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

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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 & Hedges 2004, IUCN Red List 2008, Fernando *et al.* 2011). A better understanding of Asian elephant habitat use will significantly aid conservation efforts (Fernando & 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 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 & Gentle 1998), composition (Gooden *et al*. 2009) and function of a landscape (Vitousek *et al.* 1987), and change its fire regime (Hiremath & Sundaram 2005). Lantana is toxic to cattle (Gentle & 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 (Figure 1). Both protected areas have an average annual temperature of 28 ºC and annual rainfall of ~1,500 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 1,000 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. 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 & 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, in July-October 2011 and June-August 2012.

Table 1. Habitat types within the 50 x 50 m grid cells at Udawalawe National Park (UWNP) and Hurulu Eco-Park (HEP).

Habitat Type	UWNP (ha)	HEP (ha)
Forest	16.2	0.2
Scrub	39.7	0.5
Grassland	43.7	6.3
Bareground	3.8	0.1
Water	0.3	-
Floodplain	1.0	-

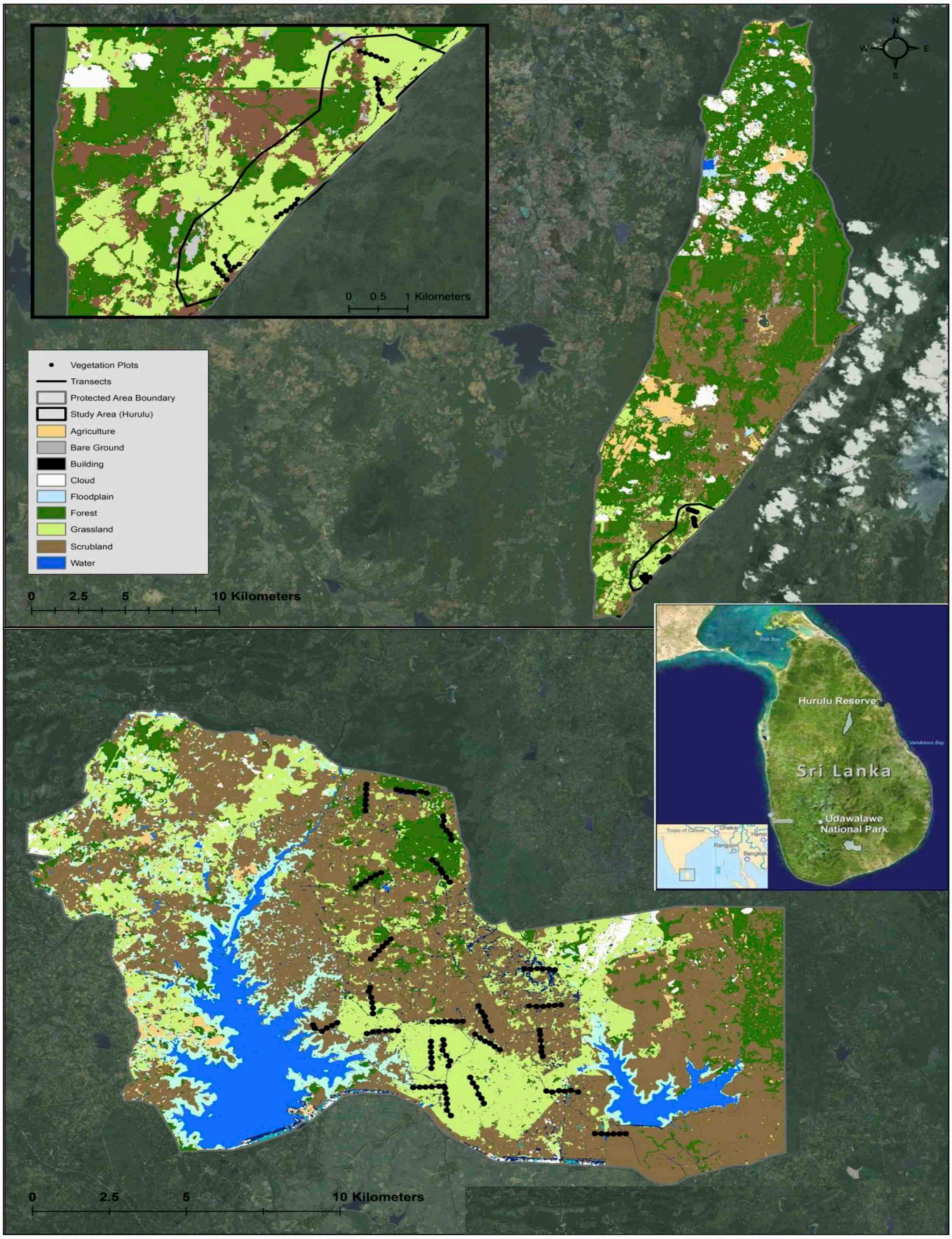

Figure 1. Vegetation maps of Udawalawe National Park and Hurulu Forest Reserve (which contains Hurulu Eco-Park), with locations of transects and plots. Insert: Locations of Udawalawe National Park and Hurulu Forest Reserve in Sri Lanka. Image source: Google Earth 2012.

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 m x 20 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 used ESRI ArcMAP 10.0 (ESRI 2011) and the previously defined effective bandwidth to overlay adjacent 50 m x 50 m grid cells along each transect. We aligned the center of the each grid cell on the transect line so that the two sides of each cell were a distance of 25 m and parallel to the transect line. We then used only the grid cells that also contained vegetation plots (UWNP, n = 139; HEP, n = 29) in our analyses. The 50 x 50 m cell size was chosen to minimize impacts on the accuracy of dung counts due to visibility differences within the microhabitat types within each generalized habitat type. To assess elephant and livestock use of a cell, we counted the number of elephant and livestock dung piles found in each 50 m x 50 m cell.

2.5 Measuring and mapping habitat variables

