Biological Conservation 220 (2018) 50–59

Contents lists available at ScienceDirect

Biological Conservation

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

Effects of illegal grazing and invasive *Lantana camara* on Asian elephant habitat use

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ARTICLE INFO

Keywords:
Asian elephant
Grazing
Habitat
Invasive species
Lantana camara
Grassland

ABSTRACT

Protected areas provide some of the last refuges for Asian elephants in the wild. Managing these areas for elephants will be critical for elephant conservation. Scientists know little about elephant habitat use in Asia and how invasive species or livestock grazing influence habitat use. We studied these issues in two protected areas in Sri Lanka, Udawalawe National Park and Hurulu Eco-Park. These areas contain some of Sri Lanka's largest remaining grasslands. These grasslands are threatened by the invasive and toxic shrub, *Lantana camara*, and are used for illegal livestock grazing. To measure habitat use by elephants and livestock, we conducted dung surveys along over 50 km of transects stratified across grassland, scrub, and forest. We surveyed 159 vegetation plots along these transects to assess plant composition, and mapped habitat types based on satellite images. We used mixed-effect models to determine the relative importance of habitats, livestock presence, and plant associations for elephant use. Elephant presence was greatest in scrub and grassland habitats, positively associated with both livestock presence and short graminoids, and unaffected by *L. camara*, which was widespread but at low densities. Given the importance of these areas to elephants, we recommend a precautionary management approach that focuses on curbing both illegal grazing and the spread of *L. camara*.

1. Introduction

There have been few systematic studies of habitat use by Asian elephants (*Elephas maximus* L.; McKay, 1973, Sukumar, 1989), although the species is threatened throughout its range (Blake and Hedges, 2004; IUCN Red List, 2008; Fernando et al., 2011). A better understanding of Asian elephant habitat use will significantly aid conservation efforts (Fernando and Leimgruber, 2011). Asian elephants' nutritional ecology suggests that they prefer grazing over browsing (Dierenfeld, 2006), and consequently select grassland or open savanna habitats for foraging (Sukumar, 1989, 2003). The importance of grass as forage for elephants has been observed in some African elephant (*Loxodonta africana*) studies (Tangley, 1997), though habitat use and grass species consumption can vary with location and season (Barnes, 1982; Cerling et al., 2004; Cerling et al., 2009; Codron et al., 2006; Koch et al., 1995). The largest remaining populations of Asian elephants are found in the disturbed dry forest ecosystems of India and Sri Lanka that are typically interspersed by grassland and agriculture (Fernando et al., 2005; Leimgruber et al., 2003).

Much of current Asian elephant habitat is also densely populated by humans (Leimgruber et al., 2003), placing elephants at risk and increasingly restricting them to protected areas (Fernando et al., 2005, 2008). As Sri Lanka's human population has grown and its wild areas have become more developed, the country is moving from slash-and-burn agricultural practices, termed ‘chena’, to permanent agriculture. Traditional chena agriculture enabled land sharing between humans and elephants, where elephants used previously cultivated areas after the crops were harvested (Pastorini et al., 2013). As Sri Lanka is moving away from chena to permanent fields, elephants are losing these critical areas and coming into increasing conflict with humans (Fernando, 2000). In this context, protected areas may have to play a growing role for conserving elephants through providing and preserving remaining key foraging areas (Fernando, 2000).

Research in other parts of the Asian elephant range demonstrated

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https://doi.org/10.1016/j.biocon.2018.01.021
Received 27 January 2017; Received in revised form 10 December 2017; Accepted 23 January 2018

that grassland ecosystems may be critical for supporting elephant populations (Sukumar, 1989, 2003). But even within protected areas, grassland habitats may be vulnerable to livestock overgrazing (Cerling et al., 2009), replacement by invasive species such as the toxic shrub *Lantana camara*, L. (hence forth lantana), and succession. Factors such as its extensive range across 60 countries, accelerated growth rates, ability to form dense thickets, allelopathic properties, as well as the serious impact it has on both agricultural and natural systems, have led lantana to be classified as is one of the world's top 100 invasive species (Lowe et al., 2004, Peiris et al., 2017, Global Invasive Species Database). This species can severely alter the structure (Duggin and Gentle, 1998), composition (Gooden et al., 2009) and function of a landscape (Vitousek et al., 1987), and change its fire regime (Hiremath and Sundaram, 2005). Lantana is toxic to cattle (Gentle and Duggin, 1997) and perhaps other herbivores. Elephants use areas dense with lantana (Wilson et al., 2013, 2014), but they do not consume it, and its presence may directly reduce the amount of grasses and other forage that elephants could eat. We need to understand habitat use of wild Asian elephants within these systems, and the threats to those habitats, in order to preserve remaining populations.

Our research was aimed at measuring the relative use of grassland, scrub, and forest habitats by wild Asian elephants. We also wanted to assess whether elephant habitat use was influenced by the presence of forage plants, lantana, or grazing livestock. We obtained indirect estimates of elephant and livestock presence from dung transects that were stratified across grassland, scrub and forest habitats using satellite imagery and landcover maps. We also conducted detailed vegetation surveys along these same transects to generate fine-scale data on habitat characteristics. Finally, we incorporated these data into model selection procedures to determine which habitats elephants predominantly used, and whether elephant presence was related to specific forage plants, lantana, or livestock presence.

