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# Protected area management priorities crucial for the future of Bornean elephants

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ABSTRACT

Tropical protected area management strategies have traditionally been heavily skewed towards high carbon, primary forests. This focus can result in areas, such as heavily logged forests, being viewed as low quality and thus offered up for conversion. We assessed the importance of intact to heavily logged forests for the Bornean elephant in the Malaysian state of Sabah. By modelling distributions of elephants throughout Sabah based on GPS telemetry tracking of 29 individuals and airborne three-dimensional forest mapping, we present the most wide-scale analysis of forest use by Bornean elephants to date. Forests of 13 m in stature were found to be of highest suitability for elephants, especially when these areas were flat and low lying. Forest statures of this order are consistent with degraded landscapes, often viewed as suitable for oil palm conversion. Less than a quarter of fully-protected intact forests in Sabah were of suitable stature for elephants, whereas disturbed commercial forest reserves were found to be highly suitable. We suggest that the importance of degraded landscapes for the future of elephants is currently underestimated, and thus, the need for the preservation of such habitats is not seen as a priority. The loss of these landscapes to large-scale agriculture could prove detrimental to the longevity of the species in Borneo.

## 1. Introduction

Land use change has had, and is predicted to have, the broadest negative effects on global biodiversity (Foley et al., 2005; Sala et al., 2000). Areas currently experiencing high rates of land-use change are tropical biomes, with this trend increasing (Hansen et al., 2013). Land use conversions occur for a variety of reasons including timber production, conversion to agriculture, mining, human settlements and many more (Brandt et al., 2016; DeFries et al., 2004; Laurance et al., 2014; Meyer and Turner, 1992). Furthermore, activity such as selective logging has the potential to degrade remaining habitat, which is often subsequently viewed as of lower conservation priority (Edwards et al., 2014). Rather, logged forests may represent a major, currently undervalued, tool for biodiversity conservation, with much of the original biodiversity often being maintained (Berry et al., 2010; Bicknell et al., 2015; Edwards et al., 2014; Prosser et al., 2016).

In Southeast Asian forests, selective logging has historically targeted valuable dipterocarps, which contributed ~80% of timber exports from the region between 2006 and 2007 (ITTO, 2008). Across studies, logged forests appear to maintain ~90% of original biodiversity, when compared to that of primary forest (Berry et al., 2010; Brodie et al., 2015; Meijaard et al., 2005). Retention forestry, whereby a proportion of original vegetation is left unlogged, has been shown to further reduce negative impacts on biodiversity (Fedrowitz et al., 2014; Gustafsson et al., 2012). Although myriad studies have examined the effects of logging on fauna (Prosser et al., 2016), many suffer from inconsistencies in design (Laufer et al., 2013). Furthermore, many meta-studies foster broad generalizations about selectively logged forests that may lead to misleading conclusions, particularly with regard to differing logging intensities (Burivalova et al., 2014). The effects of logging on large mammals present further challenges, with many species elusive and habitats inaccessible.

The Bornean elephant (*Elephas maximus borneensis*), as sub-species of the Asian elephant (*E. maximus*) and the largest mammal in Borneo,