The percent cover of the different habitat types (grassland, scrub, and forest) within each cell and the Euclidian distance from each plot center to the nearest permanent water body was obtained from the most recent maps of UWNP and HEP created from geo-referenced, high-resolution satellite imagery provided by Google Earth V6.2 (Google Earth 2012). For this map, habitat classifications were evaluated visually from the satellite imagery and assigned in the same manner as the dung transects. These images were analyzed in eCognition V8.8 (Trimble 2012), and the percent of each habitat was summarized for each cell. In HEP there are no significant water bodies located near the vegetation plots, so we were unable to conduct these analyses or include this variable in the model. We then used ESRI ArcMAP 10.0 (ESRI 2011) to spatially join the elephant dung counts with the livestock dung counts, habitat types, vegetation data, and distance to the nearest water source.

2.6 Model Selection

We created one model for each protected area using the number of elephant dung piles found within each cell, an indicator of relative elephant abundance, as the dependent variable. We assumed that the elephant dung counts were Poisson distributed. We created mixed effect models to examine the relationship between these counts and independent predictor variables previous literature indicated were related to elephant presence in a habitat. Both models included a random effect term to account for the year the survey was conducted, and two terms to account for spatial correlation between the transects and plots. The random effect terms for the spatial correlation included the plot and the transect, with transect nested within plot so that we had the terms plot and the interaction of transect*plot. For UWNP we evaluated a model using livestock presence, the distance to the nearest water source, and the relative coverage of the most common forage plants, *M. maximus* and short graminoid, and lantana densities, as fixed effects. For HEP, we created a model using the lantana, *M. maximus*, and short graminoid densities, and livestock dung counts found within each cell as fixed effects. The habitat variables, including the percentages of grassland, scrub, and forest in each cell and the distance to the nearest water source, tested whether elephant use differed among three habitat types or distance to the nearest permanent waterbody in UWNP. The densities of *M. maximus*, and short graminoids were derived from the vegetation point intercept data, and included to test whether these staple forage species predicted elephant abundance. Similarly, we used the density of lantana at each site to test whether the density of lantana was associated with elephant use. We used livestock dung counts, as indicators of relative livestock abundance and therefore potential competition for resources, and tested whether it predicted elephant abundance.

After analyzing the full linear mixed model with all possible covariates included, we conducted a Type III (partial) Sums of Squares analysis of each potential covariate in order to better understand the relative contribution of each covariate to the model's ability to estimate the average elephant dung. We tested the variables for correlations (Appendix 3) and conducted all statistical analyses in JMP Pro 12 (JMP 2015).