2. Materials and methods

2.1. Study sites

We conducted our research in two protected areas, Udawalawe National Park (UWNP) and Hurulu Eco-Park (HEP), which contain some of the largest remaining grassland-dominated habitats accessible to elephants in Sri Lanka (Fig. 1). Both protected areas have an average annual temperature of 28 °C and annual rainfall of ~1500 mm, with a bimodal rainfall distribution (Zubair et al., 2008) with the main rainy season lasting from mid-October to December during the north-east monsoon and some rains from March to May.

UWNP (~30,000 ha) is located in southern Sri Lanka and was established in 1972 in an area previously under slash and burn agriculture, and teak (*Tectona grandis*, L.) and eucalyptus (*Eucalyptus camaldulensis*, Dehnh.) plantations. It protects the catchment area of the Udawalawe reservoir, a man-made reservoir that provides water for agriculture. The park is managed by the Department of Wildlife Conservation and provides refuge for approximately 1000 elephants (de Silva et al., 2011). It is surrounded by an electric fence with two small unfenced openings in the north and east. These openings, periodic disrepair of fences, and fence breaks allow elephant movement in and out of the park (Ranjeewa et al., 2015). The center of UWNP is dominated by a large grassland area east of the reservoir that transitions into scrub and secondary forest toward the northern and eastern borders of the park.

Hurulu Forest Reserve (~25,000 ha) in northern Sri Lanka was designated a biosphere reserve in 1977 and is managed by the Forest Department. Its vegetation is composed primarily of dry evergreen forest with few permanent water sources. The southern part of the Hurulu Forest Reserve is dominated by grassland in a logged teak plantation, known as the Hurulu Eco-Park (~1000 ha, HEP), and was the primary location of our study in Hurulu Forest Reserve. Hurulu Forest Reserve is contiguous with the Gal-Oya Reserve in the east and lies in close proximity to several other protected areas. It is not fenced, allowing elephants free movement in and out of the reserve.

2.2. Elephant and livestock relative abundance

We conducted dung transect surveys to quantify the relative abundance and distribution of elephants and livestock in relation to habitat types within UWNP and HEP (Barnes and Jensen, 1987). Livestock species we recorded in UWNP and HEP included both water buffalo (*Bubalus bubalis*, L.) and cattle (*Bos taurus*, L), and we combined both of these species under the term ‘livestock’ in the analyses. We conducted an additional study monitoring dung piles for both elephants and livestock and found there was no difference in decay rates between habitat types (Appendix 1).

In UWNP, we established 23 1-km transects in total stratified across all three major habitats- grasslands, scrub and forest- with the amount of area surveyed in each habitat summarized in Table 1. Transect origins were located near park roads and transect directions were chosen to confine each transect to one habitat type. We surveyed each transect twice during the dry season, once in July–October 2011 and once in June–August 2012.

In HEP, we established five transects that were sampled twice during the dry season, once in September–October 2011, and again in August 2012. All HEP transects were located within grassland habitats. Due to recent wildfires within the park, we reduced the length of the transects from 1 km to 400–500 m to avoid recently burnt areas.

During surveys we identified all visible elephant and livestock dung piles on either side of the transect, and recorded its position from the start of the transect and perpendicular distance to the transect line. Analysis of the distance data showed that 95% of the dung piles were found within 25 m of the transect line. We use this distance, 25 m on either side of the transect, to define the effective bandwidth for search. These data were then imported into ESRI ArcMAP 10.0 (ESRI, 2011) for spatial analysis and modeling of elephant habitat selection.

2.3. Vegetation analysis

We established 129 vegetation plots in UWNP and 29 in HEP. The plots were visually stratified by dominant habitat type using satellite images at the start of the project (UWNP grassland $n = 57$, UWNP scrub $n = 55$, UWNP forest $n = 17$, and HEP grassland $n = 29$). The $20\ \text{m} \times 20\ \text{m}$ plots were evenly distributed along each dung transect, separated by 200 m at UWNP and by 100 m at HEP. We marked the plot centers with PVC pipes and recorded their coordinates with a GPS to relocate them during subsequent surveys.

We conducted a point-intercept sampling of the vegetation at 1 m increments along four perpendicular 10 m axes from the center point of each plot. At each sample point, we recorded any plant species that intersected a vertical pole within four scaled 0.5 m intervals (0–0.5 m, 0.5–1 m, 1–1.5 m, 1.5–2 m). We also recorded any plant that would intersect this scale above 2 m.

We compiled a complete list of vegetation recorded in both UWNP and HEP (Appendix 1). We identified to species level all woody plants, common herbaceous plants, and two common grasses that are consumed by elephants, *Imperata cylindrical*, L., and the invasive *Megathyrsus maximus*, Jacq., (previously *Panicum maximum*, Jacq.). All other grasses were categorized either as tall graminoids (≥ 25 cm in height) or short graminoids (< 25 cm). We used these data to find the most abundant plant species in each of the habitat types. We then used the point-intercept data of the two most abundant grasses (*M. maximus* and short graminoids), and lantana in the habitat use models.

2.4. Data analysis

To construct spatially-explicit models of elephant habitat use, we