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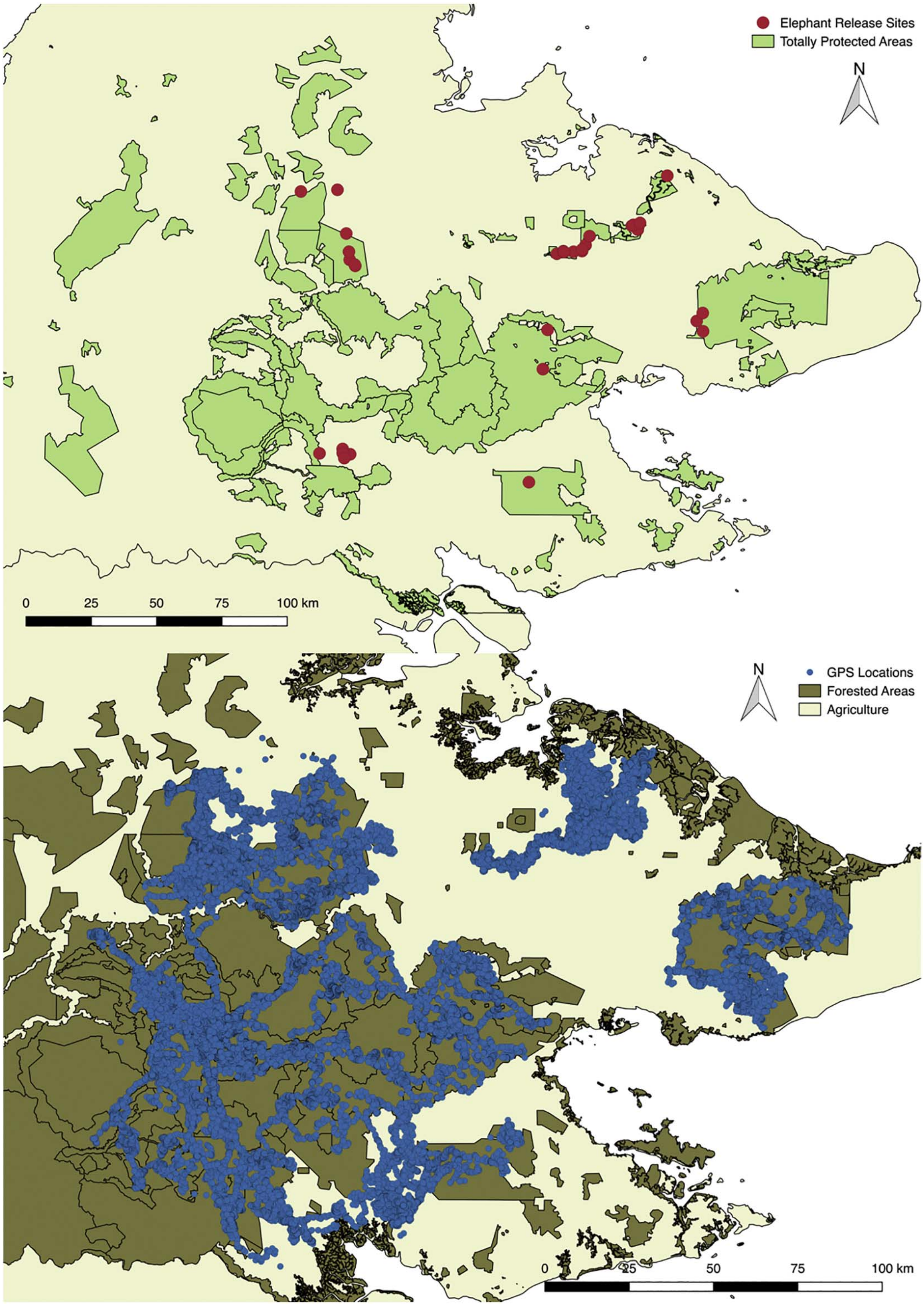


**Fig. 1.** a. Release locations of GPS collared elephants throughout Sabah. b. Location data for the metapopulation of GPS-tagged individual elephants indicating the spread of data.

is now thought to be indigenous to the island, with genetic evidence dispelling a widely held notion that the sub-species was introduced by humans (Fernando et al., 2003; Sharma et al., 2018). Asian elephants are broadly listed as endangered on the IUCN Red List (IUCN Red List, 2008), with Bornean elephants numbering just ~2040 individuals (Alfred et al., 2010). A large proportion of existing ecological research on Asian elephants has focused on populations in mainland Asia (Koirala et al., 2016; Kumar et al., 2010; Jathanna et al., 2015; Liu et al., 2016; Sukumar, 1990; Steinheim et al., 2005; Wadey et al., 2018). Mainland Asian elephants are found in a variety of habitats, ranging from savanna, where their presence is negatively associated with increasing rainfall and normalized difference vegetation index (NDVI) (Jathanna et al., 2015), to rainforest habitats, where riparian vegetation plays a key role in water and food availability (Kumar et al., 2010). Bornean elephants, conversely, being restricted to Northern Borneo, are found in largely lowland rainforest habitats (Alfred et al., 2012).