3. RESULTS

3.1 Dung transects

Dung from both elephants and livestock were found in all habitat types surveyed (Table 2). Average counts (mean ± S.E., Table 2) were highest in scrub (elephant = 8.25 ± 9.14, livestock = 2.70 ± 3.70) and grassland habitats (elephant = 7.22 ± 5.22, livestock = 3.51 ± 5.59), with very few dung samples from either species found in forested areas (elephant = 1.86 ± 2.4, livestock = 0.19 ± 0.82). Dung counts were significantly different between habitats in UWNP for both elephants and livestock (Appendix 4). Dung counts for both elephants and livestock were significantly lower in HEP than in UWNP (Table 2, Appendix 4).

Table 2. Dung abundance for 50 x 50 m cells by habitat for elephants and livestock species in Udawalawe National Park (UWNP, n= 130) and Hurulu Eco-Park (HEP, n = 29).

Protected Area	Habitat Type	# of Cells	Species	Range of Dung Piles	Average # of Dung Piles	Standard Deviation
UWNP	Grassland	59	Elephant	0-21	7.2	5.2
			Livestock	0-42	3.5	5.6
UWNP	Scrub	53	Elephant	0-51	8.3	9.1
			Livestock	0-18	2.7	3.7
UWNP	Forest	18	Elephant	0-10	1.9	2.4
			Livestock	0-4	0.2	0.8
HEP	Grassland	29	Elephant	0-17	4.0	3.2
			Livestock	0-5	0.5	1.1

3.2 Plant communities

The grasses *M. maximus* and short graminoids were the most abundant plants found in grassland habitats in both UWNP and HEP vegetation plots (Table 3). In UWNP, short graminoids and *M. maximus* were dominant in scrub habitats, and lantana and short graminoids dominant in the understory of forest habitats. Lantana was widespread in UWNP, occurring in 67% of forest, 71% of scrub, and 68% of grassland plots (Table 3), compared with only 21% of grassland plots in HEP. Though lantana was widespread, it was found in much lower densities (Table 3) than the most common plant species in UWNP and HEP, with an average percent cover of 1-3%.

3.3 Models

In the UWNP model (Table 4) short graminoids and livestock dung, and lower percentages of forest and decreasing distances to water positively associated with elephant presence. Neither *M. maximus* nor lantana was significantly associated with elephant occurrence in UWNP (Table 4).

In HEP, the livestock model best predicted elephant presence, showing increases in elephant presence with increasing livestock presence (Table 5). We also found that an increase in both short graminoid and *M. maximus* were significant predictors of elephant habitat use, the former resulting in a positive association, the latter in a negative association. As in UWNP, lantana does not appear to have much influence on elephant occurrence in HEP.

Table 3. Presence and percent cover for short graminoid, *Megathyrsus maximus*, and *Lantana camara* by habitat type in Udawalawe National Park (UWNP) and Hurulu Eco-Park (HEP). Dat represent total point intercept counts across all plots (UWNP grassland n = 57, UWNP scrub n = 55, UWNP forest n = 18, and HEP grassland n= 29).

Protected Area	Habitat	Plant	# of Plots	% of Plots	Average Cover	Cover Range
UWNP	Grassland	Short graminoid	54	95	18%	0-80%
		Megathyrsus maximus	54	95	17%	0-43%
		Lantana camara	39	68	2%	0-19%
UWNP	Scrub	Short graminoid	53	96	30%	0-95%
		Megathyrsus maximus	39	71	6%	0-60%
		Lantana camara	34	62	3%	0-29%
UWNP	Forest	Short graminoid	14	78	18%	0-85%
		Lantana camara	12	67	3%	0-22%
		Megathyrsus maximus	2	11	1%	0-19%
HEP	Grassland	*Megathyrsus maximus*	29	10	28%	3-22%
		Short graminoid	25	86	6%	0-30%
		Lantana camara	6	21	1%	0-2%

Table 4. Summary of the Type III fixed effect model designed to predict elephant habitat use in Udawalawe National Park (UWNP), with the covariates included.

