Environmental Challenges 9 (2022) 100625

Contents lists available at ScienceDirect

Environmental Challenges

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

Assessing protected area networks in the conservation of elephants (Elephas Maximus) in Sri Lanka

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ARTICLE INFO

Keywords:
Human–elephant conflict
Protected area
Fragmentation
Land use land cover change
Asian elephant (*Elephas maximus*)
Sri Lanka

ABSTRACT

Protected areas play a crucial role in the conservation and management of wildlife, but land use and land cover change (LULCC) threatens the status of protected areas. Sri Lanka has a history of severe human–elephant conflict (HEC). In the last 15 years, Sri Lanka has recorded the highest mortality of elephants and the second-highest human casualties among countries where the Asian elephant is native. In this study, we conducted a whole of country analysis of the effect of LULCC on protected areas using a land cover change map (1993–2018) recently developed by the authors using Landsat satellite data. Protected area performances were measured using five criteria including LULCC, the protected areas, and categorised into three performance levels. The protected area performances were then compared with number of HEC incidents. We found that 12% of Sri Lanka's protected area was affected by LULCC events, and every individual protected area experienced LULCC. We also found that 86% of elephant death incidents occurred within a 5 km radius of protected areas, with a strong negative correlation with distance from protected areas ($r = -0.94$, $p < 0.05$). Some 43% of HEC incidents and 23% of elephant deaths occurred inside protected areas, while 40% of elephant deaths in the last two years occurred inside protected areas. These areas were also found to fragment over time and elephant deaths increased, and showed a strong positive correlation, with fragmentation ($r = 0.88$, $p < 0.05$). Wildlife regions that experienced higher LULCC also experienced a greater number of elephant deaths, with a moderately positive correlation ($r = 0.54$, $p < 0.05$). Irrespective of the level of performance, all protected areas reported elephant deaths as well as HEC incidents, indicating that protected areas are failing to protect the endangered *Elephas maximus* population in Sri Lanka. These country-wide insights into protected areas can be used to re-evaluate the function and effectiveness of protected areas in managing and mitigating HEC while providing protection to elephants in Sri Lanka.

1. Introduction

1.1. Human-Wildlife Conflict and Habitat Loss

Human–wildlife conflict (HWC) has become a serious concern in a number of nations as a result of the loss of natural vegetative cover (Gara et al., 2017; Haddad et al., 2015; Liu et al., 2017; Padalia et al., 2019; Sharma et al., 2017; Sharma et al., 2019). Conversion, modification, and fragmentation of the earth's natural areas (or Land Use and Land Cover Change (LULCC)) due to exponential human population growth and widespread demand for land and other natural resources have substantially altered wildlife habitat shape (Gara et al., 2017; Köpke et al., 2021; Padalia et al., 2019; Santini et al., 2016; Sharma et al., 2020), resulting in wildlife being increasingly confined to small and sparse habitat fragments.

This loss of habitat has a variety of negative consequences, including isolated small populations, a high probability of human–wildlife conflict, increased vulnerability to environmental change, and even local extinctions (Acharya et al., 2017; Santini et al., 2016) al., 2016). When LULCC extends into the habitats of mega herbivores such as elephants, which require a significantly larger area to roam for their daily needs, this conflict becomes more complex (Jadhav et al., 2012; Sukumar, 2006).

1.2. Human-Elephant Conflict in Sri Lanka

The conflict between humans and elephants, commonly referred to as human–elephant conflict (HEC), is a prominent example of human–wildlife conflict (Köpke et al., 2021; Talukdar et al., 2020). HEC is not new, but in recent years has become a key environmental issue in elephant range countries, particularly in Asia (Chartier et al., 2011;

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https://doi.org/10.1016/j.envc.2022.100625
Received 23 June 2022; Received in revised form 28 September 2022; Accepted 28 September 2022

Choudhury et al., 2008; Riddle et al., 2010a; Sukumar, 2006) due to high population pressure and heterogonous landscapes.

Asian elephants (*Elephas maximus*) were declared an endangered species in 2008 due to continuous threats to elephant habitat in the region (Choudhury et al., 2008; IUCN, 2008; Sukumar, 2006). The original estimated Asian elephant habitat of 9 million km^2 had declined to 500,000 km^2 by 2003 (Sukumar, 2003). This loss of elephant habitat has driven elephants into contact with humans, particularly in cultivated areas (Jadhav et al., 2012). Conflicts often arise when people retaliate against elephants that feed on crops, damage property or destroy cultivation (Chartier et al., 2011; Shaffer et al., 2019; Sukumar, 2006).

Sri Lanka contains approximately 10% of the global Asian elephant population, and 2% of the Asian elephant range (IUCN, 2008). The last elephant census undertaken by the department of wildlife conservation in 2011 revealed that there were 5,879 elephants living in the area (DWC, 2013). There is elephant habitat in approximately 60% of Sri Lanka, and the reported incidence of HEC occurs within these same regions (Fernando et al., 2019). Sri Lanka reports the highest number of elephant deaths and the second-highest number of HEC-related human deaths after India (Prakash et al., 2020; Santiapillai et al., 2010). In 2019 and 2020, annual reported elephant deaths due to HEC exceeded 400 for the first time (in 2019 there were 405 elephant deaths; in 2020 there were 407 elephant deaths). Additionally, annual human deaths as a result of HEC surpassed 100, the largest number in the last 50 years. Alongside these mortalities, the frequency of property damage, crop raids, and human–elephant injury have also increased dramatically over the last decade (Choudhury et al., 2008; Fernando et al., 2011a; Köpke et al., 2021; Prakash et al., 2020; Santiapillai., 2013).

1.3. Protected Areas

In response to considerable biodiversity loss, the number and extent of protected areas have increased substantially over the last few decades, and now cover 14.5% of global terrestrial land (Watson et al., 2014). This recent expansion is closely related to the Aichi Biodiversity Target 11 (Convention on Biological Diversity [CBD]), which required that 17% of terrestrial land be effectively managed, ecologically representative protected areas by 2020 (Jones et al., 2018), a target that was not reached. The International Union for Conservation of Nature (IUCN) defines protected areas as “a clearly defined geographical space, recognised, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (IUCN, 2013). In addition to biodiversity conservation, protected areas provide a variety of other services, such as watershed protection and carbon storage, and intangible benefits such as recreation and spiritual fulfilment. But increasingly, protected areas are becoming the primary line of defence against biodiversity loss and wildlife extinction across the world (Dudley et al., 2014; Jones et al., 2018; Roever et al., 2013).

As a nation guided by the CBD guidelines, Sri Lanka has made policy decisions over the last two decades to increase its total protected area extent to meet the requirement of 17% of total territorial extent. Sri Lanka experienced a protracted civil war from 1980 to 2009, and the subsequent war-free environment has brought enhanced infrastructure development, expansion of farming land, resettlement, and population redistribution. Consequently, nationwide LULCC events have significantly increased, with a greater number in the northern and eastern parts of the country where the civil war had the greatest impact (Mapa et al., 2002; Rathnayake et al., 2020). In response to this post-war LULCC, since 2010 Sri Lanka has expanded its total protected area extent at a greater rate than previously by adding scattered forest areas as protected area. As of 2020, 660 protected areas had been declared, covering at least 29.86% of Sri Lanka’s total land surface area. However, it is still debatable whether Sri Lanka’s protected areas contribute enough to the conservation of biodiversity or elephant habitat, or the management of HEC.

1.4. Aims and Objectives

The purpose of the research is to determine whether Sri Lanka’s protected area network contributes to the conservation of the endangered Asian elephant population in the country. We specifically intended to (a) quantify the annual change in and around protected areas caused by LULCC from 1994 to 2018; (b) investigate the spatial proximity of HEC and elephant death incidents to protected areas; (c) identify protected area performance levels using LULCC, fragmentation, and human footprint data, and compare these with HEC incidents, with a special focus on elephant deaths; and (d) conduct two case studies to investigate these metrics in the highest HEC reporting wildlife regions in Sri Lanka.

2. Materials and Methods

2.1. Study Area

As shown in Fig. 1, the study area encompasses all terrestrial protected areas in Sri Lanka’s HEC Region. The HEC Region, as defined by Sri Lanka’s Department of Wildlife Conservation (DWC), is the area in which elephant habitat and HEC coexist. The HEC Region comprises ten of the eleven wildlife regions in Sri Lanka: Southern, Uva, Ampara, Central, Polonnaruwa, Anuradhapura, North Western, Kilinochchi, Trincomalee, and Vavuniya. All terrestrial protected areas in Sri Lanka’s HEC Region were retrieved using the most recent available data (2020) from the World Database on Protected Areas (WDPA) (UNEP-WCMC, 2020). The HEC Region contains 437 protected areas, varying in size from 2 to 90,000 hectares, comprising 60% of Sri Lanka’s total protected area.

The proportion of protected areas in the HEC Region of Sri Lanka has increased substantially over the past three decades. Most of the protected area extent declared in the past two decades (2000–2020) is distributed in the northern part of the HEC Region, with some in southern and eastern regions. Protected areas proclaimed from 1980 to 2000 are distributed in the central part of the HEC Region. Protected areas declared before the 1980s are scattered throughout the HEC Region.

2.2. Data

To examine the role of the protected area network in elephant conservation in Sri Lanka, we used three key datasets: HEC incidents collected by the Sri Lankan DWC (obtained under the *Right to Information Act 2016*); protected area data extracted from the WDPA (UNEP-WCMC, 2020); and LULCC data derived from the Landsat satellite image archive (Rathnayake et al., 2020).

2.2.1. Human–Elephant Conflict Data

In Sri Lanka, DWC is the custodian of reported HEC incidents. HEC data are reported in four major categories: (a) human death; (b) human injury; (c) property damage (e.g., to houses, crops) available beginning in 2003; and (d) elephant deaths. These data have been documented with address information from 2003, including village, city, division name, and district, as well as the date (or year) of the incident. However, over the last three to four years, as the DWC began to use global positioning systems, the reporting of elephant and human deaths has become more accurate. DWC has reported more than 19,700 of all four types of HEC incidents during the last 17 years, beginning in 2003 (DWC, 2018). Although HEC incidents had been reported prior to 2003 (from 1990), they were aggregated and published for wildlife regions without their actual locations. As a result, this study relied on HEC data from 2003 onwards.

2.2.2. Protected Areas

All terrestrial protected areas in Sri Lanka’s HEC region were retrieved from the most recent updated (2021) version of the WDPA (UNEP-WCMC, 2021). More than 60% of protected areas were established after 2010. Some protected areas that were also designated as

