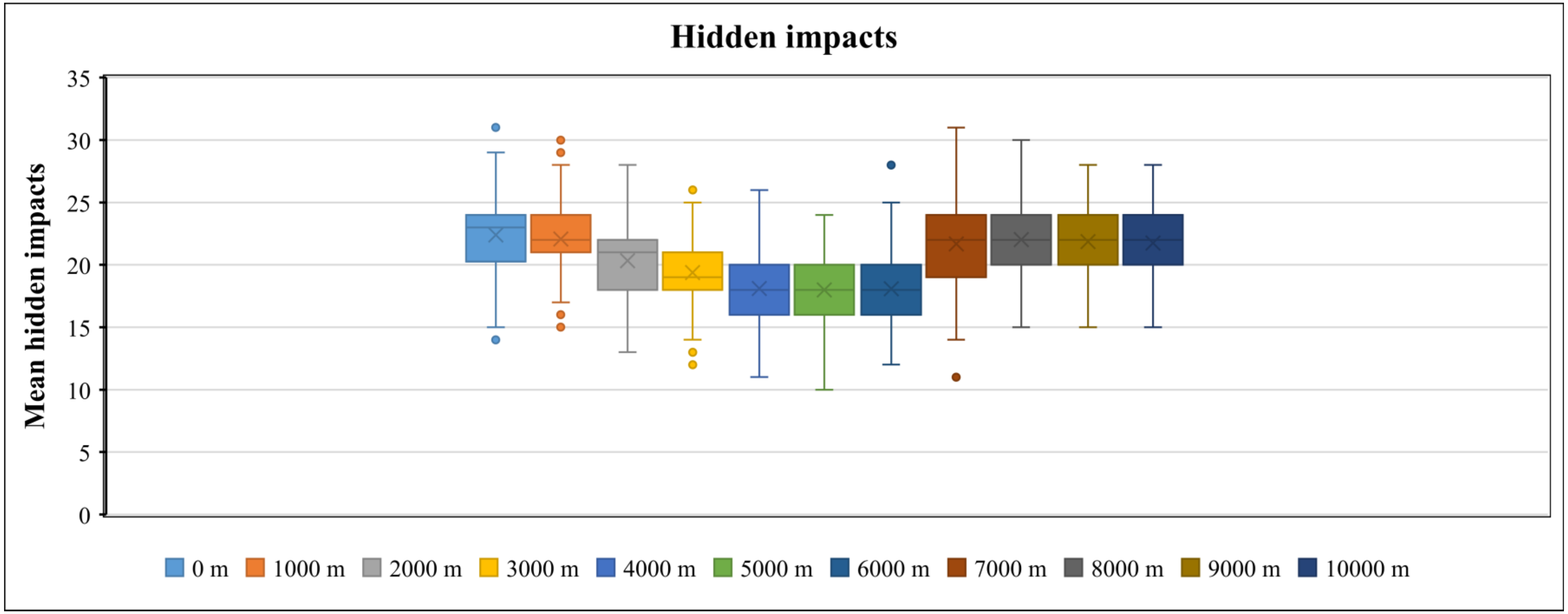


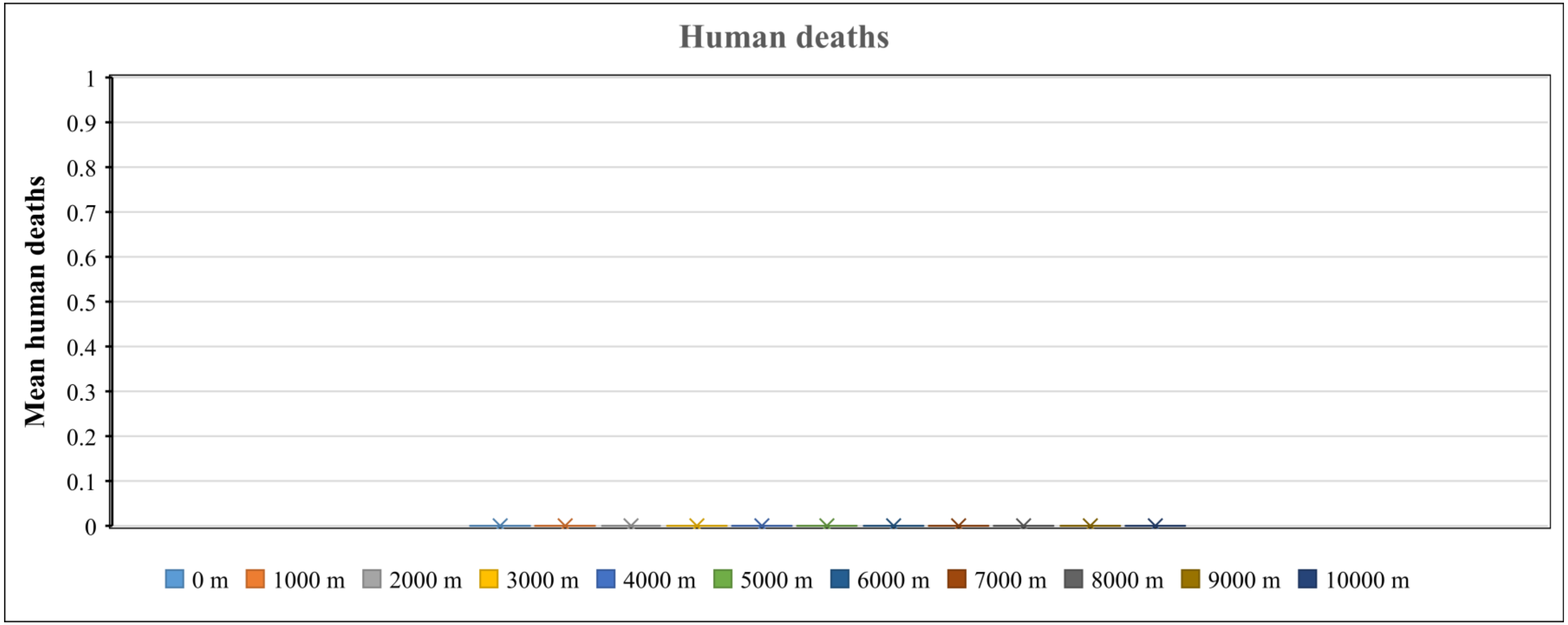

Human deaths
Mean human deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

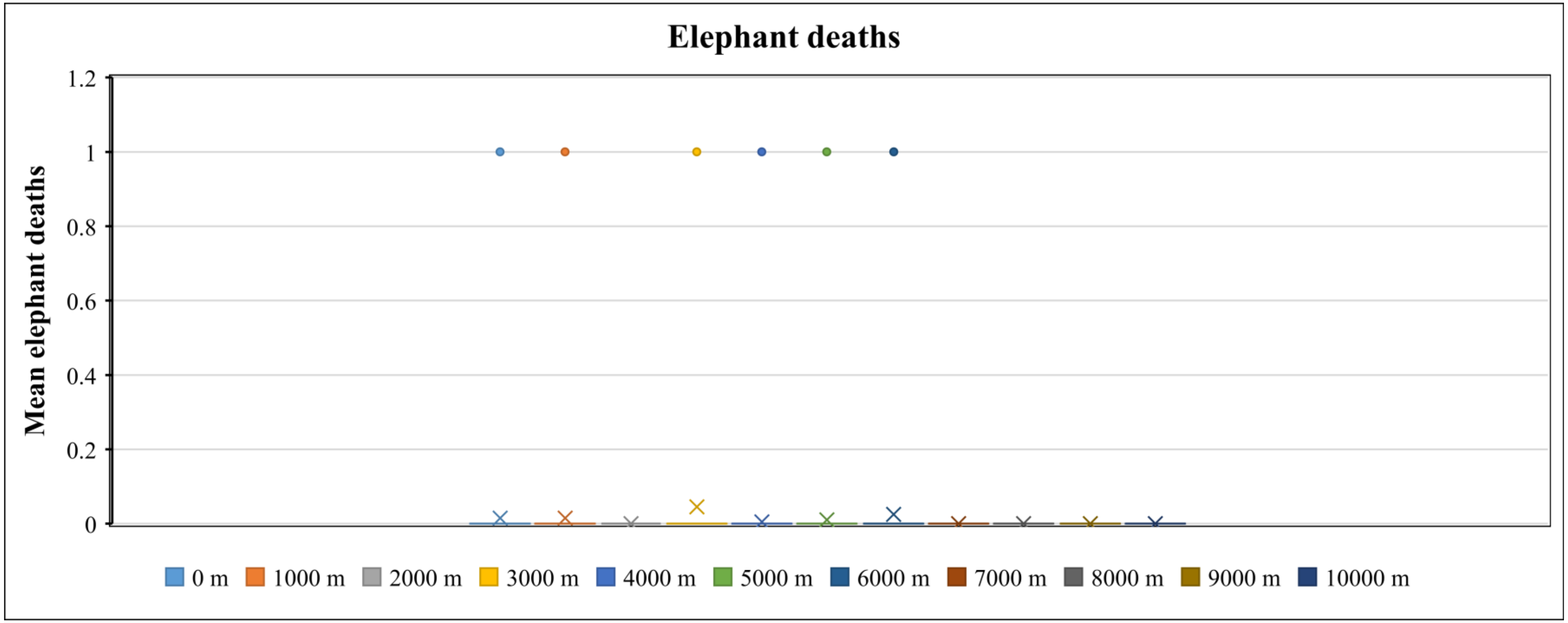

Elephant deaths
Mean elephant deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

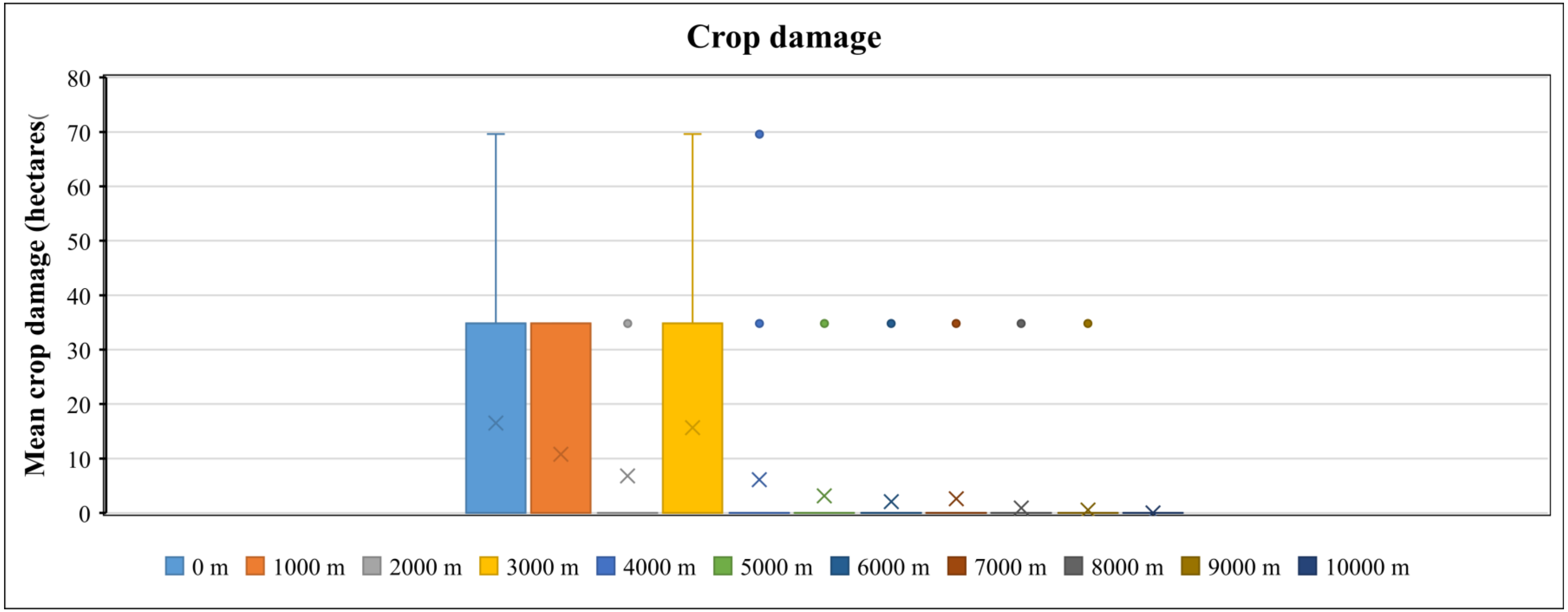

Crop damage
Mean crop damage (hectares(
160
140
120
100
80
60
40
20
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HEES-River

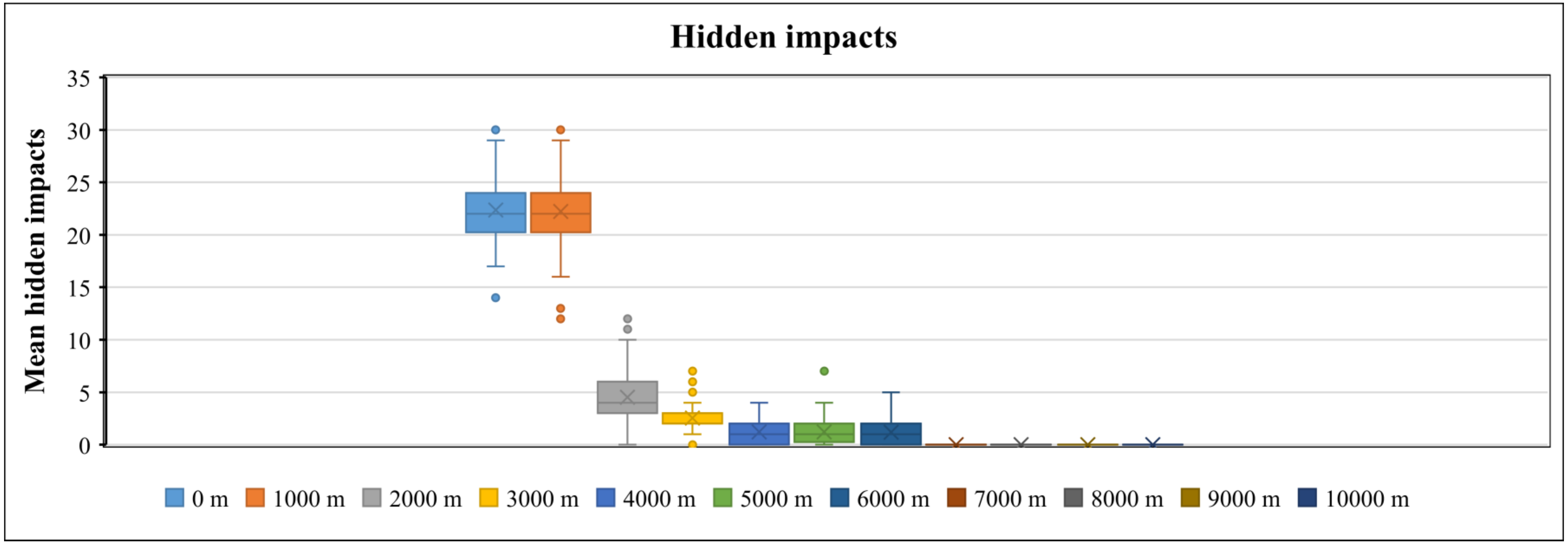

Hidden impacts
Mean hidden impacts
35
30
25
20
15
10
5
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

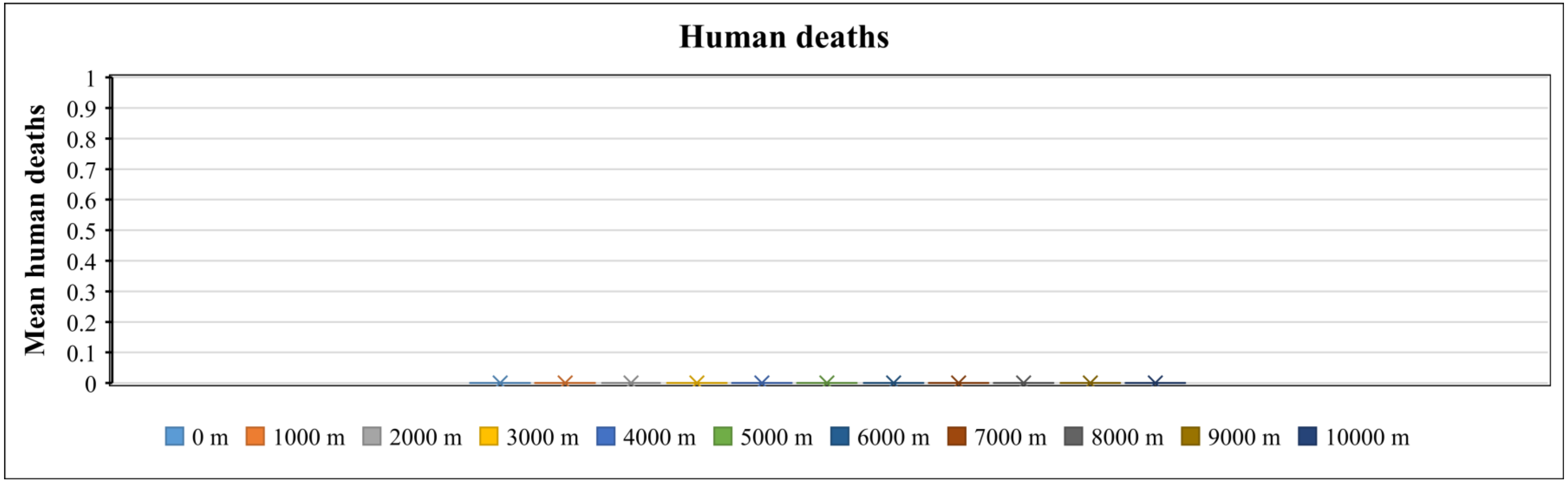

Human deaths
Mean human deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

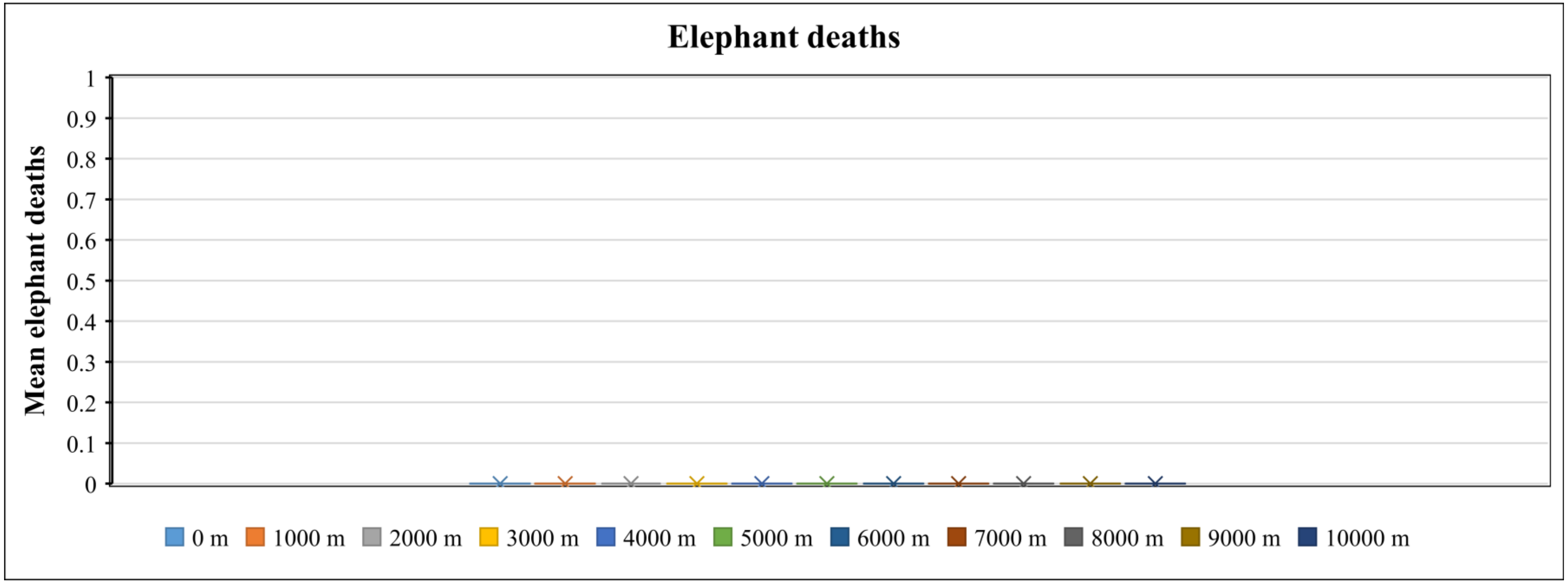

Elephant deaths
Mean elephant deaths
1.2
1
0.8
0.6
0.4
0.2
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

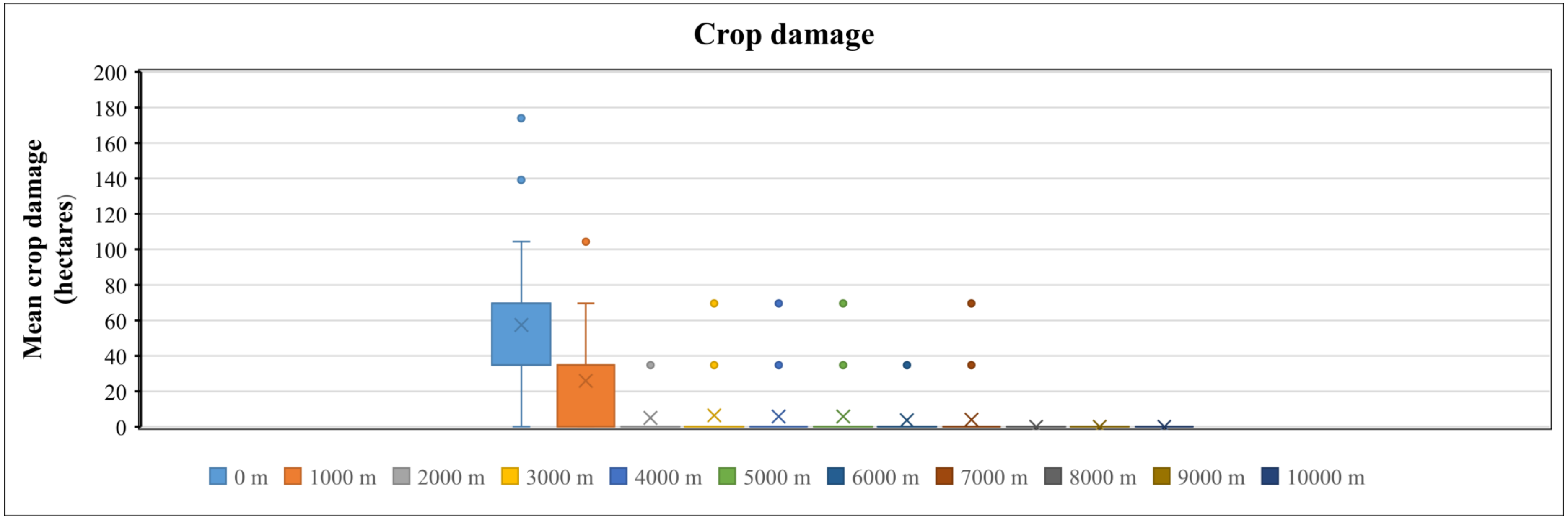

Crop damage
Mean crop damage (hectares(
80
70
60
50
40
30
20
10
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# HEES-River_Protect_Corridor