Type III Tests of Fixed Effects		
Covariate	**F Value**	**Pr > F**
Distance to water	12.14	0.00
Livestock dung	15.67	<.0001
Year	6.63	0.01
% Short Graminoid	19.03	<.0001
% *Megathyrsus maximus*	0.00	0.95
% *Lantana camara*	1.26	0.26
% Forest	2.72	0.10
% Scrub	0.71	0.40
% Grassland	0.32	0.58
% Forest * Year	9.03	0.00

% Scrub * Year	0.19	0.66
% Grassland * Year	9.62	0.00
% Short Graminoid * Year	2.11	0.15
% *Megathyrsus maximus* * Year	0.97	0.32
% *Lantana camara* * Year	2.25	0.13

Table 5. Summary of the Type III fixed effect model designed to predict elephant habitat use in Hurulu Eco-Park (HEP), with the covariates included.

Type III Tests of Fixed Effects

Covariate	**F Value**	**Pr > F**
Livestock dung	8.95	0.00
Year	0.41	0.52
% Short Graminoid	1.29	0.26
% *Megathyrsus maximus*	1.39	0.24
% *Lantana camara*	0.02	0.88
% Short Graminoid * Year	0.08	0.78
% *Megathyrsus maximus* * Year	0.21	0.65
% *Lantana camara* *Year	0.04	0.85

4. DISCUSSION

4.1 Plant preferences

Our study clearly showed that elephant prefer open habitats with abundant graminoid grasses, which is consistent with what we know about their nutritional ecology. The best model for UWNP, UWNP-mixed, included four covariates: percentage of forest cover, amount of short graminoids, distance to water, and livestock presence. Elephant presence was negatively associated with percent forest cover, indicating the elephants used grassland and scrub habitats over forest habitats. This is likely due to the dominance of short graminoid species in both grassland and scrub habitats, which was positively associated with elephant habitat use in our models and one of the strongest predictors of elephant occurrence in the regression analysis. The composition of the plant communities in the scrub and grassland habitats in UWNP also explains why we found the percentage of scrub to be a better predictor of elephant habitat use than percentage of grassland. Vegetation plots surveyed in scrub habitats had a much higher ratio of short graminoids to *M. maximus* than plots in grassland habitat. Our models and regression analysis indicate that elephants avoided areas with high abundance of invasive grass *M. maximus*. However, this could also be related to seasonal preferences as our field studies were conducted during the dry season, when *M. maximus* is mature and of low platability.

The importance of grass as forage for elephants has been found in other parts of the Asian elephant range (Sukumar 1989, 2003), and 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). In both protected areas in our study we found a positive correlation between elephants and short graminoids, suggesting that short graminoid vegetation provides important foraging opportunities for elephants. Grassland plant composition likely is more important than general habitat type, and managing protected areas to increase the abundance of short graminoids should be tested for improving elephant habitats and increasing elephant abundance in Sri Lankan protected areas.

4.2 Water availability

Not surprisingly, water availability influences elephant habitat use, with elephant presence increasing closer to water sources. This effect is likely to be stronger during the dry seasons when open water is scarce, and when our study was conducted. Creating additional, year-round artificial water sources in areas appropriate for the ecosystem should also help improve elephant habitat, and increase elephant presence and abundance in protected areas. Moreover, as water levels in these reservoirs recede, short graminoid species quickly spread across the flood plain, providing abundant forage for the elephants.

4.3 Presence of livestock

Contrary to our assumption that elephants avoid areas used by livestock, our models showed that livestock abundance was a positive indicator of elephant presence and was a covariate included in the best models for each protected area. Whether there is a positive relationship between elephants and livestock through feeding facilitation or a negative competitive interaction (Odadi 2011, Arsenault & Owen-Smith 2002, Cerling *et al*. 2009), is uncertain. It is also possible that both have similar habitat preferences, resulting in increasing elephant and livestock presence as habitat quality improves. This warrants future study, specifically experimentation that allows for exclusion of cattle, as well as elephants.