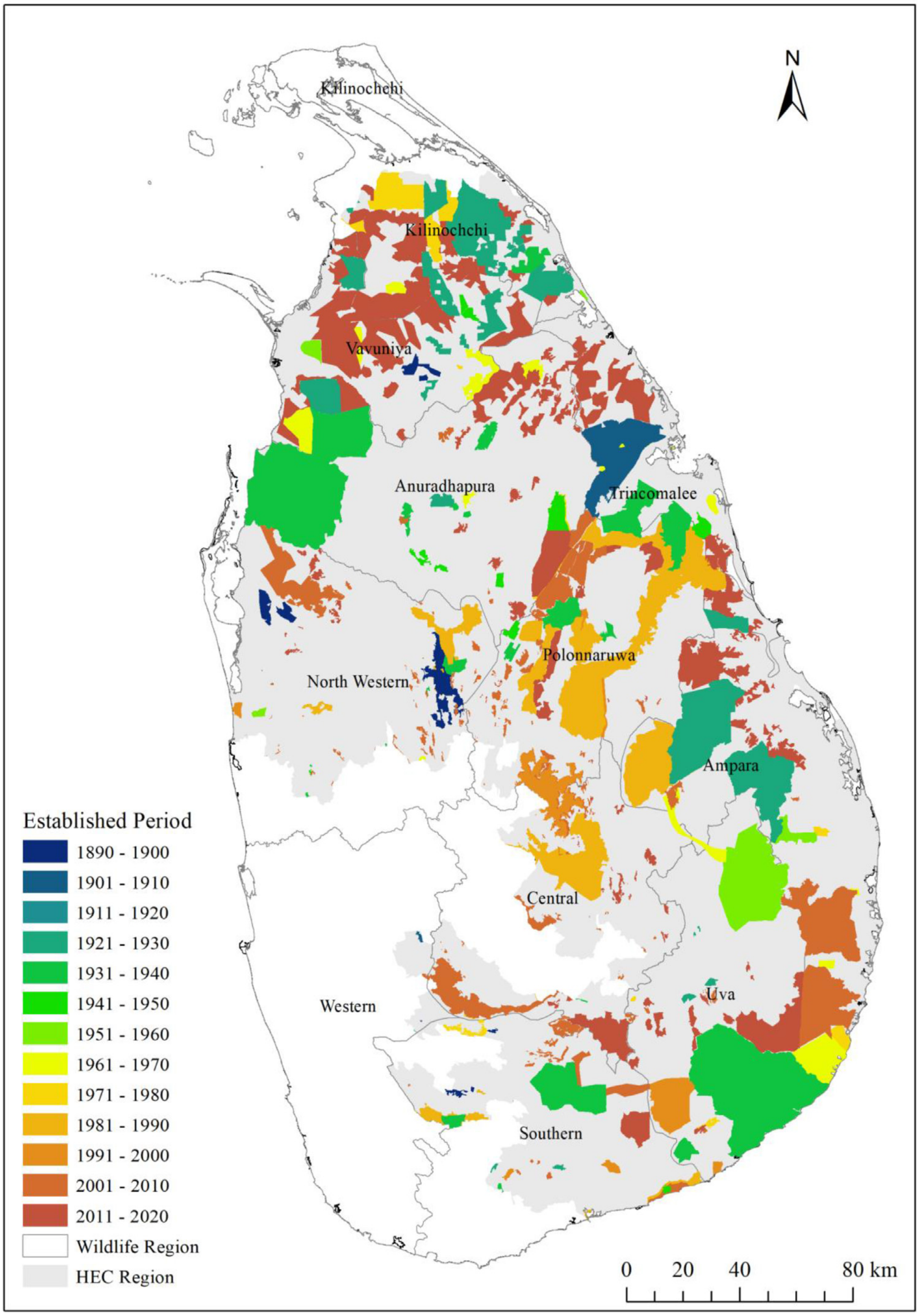


Fig. 1. Study area, showing HEC Region based on HEC data from Sri Lanka DWC (grey areas), and protected areas categorised according to period of establishment (graduated colour).

man and biosphere reserves and world heritage sites were excluded from the study.

2.2.3. LULCC Data

Landsat time-series data spanning the period from 1993 to 2018 were used to produce a Sri Lanka–wide LULCC map. All available Landsat TM (Thematic Mapper), ETM+ (Enhanced Thematic Mapper Plus), and OLI (Operation Land Manager) surface reflectance products from 1 January to 31 December for the years 1988–2018 were gathered from the USGS data repository to construct this LULCC map (Masek et al., 2006; Masek et al., 2020). To build annual composites, a total of 4,440 Landsat images spanning Sri Lanka's nine Landsat tiles were used for the period. The LandTrendr (Kennedy et al., 2015; Kennedy et al., 2010) change detection algorithm was used to extract spectral trajectories, which were then used as input for a random forest model with a reference dataset of over 2,000 reference pixels to create a map depicting areas where LULCC had occurred, with an overall accuracy of 94% (Rathnayake et al., 2020).

2.3. Data Processing and Analysis

2.3.1. Protected Area Performance

Protected areas were classified based on their performance. Five criteria were used to evaluate the performance of protected areas: total LULCC within protected areas, human footprint index, effective mesh size, Euclidian nearest neighbour distance, and perimeter area ratio.

Each criterion was given equal weight, and depending on the overall score, protected areas were classified as low, moderate, or high. The above-mentioned number of elephant deaths in and around protected areas were then compared to protected area performance.

2.3.2. Protected Area Fragmentation

To quantify the degree of fragmentation of protected areas caused by LULCC, the following statistics on landscape level fragmentation were calculated using four neighbour cell connections (rook case). Fragstats (version 4.2) was used to calculate fragmentation statistics (McGarigal and Cushman, 2012). To provide a sufficient period to observe the temporal patterns of fragmentation, we assumed that all of the protected areas were linked together over the study period.

i Number of Patches

The total number of patches in a landscape is a fundamental fragmentation criterion that is used to describe patchiness in a landscape. A correlation analysis was performed to determine the relationship between the annual number of elephant deaths and the number of patches.

i Mean Patch Size and Standard Deviation of Patch

Patch size is another main index to investigate the size change of patches over time, with variation in patch size described by the standard deviation (SD) of patch size.

Patch mean (MN) is the sum of the corresponding patch metric values across all patches in the landscape, divided by the total number of patches. MN is expressed in the same units as the patch metric. Patch SD equals the square root of the sum of the squared deviations of each patch metric value from the mean metric value computed for all patches in the landscape, divided by the total number of patches. That is, the root mean squared error (deviation from the mean) in the corresponding patch metric.

2.3.3. LULCC in Protected Areas and Wildlife Regions

For the study period, the total LULCC for each protected area and wildlife region was estimated. The number of elephant deaths in each wildlife region was then examined to see if there was an association between the degree of change and the number of events. Performing wildlife area-based analyses significantly aids the DWC in making decisions related to wildlife management. The Vavuniya and Kilinochchi wildlife regions were excluded from this analysis because of incomplete data (HEC reporting began there only recently, in 2010, following the civil war that lasted nearly three decades). Based on this information as well as the protected area, the two wildlife regions with the highest number of elephant deaths and HEC incidents were chosen as case studies, and the results are presented accordingly.

2.3.4. Proximity of HEC and Protected Areas

The distance between elephant death locations and protected areas was calculated separately using three methods: first, incidents occurring within protected areas were extracted using the point count on polygon method; second, all elephant deaths occurring outside protected areas were extracted using a 5 km buffer and aggregated with the incidents occurring inside the protected areas. Finally, the distance between each elephant death incident was determined using ArcMap's 'near' distance tool. The number of occurrences was then classified into 1 km increments up to the 5th km, with all further incidents being assigned to a single distance class.

2.3.5. Elephant Death Density Hotspots and Protected Areas

Kernel density estimation was used to create density maps for each type of HEC incident. The density maps were then compared to the distribution of protected areas in order to discover their spatial distribution. The Pearson correlation coefficients between elephant death density and human death, human injury, and property damage were then calculated to determine their correlation. The density was calculated as number of incidents per km^2. Case Study 1 was selected for further examination based on these areas having the highest density of elephant deaths and HEC.

2.3.6. LULCC and HEC Before and After

To investigate the impact of protected areas in managing HEC in Sri Lanka, we compared LULCC and HEC in protected areas declared after 2010. Post-2010, 171 protected areas were declared in the HEC region. To evaluate the impact of the protected status, the cumulative LULCC change from 1994 to 2009 (pre-2010) and 2010 to 2018 (post-2010) was estimated. The total HEC for each time period was also computed annually. These findings are presented in Case Study 2.

3. Results

3.1. Protected Areas LULCC

More than 400 protected areas covering 2,115,520 ha are included within Sri Lanka's HEC region. Over the past 27 years, 12% (250,000 ha) of these protected areas have experienced LULCC activities. Approximately 30% of the changes occurred in two periods: 2000–2004 and 2009–2014, measuring 48,000 ha (19%) and 30,000 ha (11%) respectively. Fewer LULCC events were reported during the earlier periods of 1993–1998 and 1999–2003. LULCC in the 5 km buffer zone of protected areas also showed similar patterns and trends (Fig. 2).

The severity of LULCC impacts in protected areas varies, as illustrated in Fig. 3. From 1994 to 2018, all protected areas in the HEC region experienced some level of LULCC, with a mean change rate of 9%. There were 184 (42%) protected areas that experienced less than 5% change, 97 (22%) that experienced 5–10% change, 115 (26%) that experienced 10–20% change, and 36 (8%) that experienced 20–40% change. Four protected areas (Kokilai, Ambakola Kanda, Nawaneliya Beligoda, Ulugala) changed by more than 40%, although these account for less than 1% of the total number of protected areas. Appendix 1 summarizes the total area of change in protected areas.

LULCC has had considerable impact on wildlife regions over the past 27 years. LULCC in protected areas was found to be high in the Vavuniya wildlife region (16%), followed by Ampara and Uva (each 15%), Kilinochchi (13%), and Anuradhapura, North Western and Polonnaruwa (each 10%). The lowest rates of LULCC impact were reported in the Central and Southern regions (6%) (Table 1). A strong positive correlation ($r = 0.54$, $p < 0.05$) was observed between number of elephant deaths and rate of LULCC, while a weak positive correlation ($r = 0.21$, $p < 0.05$) was observed between total number of HEC incidents and LULCC (as explained in section 2.3.3, Kilinochchi and Vavuniya were excluded from this analysis).

Fig. 4 shows annual elephant death incidents versus number of patches, as well as a scatter plot of the number of elephant deaths versus number of patches. The total number of patches increased in every period where intense LULCC events occurred. Considering all protected areas in the HEC region, it can be seen that the number of patches has increased since 2000 and has risen rapidly since 2010 (Fig. 4a). The mean patch size dropped substantially in the period between 1994 and 2004, before stabilising after 2005 (Fig. 4b). The variation in mean patch size was also higher during 2000–2004 and became much more stable after 2006 (Fig. 4b). We observed that the total number of HEC and the number of elephant deaths increased as the total number of patches increased due to LULCC in the HEC region. The Pearson r coefficient between elephant deaths and the number of patches was 0.88, $p < 0.05$ (Fig. 4c).

3.2. HEC In and Around Protected Areas

In our study, we found that nationally, 14% (3,039 incidents) of total reported HEC incidents and 23% (783) of elephant deaths occurred within protected areas. The last two years of DWC elephant death

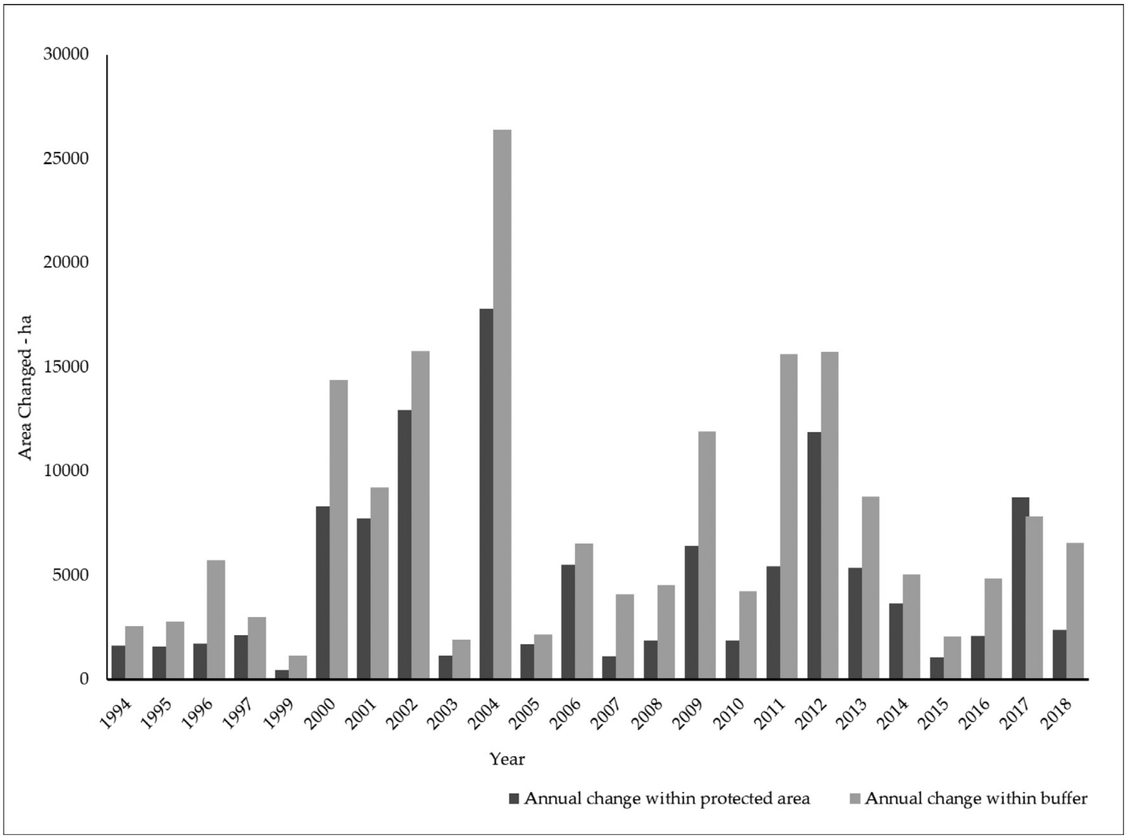


Fig. 2. Annual LULCC within Sri-Lanka's protected areas (dark grey) and LULCC within a 5 km buffer zone surrounding the protected areas (light grey).