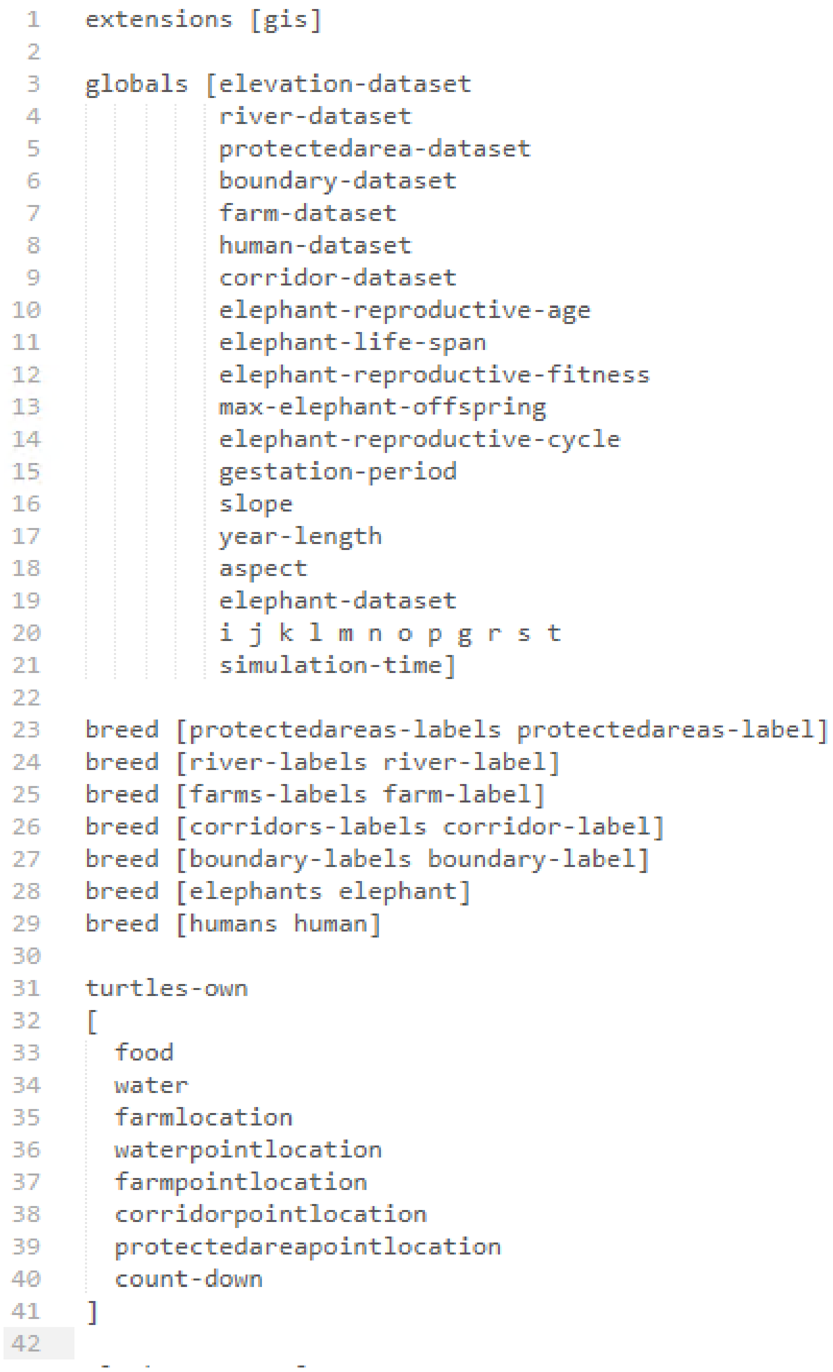

Human deaths
Mean human deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m


Elephant deaths
Mean elephant deaths
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

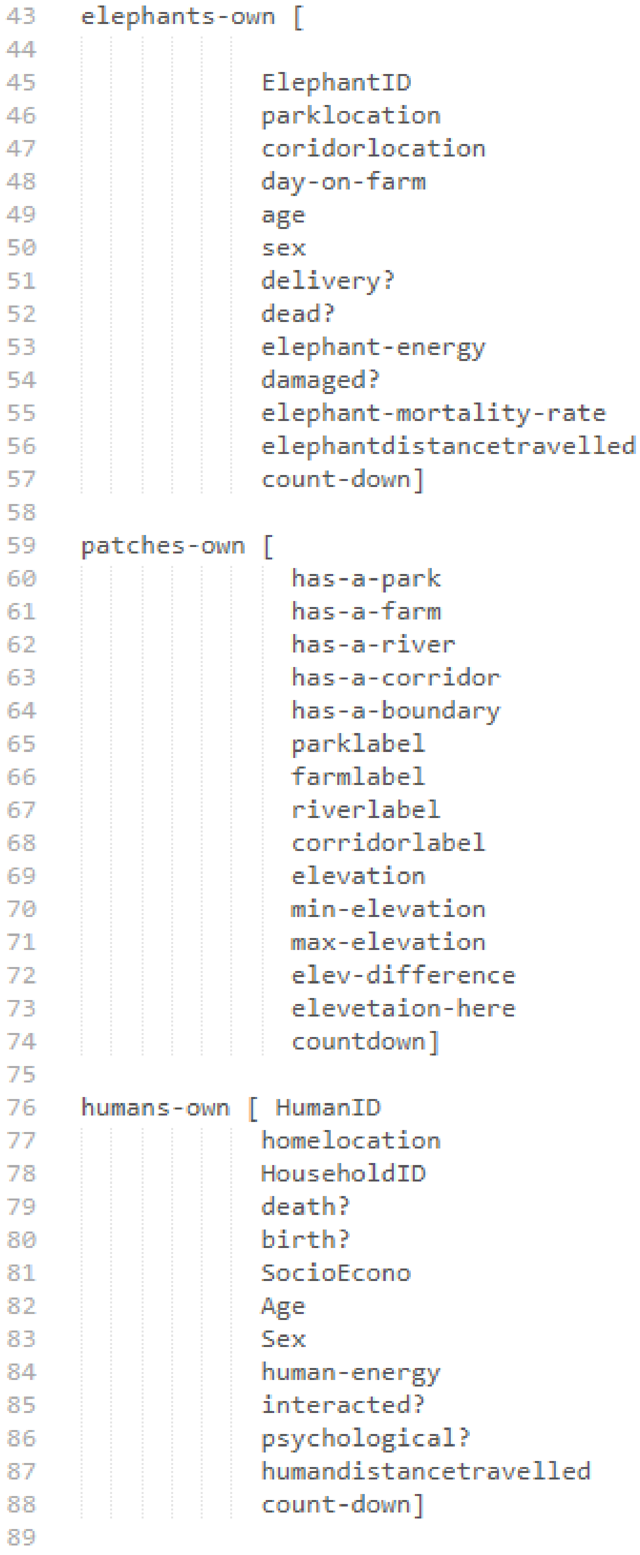

Crop damage
Mean crop damage (hectares)
200
180
160
140
120
100
80
60
40
20
0
0 m
1000 m
2000 m
3000 m
4000 m
5000 m
6000 m
7000 m
8000 m
9000 m
10000 m

# Appendix F Netlogo Model Codes

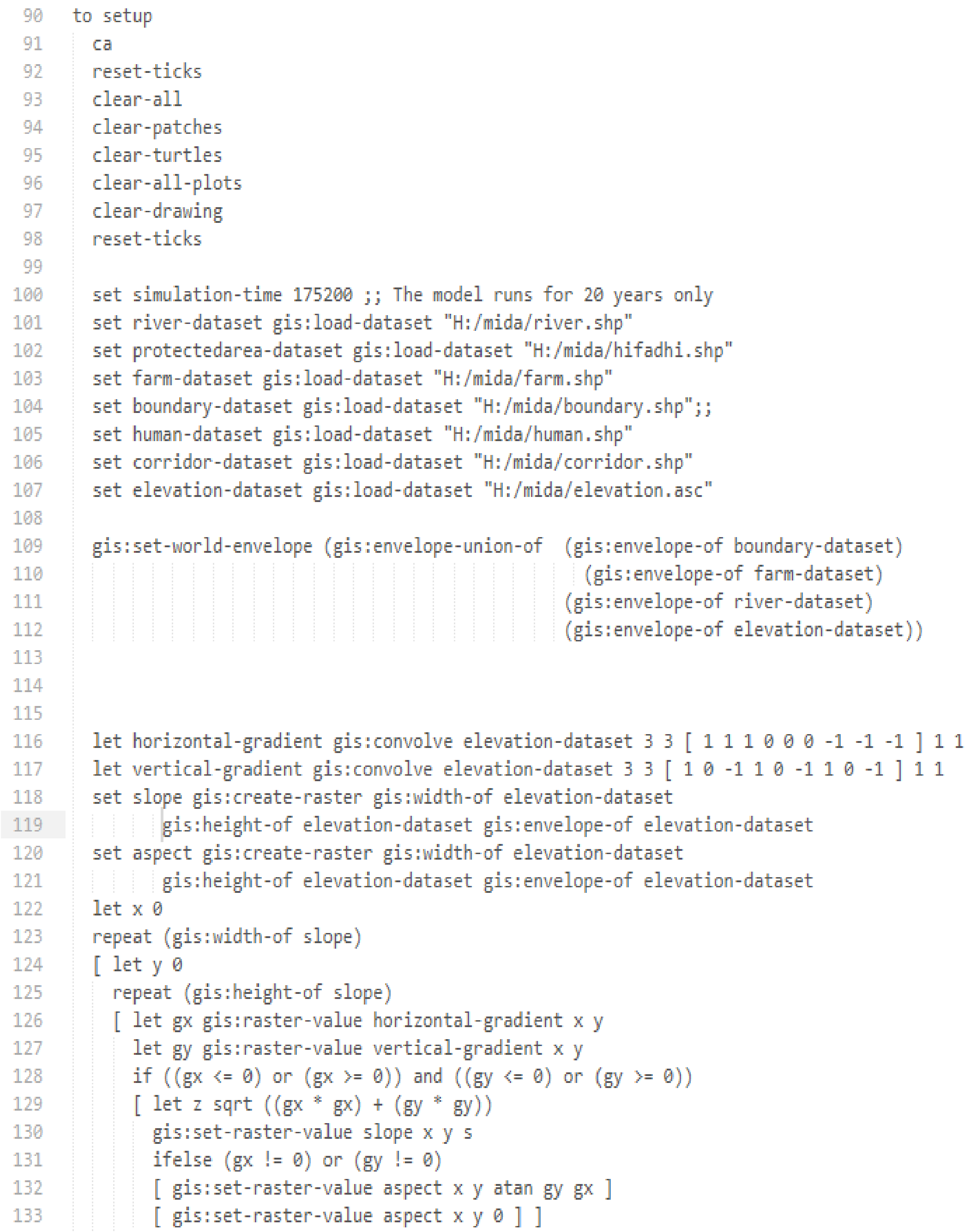
## Netlogo code used for development of AGHEI model



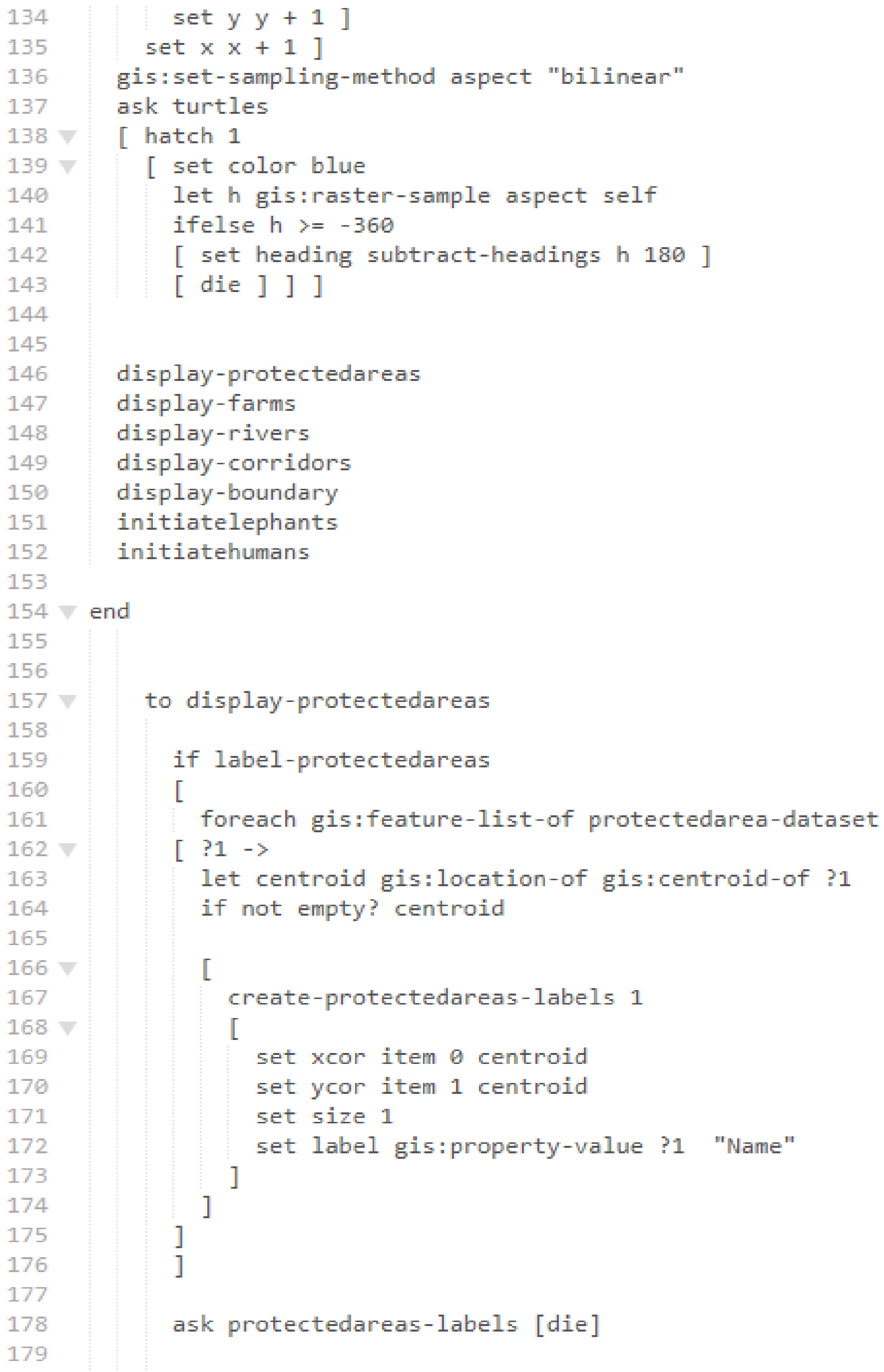
```
extensions [gis]

globals [elevation-dataset
         river-dataset
         protectedarea-dataset
         boundary-dataset
         farm-dataset
         human-dataset
         corridor-dataset
         elephant-reproductive-age
         elephant-life-span
         elephant-reproductive-fitness
         max-elephant-offspring
         elephant-reproductive-cycle
         gestation-period
         slope
         year-length
         aspect
         elephant-dataset
         i j k l m n o p g r s t
         simulation-time]

breed [protectedareas-labels protectedareas-label]
breed [river-labels river-label]
breed [farms-labels farm-label]
breed [corridors-labels corridor-label]
breed [boundary-labels boundary-label]
breed [elephants elephant]
breed [humans human]

turtles-own
[
  food
  water
  farmlocation
  waterpointlocation
  farmpointlocation
  corridorpointlocation
  protectedareapointlocation
  count-down
]

```



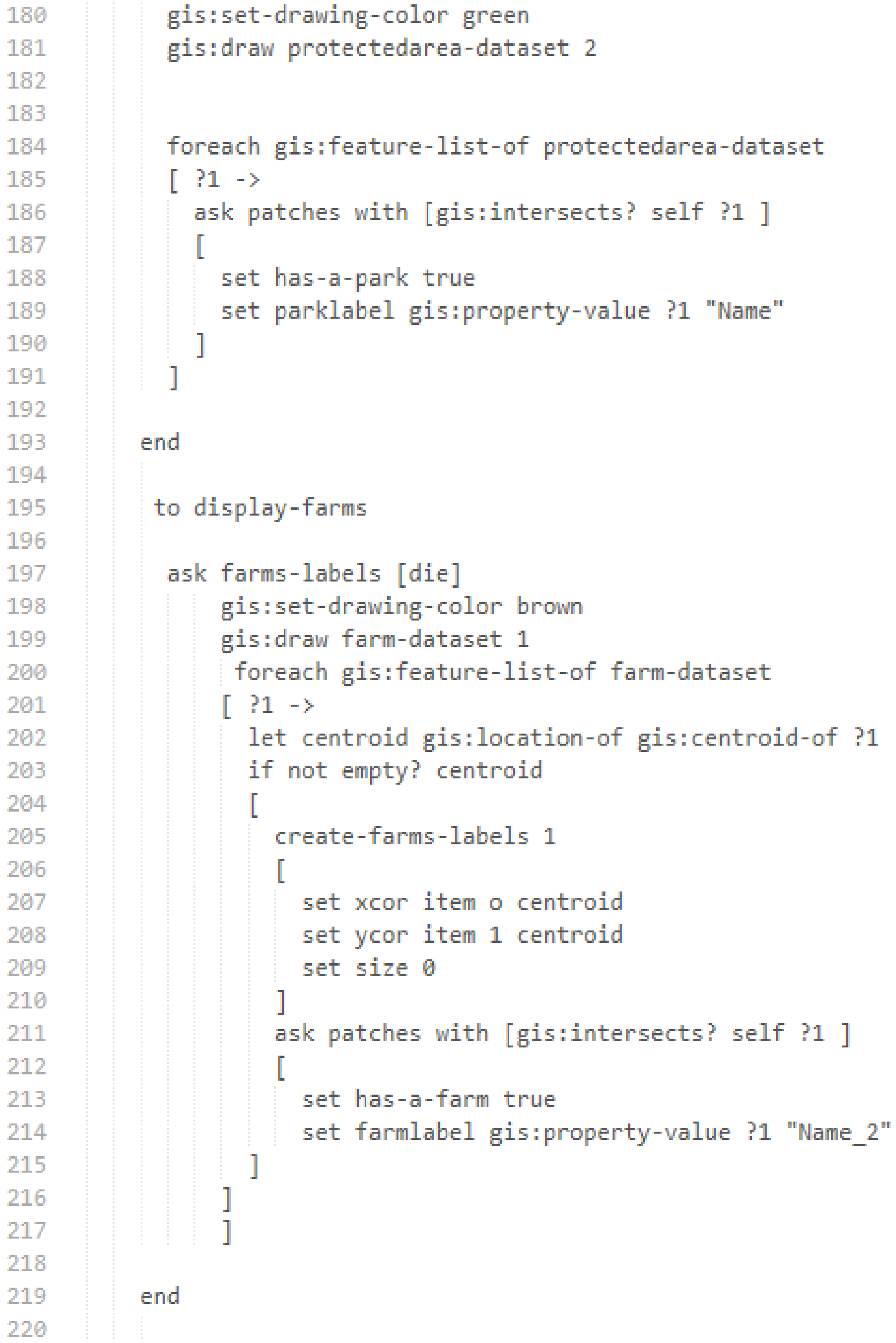
```
elephants-own [

            ElephantID
            parklocation
            coridorlocation
            day-on-farm
            age
            sex
            delivery?
            dead?
            elephant-energy
            damaged?
            elephant-mortality-rate
            elephantdistancetravelled
            count-down]

patches-own [
              has-a-park
              has-a-farm
              has-a-river
              has-a-corridor
              has-a-boundary
              parklabel
              farmlabel
              riverlabel
              corridorlabel
              elevation
              min-elevation
              max-elevation
              elev-difference
              elevetaion-here
              countdown]

humans-own [ HumanID
            homelocation
            HouseholdID
            death?
            birth?
            SocioEcono
            Age
            Sex
            human-energy
            interacted?
            psychological?
            humandistancetravelled
            count-down]

```



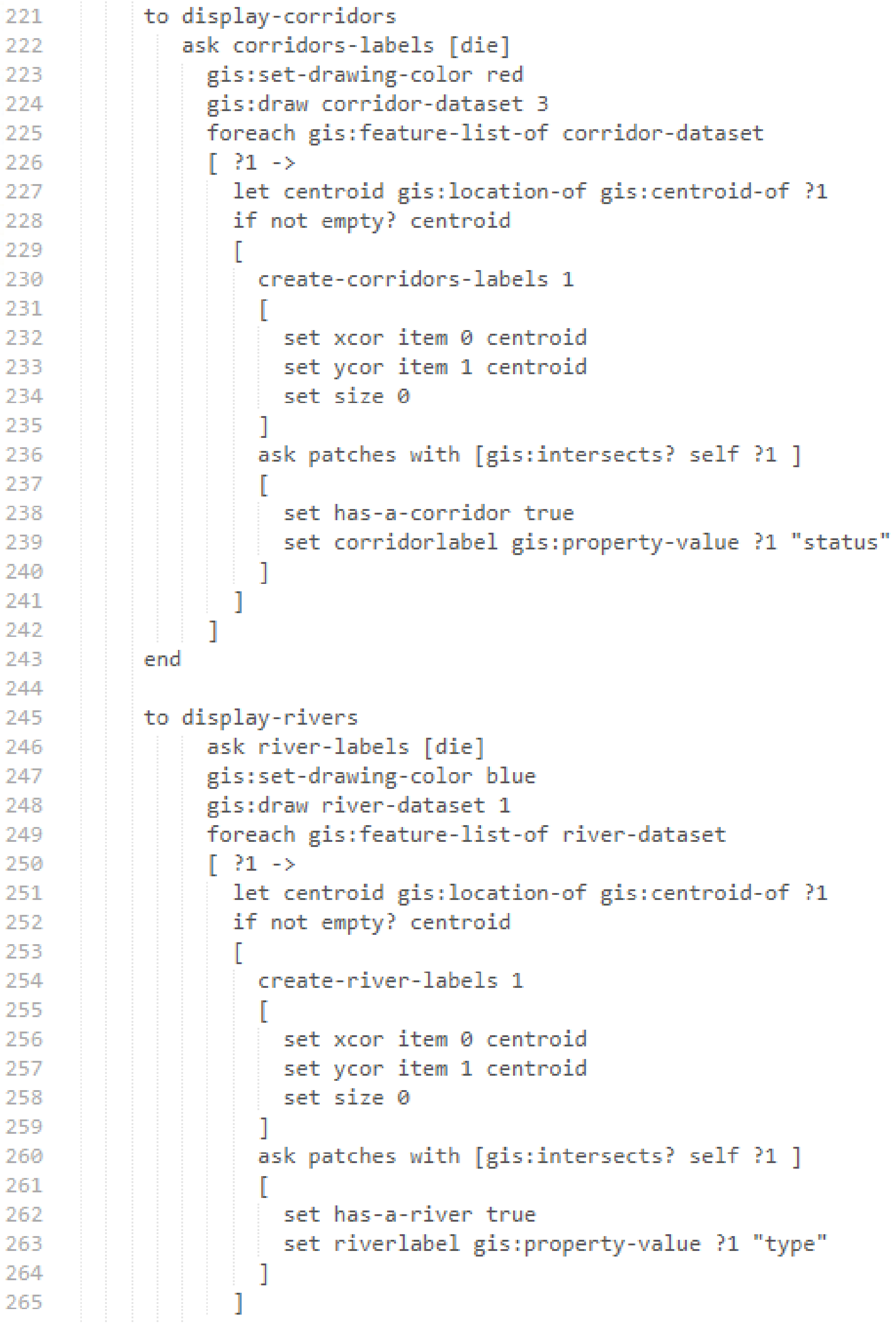
```
to setup
  ca
  reset-ticks
  clear-all
  clear-patches
  clear-turtles
  clear-all-plots
  clear-drawing
  reset-ticks

  set simulation-time 175200 ;; The model runs for 20 years only
  set river-dataset gis:load-dataset "H:/mida/river.shp"
  set protectedarea-dataset gis:load-dataset "H:/mida/hifadhi.shp"
  set farm-dataset gis:load-dataset "H:/mida/farm.shp"
  set boundary-dataset gis:load-dataset "H:/mida/boundary.shp";;
  set human-dataset gis:load-dataset "H:/mida/human.shp"
  set corridor-dataset gis:load-dataset "H:/mida/corridor.shp"
  set elevation-dataset gis:load-dataset "H:/mida/elevation.asc"

  gis:set-world-envelope (gis:envelope-union-of  (gis:envelope-of boundary-dataset)
                                                   (gis:envelope-of farm-dataset)
                                                 (gis:envelope-of river-dataset)
                                                 (gis:envelope-of elevation-dataset))



  let horizontal-gradient gis:convolve elevation-dataset 3 3 [ 1 1 1 0 0 0 -1 -1 -1 ] 1 1
  let vertical-gradient gis:convolve elevation-dataset 3 3 [ 1 0 -1 1 0 -1 1 0 -1 ] 1 1
  set slope gis:create-raster gis:width-of elevation-dataset
         gis:height-of elevation-dataset gis:envelope-of elevation-dataset
  set aspect gis:create-raster gis:width-of elevation-dataset
         gis:height-of elevation-dataset gis:envelope-of elevation-dataset
  let x 0
  repeat (gis:width-of slope)
  [ let y 0
    repeat (gis:height-of slope)
    [ let gx gis:raster-value horizontal-gradient x y
      let gy gis:raster-value vertical-gradient x y
      if ((gx <= 0) or (gx >= 0)) and ((gy <= 0) or (gy >= 0))
      [ let z sqrt ((gx * gx) + (gy * gy))
        gis:set-raster-value slope x y s
        ifelse (gx != 0) or (gy != 0)
        [ gis:set-raster-value aspect x y atan gy gx ]
        [ gis:set-raster-value aspect x y 0 ] ]
```