Regardless of the outcome of such studies, the illegal grazing of livestock in the protected areas is a problem as it may lead to increased human-elephant conflict through frequent contact with cattlemen tending herds in protected areas, and might further the spread of lantana. Gentle & Duggin (1997) examined the role of cattle in promoting the growth of lantana in a dry rainforest in Australia. They determined that the biomass reduction and soil disturbance caused by cattle can increase lantana's success. This relationship was primarily driven by grazing, which reduced the above ground biomass, increasing light penetration to the soil and any lantana seeds or seedlings it contained (Gentle & Duggin 1997).

Cattlemen in Sri Lanka rarely own their own pastures and instead graze their livestock, mainly cattle and domesticated water buffalo, on government lands where elephants also feed. Losing grazing lands due to agricultural development, fire suppression or invasive species can put pressure on cattlemen to provide food for their livestock. Illegal grazing by livestock within protected areas can reduce the forage available for wild herbivore populations (Odadi 2011, Cerling *et al*. 2009). It can also alter the vegetation structure (Schulz & Leininger 1990) and diversity within an ecosystem (Szaro 1989), possibly posing an additional threat to elephant habitat. The specific location of a grassland or grazing site can also hinder vegetation recovery after disturbance. However, preventing livestock from grazing in protected areas can create difficulties for wildlife managers, since excluding livestock from protected areas can foster local resentment towards conservation (Mishra 1982).

4.4 Lantana

The presence of lantana did not predict elephant habitat use within our models, possibly because the lantana density is too low across the study sites (average 1-5% cover, Table 3). Yet, lantana was present in at least half of the plots in each habitat type in UWNP, with individual plot cover as high as 23%, and in more than 20% of the plots surveyed in HEP. Given the extreme difficulty in removing a lantana infestation once established (Julien & Griffiths 1998, Day *et al.* 2003, Zalucki *et al.* 2007) and the devastating impacts this plant can have on the structure and composition of an ecosystem, managers of areas with the potential for lantana invasion should attempt to prevent any disturbance which could advance its spread. However, Sri Lanka and most of the elephant range countries are experiencing rapid lantana growth, and conservation officials need to consider future management issues of the disturbed natural areas this development is creating.

5. CONCLUSIONS

Our results indicate it is the presence of short graminoids that drive elephant use of an area rather than specific habitat types. Therefore, maintaining or increasing areas with short graminiods will be beneficial to wild elephant populations at HEP and UWNP, and possibly throughout the Asian elephant range, especially during the dry season. However, though the invasive *M. maximus* is known to be consumed by elephants, elephants avoided areas with high density of this grass, which is pervasive throughout the grassland habitat vegetation plots we surveyed. Protected area managers need to actively maintain and promote landcover with short graminoids and proximity to water sources, especially as elephants in Sri Lanka are rapidly losing habitat outside of protected areas as the country shifts from chena to permanent agriculture. Our study should be repeated during the wet season to identify additional trends.

While density of lantana within the study site is currently low and does not appear to influence elephant habitat use, this invasive weed is widespread and capable of rapid growth, and has been shown adversely affect elephant habitat in other locations (Wilson *et al.* 2013). These habitats need to be monitored for lantana to ensure that fire or disturbance due to removal of woody vegetation do not promote further lantana invasion into the area.

Livestock and elephants are using the same habitat, possibly competing for resources. In UWNP, an electric fence offers a clear and defining line between public and protected areas. To enforce the boundaries of the reserve especially after a disturbance to the flora would offer a chance for grasses to recover and possibly provide more forage for the elephants, especially during the wet season. These recommendations will prove useful not only for habitat management in Sri Lanka but also for other areas of the elephant range where similar ecosystems occur and where lantana and illegal grazing are concerns.

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Appendix 1

In conjunction with the line-transect surveys, we conducted studies in Udawalawe National Park (UWNP) to determine if there was a difference in the decay rate of the elephant and livestock dung between habitat types. Beginning in July 2011, we located 85 fresh (<24 hr old) elephant dung samples in three habitats, grassland (n=51), scrub (n=10), and forest (n=24), and 14 livestock dung in two habitats, grassland (n=11), and scrub (n=3). We could not locate fresh livestock dung in forest habitat. We marked and numbered each dung sample with flagging and recorded its location with a GPS unit then revisited each sample at 2 to 6 week intervals until the sample had decayed beyond recognition as dung. A Kruskal-Wallis rank sum test was used to compare differences in decay rates between the habitat types for each of the two animal groups. Elephant dung decay rates did not differ significantly among the three habitat types.