Table 1
Distribution of protected area change in wildlife regions and number of elephant deaths and total number of HEC incidents.

Region	Protected area change (%)	Protected area extent (%)	Unprotected area change (%)	Elephant death incidents	Total HEC incidents
Vavuniya	16	49	16	159	202
Ampara	15	47	12	597	3,630
Uva	15	44	9	343	1,803
Kilinochchi	13	39	17	38	51
Trincomalee	11	54	15	355	966
Anuradhapura	10	30	11	502	1,937
North Western	10	21	8	334	2,969
Polonnaruwa	10	45	8	633	4,452
South	6	13	7	294	1,718
Central	6	18	9	123	2,018

records indicate that more than 40% of elephant death incidents occurred within protected areas, which is higher than ever before.

Fig. 5 depicts the location of total incidents of elephant deaths reported from 2008 to 2020, as well as the density of elephant deaths that occurred within the protected area and the 5 km buffer zone. Appendix 2 illustrates the total number of elephant deaths that occurred within protected areas and within the 5 km buffer zone. Elephant deaths are more likely to be reported close to protected areas (86%, 2,918). The number of incidents is very high where there are proximal protected areas. There was a clear relationship between the size of the protected area and the number of incidents reported, with larger areas reporting 50–100 incidents. Protected areas in the northern part of the HEC region typically reported 10–25 cases because they are relatively smaller. Many protected areas throughout the HEC region reported more than 50 elephant death incidents and average elephant death density is 0.12 per km^2.

As demonstrated in Table 2, the highest number of all types of HEC incidents occurred closer to protected areas (7,311, within the first kilometre).The number of incidents and the distance from the protected area therefore show a strong negative correlation ($r = -0.94$, $p < 0.05$). Some 84% (16,573) of total HEC incidents were within a 5 km radius of protected areas while 14% were located beyond 5 km. Of the closer incidents, 37% occurred within a 1 km radius, followed by 16% within 1–2 km, 14% within 2–3 km, 13% within 3–4 km, 10% within 4–5 km and 8% in the zone beyond the 5th km.

Elephant deaths followed a similar trend to total HEC, except that a greater percentage (48%) of deaths occurred within the first 1 km, followed by 16%, 9%, 7%, and 6% within 2, 3, 4, and 5 km, respectively. When the distance increased, elephant death events decreased significantly ($r = -0.86$, $p < 0.05$); 86% (2,918) of elephant deaths occurred within the 5 km zone, whereas just 14% occurred outside the 5 km zone.

According to kernel density estimation and as shown in Fig. 6, elephant death hotspots were recorded both within and outside protected areas. This trend was particularly noticeable in the Polonnaruwa, Anuradhapura, Trincomalee, Ampara and Southern wildlife regions, which have a high number of elephant deaths. Human deaths and human in-

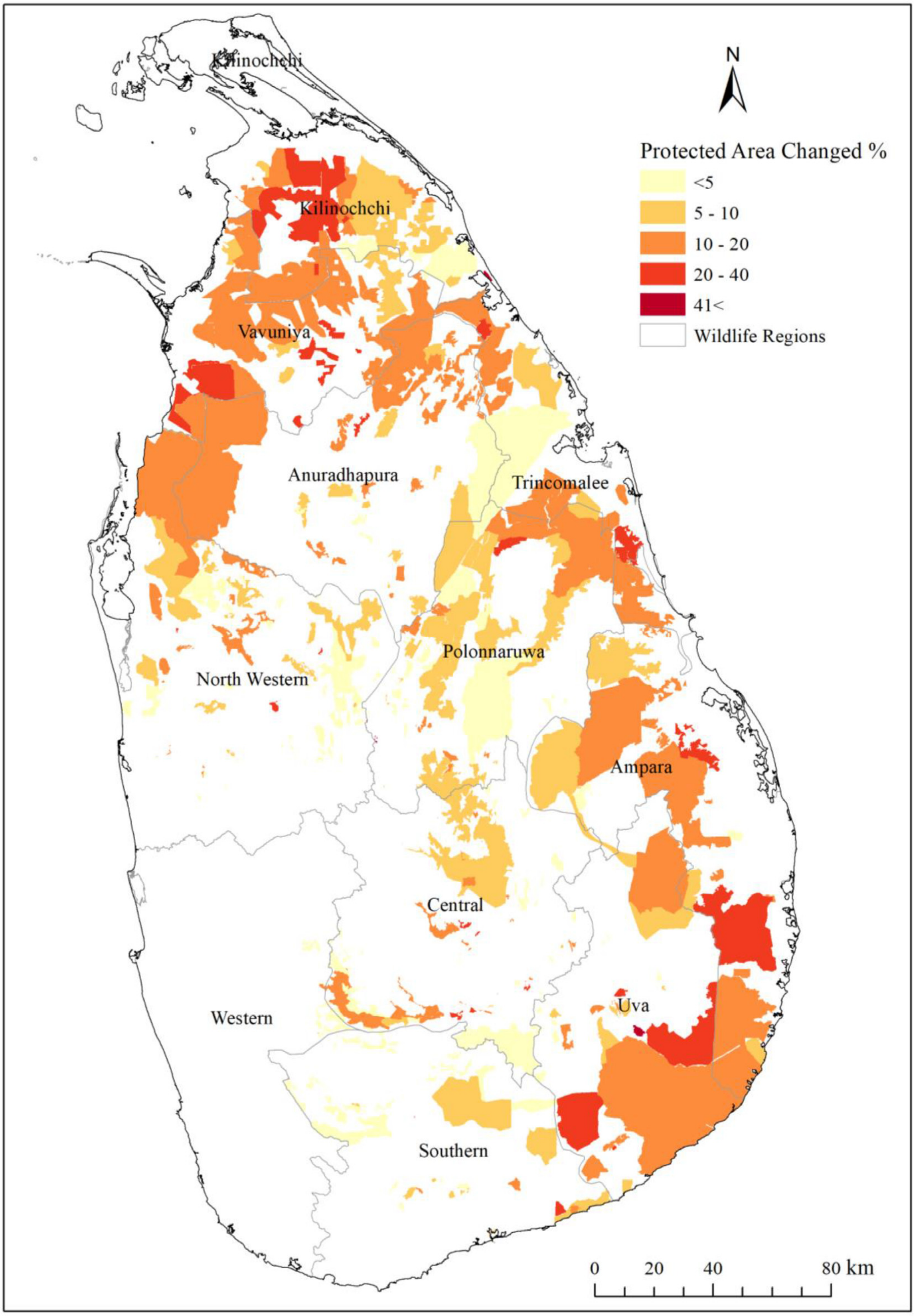


Fig. 3. Proportionate change in protected areas as a result of LULCC. Yellow represents the least changed areas, while red represents the most changed areas.

juries were noted to occur along protected area borders. Property damage hotspots were found to have a clustered distribution, being surrounded by a large number of protected areas and occurring outside and far away from protected areas, as well as being geographically distant from human fatalities and injury incidents. Of the four major property damage clusters, the largest is in the Central region and is surrounded by four to five larger protected areas; the second largest is in the Ampara region and is also surrounded by three or four larger protected areas. The other two clusters, in the south and north, mirror this situation.

There was a moderate to strong association between elephant death density and other HEC incidence types. Elephant death and human mortality had the strongest correlation ($r = 0.62$, $p < 0.05$), followed by elephant death and human injury ($r = 0.56$, $p < 0.05$), and elephant death and property damage ($r = 40$, $p < 0.05$). This means elephant deaths

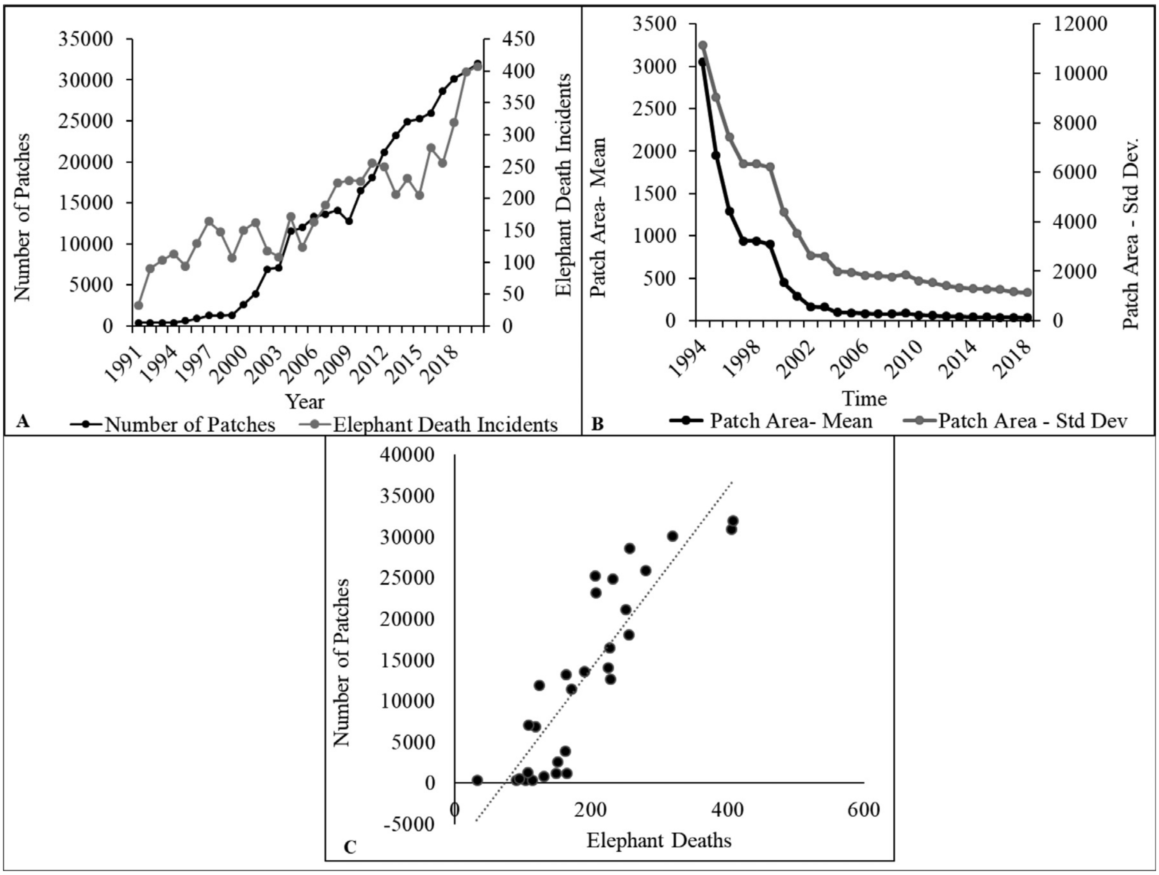


Fig. 4. (A) Annual total elephant death and number of patches within all protected areas in Sri Lanka's HEC region; (B) Mean patch size and standard deviation within protected areas in Sri Lanka's HEC region; (C) Scatter plot of the association between annual elephant deaths and number of patches within protected areas in Sri Lanka's HEC region.

Table 2
Frequency of total elephant death incidents and total HEC incidents against distance from protected area.

Distance from protected area (km)	Elephant death incidents	Total HEC incidents
1	1,657	7,311
2	534	3,218
3	292	2,645
4	247	1,986
5	188	1,413
> 5	464	3,187

can be more prevalent as human deaths, human injuries and property damage increase.

We observed that the four main HEC hotspots are located close to protected areas, while there was a high density of LULCC events in many large protected areas, except for those in the Central region. The largest HEC hotspot, within the Central region, is surrounded by five major protected areas, and exhibits similar spatial trends to the two HEC hotspots in the Southern and Ampara wildlife regions. The other HEC hotspot, in the North Western region, spreads to several smaller protected areas. Comparing the HEC and LULCC hotspots, we found that only the two HEC hotspots in the Southern and Ampara regions were coincidental. Appendix 3 summarizes the overall number of HEC and LULCC hotspots, as well as the network of protected areas.

3.3. Protected Area Performance and HEC

According to our score analysis, more than 95% of protected areas performed at a low to moderate level, which could account for the reporting of elephant deaths inside the protected areas as well as areas adjacent to them (Fig. 7). The few protected areas that showed high performance also reported high numbers of elephant deaths. In the HEC region, over the study period, the mean LULCC has been 10% with an average of 20 elephant deaths per protected area (Fig. 8). Appendix 4 illustrates the proportion of total HEC incidents in relation to the performance of protected areas.