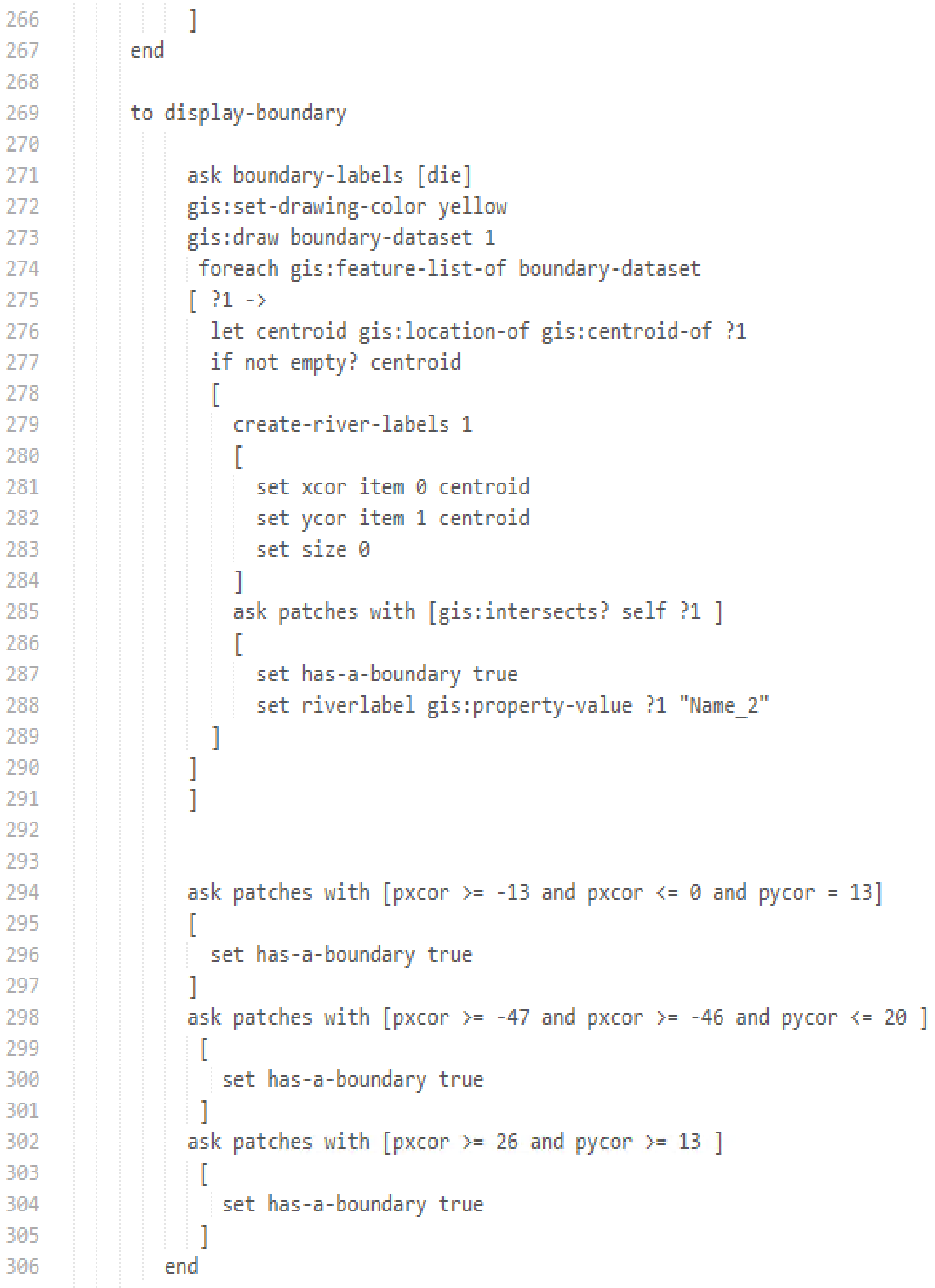
```
      set y y + 1 ]
    set x x + 1 ]
  gis:set-sampling-method aspect "bilinear"
  ask turtles
  [ hatch 1
    [ set color blue
      let h gis:raster-sample aspect self
      ifelse h >= -360
      [ set heading subtract-headings h 180 ]
      [ die ] ] ]


  display-protectedareas
  display-farms
  display-rivers
  display-corridors
  display-boundary
  initiatelephants
  initiatehumans

end


    to display-protectedareas

      if label-protectedareas
      [
        foreach gis:feature-list-of protectedarea-dataset
      [ ?1 ->
        let centroid gis:location-of gis:centroid-of ?1
        if not empty? centroid

        [
          create-protectedareas-labels 1
          [
            set xcor item 0 centroid
            set ycor item 1 centroid
            set size 1
            set label gis:property-value ?1  "Name"
          ]
        ]
      ]
      ]

      ask protectedareas-labels [die]

```



```
  gis:set-drawing-color green
  gis:draw protectedarea-dataset 2


  foreach gis:feature-list-of protectedarea-dataset
  [ ?1 ->
    ask patches with [gis:intersects? self ?1 ]
    [
      set has-a-park true
      set parklabel gis:property-value ?1 "Name"
    ]
  ]

end

 to display-farms

  ask farms-labels [die]
      gis:set-drawing-color brown
      gis:draw farm-dataset 1
       foreach gis:feature-list-of farm-dataset
      [ ?1 ->
        let centroid gis:location-of gis:centroid-of ?1
        if not empty? centroid
        [
          create-farms-labels 1
          [
            set xcor item o centroid
            set ycor item 1 centroid
            set size 0
          ]
          ask patches with [gis:intersects? self ?1 ]
          [
            set has-a-farm true
            set farmlabel gis:property-value ?1 "Name_2"
        ]
      ]
      ]

end

```

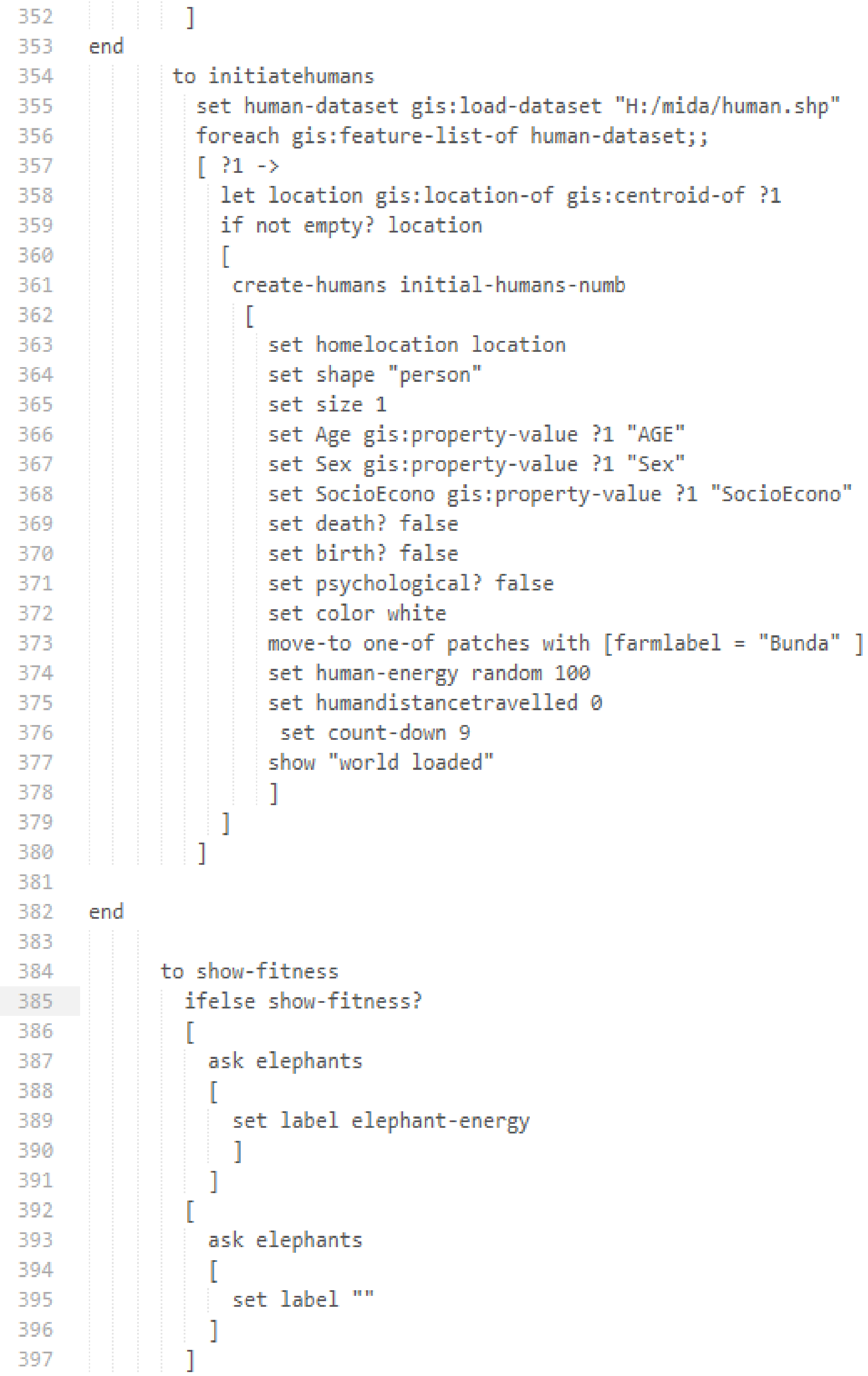


```
to display-corridors
   ask corridors-labels [die]
     gis:set-drawing-color red
     gis:draw corridor-dataset 3
     foreach gis:feature-list-of corridor-dataset
     [ ?1 ->
       let centroid gis:location-of gis:centroid-of ?1
       if not empty? centroid
       [
         create-corridors-labels 1
         [
           set xcor item 0 centroid
           set ycor item 1 centroid
           set size 0
         ]
         ask patches with [gis:intersects? self ?1 ]
         [
           set has-a-corridor true
           set corridorlabel gis:property-value ?1 "status"
         ]
       ]
     ]
end

to display-rivers
     ask river-labels [die]
     gis:set-drawing-color blue
     gis:draw river-dataset 1
     foreach gis:feature-list-of river-dataset
     [ ?1 ->
       let centroid gis:location-of gis:centroid-of ?1
       if not empty? centroid
       [
         create-river-labels 1
         [
           set xcor item 0 centroid
           set ycor item 1 centroid
           set size 0
         ]
         ask patches with [gis:intersects? self ?1 ]
         [
           set has-a-river true
           set riverlabel gis:property-value ?1 "type"
         ]
       ]
```

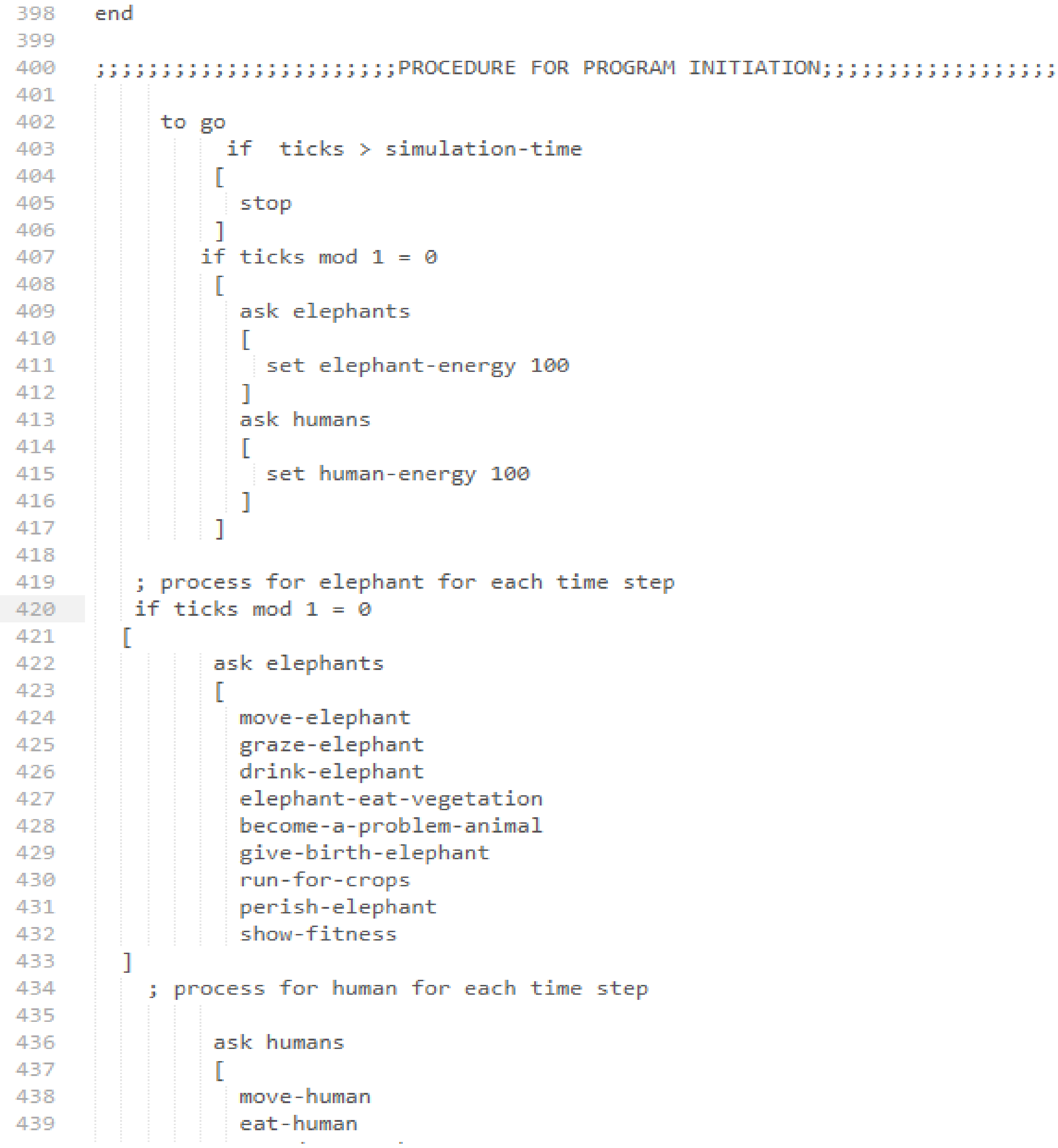


```
      ]
end

to display-boundary

     ask boundary-labels [die]
     gis:set-drawing-color yellow
     gis:draw boundary-dataset 1
      foreach gis:feature-list-of boundary-dataset
     [ ?1 ->
       let centroid gis:location-of gis:centroid-of ?1
       if not empty? centroid
       [
         create-river-labels 1
         [
           set xcor item 0 centroid
           set ycor item 1 centroid
           set size 0
         ]
         ask patches with [gis:intersects? self ?1 ]
         [
           set has-a-boundary true
           set riverlabel gis:property-value ?1 "Name_2"
       ]
     ]
     ]


     ask patches with [pxcor >= -13 and pxcor <= 0 and pycor = 13]
     [
       set has-a-boundary true
     ]
     ask patches with [pxcor >= -47 and pxcor >= -46 and pycor <= 20 ]
      [
        set has-a-boundary true
      ]
     ask patches with [pxcor >= 26 and pycor >= 13 ]
      [
        set has-a-boundary true
      ]
   end
```

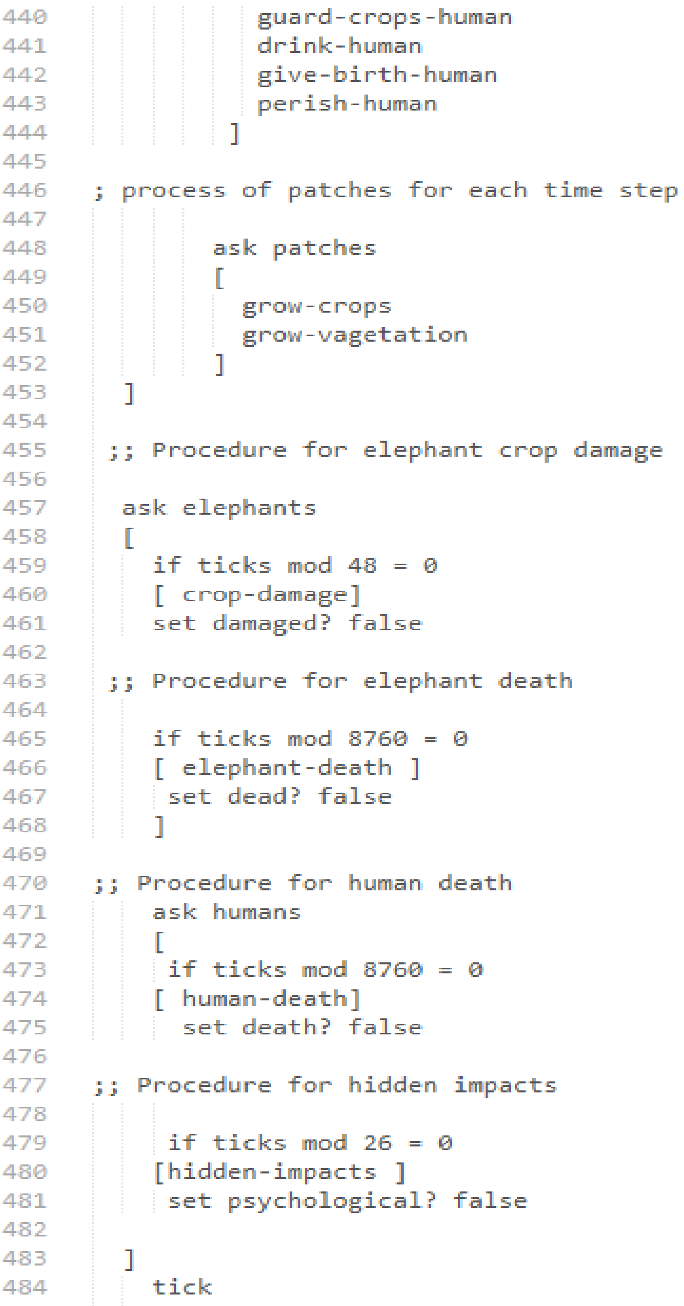
```
to initiatelephants

  set elephant-dataset gis:load-dataset "H:/mida/elephant.shp"
   gis:set-world-envelope (gis:envelope-union-of   (gis:envelope-of elephant-dataset);;
                                                   (gis:envelope-of farm-dataset)
                                                   (gis:envelope-of river-dataset)
                                                   (gis:envelope-of human-dataset)
                                                   (gis:envelope-of elevation-dataset)
                                                   (gis:envelope-of boundary-dataset)
                                                   (gis:envelope-of protectedarea-dataset) )

  foreach gis:feature-list-of elephant-dataset;;
  [ ?1 ->
    let location gis:location-of gis:centroid-of ?1
    if not empty? location
    [
      create-elephants initial-elephant-numb

          set parklocation location
          set shape "elephant"
          set size 1.5
          set ElephantID gis:property-value ?1 "ElephantID"
          set Age gis:property-value ?1 "Elephage"
          set Sex gis:property-value ?1 "Sex"
          set color black
          set xcor item 0 parklocation
          set ycor item 1 parklocation
          move-to one-of patches with [parklabel = "Reserved Land" ]
          set delivery? false
          set dead? false
          set damaged? false
          set elephant-life-span 59
          set elephant-carrying-capacity elephant-carrying-capacity
          set max-elephant-offspring 1
          set elephant-energy random 100
          set elephant-reproductive-age 20
          set elephant-mortality-rate 0.05
          set elephant-reproductive-fitness 5
          set elephantdistancetravelled 0
          set count-down 9
          show "world loaded"

        ]
    ]
  ]
```



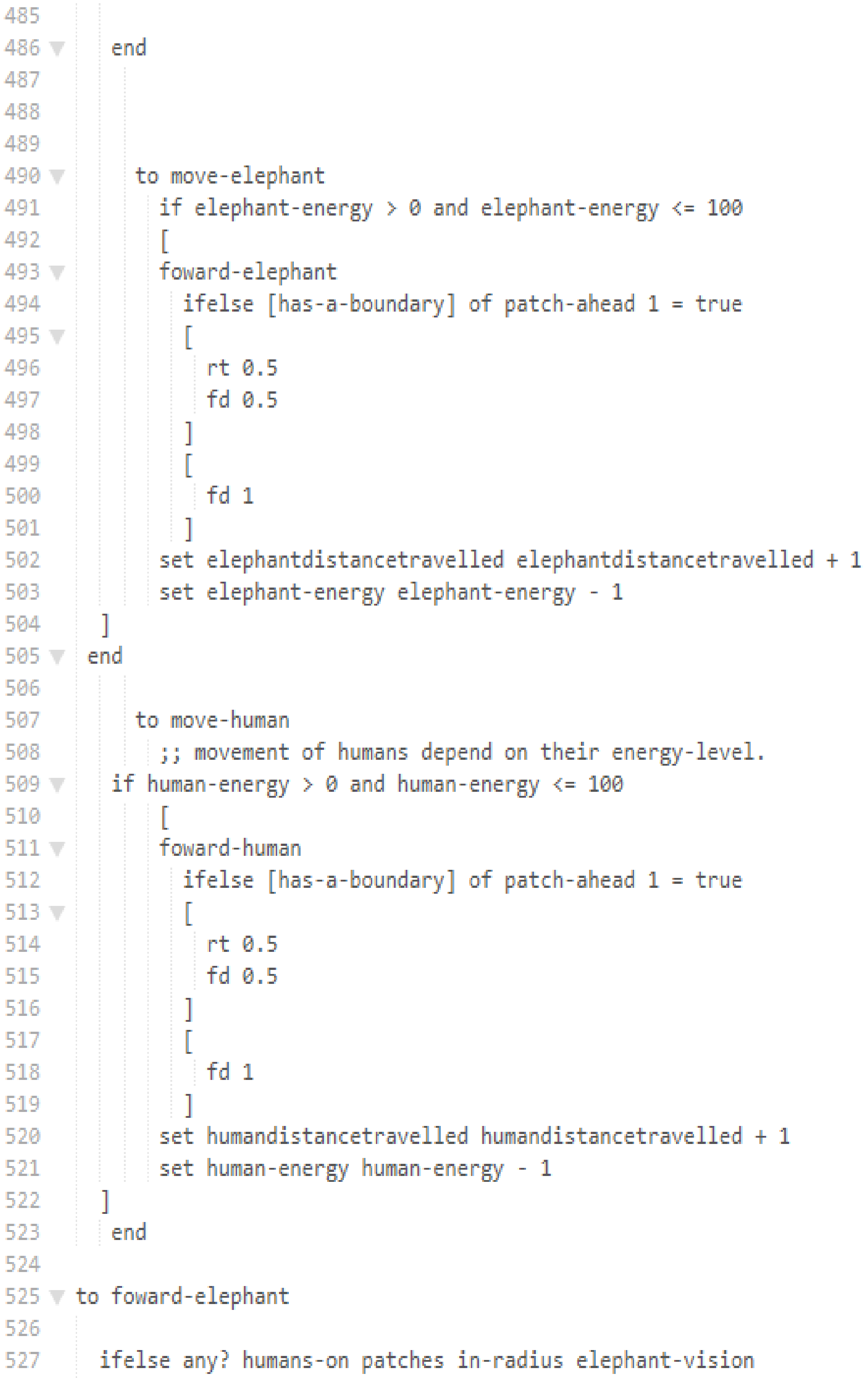
```
        ]
end
       to initiatehumans
         set human-dataset gis:load-dataset "H:/mida/human.shp"
         foreach gis:feature-list-of human-dataset;;
         [ ?1 ->
           let location gis:location-of gis:centroid-of ?1
           if not empty? location
           [
            create-humans initial-humans-numb
             [
               set homelocation location
               set shape "person"
               set size 1
               set Age gis:property-value ?1 "AGE"
               set Sex gis:property-value ?1 "Sex"
               set SocioEcono gis:property-value ?1 "SocioEcono"
               set death? false
               set birth? false
               set psychological? false
               set color white
               move-to one-of patches with [farmlabel = "Bunda" ]
               set human-energy random 100
               set humandistancetravelled 0
                set count-down 9
               show "world loaded"
               ]
           ]
         ]

end

      to show-fitness
        ifelse show-fitness?
        [
          ask elephants
          [
            set label elephant-energy
            ]
          ]
        [
          ask elephants
          [
            set label ""
          ]
        ]
```