Dung counts are often the most practical survey method for estimating elephant population sizes and provide similar results as other procedures such as aerial surveys, direct observation, and camera trapping (Barnes 2001). There are, however, several problems with this method, that arise from the estimation of defecation and decay rates rather than the transect surveys themselves. While we found no difference in the decay rates between habitats, other studies have shown that both defecation and decay rates can vary with habitat and season (Barnes 1982, Barnes *et al*. 1997, Guy 1975, White 1995). Our dung decay studies were conducted during the dry season and therefore could not be used to estimate decay rate for the surveys conducted in HEP during the wet season. Given that there was no difference in dung decay rates between habitat types, we used the dung counts directly as estimates of elephant presence in the different habitats. We found the greatest amount of elephant dung in the grassland habitat followed by scrub, and finally forest.

We chose not to use dung decay rates from other studies because of potential differences in microclimate and other variables such as insect presence, fungi and plant germination, and environmental conditions such as exposure to sun (Pastorini *et al.* 2007) and rain (White 1995; Barnes *et al.*1997; Nchanji & Plumptre 2001), which can all alter decay rates and introduce error into the estimates. In addition, differences in vegetation consumption can alter defecation rates (Barnes 2001). Instead, our results are comparable within the time frame of each survey (*i.e.*, all results from H1 are comparable to each other but not to H2, conducted two months later) and study site, but do not allow for an accurate estimate of true elephant or livestock population within the protected areas or habitats.

Table 1-1. The number of dung decay samples for elephants and livestock by habitat with the range, mean and standard deviation (SD) in the number of days until the samples had completely decayed (visually indistinguishable from soil) and the standard deviation of the time to decay.

Habitat	**Species**	**Number of samples**	**Number of days until decay**	**Average**	**SD**
Grassland	Elephant	51	25-144	76	31
Scrub	Elephant	10	38-117	66	19
Forest	Elephant	24	25-117	86	34
Grassland	Livestock	11	25-36	22	10
Scrub	Livestock	3	11-22	18	5

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Appendix 2 Taxonomic names of plant species recorded during this study within Udawalawe National Park and Hurulu Eco-Park. The table includes the current plant name, taxonomic status, and alternative accepted names. It also lists the accepted author that described the species, accepted family, and data source.