3.4. Polonnaruwa and Ampara Wildlife Regions (Case Study 1)

For many years, the Polonnaruwa and Ampara wildlife regions have had more elephant deaths than any other in the country, with 633 and 597 deaths, respectively. In addition, these two regions had the highest total number of HEC incidents, at 4,452 and 3,630, respectively. These regions also have the highest proportion of protected land area: Ampara at 49%, and Polonnaruwa at 47% of total region land area. As shown in Fig. 9, the total unchanged protected area extent has dropped in both regions over the last 25 years, while other fragmentation statistics such as effective mesh size and mean patch size also decreased.

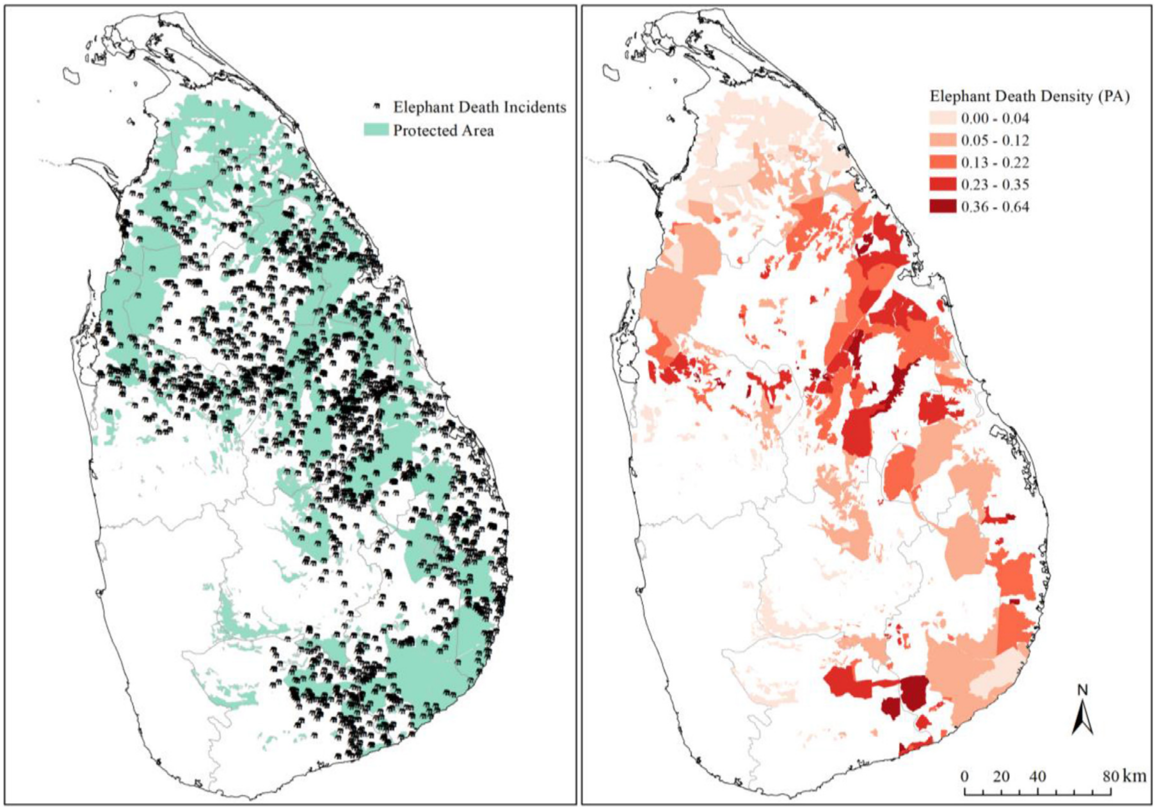


Fig. 5. (L) Distribution of reported elephant death incidents; (R) Aggregated density of elephant death incidents per km^2 within protected areas and a 5 km buffer zone.

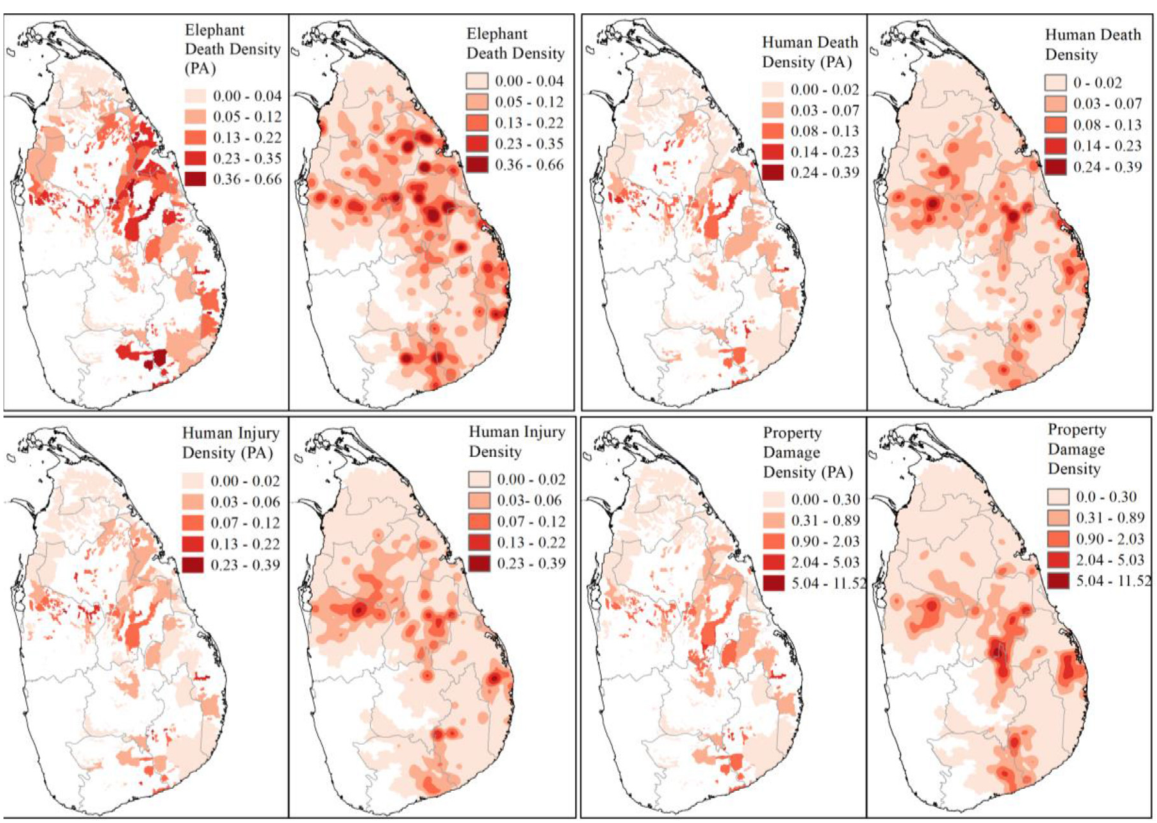


Fig. 6. Density of the four types of HEC incidents (elephant death, human death, human injury, property damage) shown by protected areas (left in each panel), and HEC region (right in each panel).

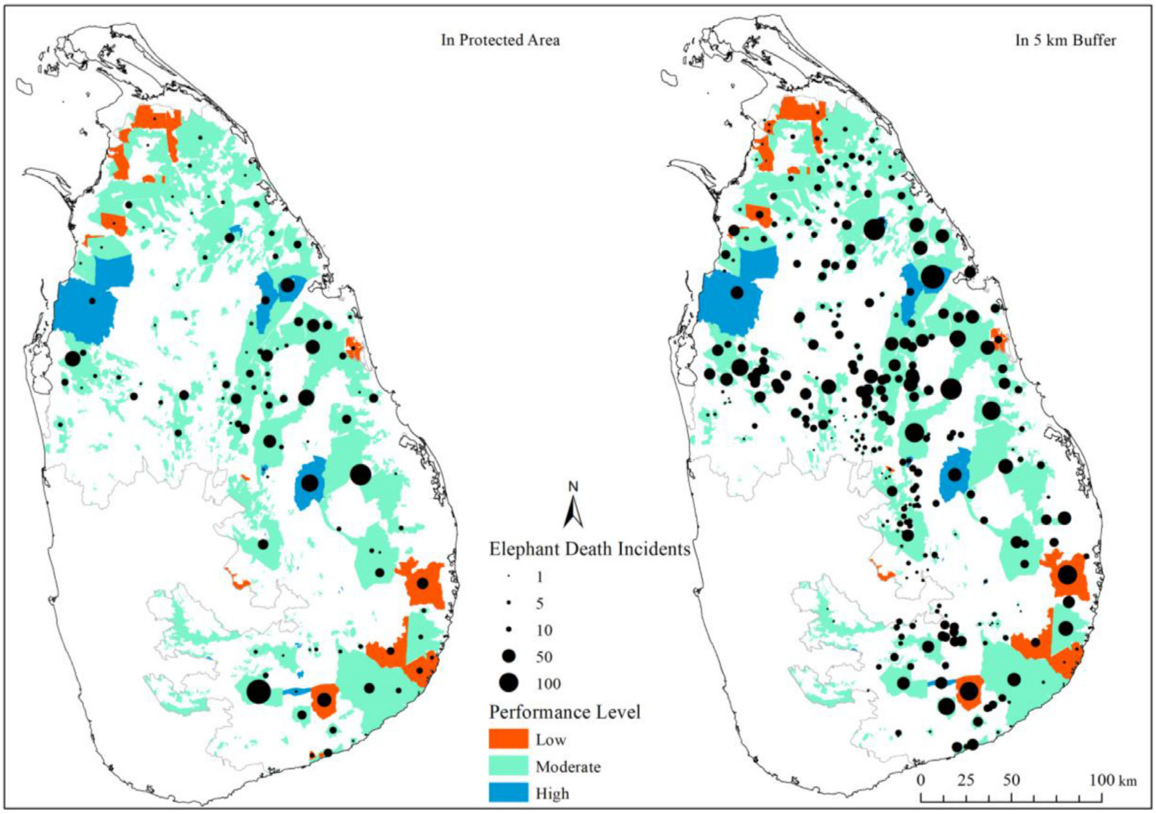


Fig. 7. Protected area performance and number of elephant incidents within the protected areas and within the 5 km buffer.

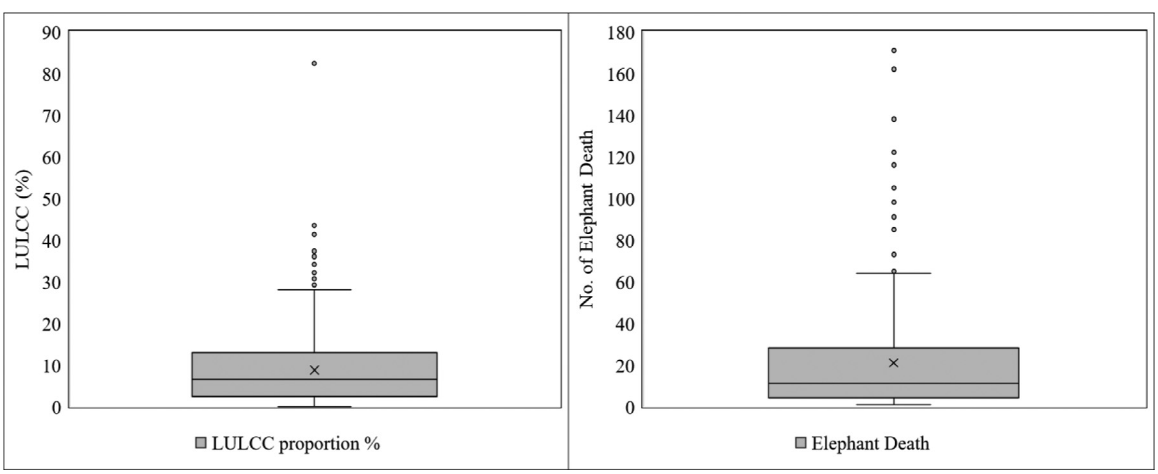


Fig. 8. Box plots of proportion (%) of LULCC, and number of elephant deaths reported in protected areas.

Fig. 10 shows that no protected area (except one very small area) performs well, and all protected areas and their immediate vicinity have elephant death reports. Moreover, elephant death hotspots are located closer to protected areas in the range 10 km radius. Property damage was less reported. In Ampara, we observed that a larger protected area known as Maduru Oya National Park performed well in terms of our score, although there were still reports of elephant deaths in and around this protected area (40-80 elephant death incidents). Appendix 5 shows a range of elephant incidents that were observed outside of the protected areas with many occurring in Polonnaruwa wildlife region.