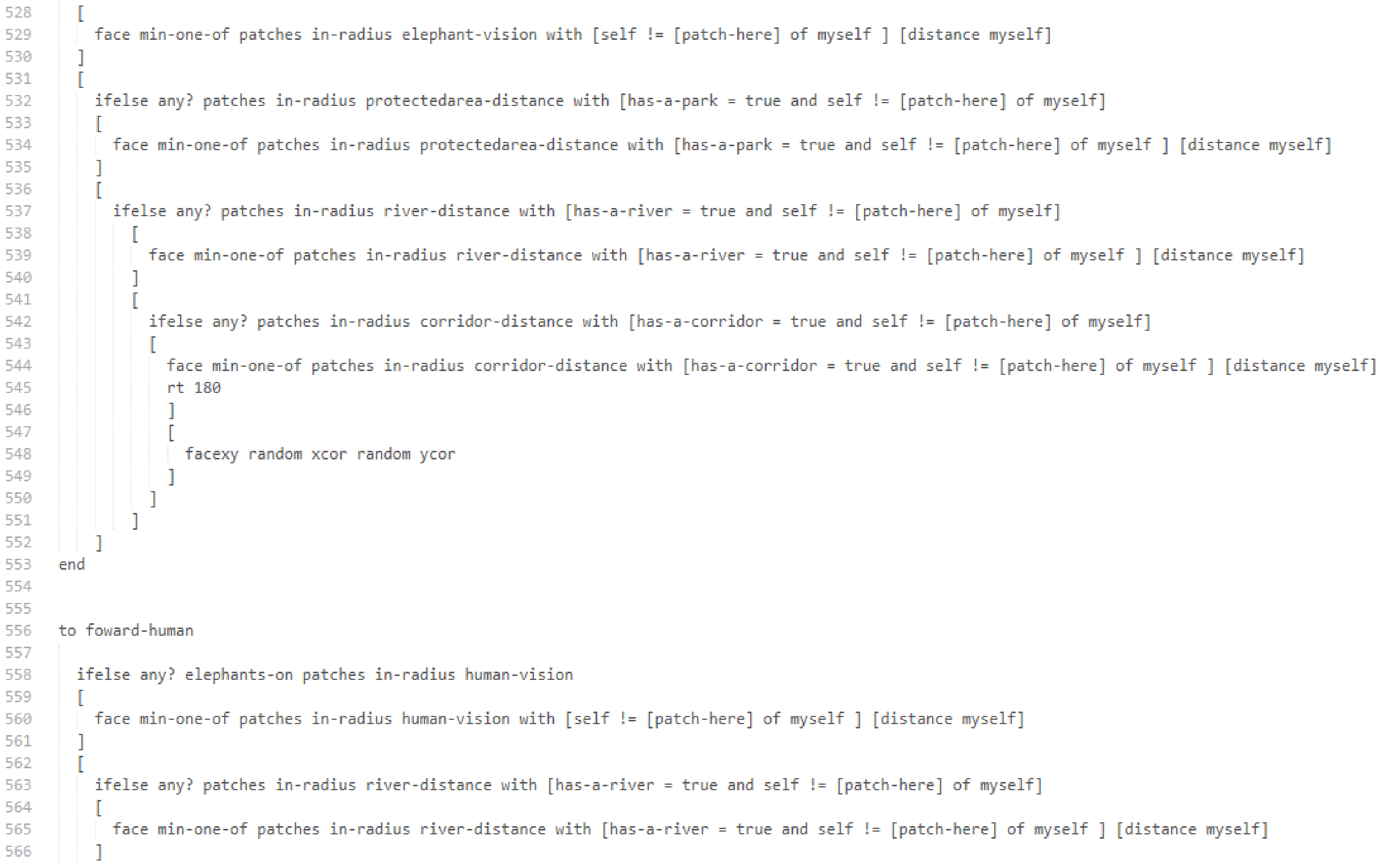
```
end

;;;;;;;;;;;;;;;;;;;;;;;PROCEDURE FOR PROGRAM INITIATION;;;;;;;;;;;;;;;;;;

     to go
          if  ticks > simulation-time
         [
           stop
         ]
        if ticks mod 1 = 0
         [
           ask elephants
           [
             set elephant-energy 100
           ]
           ask humans
           [
             set human-energy 100
           ]
         ]

   ; process for elephant for each time step
   if ticks mod 1 = 0
  [
         ask elephants
         [
           move-elephant
           graze-elephant
           drink-elephant
           elephant-eat-vegetation
           become-a-problem-animal
           give-birth-elephant
           run-for-crops
           perish-elephant
           show-fitness
  ]
    ; process for human for each time step

         ask humans
         [
           move-human
           eat-human
```



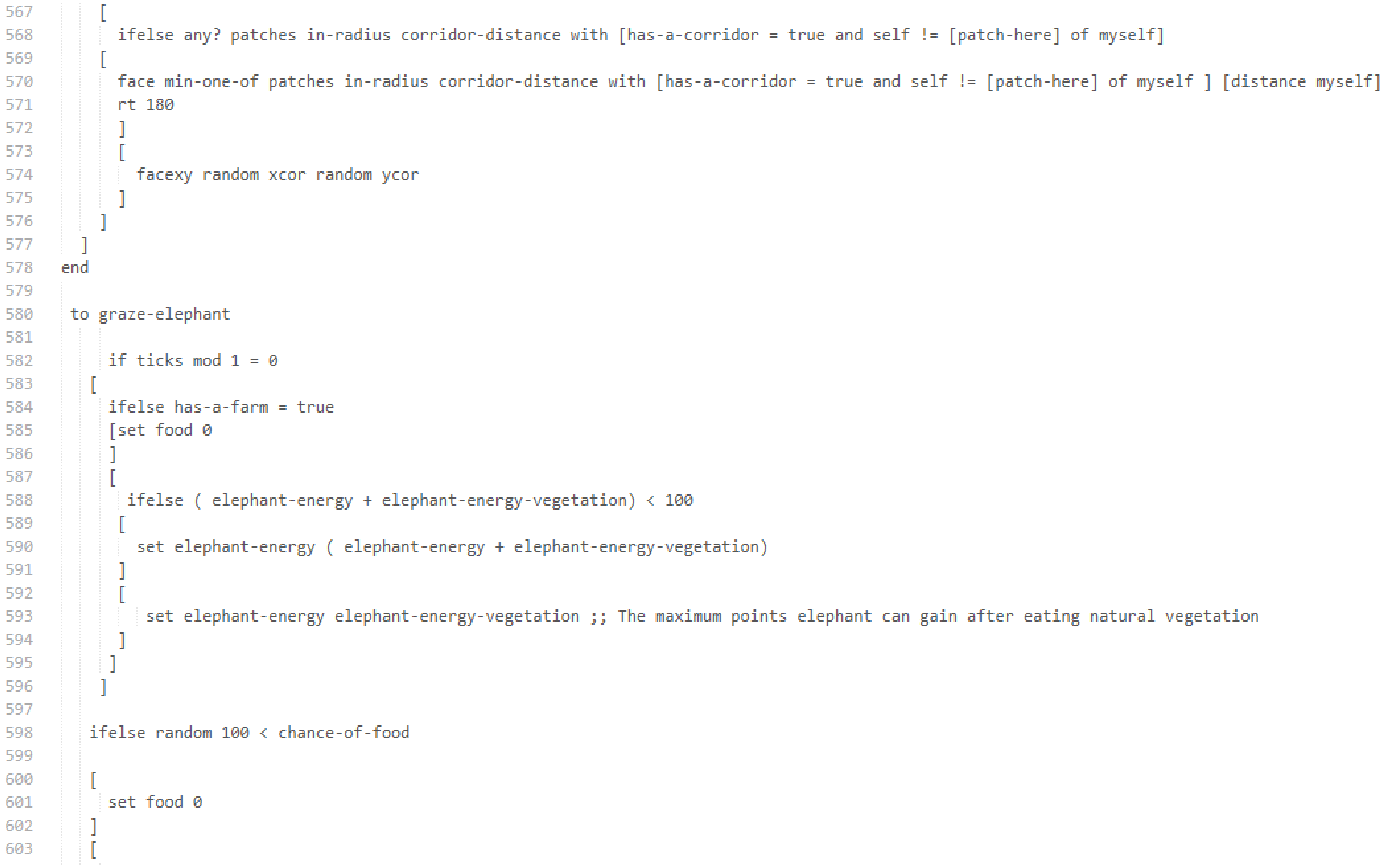
```
           guard-crops-human
           drink-human
           give-birth-human
           perish-human
         ]

; process of patches for each time step

        ask patches
        [
          grow-crops
          grow-vagetation
        ]
  ]

 ;; Procedure for elephant crop damage

  ask elephants
  [
    if ticks mod 48 = 0
    [ crop-damage]
    set damaged? false

 ;; Procedure for elephant death

    if ticks mod 8760 = 0
    [ elephant-death ]
     set dead? false
    ]

;; Procedure for human death
    ask humans
    [
     if ticks mod 8760 = 0
    [ human-death]
      set death? false

;; Procedure for hidden impacts

     if ticks mod 26 = 0
    [hidden-impacts ]
     set psychological? false

  ]
    tick
```



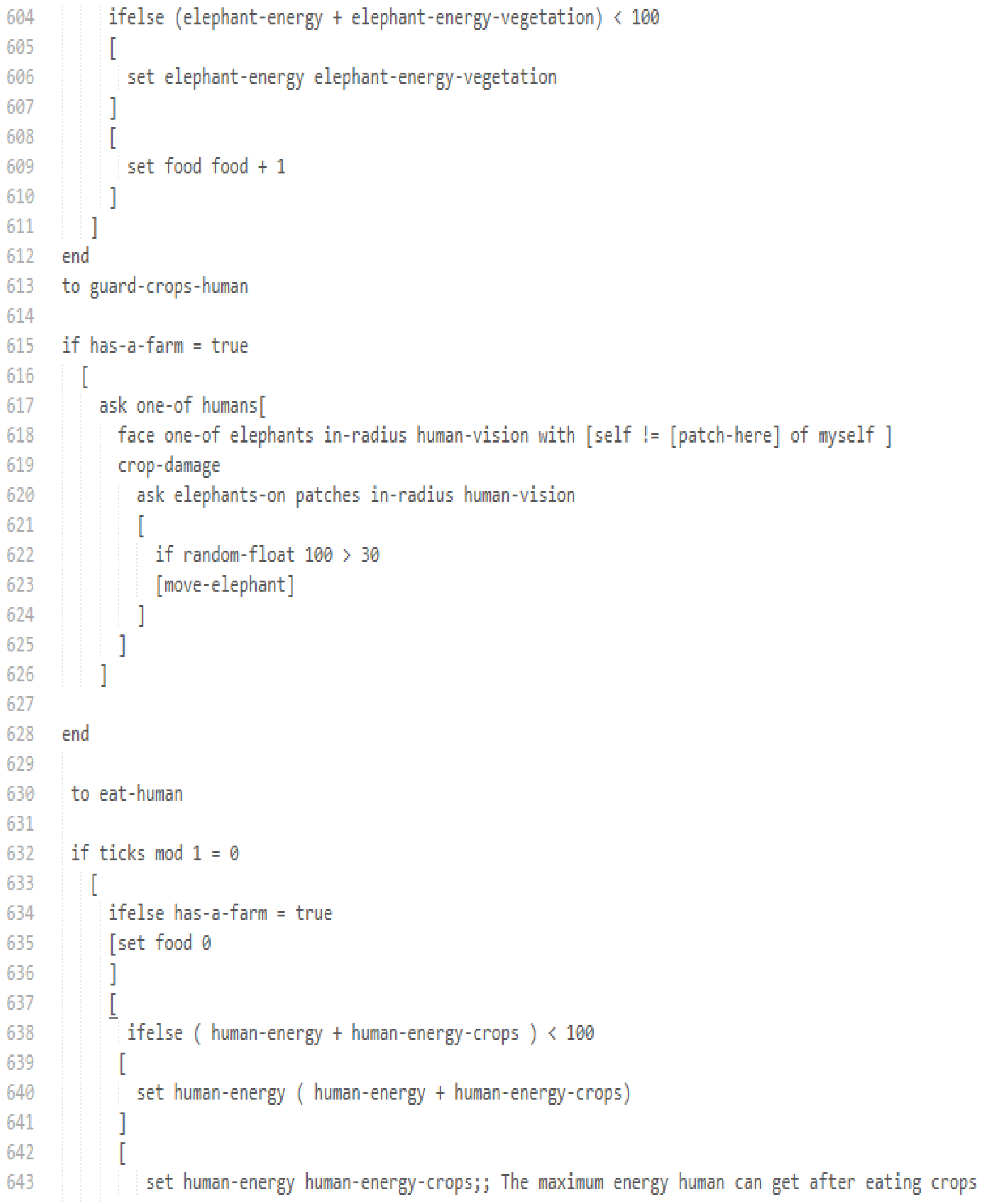
```
   end



     to move-elephant
       if elephant-energy > 0 and elephant-energy <= 100
       [
       foward-elephant
         ifelse [has-a-boundary] of patch-ahead 1 = true
         [
           rt 0.5
           fd 0.5
         ]
         [
           fd 1
         ]
       set elephantdistancetravelled elephantdistancetravelled + 1
       set elephant-energy elephant-energy - 1
  ]
 end

     to move-human
       ;; movement of humans depend on their energy-level.
   if human-energy > 0 and human-energy <= 100
       [
       foward-human
         ifelse [has-a-boundary] of patch-ahead 1 = true
         [
           rt 0.5
           fd 0.5
         ]
         [
           fd 1
         ]
       set humandistancetravelled humandistancetravelled + 1
       set human-energy human-energy - 1
  ]
   end

to foward-elephant

  ifelse any? humans-on patches in-radius elephant-vision
```



```
  [
    face min-one-of patches in-radius elephant-vision with [self != [patch-here] of myself ] [distance myself]
  ]
  [
    ifelse any? patches in-radius protectedarea-distance with [has-a-park = true and self != [patch-here] of myself]
    [
      face min-one-of patches in-radius protectedarea-distance with [has-a-park = true and self != [patch-here] of myself ] [distance myself]
    ]
    [
      ifelse any? patches in-radius river-distance with [has-a-river = true and self != [patch-here] of myself]
        [
          face min-one-of patches in-radius river-distance with [has-a-river = true and self != [patch-here] of myself ] [distance myself]
        ]
        [
          ifelse any? patches in-radius corridor-distance with [has-a-corridor = true and self != [patch-here] of myself]
          [
            face min-one-of patches in-radius corridor-distance with [has-a-corridor = true and self != [patch-here] of myself ] [distance myself]
            rt 180
            ]
            [
              facexy random xcor random ycor
            ]
          ]
        ]
    ]
end


to foward-human

  ifelse any? elephants-on patches in-radius human-vision
  [
    face min-one-of patches in-radius human-vision with [self != [patch-here] of myself ] [distance myself]
  ]
  [
    ifelse any? patches in-radius river-distance with [has-a-river = true and self != [patch-here] of myself]
    [
      face min-one-of patches in-radius river-distance with [has-a-river = true and self != [patch-here] of myself ] [distance myself]
    ]
```

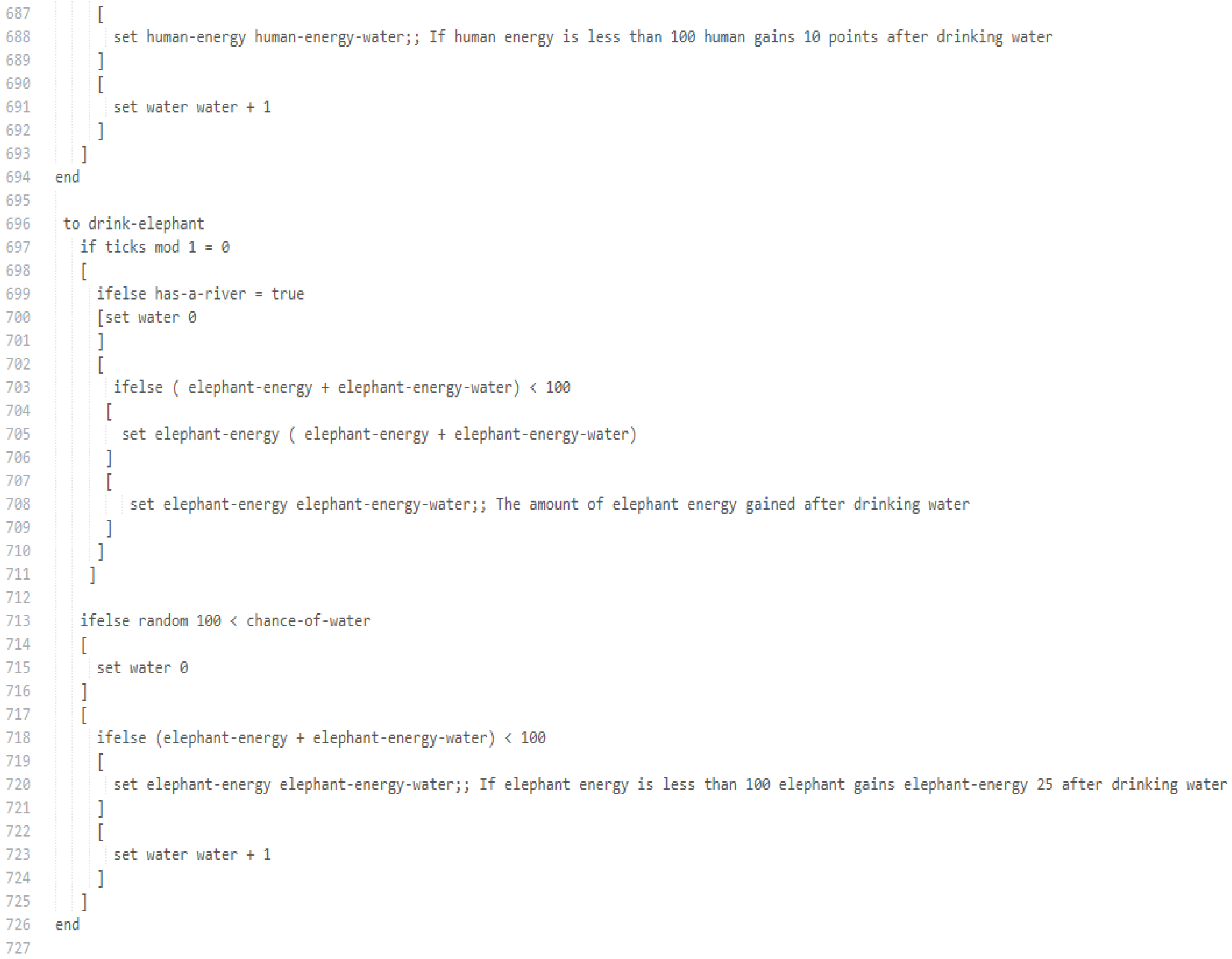


```
    [
      ifelse any? patches in-radius corridor-distance with [has-a-corridor = true and self != [patch-here] of myself]
    [
      face min-one-of patches in-radius corridor-distance with [has-a-corridor = true and self != [patch-here] of myself ] [distance myself]
      rt 180
      ]
      [
        facexy random xcor random ycor
      ]
    ]
  ]
end

 to graze-elephant

     if ticks mod 1 = 0
   [
     ifelse has-a-farm = true
     [set food 0
     ]
     [
       ifelse ( elephant-energy + elephant-energy-vegetation) < 100
      [
        set elephant-energy ( elephant-energy + elephant-energy-vegetation)
      ]
      [
         set elephant-energy elephant-energy-vegetation ;; The maximum points elephant can gain after eating natural vegetation
      ]
     ]
    ]

   ifelse random 100 < chance-of-food

   [
     set food 0
   ]
   [
```

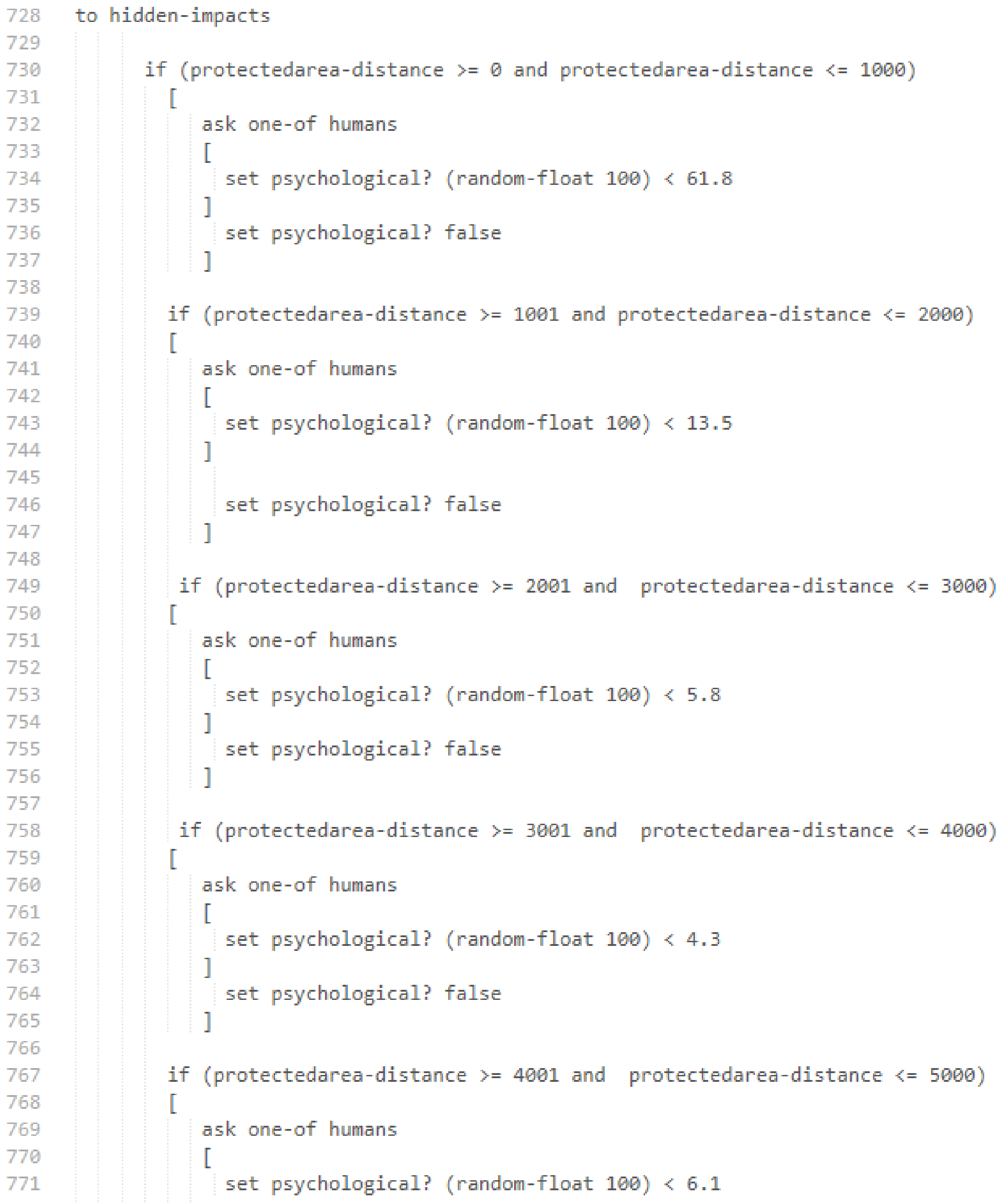


```
     ifelse (elephant-energy + elephant-energy-vegetation) < 100
     [
       set elephant-energy elephant-energy-vegetation
     ]
     [
       set food food + 1
     ]
   ]
end
to guard-crops-human

if has-a-farm = true
  [
    ask one-of humans[
      face one-of elephants in-radius human-vision with [self != [patch-here] of myself ]
      crop-damage
        ask elephants-on patches in-radius human-vision
        [
          if random-float 100 > 30
          [move-elephant]
        ]
      ]
    ]

end

 to eat-human

 if ticks mod 1 = 0
   [
     ifelse has-a-farm = true
     [set food 0
     ]
     [
       ifelse ( human-energy + human-energy-crops ) < 100
      [
        set human-energy ( human-energy + human-energy-crops)
      ]
      [
         set human-energy human-energy-crops;; The maximum energy human can get after eating crops
```