Plant name	Taxonomic status	Accepted name	Accepted author	Accepted family	Source
Abutilon indicum	Accepted	*Abutilon indicum*	(L.) Sweet	Malvaceae	tropicos;usda
Azadirachta indica	Accepted	*Azadirachta indica*	A. Juss.	Meliaceae	tropicos;usda
Bauhinia racemosa	Accepted	*Bauhinia racemosa*	Lam.	Fabaceae	tropicos
Carissa spinarum	Accepted	*Carissa spinarum*	L.	Apocynaceae	tropicos
Cassia fistula	Accepted	*Cassia fistula*	L.	Fabaceae	tropicos;usda
Catunaregam spinosa	Accepted	*Catunaregam spinosa*	(Thunb.) Tirveng.	Rubiaceae	tropicos
Cordia dichotoma	Accepted	*Cordia dichotoma*	G. Forst.	Boraginaceae	tropicos;usda
Crotalaria laburnifolia	Accepted	*Crotalaria laburnifolia*	L.	Fabaceae	tropicos;usda
Croton bonplandianus	Accepted	*Croton bonplandianus*	Baill.	Euphorbiaceae	tropicos;usda
Croton officinalis	Accepted	*Croton officinalis*	(Klotzsch) Alston	Euphorbiaceae	tropicos
Diospyros ebenum	Accepted	*Diospyros ebenum*	J. Koenig	Ebenaceae	tropicos
Drypetes sepiaria	Accepted	*Drypetes sepiaria*	(Wight & Arn.) Pax & K. Hoffm.	Putranjivaceae	tropicos
Eucalyptus camaldulensis	Accepted	*Eucalyptus camaldulensis*	Dehnh.	Myrtaceae	tropicos;usda
Ficus benghalensis	Accepted	*Ficus benghalensis*	L.	Moraceae	tropicos;usda
Flacourtia inermis	Accepted	*Flacourtia inermis*	Roxb.	Salicaceae	tropicos;usda
Flueggea leucopyrus	Accepted	*Flueggea leucopyrus*	Willd.	Phyllanthaceae	tropicos
Gmelina asiatica	Accepted	*Gmelina asiatica*	L.	Lamiaceae	tropicos;usda
Hibiscus micranthus	Accepted	*Hibiscus micranthus*	L. f.	Malvaceae	tropicos
Imperata cylindrica	Accepted	*Imperata cylindrica*	(L.) Raeusch.	Poaceae	tropicos
Lannea coromandelica	Accepted	*Lannea coromandelica*	(Houtt.) Merr.	Anacardiaceae	tropicos
Lantana camara	Accepted	*Lantana camara*	L.	Verbenaceae	tropicos;usda
Lepisanthes sp.	Accepted	*Lepisanthes*	Blume	Sapindaceae	tropicos
Madhuca longifolia	Accepted	*Madhuca longifolia*	(J. Koenig ex L.) J.F. Macbr.	Sapotaceae	tropicos
Manilkara hexandra	Accepted	*Manilkara hexandra*	(Roxb.) Dubard	Sapotaceae	tropicos
Mimosa pudica	Accepted	*Mimosa pudica*	L.	Fabaceae	tropicos;usda
Mitragyna parvifolia	Accepted	*Mitragyna parvifolia*	(Roxb.) Korth.	Rubiaceae	tropicos
Morinda coreia	Accepted	*Morinda coreia*	Buch.-Ham.	Rubiaceae	tropicos
Murraya koenigii	Accepted	*Murraya koenigii*	(L.) Spreng.	Rutaceae	tropicos;usda
Pterospermum suberifolium	Accepted	*Pterospermum suberifolium*	(L.) Willd.	Malvaceae	tropicos
Sapindus emarginatus	Accepted	*Sapindus emarginatus*	Vahl	Sapindaceae	tropicos
Schleichera oleosa	Accepted	*Schleichera oleosa*	(Lour.) Merr.	Sapindaceae	tropicos
Sida sp.	Accepted	*Sida*	L.	Malvaceae	tropicos
Sida acuta	Accepted	*Sida acuta*	Burm. f.	Malvaceae	tropicos;usda
Sida cordifolia	Accepted	*Sida cordifolia*	L.	Malvaceae	tropicos;usda
Sida rhombifolia	Accepted	*Sida rhombifolia*	L.	Malvaceae	tropicos;usda
Strychnos potatorum	Accepted	*Strychnos potatorum*	L. f.	Loganiaceae	tropicos
Syzygium cumini	Accepted	*Syzygium cumini*	(L.) Skeels	Myrtaceae	tropicos;usda
Tectona grandis	Accepted	*Tectona grandis*	L. f.	Lamiaceae	tropicos;usda
Tephrosia purpurea	Accepted	*Tephrosia purpurea*	(L.) Pers.	Fabaceae	tropicos;usda
Urena sinuata	Accepted	*Urena sinuata*	L.	Malvaceae	tropicos;usda
Ziziphus oenopolia	Accepted	*Ziziphus oenopolia*	(L.) Mill.	Rhamnaceae	tropicos
Vitex altissima	Accepted	*Vitex altissima*	L. f.	Lamiaceae	tropicos
Allophylus zeylanicus	Accepted	*Allophylus zeylanicus*	L.	Sapindaceae	WCSP
Canthium coromandelicum	Accepted	*Canthium coromandelicum*	(Burm.f.) Alston	Rubiaceae	WCSP
Dimorphocalyx glabellus	Accepted	*Dimorphocalyx glabellus*	Thwaites	Euphorbiaceae	WCSP
Diospyros ovalifolia	Accepted	*Diospyros ovalifolia*	Wight	Ebenaceae	WCSP
Diplodiscus verrucosus	Accepted	*Diplodiscus verrucosus*	Kosterm.	Malvaceae	WCSP
Premna tomentosa	Accepted	*Premna tomentosa*	Willd.	Lamiaceae	WCSP
Eupatorium odoratum	Synonym	*Chromolaena odorata*	(L.) R.M. King & H. Rob.	Asteraceae	tropicos
Phyllanthus polyphyllus	Synonym	*Diasperus polyphyllus*	(Willd.) Kuntze	Euphorbiaceae	tropicos
Syzygium gardneri	Synonym	*Eugenia gardneri*	(Thwaites) Bedd.	Myrtaceae	tropicos
Grewia orientalis	Synonym	*Grewia picta var. picta*	Baill.	Malvaceae	tropicos
Adina cordifolia	Synonym	*Haldina cordifolia*	(Roxb.) Ridsdale	Rubiaceae	tropicos
Panicum maximum	Synonym	*Megathyrsus maximus*	(Jacq.) B.K. Simon & S.W.L. Jacobs	Poaceae	tropicos
Hyptis suaveolens	Synonym	*Mesosphaerum suaveolens*	(L.) Kuntze	Lamiaceae	tropicos
Vicoa indica	Synonym	*Pentanema indicum var. indicum*	(L.) Ling	Asteraceae	tropicos
Derris parviflora	Synonym	*Pterocarpus parviflorus*	(Benth.) Kuntze	Fabaceae	tropicos
Cassia siamea	Synonym	*Senna siamea*	(Lam.) H.S. Irwin & Barneby	Fabaceae	tropicos
Salvia reticulata	Synonym	*Salvia glechomifolia*	M. Martens & Galeotti	Lamiaceae	WCSP