3.5. Protected Area Designation, LULCC and HEC Incidents (Case study 2)

More of Sri Lanka has been protected since 2010, with 171 areas added to the existing protected area network. To observe the impact of protected area designations on LULCC, we analysed the number of HECs and the total area change before and after each area's designation as a protected area. LULCC in 60 protected areas reduced after the area was designated as protected, although other protected areas continue to report considerable land cover change (Fig. 11). For 70 protected areas, HEC incidents were still frequently reported even after protected area designation in 2010. LULCC still occurs in protected areas as it did prior to their declaration as protected areas (Fig. 11). There was an average LULCC change of 1,100 ha in protected areas both before and after they were designated as protected areas. There were also more incidents of HEC reported after the areas were declared protected in 2010 than there had been before: the average of 20 HEC incidents per year before 2010 increased to 30 after they became protected. Appendix 6 shows trends in LULCC and HEC for areas which became protected after 2010 in the whole HEC region.

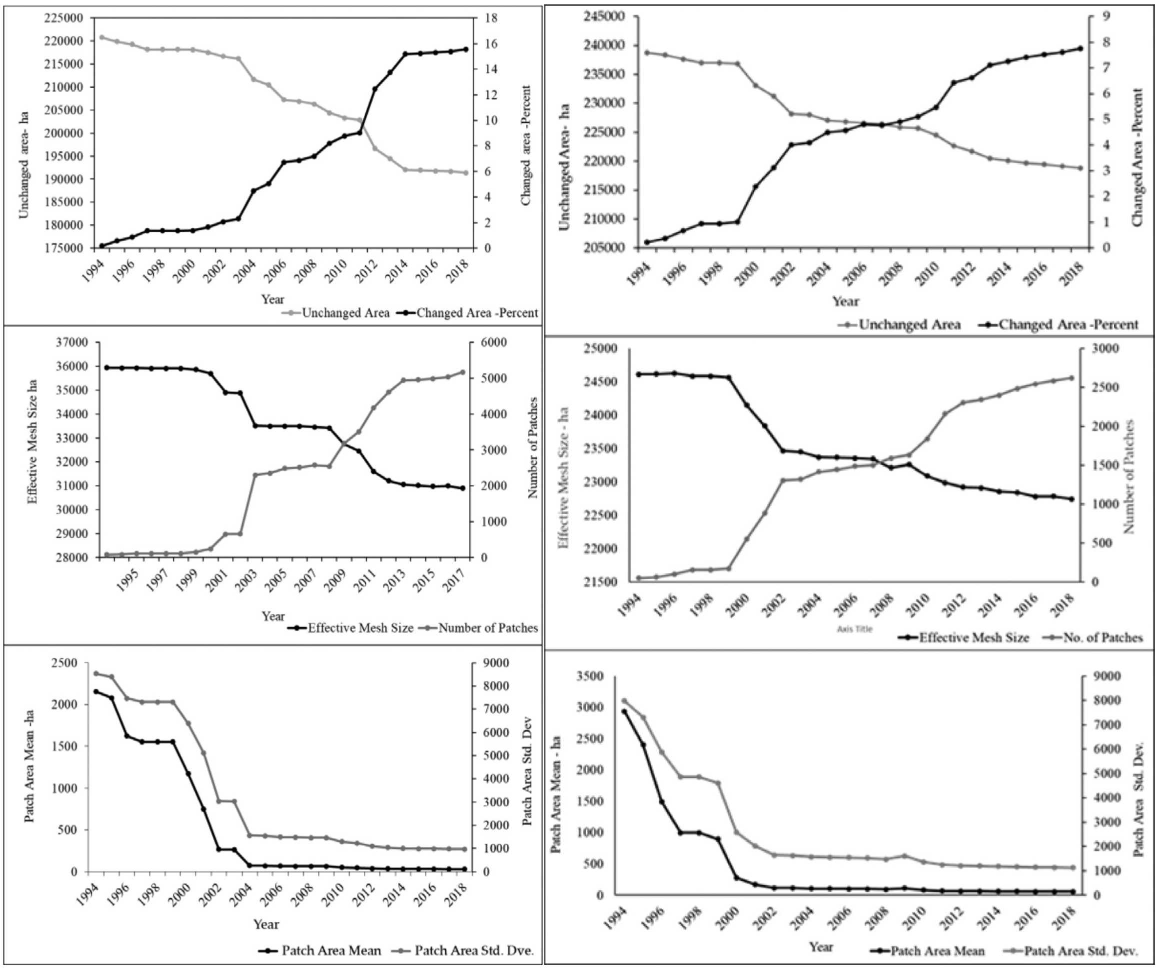


Fig. 9. Changed and unchanged protected area from 1994 –2018, effective mesh size 1994 –2018, and mean and standard deviation of patch size 1994 –2018. (L) Polonnaruwa wildlife region; (R) Ampara wildlife region.

4. Discussion

The extent of protected area in Sri Lanka has expanded over the last three decades, as the country pursues requirements set by the Convention on Biological Diversity (CBD). Although protected area extent has expanded, the performance of such areas lags far behind in protecting keystone species in Sri Lanka, as (a) significant areas of land within protected areas experienced LULCC activities; (b) this resulted in habitat within protected areas becoming increasingly fragmented (e.g., the number of patches of unchanged area has increased, and mean patch size has decreased); (c) elephant deaths and HEC have become more intense within and around protected areas, with a threefold increase in the total number of elephant deaths and HEC incidents (the highest number of elephant death incidents were reported in the last several years); and (d) a considerable proportion of elephant deaths and other types of HEC incidents have been reported in closer proximity to protected areas (e.g., 23% of elephant deaths are reported inside protected areas and 86% of HECs are reported within a 5 km radius of a protected area). There are a very few protected areas that have not reported any elephant death incidents. However, these are located in highly urbanising areas, and contain no elephants due to isolation from other protected areas.

We found that 92% of protected areas have been disturbed over the last 30 years. Further investigation suggests this is due to infrastructure development and reservoir construction projects. Where there is ongoing LULCC within protected areas and forest reserves, many of these areas and reserves as well as the adjacent zones had experienced disturbance (Rathnayake et al., 2020). Consequently, HEC has increased in several wildlife regions (including South, Uva, Ampara, and Trincomalee) where intense land cover change activities have occurred. The areas previously impacted by the civil war in the east (Ampara and Trincomalee wildlife regions) and the north (Kilinochchi and Vavuniya regions) have experienced more HEC events in recent years. LULCC in the northern part of the country has shown a significant increase over the last 10 years, since the 30-year civil war ended in 2009. It is likely that the increased reporting of HEC in northern regions is related to ongoing LULCC.

From the analysis presented here, it is clear that expanding the protected area network has not been effective in protecting Asian elephants in Sri Lanka. We found that density of HEC events was related to the spatial proximity to protected areas. In addition, no Sri Lankan wildlife region has done well in terms of elephant conservation, as highlighted by DWC data: none has reported zero elephant deaths due to HEC over the last 10 years and, in fact, each year has seen more elephant deaths (reported natural deaths are less than 10% of total elephant deaths). Polonnaruwa wildlife region has shown an exceptional growth in elephant deaths with a 154% increase in 2020 compared to 2010, while the other regions experienced an average 80% increase in elephant deaths when comparing the same years. Of elephant deaths, more than 75% were unnatural deaths from a variety of causes, mainly due to gunshots, followed by poisoning, electrocution, and other human-induced methods.

Habitat fragmentation and loss of elephant habitat (i.e., protected area) are found to be the major threats to the conservation of elephants in Sri Lanka. Loss of elephant habitat has been primarily driven by pop-

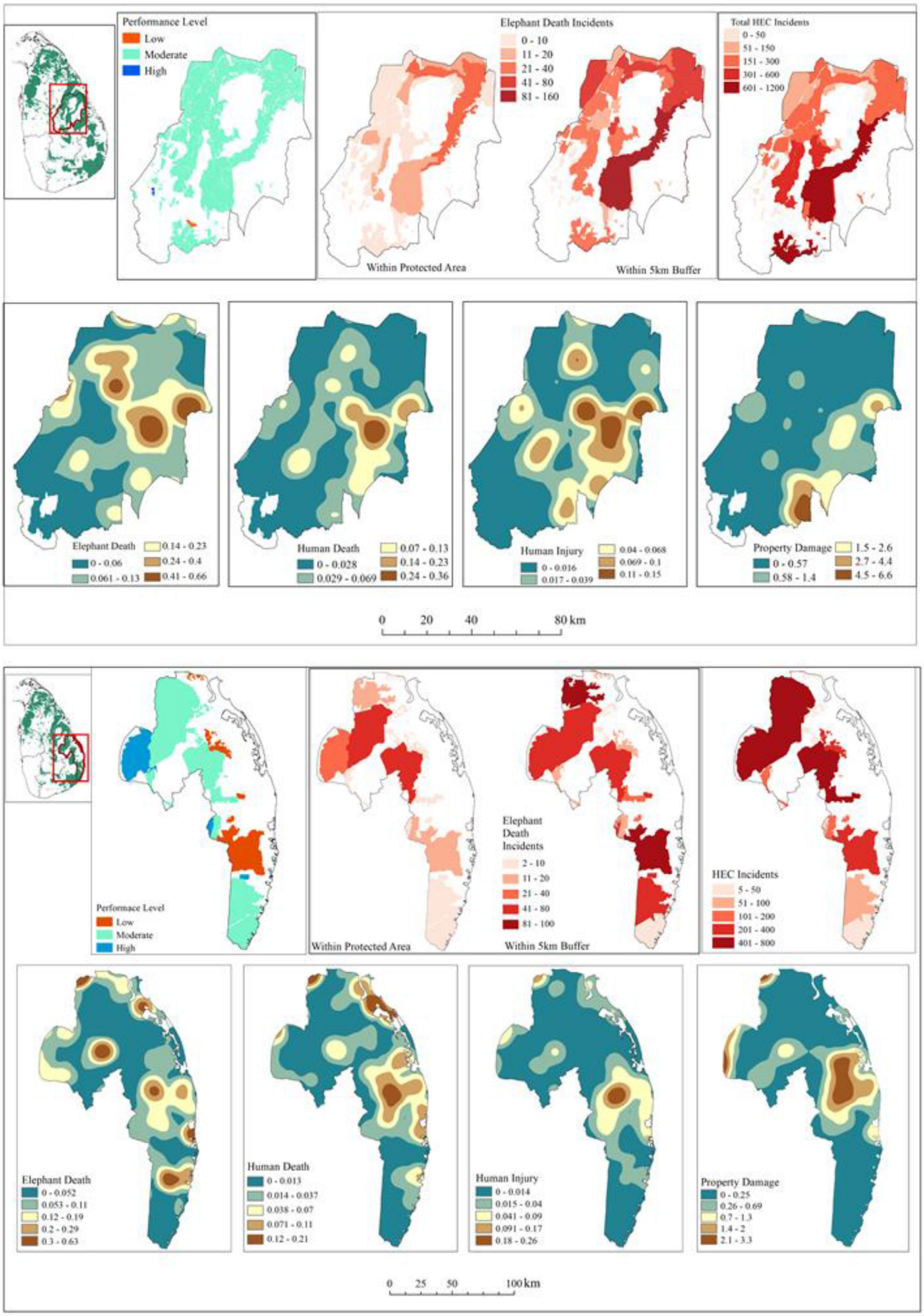


Fig. 10. Protected area performance and HEC, Polonnaruwa wildlife region (top), and Ampara wildlife region (bottom). Row 1: Protected area performance, elephant deaths in and outside protected areas, total HEC in and outside protected areas; Row 2: Densities of HEC types.