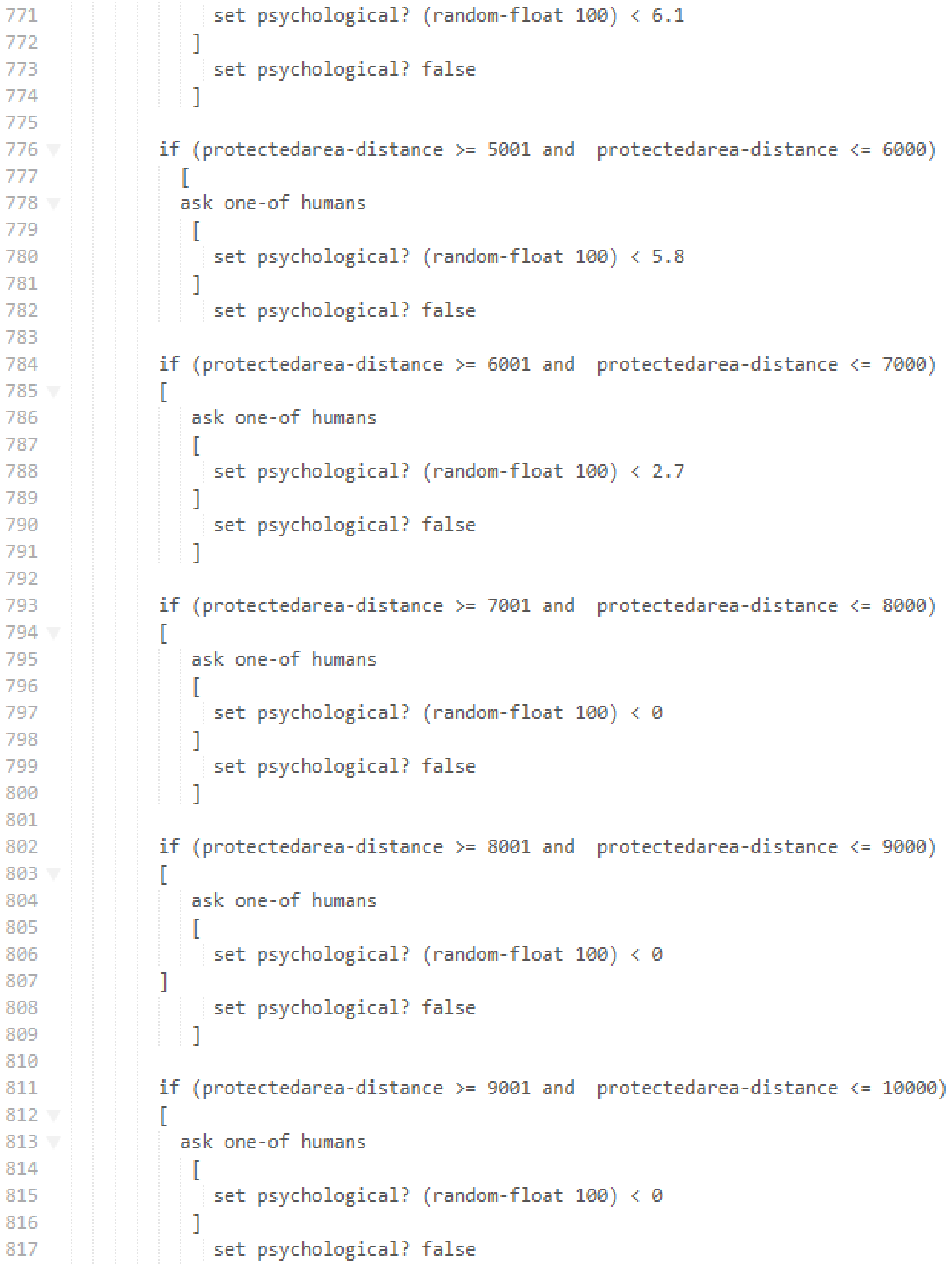
```
      ]
     ]
    ]
   ifelse random 100 < chance-of-food
   [
     set food 0
   ]
   [
     ifelse (human-energy + human-energy-crops ) < 100
     [
       set human-energy human-energy-crops;; If human energy is less than 100 human gains 68 points after eating food
     ]
     [
       set food food + 1
     ]
   ]

end

 to drink-human
   if ticks mod 1 = 0
   [
     ifelse has-a-river = true
     [set water 0
     ]
     [
       ifelse ( human-energy + human-energy-water) < 100
      [
        set human-energy ( human-energy + human-energy-water)
      ]
      [
         set human-energy human-energy-water;; The maximum energy human can get after drinking water
      ]
     ]
    ]

   ifelse random 100 < chance-of-water

   [
     set water 0
   ]
   [
     ifelse (human-energy + human-energy-water) < 100
```



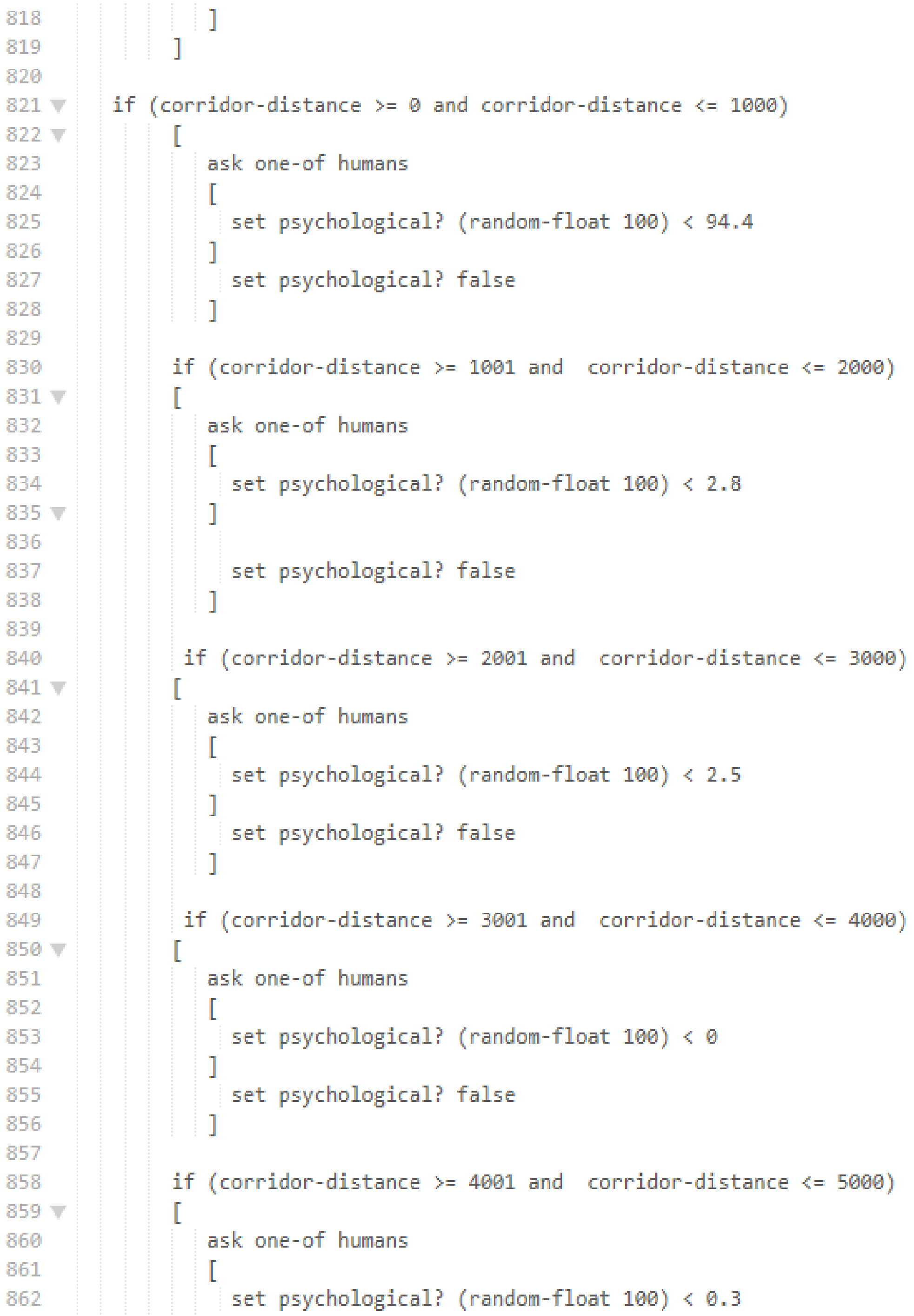
```
     [
       set human-energy human-energy-water;; If human energy is less than 100 human gains 10 points after drinking water
     ]
     [
       set water water + 1
     ]
   ]
end

 to drink-elephant
   if ticks mod 1 = 0
   [
     ifelse has-a-river = true
     [set water 0
     ]
     [
       ifelse ( elephant-energy + elephant-energy-water) < 100
      [
        set elephant-energy ( elephant-energy + elephant-energy-water)
      ]
      [
         set elephant-energy elephant-energy-water;; The amount of elephant energy gained after drinking water
      ]
     ]
    ]

   ifelse random 100 < chance-of-water
   [
     set water 0
   ]
   [
     ifelse (elephant-energy + elephant-energy-water) < 100
     [
       set elephant-energy elephant-energy-water;; If elephant energy is less than 100 elephant gains elephant-energy 25 after drinking water
     ]
     [
       set water water + 1
     ]
   ]
end
```



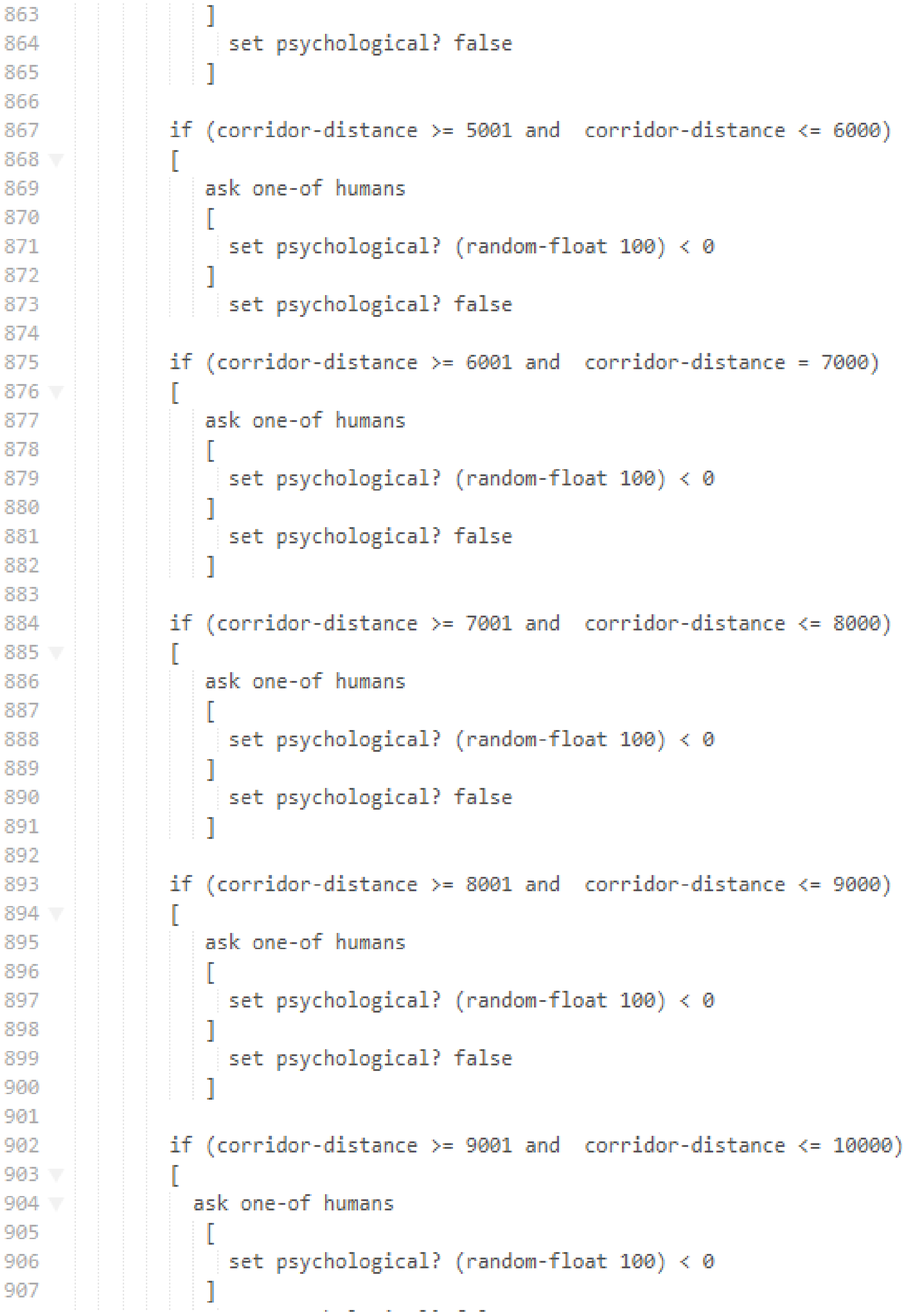
```
to hidden-impacts

      if (protectedarea-distance >= 0 and protectedarea-distance <= 1000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 61.8
           ]
             set psychological? false
           ]

        if (protectedarea-distance >= 1001 and protectedarea-distance <= 2000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 13.5
           ]

             set psychological? false
           ]

         if (protectedarea-distance >= 2001 and  protectedarea-distance <= 3000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 5.8
           ]
             set psychological? false
           ]

         if (protectedarea-distance >= 3001 and  protectedarea-distance <= 4000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 4.3
           ]
             set psychological? false
           ]

        if (protectedarea-distance >= 4001 and  protectedarea-distance <= 5000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 6.1
```



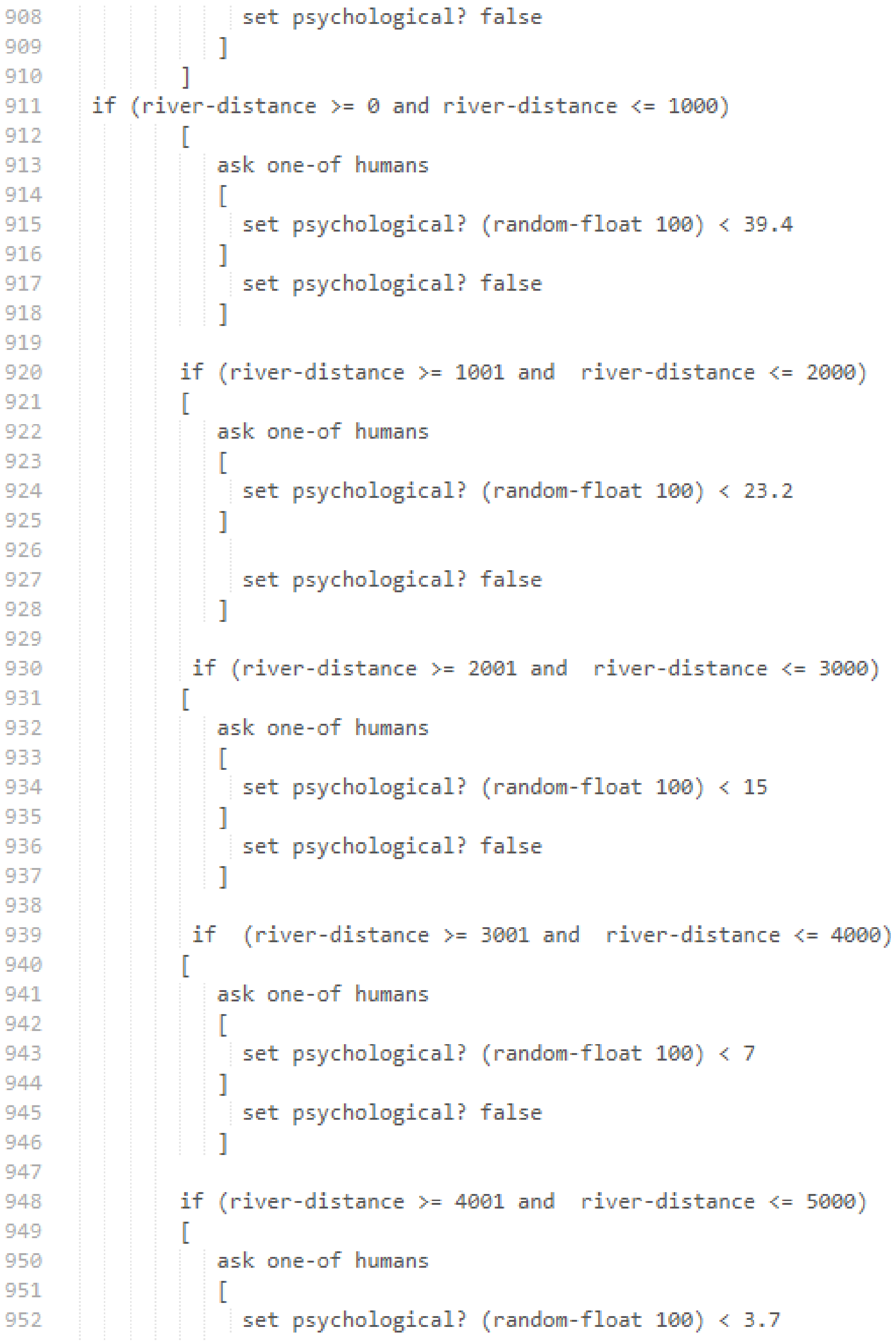
```
             set psychological? (random-float 100) < 6.1
           ]
             set psychological? false
           ]

        if (protectedarea-distance >= 5001 and  protectedarea-distance <= 6000)
          [
          ask one-of humans
           [
             set psychological? (random-float 100) < 5.8
           ]
             set psychological? false

        if (protectedarea-distance >= 6001 and  protectedarea-distance <= 7000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 2.7
           ]
             set psychological? false
           ]

        if (protectedarea-distance >= 7001 and  protectedarea-distance <= 8000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false
           ]

        if (protectedarea-distance >= 8001 and  protectedarea-distance <= 9000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
        ]
             set psychological? false
           ]

        if (protectedarea-distance >= 9001 and  protectedarea-distance <= 10000)
        [
          ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false
```



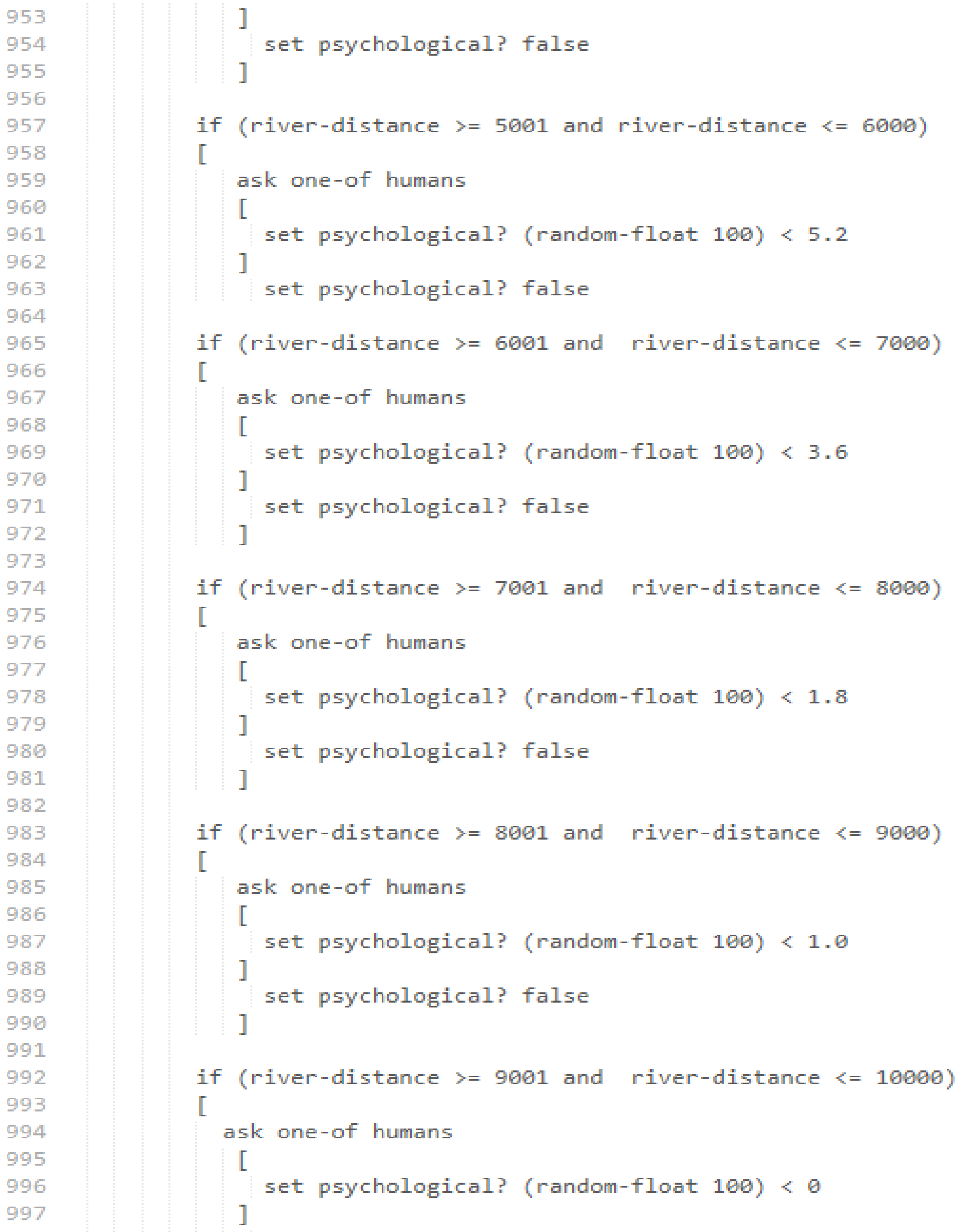
```
        ]
     ]

if (corridor-distance >= 0 and corridor-distance <= 1000)
     [
        ask one-of humans
        [
          set psychological? (random-float 100) < 94.4
        ]
          set psychological? false
        ]

     if (corridor-distance >= 1001 and  corridor-distance <= 2000)
     [
        ask one-of humans
        [
          set psychological? (random-float 100) < 2.8
        ]

          set psychological? false
        ]

      if (corridor-distance >= 2001 and  corridor-distance <= 3000)
     [
        ask one-of humans
        [
          set psychological? (random-float 100) < 2.5
        ]
          set psychological? false
        ]

      if (corridor-distance >= 3001 and  corridor-distance <= 4000)
     [
        ask one-of humans
        [
          set psychological? (random-float 100) < 0
        ]
          set psychological? false
        ]

     if (corridor-distance >= 4001 and  corridor-distance <= 5000)
     [
        ask one-of humans
        [
          set psychological? (random-float 100) < 0.3
```



```
           ]
             set psychological? false
           ]

        if (corridor-distance >= 5001 and  corridor-distance <= 6000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false

        if (corridor-distance >= 6001 and  corridor-distance = 7000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false
           ]

        if (corridor-distance >= 7001 and  corridor-distance <= 8000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false
           ]

        if (corridor-distance >= 8001 and  corridor-distance <= 9000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
             set psychological? false
           ]

        if (corridor-distance >= 9001 and  corridor-distance <= 10000)
        [
          ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
```