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Appendix 3

Table 3-1: Correlation coefficients between variables analyzed in the dataset for Udawalawe National Park. Variables were summarized by each 50 x 50 m cell used for the model analyses.

	Elephant dung	Livestock dung	% Grassland	% Scrub	% Forest	Distance to water	*Lantana camara*	*Megathyrsus maximus*	Short graminoid
Elephant dung	1.00	0.24	-0.01	0.15	-0.31	-0.01	-0.04	-0.02	0.15
Livestock dung	-	1.00	0.16	0.00	-0.25	-0.02	-0.10	0.10	0.08
% Grassland	-	-	1.00	-0.70	-0.36	0.07	-0.13	0.56	-0.20
% Scrub	-	-	-	1.00	-0.30	-0.06	0.11	-0.31	0.23
% Forest	-	-	-	-	1.00	-0.09	0.01	-0.36	-0.06
Distance to water	-	-	-	-	-	1.00	-0.06	-0.16	0.13
Lantana camara	-	-	-	-	-	-	1.00	-0.09	0.02
Megathyrsus maximus	-	-	-	-	-	-	-	1.00	-0.32
Short graminoid	-	-	-	-	-	-	-	-	1.00

Table 3-2: Correlation coefficients between variables analyzed in the dataset for Hurulu Eco-Park. Variables were summarized by each 50 x 50 m cell used for the model analyses.

	Elephant dung	Livestock dung	*Lantana camara*	*Megathyrsus maximus*	Short graminoid
Elephant dung	1.00	0.14	-0.06	-0.21	0.24
Livestock dung	-	1.00	0.11	-0.22	0.03
Lantana camara	-	-	1.00	-0.07	-0.01
Megathyrsus maximus	-	-	-	1.00	-0.15
Short graminoid	-	-	-	-	1.00

Appendix 4

ANOVA results examining dung counts for elephants and livestock in each 50 x 50 m cell between the three habitat types in Udawalawe National Park (UWNP) and between grassland habitats in UWNP and Hurulu Eco-Park (HEP). Sampling was conducted in 2010 (sampling period 1) and 2011 (sampling period 2). In UWNP, habitat classification for each cell was assigned according to the greatest percent coverage of the habitat types within the cell and included grassland (n= 58), forest (n= 18), and scrub (n= 54). All cells surveyed in HEP were classified as grassland (n = 29).

		UWNP habitats		UWNP v HEP	
Dung type	Sampling period	F-value	P	F-value	P
Elephant	1	8.091	<0.001	8.319	0.005
	2	6.757	0.002	9.716	0.002
Livestock	1	5.345	0.006	11.34	0.001
	2	3.637	0.029	5.724	0.019