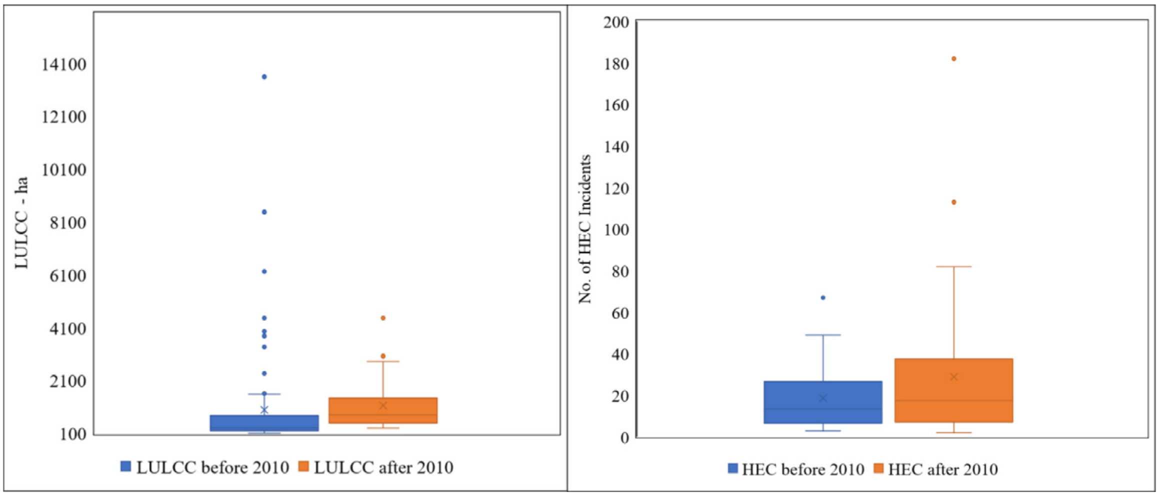


Fig. 11. Comparison of LULCC and HEC before and after designation as protected areas. (L) LULCC in protected areas and within 5km buffer; (R) HEC incidents in protected areas and within 5 km buffer.

ulation growth in Sri Lanka (Köpke et al., 2021). In the period from 1994 to 2020, the number of undisturbed patches increased (indicating fragmentation), and this was found to be correlated to the number of elephant deaths. Elephants and humans seem to be able to live side by side at a minimum density, but when human and elephant population density increases, incompatibility also increases. The increasing sparsity of undisturbed elephant habitat has led to a compression of elephant herds into protected areas, causing an escalation of HEC in adjoining human-dominated areas (Menon et al., 2019; Riddle et al., 2010b).

Elephants much prefer contiguous habitat rather than fragmented forest patches, and lack of suitable habitat makes them more stressed (Fernando et al., 2005; Sukumar, 2006; Jadhav and Barua, 2012). The protected areas such as Randenigala and Maduruoya National Parks comparatively reported less LULCC and low numbers of elephant deaths and HEC incidents. Particularly, the larger protected areas such as Yala and Galoya National Parks also reported less HEC incidents as elephants in those areas have sufficient area to roam for their daily needs.

Recent mega-developments in Sri Lanka, as well as other unplanned and poorly planned development activities, have resulted in a variety of issues related to loss of habitat: reduction of natural vegetation cover, fragmentation, encroaching, disturbance of food and water resources, and blocked elephant corridors (Biodiversity Secretariat, 2014; Yamamoto-Ebina et al., 2016). The ranging land of elephants is becoming ever smaller, and increasingly surrounded by human settlements and cultivated land. We found a strong positive correlation (88%) between annual HEC and the number of patches. Unreported activities such as illegal farming, cattle grazing, timber harvesting, and encroachment in and around protected areas have also increased in recent years as a result of a variety of socioeconomic issues such as poverty and land scarcity. These prohibited activities have evolved into underlying factors contributing to the decline in the effectiveness of protected areas. For example, the Maduru Oya National Park in Ampara wildlife region is occupied by Sri Lankan indigenous people, which may have led to disturbances inside the protected areas that resulted in elephant deaths, even though LULCC is not making much impact on the park.

For many years, it was believed that relocating elephants to protected areas would create a safer environment than allowing elephants to roam freely in unprotected areas. In accordance with this policy, Sri Lanka undertook efforts to relocate all elephants to protected areas but was unsuccessful where protected area capacity was exceeded. Recent studies have found that more elephants and a larger area of their home range (70%) are now present outside the protected areas; that is, in non-conservation areas (Fernando et al., 2011b; Fernando et al., 2006; Fernando et al., 2008; Fernando, 2015; Köpke et al., 2021; Menon et al., 2019). Incompatible conservation and development objectives have a direct effect on increasing disturbance in protected areas, and development activities in conservation areas and reducing elephant habitable space may have a cumulative effect on the deterioration of elephant populations in Sri Lanka (Fernando, 2000; (Fernando and Pastorini, 2011b; Menon and Tiwari, 2019). Electric fences have been used for many years to deter elephants from entering residential areas around protected areas. The Sri Lankan government has spent a considerable amount of money on building electric fences around many designated areas. However, electric fencing is not effective at controlling elephants escaping protected areas, as elephants have been found to be intelligent enough to avoid and break fences.

Increasing the area within protected areas has contributed to controlling LULCC in these areas compared to areas with unprotected status, but has shown less success in stopping HEC or elephant deaths, as noted in our Case Study 2. Also, 40% of elephant deaths are found in protected areas, which raises serious concerns about the effectiveness of law enforcement in restricting human activities within the parks. Case Study 2 suggests that increasing the effectiveness of the protected areas while increasing the extent is much more important than simply declaring abundant land as protected areas. Efforts to conserve elephants, a keystone species in Sri Lanka, will also reduce other forms of wildlife-human conflicts that have been occurring for many years.

5. Conclusion

The study aimed to investigate whether protected areas contributed to the protection of elephants in Sri Lanka. The results have shown that protected areas continue to be disturbed by LULCC and elephant deaths and HEC have become more prevalent and intense. Of these, human-wildlife incidents, human deaths, human injuries and property damage mostly occurred near or around protected areas, while elephant deaths were reported both inside and outside protected areas. According to our findings, every protected area in the HEC Region had a 9 percent change as a result of LULCC. Protected areas are becoming more fragmented as a result of LULCC, which has led to an increase in HEC ($r = 0.88$, p 0.05). Similar trends have been observed in the regions adjacent to the protected zones. Consequently, 14% of all HEC occurrences documented and 23% of elephant deaths occurred within protected areas. According to the performance rating criteria, 95% of the protected areas performed poorly.

This study summarizes a Sri Lanka–wide analysis of protected areas in terms of the conservation of endangered Asian elephants in Sri Lanka. Our results help to highlight the nationwide status of protected areas and provide overview for policy implementation and planning. Based on our research, more detailed local-level studies could be conducted on the ability of protected areas to manage elephant populations as well as to enhance the productivity of the protected area network. Further, this research indicates that the quality of protected areas is important for managing HEC as well as other biodiversity issues. Even if more areas are declared as protected, if they are scattered, continue to be disturbed by LULCC, and fragmented then their effectiveness in managing the key environmental issue of HEC will still be challenging.

It is hoped these results may provide key inputs to national wildlife management strategies and biodiversity conservation, particularly in managing protected areas and HEC in Sri Lanka. Beneficial outcomes of this study include identifying highly fragmented protected areas, protected areas with high HEC, and local protected area management strategies. We suggest that LULCC and protected area performance information can be utilized in the declaration of new protected areas, wildlife (e.g., elephant) corridors and reservation buffers in the future. Furthermore, this information may help public and private stakeholders engaged in elephant conservation activities.

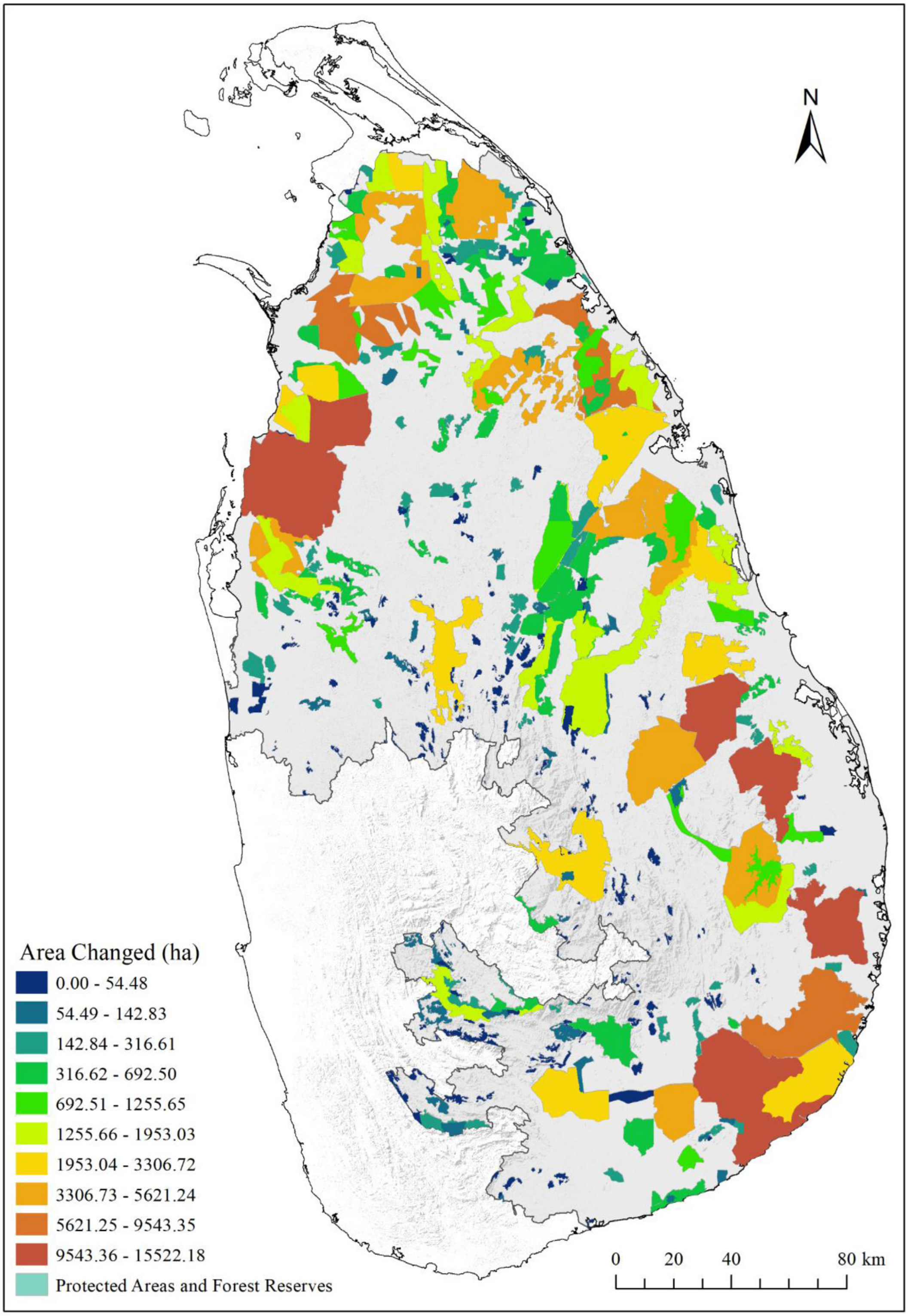
Declaration of Competing Interest

We declare that publication of this paper in the Journal of Biological Conservation does not present a conflict of interest.