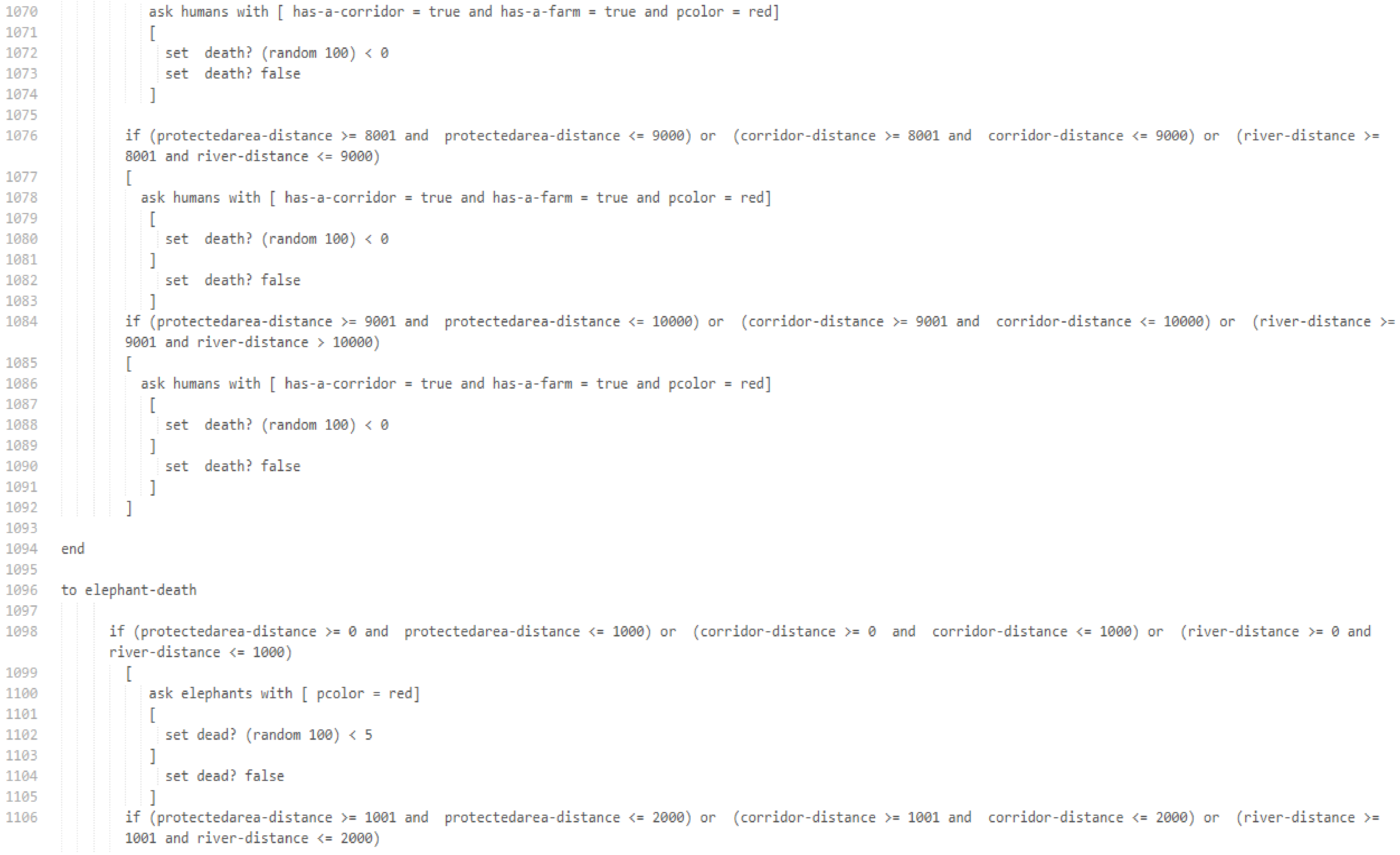
```
            set psychological? false
          ]
       ]
if (river-distance >= 0 and river-distance <= 1000)
       [
          ask one-of humans
          [
            set psychological? (random-float 100) < 39.4
          ]
            set psychological? false
          ]

       if (river-distance >= 1001 and  river-distance <= 2000)
       [
          ask one-of humans
          [
            set psychological? (random-float 100) < 23.2
          ]

            set psychological? false
          ]

        if (river-distance >= 2001 and  river-distance <= 3000)
       [
          ask one-of humans
          [
            set psychological? (random-float 100) < 15
          ]
            set psychological? false
          ]

        if  (river-distance >= 3001 and  river-distance <= 4000)
       [
          ask one-of humans
          [
            set psychological? (random-float 100) < 7
          ]
            set psychological? false
          ]

       if (river-distance >= 4001 and  river-distance <= 5000)
       [
          ask one-of humans
          [
            set psychological? (random-float 100) < 3.7
```



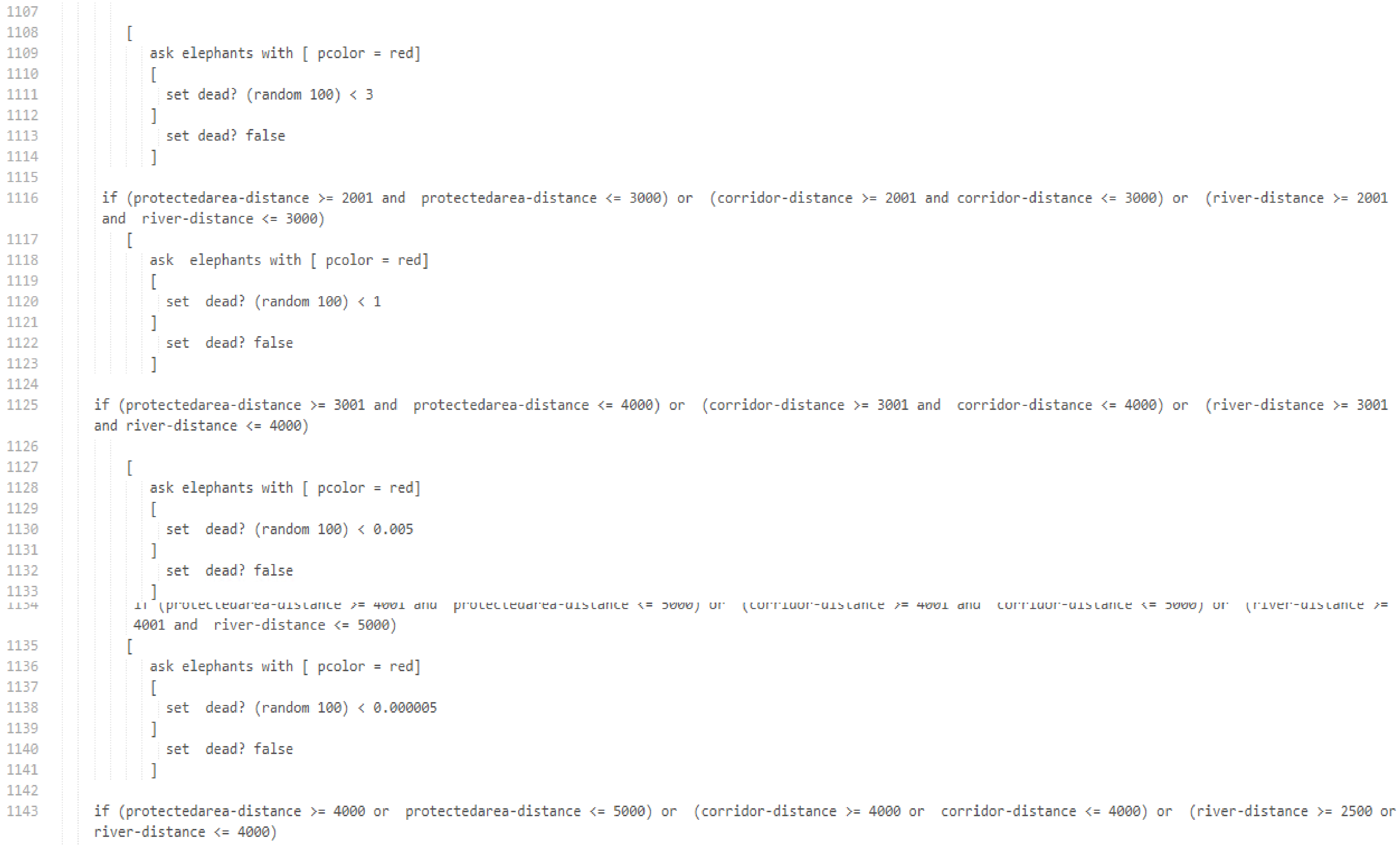
```
           ]
             set psychological? false
           ]

        if (river-distance >= 5001 and river-distance <= 6000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 5.2
           ]
             set psychological? false

        if (river-distance >= 6001 and  river-distance <= 7000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 3.6
           ]
             set psychological? false
           ]

        if (river-distance >= 7001 and  river-distance <= 8000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 1.8
           ]
             set psychological? false
           ]

        if (river-distance >= 8001 and  river-distance <= 9000)
        [
           ask one-of humans
           [
             set psychological? (random-float 100) < 1.0
           ]
             set psychological? false
           ]

        if (river-distance >= 9001 and  river-distance <= 10000)
        [
          ask one-of humans
           [
             set psychological? (random-float 100) < 0
           ]
```

```
             set psychological? false
           ]
        ]
end

to human-death

  if (protectedarea-distance >= 0 and  protectedarea-distance <= 1000) or  (corridor-distance >= 0 and  corridor-distance <= 1000) or  (river-distance >= 0 and river-distance <= 1000)
        [
           ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set death? (random 100) < 3
           ]
             set death? false
           ]

        if (protectedarea-distance >= 1001 and  protectedarea-distance <= 2000) or  (corridor-distance >= 1001 and corridor-distance <= 2000) or  (river-distance >= 1001 and river-distance <= 2000)
        [
           ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set death? (random 100) < 3
           ]
             set death? false
           ]

        if (protectedarea-distance >= 2001 and  protectedarea-distance <= 3000) or  (corridor-distance >= 2001 and  corridor-distance <= 3000) or  (river-distance >= 2001 and  river-distance <= 3000)
        [
           ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set death? (random 100) < 2
           ]
             set death? false
           ]

        if (protectedarea-distance >= 3001 and  protectedarea-distance <= 4000) or  (corridor-distance >= 3001 and  corridor-distance <= 4000) or  (river-distance >= 3001 and  river-distance <= 4000)
```

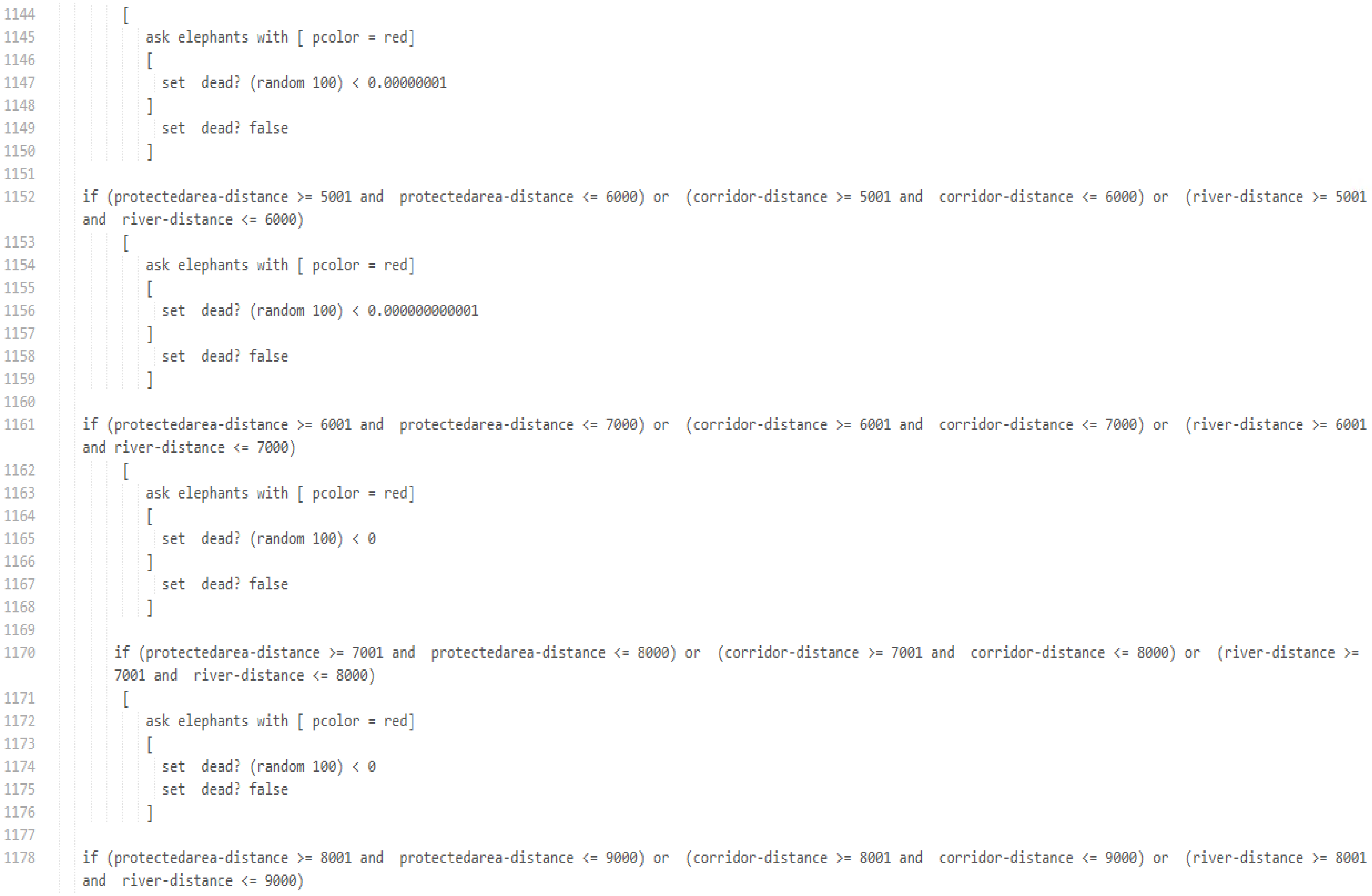
```
[
  ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
   [
     set death? (random 100) < 1
   ]
     set death? false
   ]
if (protectedarea-distance >= 4001 and  protectedarea-distance <= 5000) or  (corridor-distance >= 4001 and  corridor-distance <= 5000) or  (river-distance >= 4001 and river-distance <= 5000)
[
   ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
   [
     set death? (random 100) < 0.05
   ]
     set death? false
   ]

if (protectedarea-distance >= 5001 and  protectedarea-distance <= 6000) or  (corridor-distance >= 5001 and  corridor-distance <= 6000) or  (river-distance >= 5001 and river-distance <= 6000)
[
   ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
   [
     set death? (random 100) < 0.005
   ]
     set death? false
   ]


if (protectedarea-distance >= 6001 and  protectedarea-distance <= 7000) or  (corridor-distance >= 6001 and  corridor-distance <= 7000) or  (river-distance >= 6001 and  river-distance <= 7000)
[
  ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
   [
     set  death? (random 100) < 0
   ]
     set  death? false
   ]

if (protectedarea-distance >= 7001 and  protectedarea-distance <= 8000) or  (corridor-distance >= 7001 and corridor-distance <= 8000) or  (river-distance >= 7001 and river-distance <= 8000)
[
```



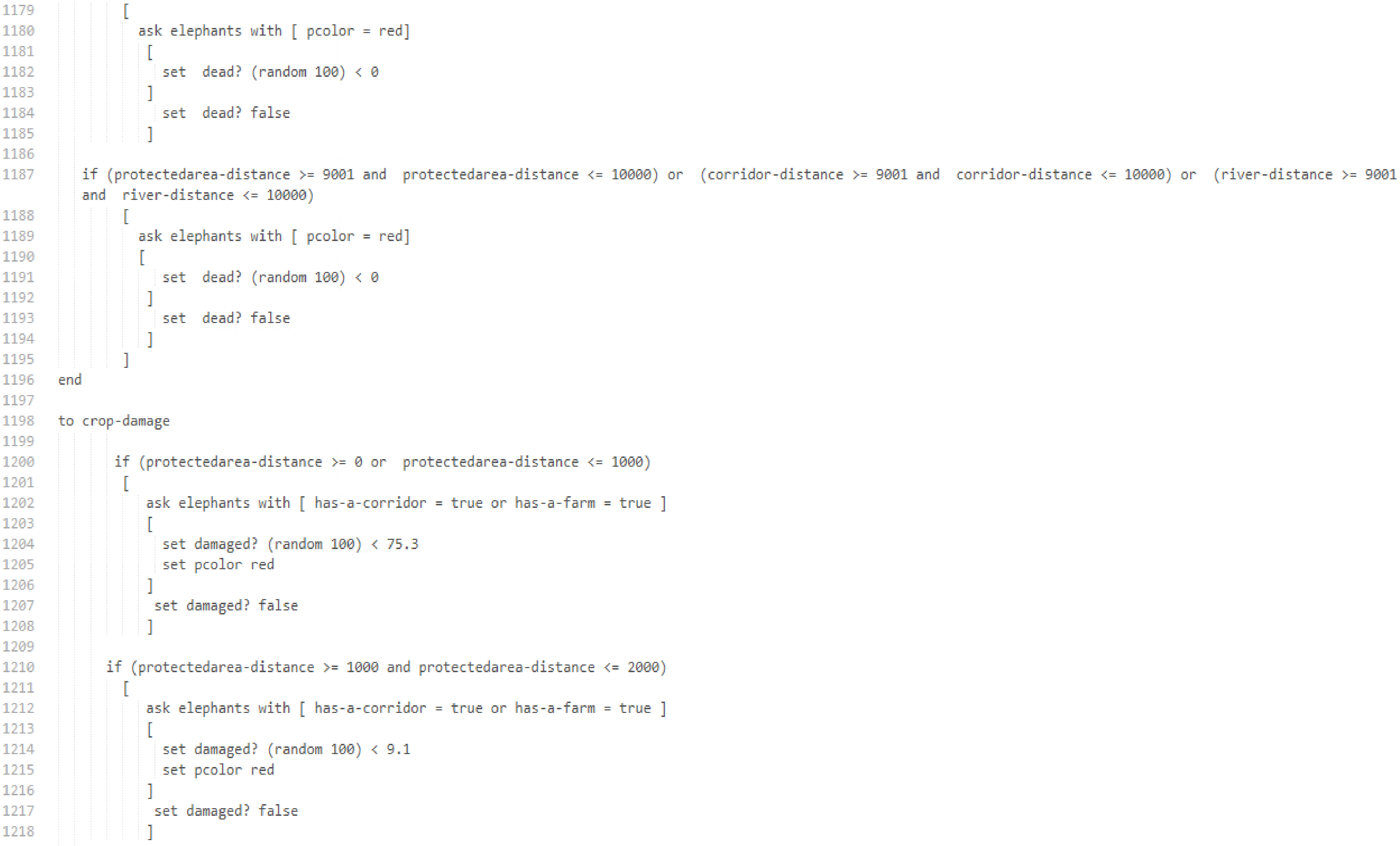
```
           ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set  death? (random 100) < 0
             set  death? false
           ]

        if (protectedarea-distance >= 8001 and  protectedarea-distance <= 9000) or  (corridor-distance >= 8001 and  corridor-distance <= 9000) or  (river-distance >= 8001 and river-distance <= 9000)
        [
          ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set  death? (random 100) < 0
           ]
             set  death? false
           ]
        if (protectedarea-distance >= 9001 and  protectedarea-distance <= 10000) or  (corridor-distance >= 9001 and  corridor-distance <= 10000) or  (river-distance >= 9001 and river-distance > 10000)
        [
          ask humans with [ has-a-corridor = true and has-a-farm = true and pcolor = red]
           [
             set  death? (random 100) < 0
           ]
             set  death? false
           ]
        ]

end

to elephant-death

      if (protectedarea-distance >= 0 and  protectedarea-distance <= 1000) or  (corridor-distance >= 0  and  corridor-distance <= 1000) or  (river-distance >= 0 and river-distance <= 1000)
        [
           ask elephants with [ pcolor = red]
           [
             set dead? (random 100) < 5
           ]
             set dead? false
           ]
        if (protectedarea-distance >= 1001 and  protectedarea-distance <= 2000) or  (corridor-distance >= 1001 and  corridor-distance <= 2000) or  (river-distance >= 1001 and river-distance <= 2000)
```