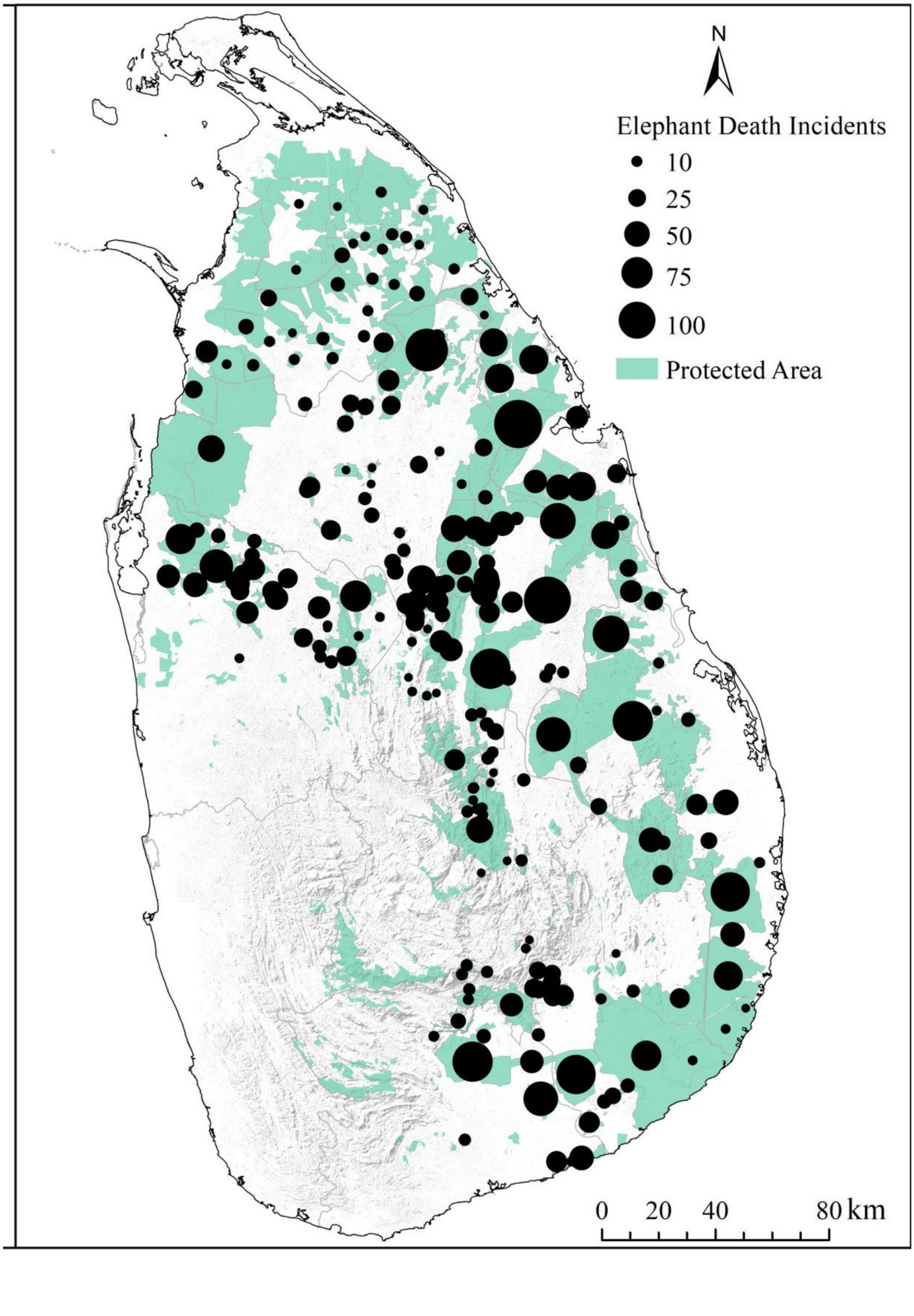
Data availability

Data will be made available on request.

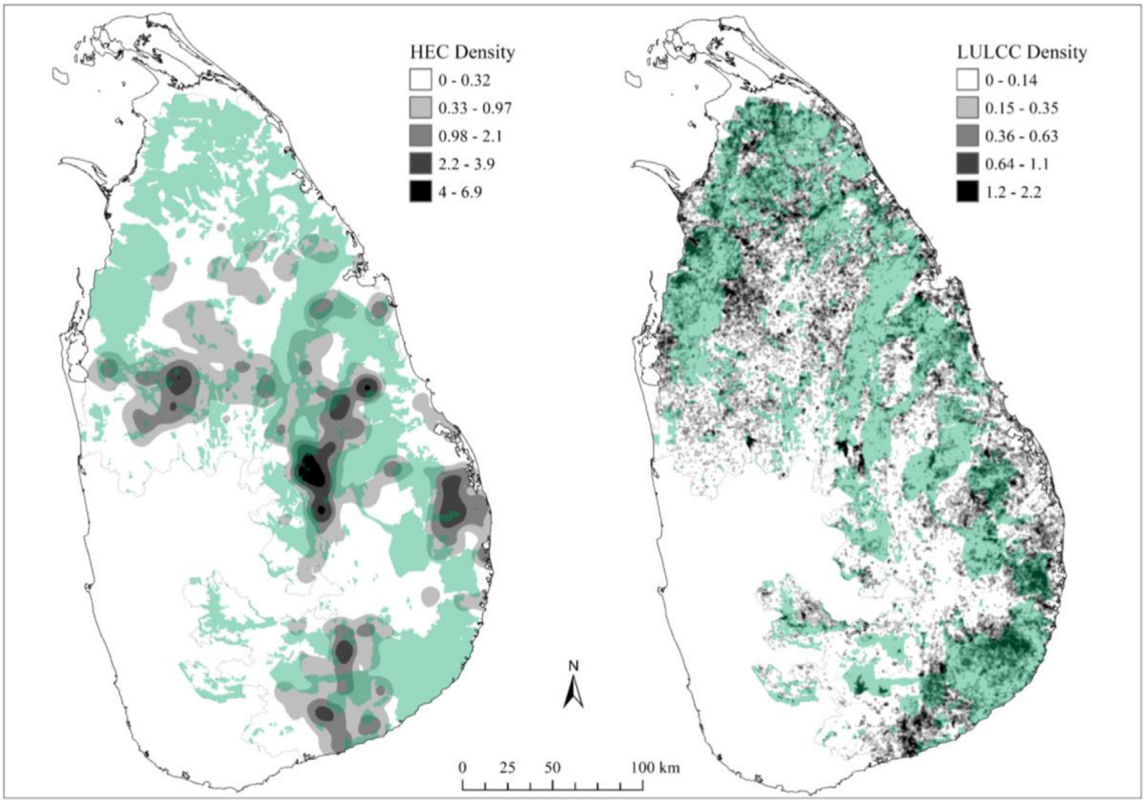
Appendix 1: Total area of LULCC in protected areas



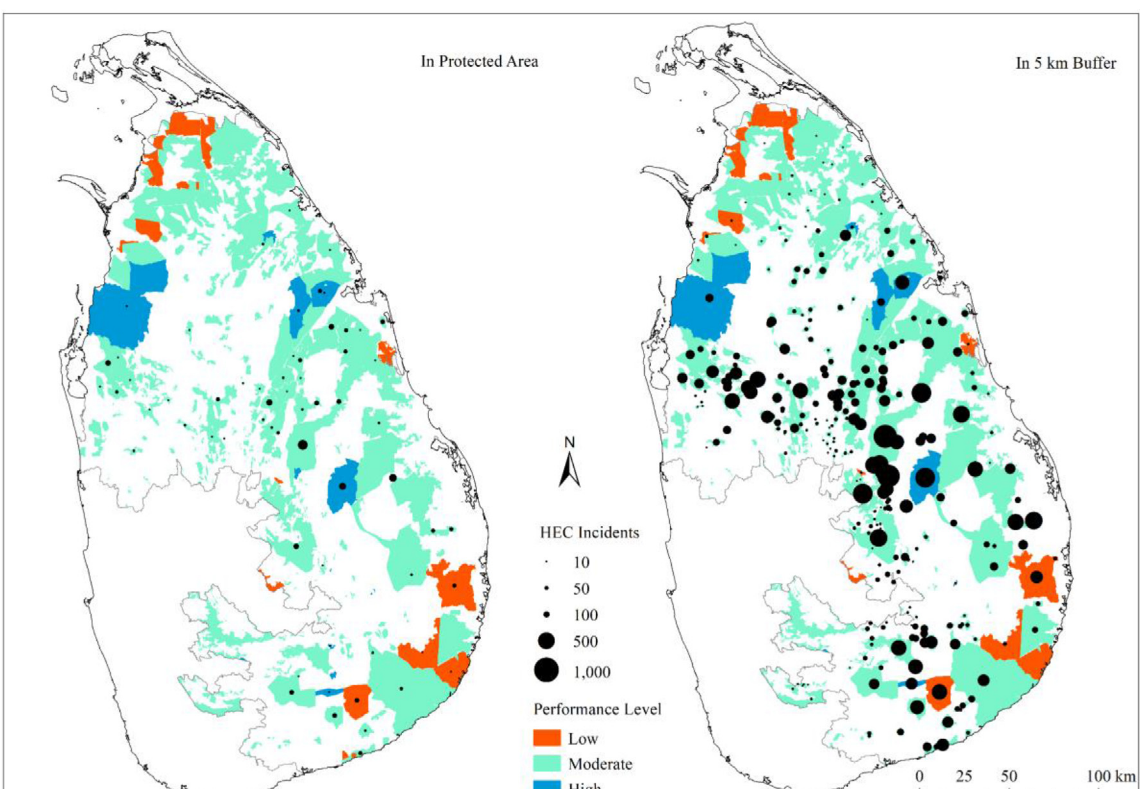
Appendix 2: Total number of elephant deaths that occurred within protected areas and within the 5km buffer zone



Appendix 3: HEC (all types) and LULCC hotspots. (L) HEC hotspots and protected areas; (R) LULCC hotspots and protected areas



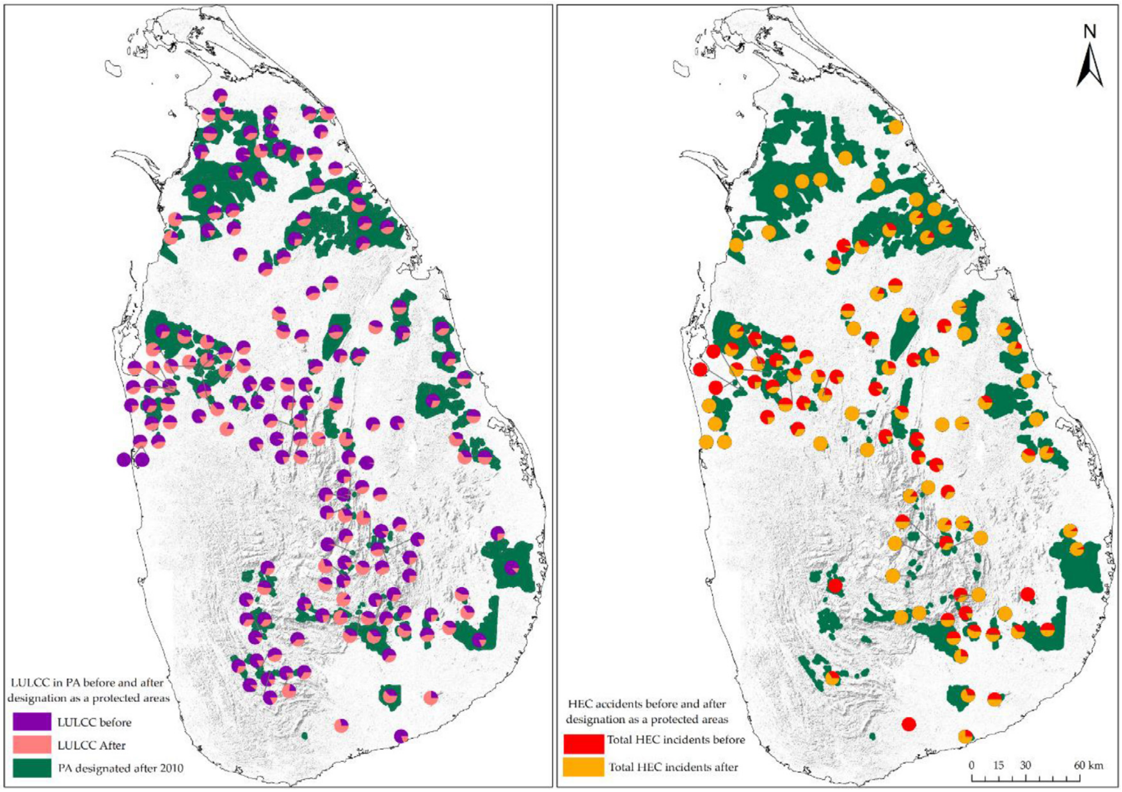
Appendix 4: Protected area performance and total HEC incidents



Appendix 5: Elephant incidents found outside of the protected areas

Image	Description	Date and Location (latitude/longitude)
a	Elephants accidentally fell into an agrarian well on their way back to the forest	2019.09.19 8.163697N, 80.634800E
b	An elephant outside a protected area on a morning	2019.09.19 8.066634N, 80.781969E
c	Elephants in a village tank, where people used to do fishing and irrigation	2019.09.27 8.029567N, 80.540470E
d	An elephant death reported inside a protected area	2019.09.27 8.108176N, 80.637544E
e	An elephant death (poisoned) closer to a protected area	2017.09.29 8.108176N, 80.637544E
f	An elephant breaking electric fence, Minneriya National Park	2021.07.31 8.089387N/80.888739E
g	A tusker and an elephant escaping from a protected area	2021.07.31 8.089387N/80.888739E
h	A tusker in a harvested paddy land	2019.09.27 7.669419N/ 80.475855E
i	A herd of elephants searching for food in a dumping site, at Manampitiya, Polonnaruwa	2019.06.24 8.07156N/81.10414E
j	Two elephants roaming in the night out closer to Anuradhapura-Kandy Highway	2019.06.24 7.928572N/80.615348E
k	A watch hut on a tree used by the farmers to protect their cultivations, and a group of elephants	2019.06.24 7.9285572N/80.711815E

Appendix 6: Comparison of LULCC and HEC before and after designation as protected areas. (L) LULCC in protected areas; (R) HEC incidents in protected areas



References

Acharya, K.P., Paudel, P.K., Jnawali, S.R., Neupane, P.R., Köhl, M., 2017. Can forest fragmentation and configuration work as indicators of human–wildlife conflict? Evidences from human death and injury by wildlife attacks in Nepal. Ecol. Indic. 80, 74–83. doi:10.1016/j.ecolind.2017.04.037.

Biodiversity Secretariat. (2014). Sri Lanka's Fifth National Report to the Convention on Biological Diversity, Ministry of Environment & Renewable Energy.

Chartier, L., Zimmermann, A., & Ladle, R., J Ladle. (2011). Habitat loss and human–elephant conflict in Assam, India: does a critical threshold exist?, 45(4), 528-533.

Choudhury, A., Lahiri Choudhury, D.K., Desai, A., Duckworth, J.W., Easa, P.S., Johnsingh, A.J.T., Fernando, P., Hedges, S., Gunawardena, M., Kurt, F., Karanth, U.L.A., Menon, V., Riddle, H., Rübel, A.W.E., 2008. Elephas maximus: The IUCN Red List of Threatened Species 2008; Retrieved 01 February 2020 from.

Dudley, N., MacKinnon, K., Stolton, S., 2014. The role of protected areas in supplying ten critical ecosystem services in drylands: a review. Biodivers. 15 (2-3), 178–184.

DWC. (2018). Human Elephant Conflict Data by Director General, Department of Wildlife Conservation Sri Lanka. Personal Communication.

Fernando, P., 2000. Elephants in Sri Lanka : past, present and future policy. Loris 22 (2).

Fernando, P., De Silva, M. K., R., C., Jayasinghe, L. K. A., Janaka, H. K., & Pastorini, J. (2019). First country-wide survey of the Endangered Asian elephant: towards better conservation and management in Sri Lanka. ORYX, 1-10. https://doi.org/10.1017/S0030605318001254

Fernando, P., Jayewardene, J., Prasad, T., Hendavitharana, W., Pastorini, J., 2011a. Current status of Asian elephants in Sri Lanka. Gajah 35, 93–103.

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

Fernando, P., Wikramanayake, E., Weerakoon, D., Janaka, H. K., Gunawardena, M., Jayasinghe, L. K. A., Nishantha, H. G., & Pastorini, J. (2006). The future of Asian elephant conservation: Setting sights beyound protected area boundaries. In (pp. 252-260).

Fernando, P., Wikramanayake, E., Weerakoon, D., Jayasinghe, L.K.A., Gunawardene, M., Janaka, H.K., 2005. Perceptions and Patterns of Human–elephant Conflict in Old and New Settlements in Sri Lanka: Insights for Mitigation and Management. Biodivers. Conserv. 14 (10), 2465–2481. doi:10.1007/s10531-004-0216-z.

Fernando, P., Wikramanayake, E.D., Janaka, H.K., Jayasinghe, L.K.A., Gunawardena, M., Kotagama, S.W., Weerakoon, D., Pastorini, J., 2008. Ranging behavior of the Asian elephant in Sri Lanka. Mammalian Biology 73 (1), 2–13. doi:10.1016/j.mambio.2007.07.007.

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

Gara, T.W., Wang, T., Skidmore, A.K., Ngene, S.M., Dube, T., Sibanda, M., 2017. Elephants move faster in small fragments of low productivity in Amboseli ecosystems: Kenya. Geocarto. Int. 32 (11), 1243–1253. doi:10.1080/10106049.2016.1206625.

Haddad, N.M., Brudvig, L.A., Clobert, J., Davies, K.F., Gonzalez, A., Holt, R.D., Lovejoy, T.E., Sexton, J.O., Austin, M.P., Collins, C.D., Cook, W.M., Damschen, E.I., Ewers, R.M., Foster, B.L., Jenkins, C.N., King, A.J., Laurance, W.F., Levey, D.J., Margules, C.R., Melbourne, B.A., Nicholls, A.O., Orrock, J.L., Song, D.-X., Townshend, J.R., 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. Sci. Adv. 1 (2), e1500052. doi:10.1126/sciadv.1500052.

IUCN. (2008). IUCN (International Union for Conservation of Nature) 2008. Elephas maximus. The IUCN Red List of Threatened Species. Version 2019-3. Retrieved 02.02.2020 from https://www.iucnredlist.org/species/7140/12828813#geographic-range

IUCN, 2013. Guidelines for applying protected area management categories including IUCN WCPA best practice guidance on recognising protected areas and assigning management categories and governance types Retrieved 10 October 2020 from.

Jadhav, S., Barua, M., 2012. The Elephant Vanishes: Impact of human–elephant conflict on people's wellbeing. Health Place 18 (6), 1356–1365. doi:10.1016/j.healthplace.2012.06.019.

Jones, K.R., Venter, O., Fuller, R.A., Allan, J.R., Maxwell, S.L., Negret, P.J., Watson, J.E.M., 2018. One-third of global protected land is under intense human pressure. Science 360 (6390), 788. doi:10.1126/science.aap9565.

Kennedy, R.E., Yang, Z., Braaten, J., Copass, C., Antonova, N., Jordan, C., Nelson, P., 2015. Attribution of disturbance change agent from Landsat time-series in support of habitat monitoring in the Puget Sound region, USA. Remote Sens. Environ. 166, 271–285. doi:10.1016/j.rse.2015.05.005.

Kennedy, R. E., Yang, Z., & Cohen, B., Warren (2010). Detecting trends in forest disturbance and recovery using yearly Landsat time series: 1. LandTrendr — Temporal segmentation algorithms. Remote Sens. Environ., 114(12), 2897-2910. https://doi.org/10.1016/j.rse.2010.07.008

Köpke, S., Withanachchi, S.S., Pathiranage, R., Withanachchi, C.R., Gamage, D.U., Nissanka, T.S., Warapitiya, C.C., Nissanka, B.M., Ranasinghe, N.N., Senarathna, C.D., Schleyer, C., Thiel, A., 2021. Human–Elephant Conflict in Sri Lanka: A Critical Review of Causal Explanations. Sustainability 13 (15), 8625. https://www.mdpi.com/2071-1050/13/15/8625.

Liu, P., Wen, H., Harich, F.K., He, C., Wang, L., Guo, X., Zhao, J., Luo, A., Yang, H., Sun, X., Yu, Y., Zheng, S., Guo, J., Li, L., Zhang, L., 2017. Conflict between conservation and development: cash forest encroachment in Asian elephant distributions. Sci. Rep. 7 (1), 6404. doi:10.1038/s41598-017-06751-6.

Mapa, R., Kumaragamage, D., Gunarathne, W., Dassanayake, A., 2002. Land use in Sri Lanka: past, present and the future. 17th World Congress of Social Science (WCSS), Thailand.

Masek, J.G., Vermote, E.F., Saleous, N.E., Wolfe, R., Hall, F.G., Huemmrich, K.F., Gao, F., Kutler, J., Lim, T.K., 2006. A Landsat Surface Reflectance Dataset for North America, 1990–2000. IEEE Geosci. Remote Sens. Lett. 3 (1), 68–72. doi:10.1109/lgrs.2005.857030.

Masek, J.G., Wulder, M.A., Markham, B., McCorkel, J., Crawford, C.J., Storey, J., Jenstrom, D.T., 2020. Landsat 9: Empowering open science and applications through continuity. Remote Sens. Environ. 248, 111968. doi:10.1016/j.rse.2020.111968.

McGarigal, K., Cushman, S., A Ene, E., 2012. FRAGSTATS v4: Spatial Pattern Analysis Program for Categorical and Continuous Maps. Computer software program produced by the authors at the University of Massachusetts, Amherst Retrieved 01.12.2020 from.

Menon, V., & Tiwari, S. K. (2019). Population status of Asian elephants Elephas maximus and key threats. 53(1), 17-30. https://doi.org/10.1111/izy.12247

Padalia, H., Ghosh, S., Sudhakar, R.C., Nandy, S., Singh, S., Senthil, K.A., 2019. Assessment of historical forest cover loss and fragmentation in Asian elephant ranges in India. Environ. Monit. Assess. 191. doi:10.1007/s10661-019-7696-5.

Prakash, T.G.S.L., Wijeratne, A.W., Fernando, P., 2020. Human-Elephant Conflict in Sri Lanka: Patterns and Extent. Gajah 51, 16–25.

Rathnayake, C. W. M., Jones, S., & Soto-Berelov, M. (2020). Mapping Land Cover Change over a 25-Year Period (1993–2018) in Sri Lanka Using Landsat Time-Series. Land, 9(1). https://doi.org/10.3390/land9010027

Riddle, H., Schulte, B., Desai, A., Meer, L., 2010a. Elephants - A conservation overview. J. Threaten. Taxa 2. doi:10.11609/JoTT.o2024.653-61.

Riddle, H.S., Schulte, B.A., Desai, A.A., van der Meer, L., 2010b. Elephants - a conservation overview. J. Threaten. Taxa 2 (1). doi:10.11609/JoTT.o2024.653-61, 653-651.

Roever, C.L., van Aarde, R.J., Leggett, K., 2013. Functional connectivity within conservation networks: Delineating corridors for African elephants. Biol. Conserv. 157, 128–135. doi:10.1016/j.biocon.2012.06.025.

Santiapillai, C., Wijeyamohan, S., Bandara, G., Athurupana, R., Dissanayake, N., Read, B., 2010. An assessment of the human-elephant conflict in Sri Lanka. J. Sci. (Bio. Sci.) 39, 21–33. doi:10.4038/cjsbs.v39i1.2350.

Santiapillai, C., 2013. The difficulty in estimating the total population size of wild elephants in Sri Lanka. Ceylon J. Sci. (Biol. Sci.) 42 (2), 101–103.

Santini, L., Saura, S., Rondinini, C., 2016. Connectivity of the global network of protected areas. Divers. Distrib. 22 (2), 199–211.

Shaffer, L. J., Khadka, K. K., Van Den Hoek, J., & Naithani, K. J. (2019). Human-Elephant Conflict: A Review of Current Management Strategies and Future Directions [Review]. 6(235). https://doi.org/10.3389/fevo.2018.00235

Sharma, K., Robeson, S.M., Thapa, P., Saikia, A., 2017. Land-use/land-cover change and forest fragmentation in the Jigme Dorji National Park, Bhutan. Phys. Geogr. 38 (1), 18–35.

Sharma, P., Panthi, S., Yadav, S.K., Bhatta, M., Karki, A., Duncan, T., Poudel, M., Acharya, K.P., 2020. Suitable habitat of wild Asian elephant in Western Terai of Nepal. Nat. Ecol. Evol. 10 (12), 6112–6119. doi:10.1002/ece3.6356.

Sharma, R., Rimal, B., Baral, H., Nehren, U., Paudyal, K., Sharma, S., Rijal, S., Ranpal, S., Acharya, R.P., Alenazy, A.A., 2019. Impact of land cover change on ecosystem services in a tropical forested landscape. Resources 8 (1), 18.

Sukumar, R., 2003. The living elephants: evolutionary ecology, behaviour, and conservation. Oxford University Press.

Sukumar, R., 2006. A brief review of the status, distribution and biology of wild Asian elephants Elephas maximus. Int. Zoo Yearb. 40 (1), 1–8. doi:10.1111/j.1748-1090.2006.00001.x.

Talukdar, N.R., Choudhury, P., Ahmad, F., Ahmed, R., Ahmad, F., Al-Razi, H., 2020. Habitat suitability of the Asiatic elephant in the trans-boundary Patharia Hills Reserve Forest, northeast India. Model Earth Syst. Environ. 6 (3), 1951–1961. doi:10.1007/s40808-020-00805-x.

UNEP-WCMC, 2020. Protected Area Country Profile for Sri Lanka from the world Database of Protected Areas.

UNEP-WCMC, I., NGS, 2021. Protected Planet Live Report 2021 April 2021. UNEP-WCMC, IUCN and NGS Retrieved 06.05.2021 from.

Watson, J.E.M., Dudley, N., Segan, D.B., Hockings, M., 2014. The performance and potential of protected areas. Nature 515 (7525), 67–73. doi:10.1038/nature13947.

Yamamoto-Ebina, S., Saaban, S., Campos-Arceiz, A., Takatsuki, S., 2016. Food Habits of Asian Elephants Elephas maximus in a Rainforest of Northern Peninsular Malaysia. Mamm. Mutagen. Study Group Commun. 41, 155–161. doi:10.3106/041.041.0306.