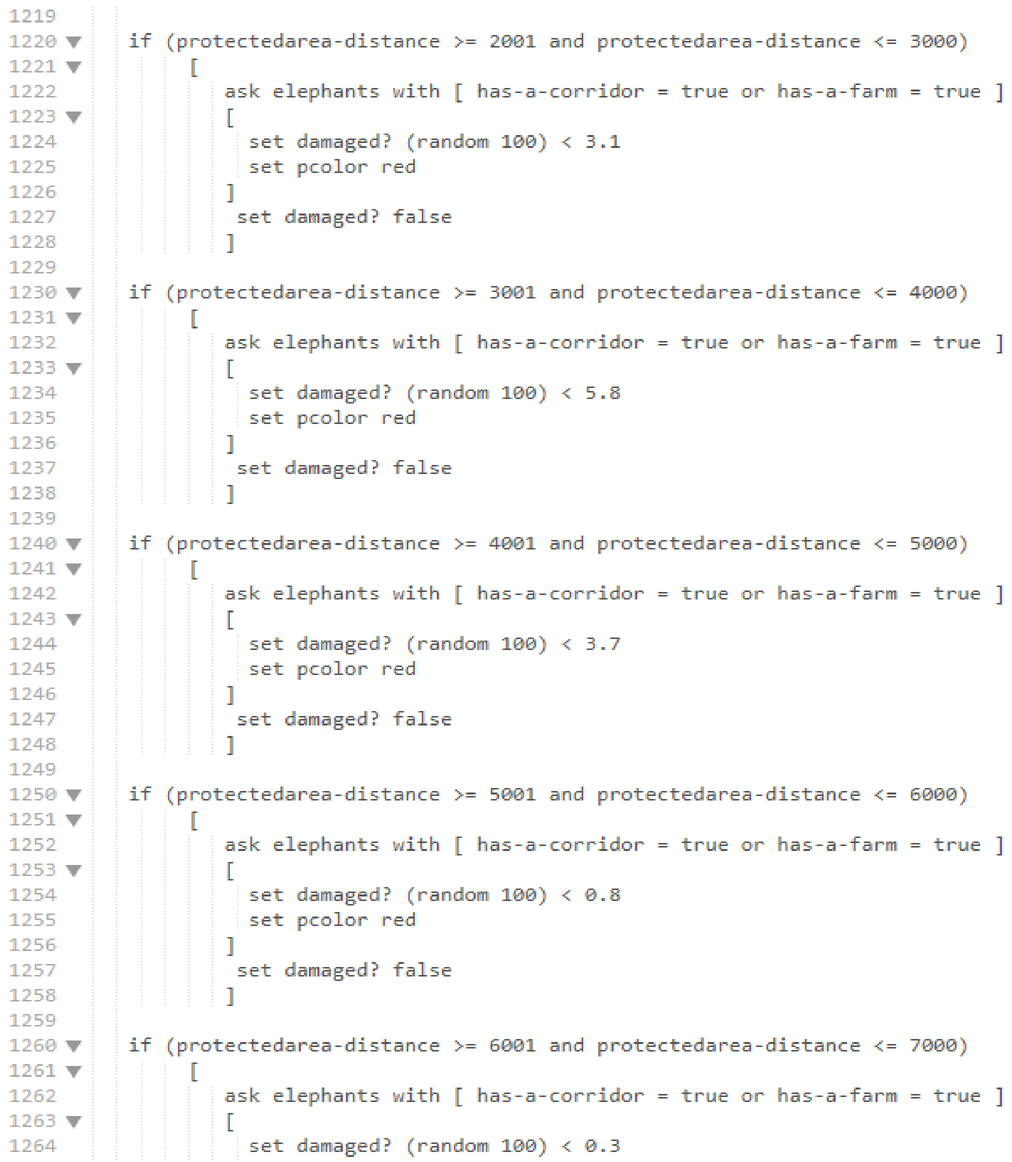
```
    [
      ask elephants with [ pcolor = red]
      [
        set dead? (random 100) < 3
      ]
        set dead? false
      ]

  if (protectedarea-distance >= 2001 and  protectedarea-distance <= 3000) or  (corridor-distance >= 2001 and corridor-distance <= 3000) or  (river-distance >= 2001 and  river-distance <= 3000)
    [
      ask  elephants with [ pcolor = red]
      [
        set  dead? (random 100) < 1
      ]
        set  dead? false
      ]

 if (protectedarea-distance >= 3001 and  protectedarea-distance <= 4000) or  (corridor-distance >= 3001 and  corridor-distance <= 4000) or  (river-distance >= 3001 and river-distance <= 4000)

    [
      ask elephants with [ pcolor = red]
      [
        set  dead? (random 100) < 0.005
      ]
        set  dead? false
      ]
     if (protectedarea-distance >= 4001 and  protectedarea-distance <= 5000) or  (corridor-distance >= 4001 and  corridor-distance <= 5000) or  (river-distance >= 4001 and  river-distance <= 5000)
    [
      ask elephants with [ pcolor = red]
      [
        set  dead? (random 100) < 0.000005
      ]
        set  dead? false
      ]

 if (protectedarea-distance >= 4000 or  protectedarea-distance <= 5000) or  (corridor-distance >= 4000 or  corridor-distance <= 4000) or  (river-distance >= 2500 or river-distance <= 4000)
```



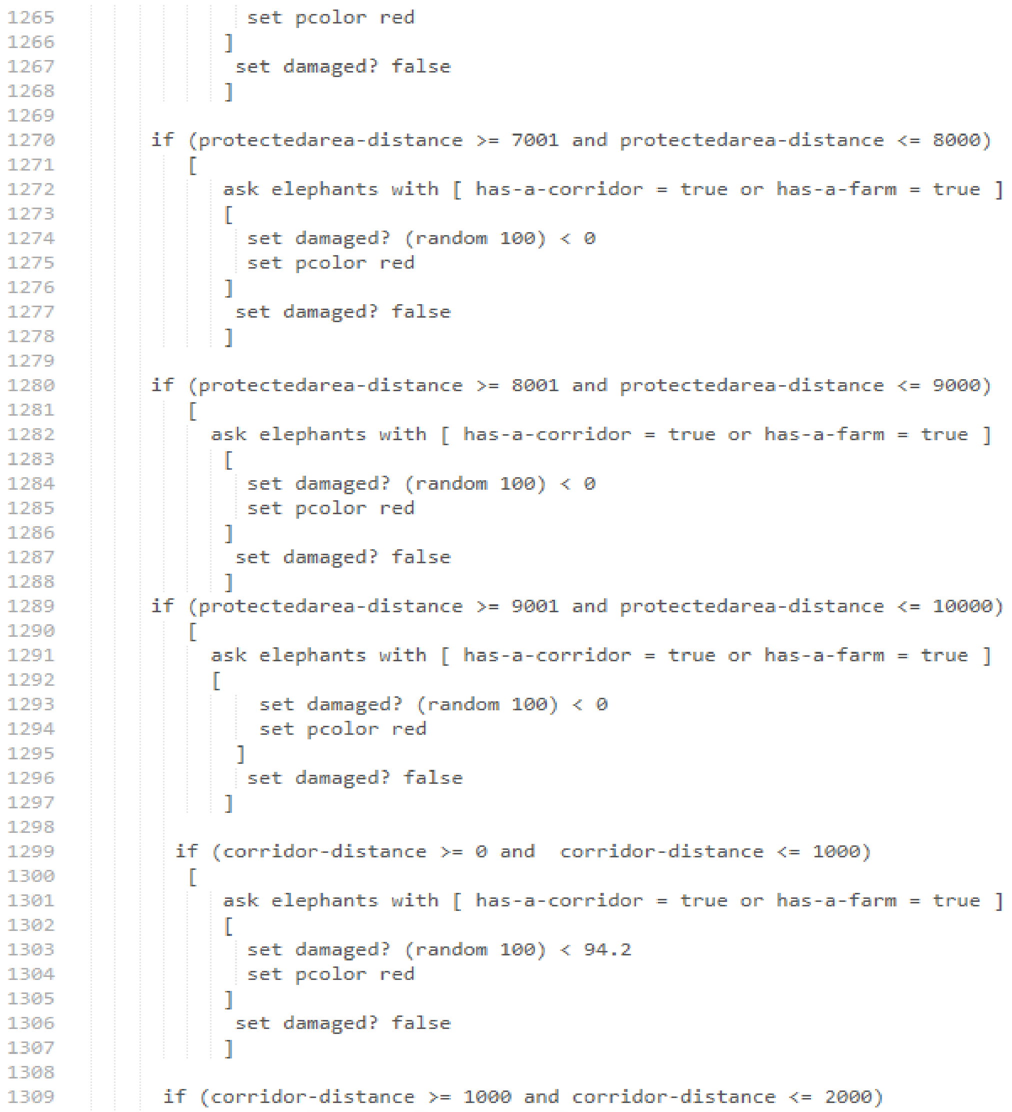
```
     [
        ask elephants with [ pcolor = red]
        [
          set  dead? (random 100) < 0.00000001
        ]
          set  dead? false
        ]

if (protectedarea-distance >= 5001 and  protectedarea-distance <= 6000) or  (corridor-distance >= 5001 and  corridor-distance <= 6000) or  (river-distance >= 5001 and  river-distance <= 6000)
     [
        ask elephants with [ pcolor = red]
        [
          set  dead? (random 100) < 0.000000000001
        ]
          set  dead? false
        ]

if (protectedarea-distance >= 6001 and  protectedarea-distance <= 7000) or  (corridor-distance >= 6001 and  corridor-distance <= 7000) or  (river-distance >= 6001 and river-distance <= 7000)
     [
        ask elephants with [ pcolor = red]
        [
          set  dead? (random 100) < 0
        ]
          set  dead? false
        ]

    if (protectedarea-distance >= 7001 and  protectedarea-distance <= 8000) or  (corridor-distance >= 7001 and  corridor-distance <= 8000) or  (river-distance >= 7001 and  river-distance <= 8000)
     [
        ask elephants with [ pcolor = red]
        [
          set  dead? (random 100) < 0
          set  dead? false
        ]

if (protectedarea-distance >= 8001 and  protectedarea-distance <= 9000) or  (corridor-distance >= 8001 and  corridor-distance <= 9000) or  (river-distance >= 8001 and  river-distance <= 9000)
```



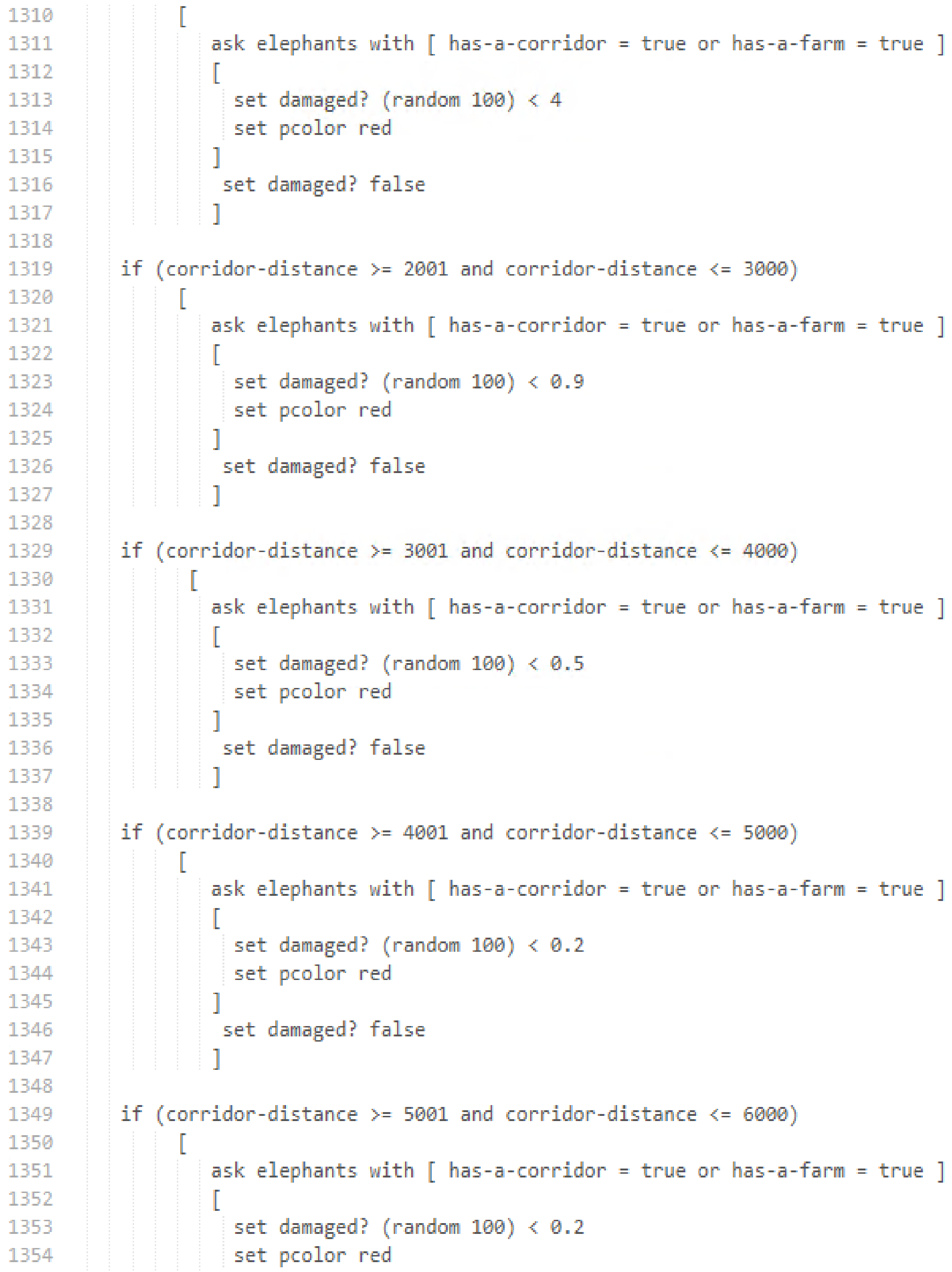
```
        [
          ask elephants with [ pcolor = red]
           [
             set  dead? (random 100) < 0
           ]
             set  dead? false
           ]

   if (protectedarea-distance >= 9001 and  protectedarea-distance <= 10000) or  (corridor-distance >= 9001 and  corridor-distance <= 10000) or  (river-distance >= 9001 and  river-distance <= 10000)
        [
          ask elephants with [ pcolor = red]
          [
             set  dead? (random 100) < 0
           ]
             set  dead? false
           ]
        ]
end

to crop-damage

       if (protectedarea-distance >= 0 or  protectedarea-distance <= 1000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 75.3
             set pcolor red
           ]
            set damaged? false
           ]

      if (protectedarea-distance >= 1000 and protectedarea-distance <= 2000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 9.1
             set pcolor red
           ]
            set damaged? false
           ]
```



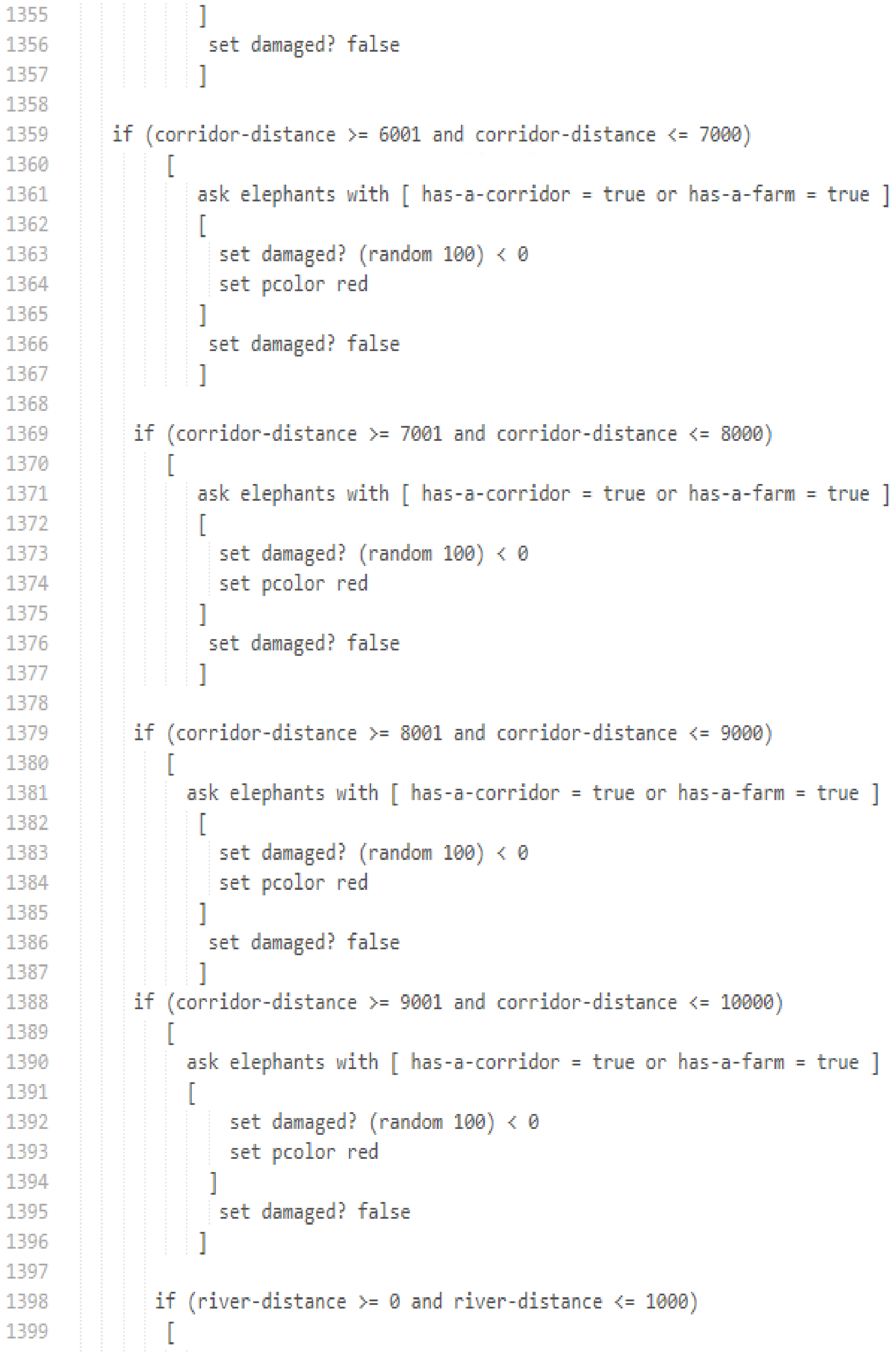
```

if (protectedarea-distance >= 2001 and protectedarea-distance <= 3000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 3.1
          set pcolor red
        ]
         set damaged? false
        ]

if (protectedarea-distance >= 3001 and protectedarea-distance <= 4000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 5.8
          set pcolor red
        ]
         set damaged? false
        ]

if (protectedarea-distance >= 4001 and protectedarea-distance <= 5000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 3.7
          set pcolor red
        ]
         set damaged? false
        ]

if (protectedarea-distance >= 5001 and protectedarea-distance <= 6000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.8
          set pcolor red
        ]
         set damaged? false
        ]

if (protectedarea-distance >= 6001 and protectedarea-distance <= 7000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.3
```



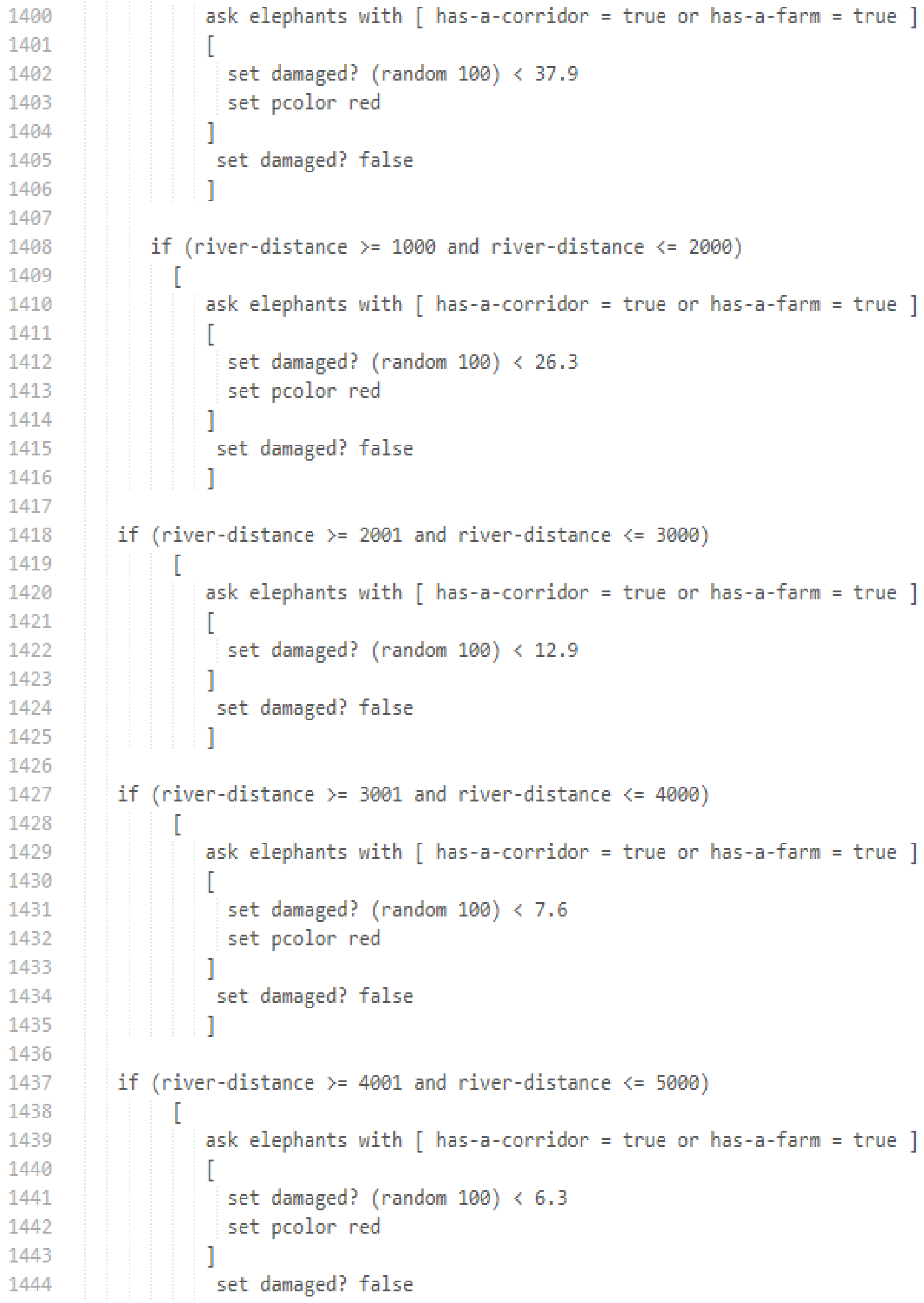
```
        set pcolor red
      ]
       set damaged? false
      ]

if (protectedarea-distance >= 7001 and protectedarea-distance <= 8000)
   [
      ask elephants with [ has-a-corridor = true or has-a-farm = true ]
      [
        set damaged? (random 100) < 0
        set pcolor red
      ]
       set damaged? false
      ]

if (protectedarea-distance >= 8001 and protectedarea-distance <= 9000)
   [
     ask elephants with [ has-a-corridor = true or has-a-farm = true ]
      [
        set damaged? (random 100) < 0
        set pcolor red
      ]
       set damaged? false
      ]
if (protectedarea-distance >= 9001 and protectedarea-distance <= 10000)
   [
     ask elephants with [ has-a-corridor = true or has-a-farm = true ]
     [
         set damaged? (random 100) < 0
         set pcolor red
       ]
        set damaged? false
      ]

  if (corridor-distance >= 0 and  corridor-distance <= 1000)
   [
      ask elephants with [ has-a-corridor = true or has-a-farm = true ]
      [
        set damaged? (random 100) < 94.2
        set pcolor red
      ]
       set damaged? false
      ]

 if (corridor-distance >= 1000 and corridor-distance <= 2000)
```



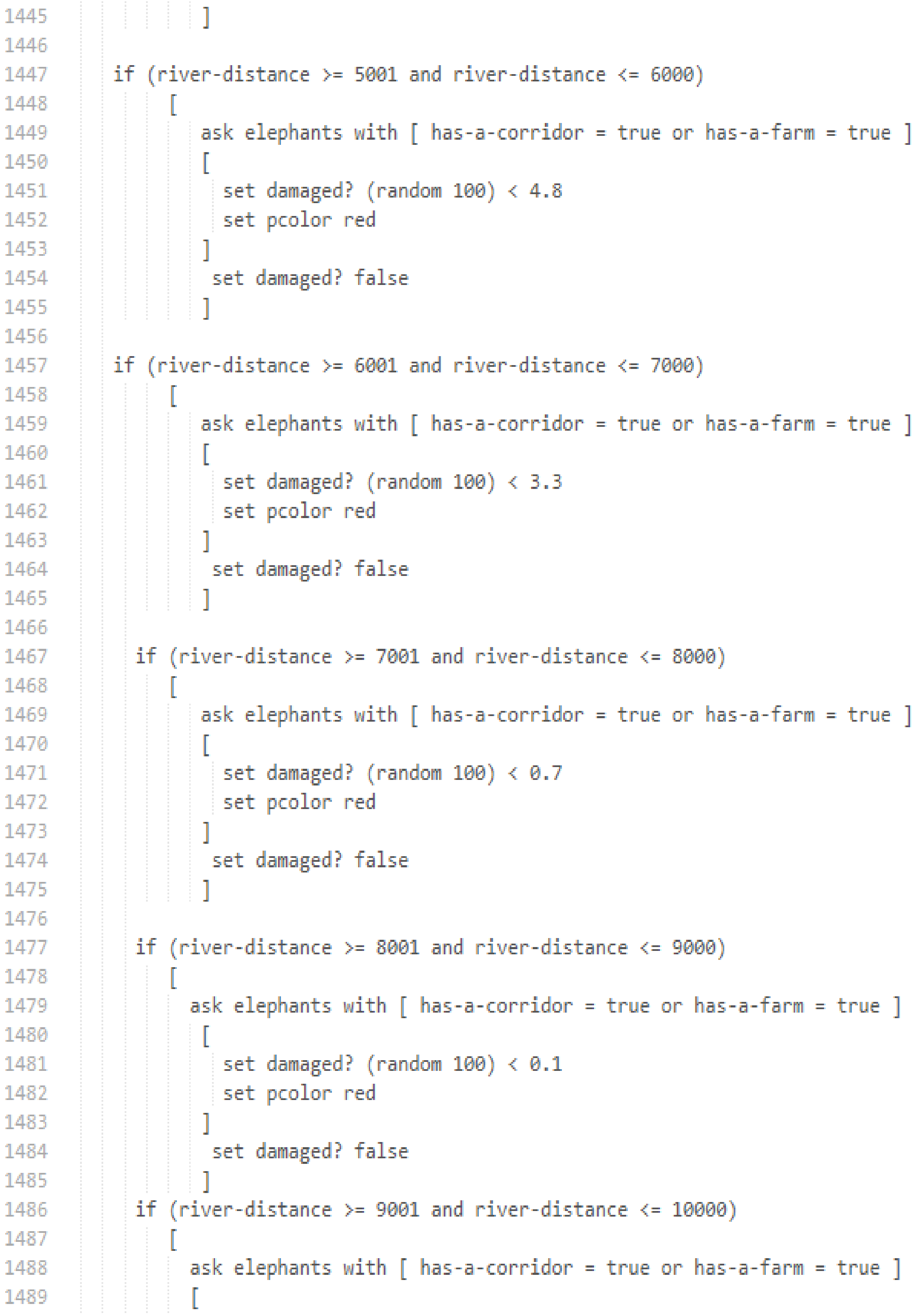
```
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 4
          set pcolor red
        ]
         set damaged? false
        ]

if (corridor-distance >= 2001 and corridor-distance <= 3000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.9
          set pcolor red
        ]
         set damaged? false
        ]

if (corridor-distance >= 3001 and corridor-distance <= 4000)
      [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.5
          set pcolor red
        ]
         set damaged? false
        ]

if (corridor-distance >= 4001 and corridor-distance <= 5000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.2
          set pcolor red
        ]
         set damaged? false
        ]

if (corridor-distance >= 5001 and corridor-distance <= 6000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.2
          set pcolor red
```



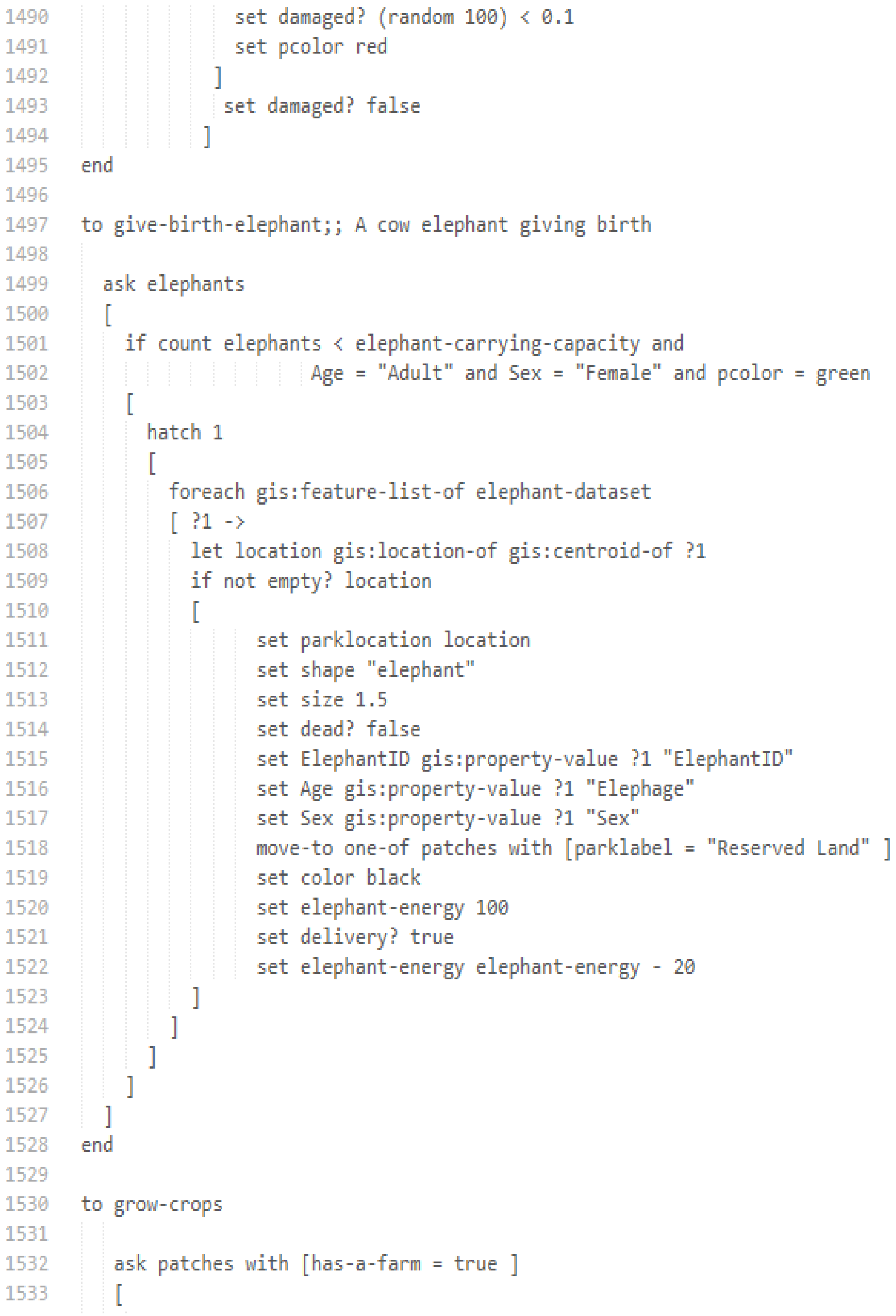
```
            ]
             set damaged? false
            ]

    if (corridor-distance >= 6001 and corridor-distance <= 7000)
         [
            ask elephants with [ has-a-corridor = true or has-a-farm = true ]
            [
              set damaged? (random 100) < 0
              set pcolor red
            ]
             set damaged? false
            ]

      if (corridor-distance >= 7001 and corridor-distance <= 8000)
         [
            ask elephants with [ has-a-corridor = true or has-a-farm = true ]
            [
              set damaged? (random 100) < 0
              set pcolor red
            ]
             set damaged? false
            ]

      if (corridor-distance >= 8001 and corridor-distance <= 9000)
         [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
            [
              set damaged? (random 100) < 0
              set pcolor red
            ]
             set damaged? false
            ]
      if (corridor-distance >= 9001 and corridor-distance <= 10000)
         [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
               set damaged? (random 100) < 0
               set pcolor red
             ]
              set damaged? false
            ]

        if (river-distance >= 0 and river-distance <= 1000)
         [
```



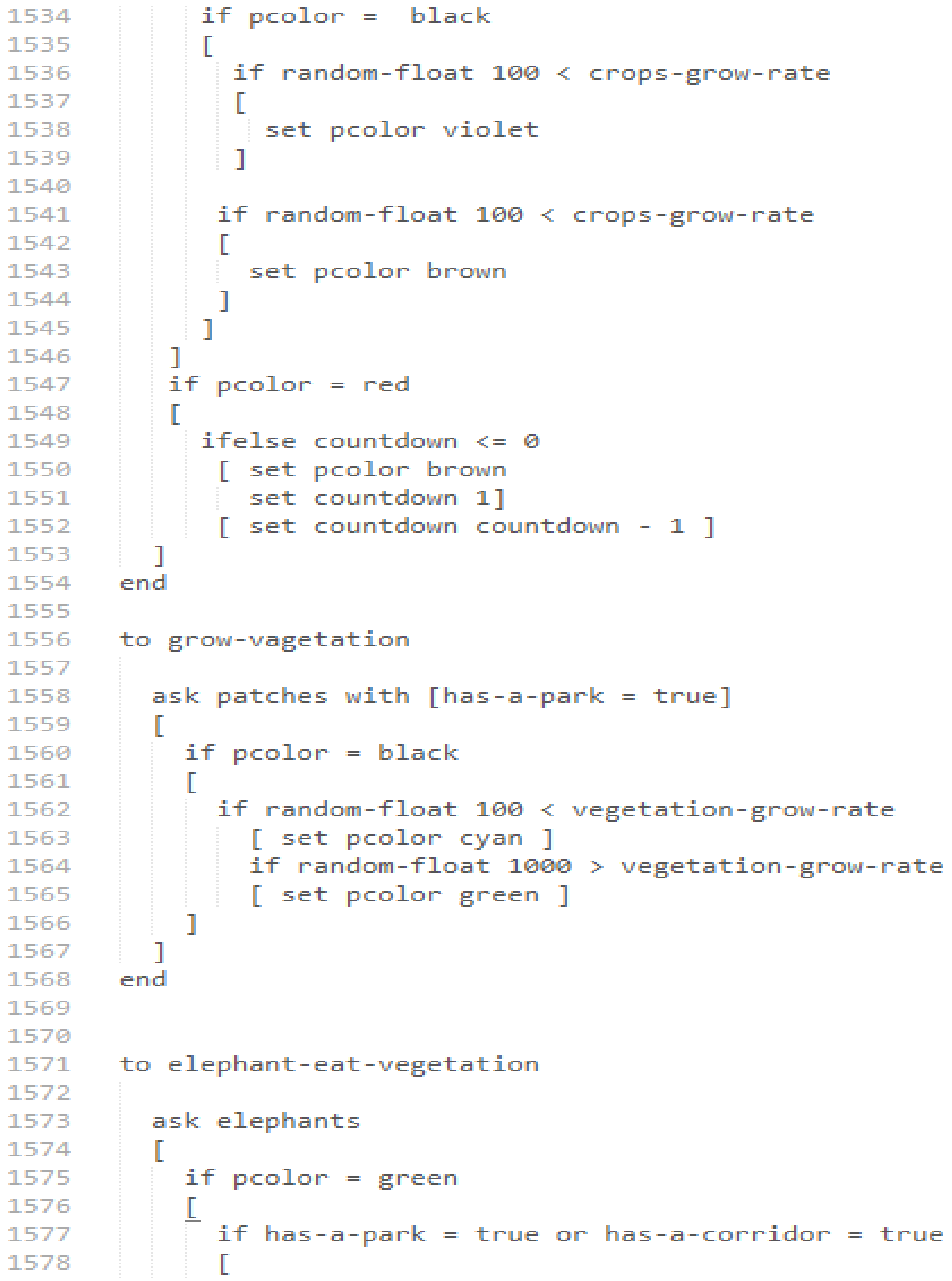
```
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 37.9
             set pcolor red
           ]
            set damaged? false
           ]

      if (river-distance >= 1000 and river-distance <= 2000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 26.3
             set pcolor red
           ]
            set damaged? false
           ]

   if (river-distance >= 2001 and river-distance <= 3000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 12.9
           ]
            set damaged? false
           ]

   if (river-distance >= 3001 and river-distance <= 4000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 7.6
             set pcolor red
           ]
            set damaged? false
           ]

   if (river-distance >= 4001 and river-distance <= 5000)
        [
           ask elephants with [ has-a-corridor = true or has-a-farm = true ]
           [
             set damaged? (random 100) < 6.3
             set pcolor red
           ]
            set damaged? false
```



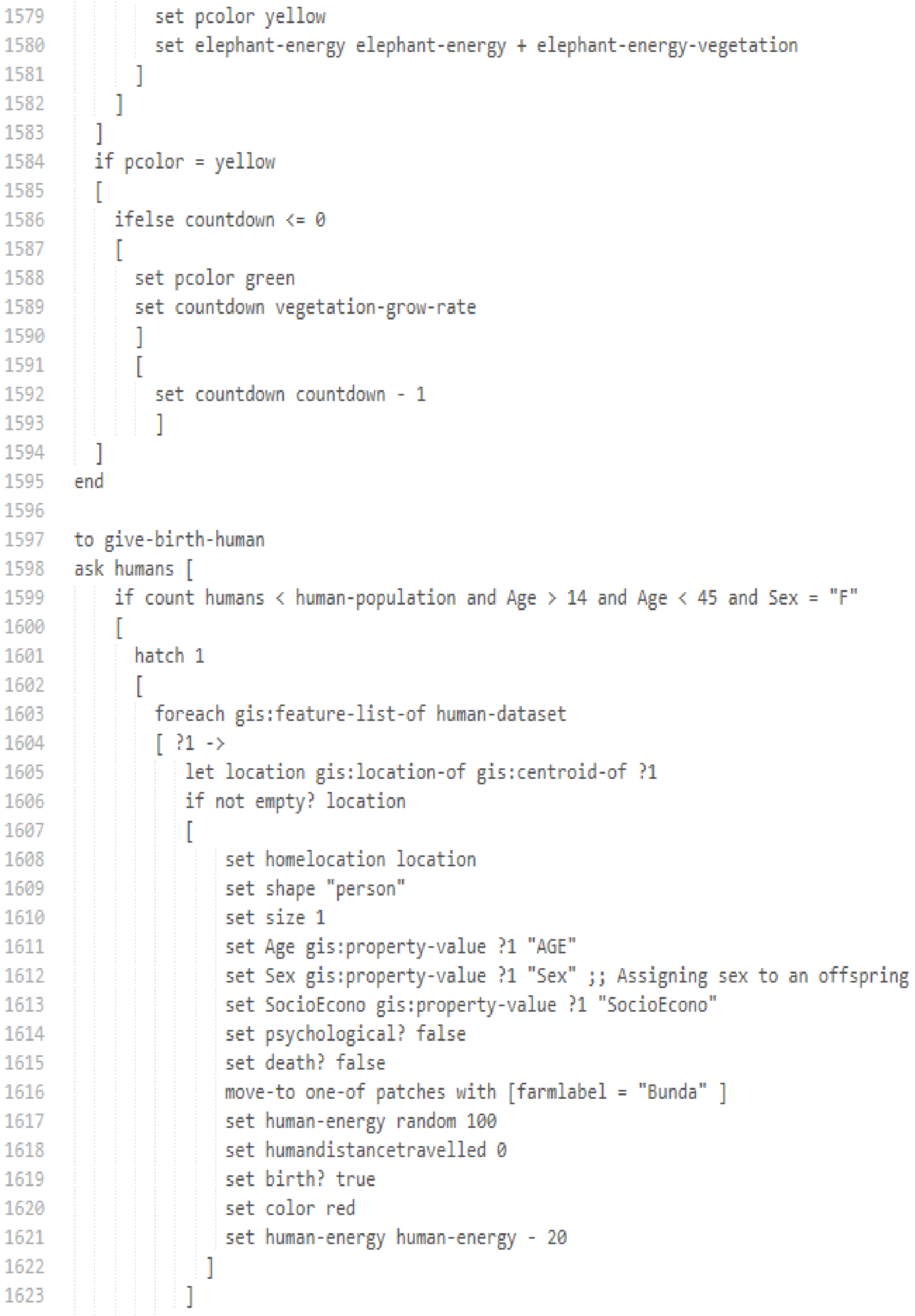
```
        ]

if (river-distance >= 5001 and river-distance <= 6000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 4.8
          set pcolor red
        ]
         set damaged? false
        ]

if (river-distance >= 6001 and river-distance <= 7000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 3.3
          set pcolor red
        ]
         set damaged? false
        ]

  if (river-distance >= 7001 and river-distance <= 8000)
     [
        ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.7
          set pcolor red
        ]
         set damaged? false
        ]

  if (river-distance >= 8001 and river-distance <= 9000)
     [
       ask elephants with [ has-a-corridor = true or has-a-farm = true ]
        [
          set damaged? (random 100) < 0.1
          set pcolor red
        ]
         set damaged? false
        ]
  if (river-distance >= 9001 and river-distance <= 10000)
     [
       ask elephants with [ has-a-corridor = true or has-a-farm = true ]
       [
```



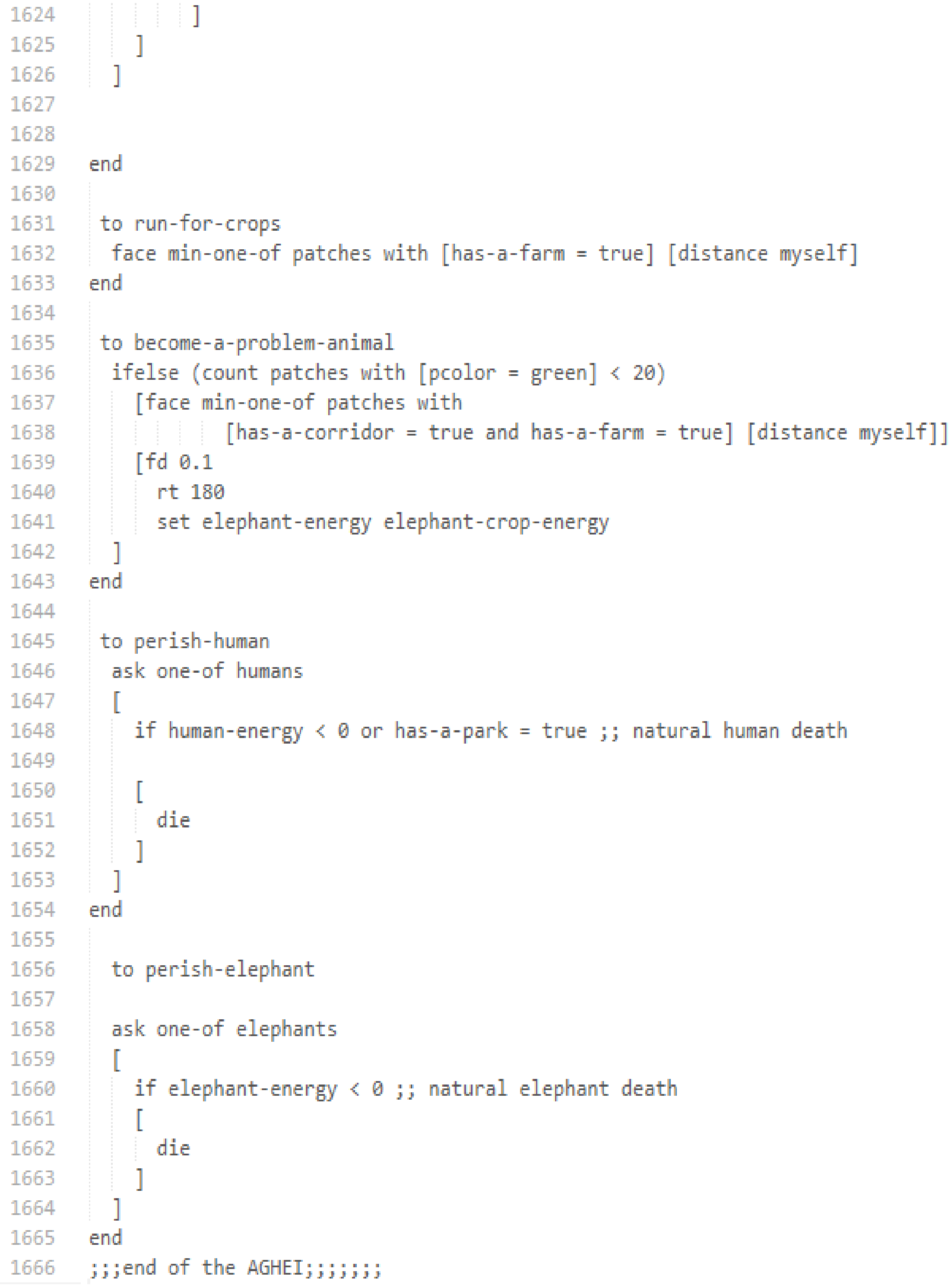
```
              set damaged? (random 100) < 0.1
              set pcolor red
            ]
             set damaged? false
           ]
end

to give-birth-elephant;; A cow elephant giving birth

  ask elephants
  [
    if count elephants < elephant-carrying-capacity and
                     Age = "Adult" and Sex = "Female" and pcolor = green
    [
      hatch 1
      [
        foreach gis:feature-list-of elephant-dataset
        [ ?1 ->
          let location gis:location-of gis:centroid-of ?1
          if not empty? location
          [
                set parklocation location
                set shape "elephant"
                set size 1.5
                set dead? false
                set ElephantID gis:property-value ?1 "ElephantID"
                set Age gis:property-value ?1 "Elephage"
                set Sex gis:property-value ?1 "Sex"
                move-to one-of patches with [parklabel = "Reserved Land" ]
                set color black
                set elephant-energy 100
                set delivery? true
                set elephant-energy elephant-energy - 20
          ]
        ]
      ]
    ]
  ]
end

to grow-crops

   ask patches with [has-a-farm = true ]
   [
```



```
     if pcolor =  black
     [
       if random-float 100 < crops-grow-rate
       [
         set pcolor violet
       ]

      if random-float 100 < crops-grow-rate
      [
        set pcolor brown
      ]
     ]
   ]
   if pcolor = red
   [
     ifelse countdown <= 0
      [ set pcolor brown
        set countdown 1]
      [ set countdown countdown - 1 ]
  ]
end

to grow-vagetation

  ask patches with [has-a-park = true]
  [
    if pcolor = black
    [
      if random-float 100 < vegetation-grow-rate
        [ set pcolor cyan ]
        if random-float 1000 > vegetation-grow-rate
        [ set pcolor green ]
    ]
  ]
end


to elephant-eat-vegetation

  ask elephants
  [
    if pcolor = green
    [
      if has-a-park = true or has-a-corridor = true
      [
```



```
        set pcolor yellow
        set elephant-energy elephant-energy + elephant-energy-vegetation
      ]
    ]
  ]
  if pcolor = yellow
  [
    ifelse countdown <= 0
    [
      set pcolor green
      set countdown vegetation-grow-rate
      ]
      [
        set countdown countdown - 1
        ]
  ]
end

to give-birth-human
ask humans [
    if count humans < human-population and Age > 14 and Age < 45 and Sex = "F"
    [
      hatch 1
      [
        foreach gis:feature-list-of human-dataset
        [ ?1 ->
           let location gis:location-of gis:centroid-of ?1
           if not empty? location
           [
               set homelocation location
               set shape "person"
               set size 1
               set Age gis:property-value ?1 "AGE"
               set Sex gis:property-value ?1 "Sex" ;; Assigning sex to an offspring
               set SocioEcono gis:property-value ?1 "SocioEcono"
               set psychological? false
               set death? false
               move-to one-of patches with [farmlabel = "Bunda" ]
               set human-energy random 100
               set humandistancetravelled 0
               set birth? true
               set color red
               set human-energy human-energy - 20
             ]
           ]
```



```
         ]
    ]
  ]


end

 to run-for-crops
  face min-one-of patches with [has-a-farm = true] [distance myself]
end

 to become-a-problem-animal
  ifelse (count patches with [pcolor = green] < 20)
    [face min-one-of patches with
            [has-a-corridor = true and has-a-farm = true] [distance myself]]
    [fd 0.1
      rt 180
      set elephant-energy elephant-crop-energy
  ]
end

 to perish-human
  ask one-of humans
  [
    if human-energy < 0 or has-a-park = true ;; natural human death

    [
      die
    ]
  ]
end

  to perish-elephant

  ask one-of elephants
  [
    if elephant-energy < 0 ;; natural elephant death
    [
      die
    ]
  ]
end
;;;end of the AGHEI;;;;;;;
```