Conservation planning in tropical forests has historically focused on

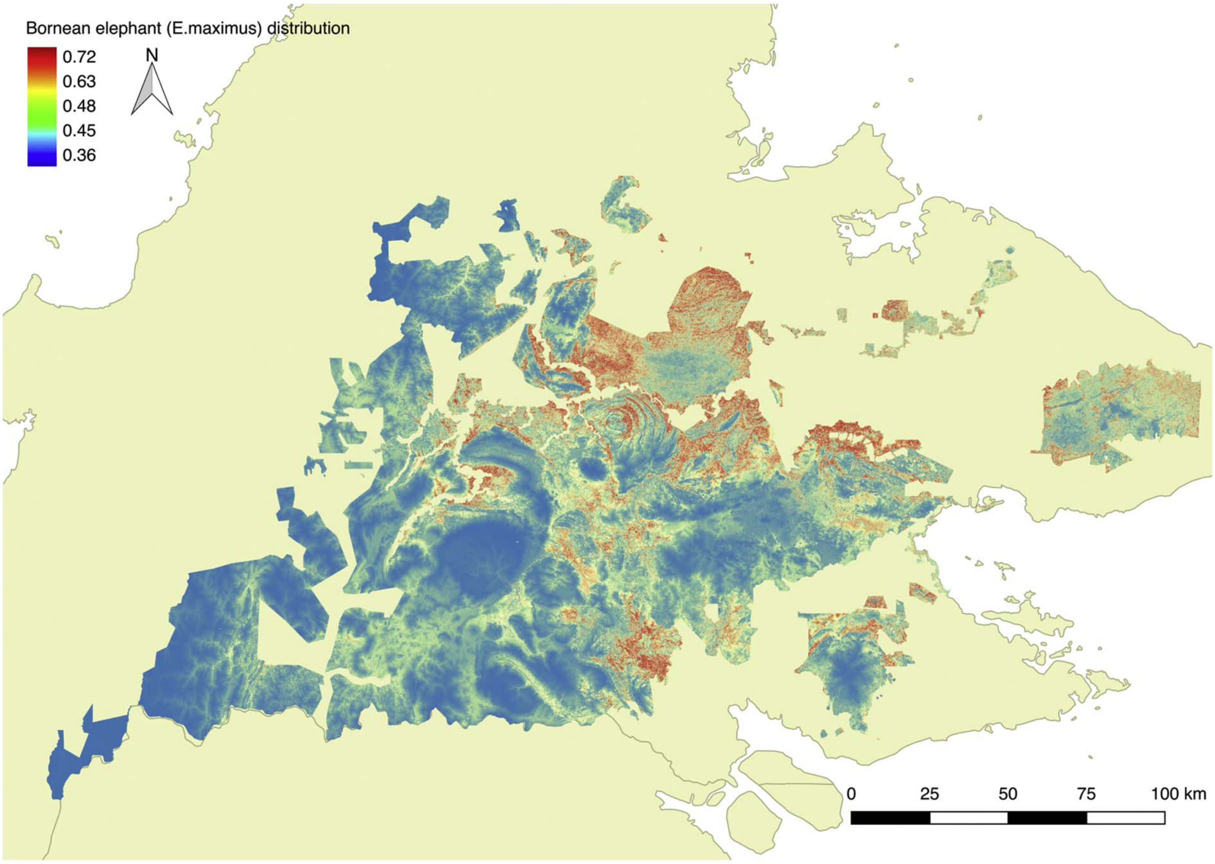


**Fig. 2.** Species distribution model for Bornean elephant (*Elephas maximus borneensis*) displaying large proportions of the central forest block in Sabah as unsuitable for elephants.

a few core traits broadly associated with intact, primary forest cover. Whether these traits aid in the sustainability of mega-faunal populations is largely unknown and of critical importance to the survival of conservation emblems such as elephants. Such species play a critically important role in the funding of conservation programs that protect habitats and biodiversity. Additionally, there are enormous positive effects of ecotourism, with Sabah gross tourism receipts for 2016 totaling USD1.72 billion and approximately 60% of that spent on ecotourism (Sabah Tourism Board, 2017; Sabah Wildlife Department, 2010). The growing ecotourism sector has the potential to outstrip the economic gains that can be achieved through traditional forest harvesting incomes, such as logging (Kirkby et al., 2010).

Here we examine the habitat preferences of Bornean elephants through the use of airborne forest canopy laser scanning, also known as LiDAR (Light Detection and Ranging), combined with Global Positioning System (GPS) animal telemetry data in the state of Sabah, Malaysia. We assessed the suitability of current protected area classifications and whether traditionally celebrated conservation areas are, in fact, suitable for Bornean elephants in Sabah. We also consider how future protected areas could be established to aid the long-term survival of this species.

## 2. Methods

### 2.1. Study region

The study examines the Bornean elephant range throughout Sabah, Malaysian Borneo. The area encompasses forested areas within central, southern and eastern Sabah. This habitat represents a largely contiguous, connected, forested region. However, although there exist two notable barriers to connectivity within the meta-population, the Lower Kinabatangan floodplain, and Tabin Wildlife Reserve, both of which are surrounded by extended areas of both mature and new oil palm plantations.

The eastern part of the state is dominated by the Kinabatangan floodplain, this low elevation and lack of slope lends itself to effective oil palm cultivation (Corley and Tinker, 2003). Despite widespread land conversion the remnant disconnected forest fragments harbored a population of 95–115 in the late nineties (Sabah Wildlife Department, 2012) with the population now thought to have grown to ~250 individuals (Alfred et al., 2010). The central forest block in Sabah is comprised of less disturbed forest, overall, largely ensured due to a lack of accessibility and challenging terrain. Maximum elevation within the study region is ~2500 m, with mean elevation ~140 m.

Protected areas in Sabah are categorized into numerous classifications. Totally Protected Areas (TPAs) are listed as Class I, under Sabah Forestry Department, but also include Wildlife Sanctuaries, under the protection of Sabah Wildlife Department, and the Park system under Sabah Parks. Commercial forest reserves in Sabah represent large proportions of land mass and are classified as Class II. Numerous other classifications exist from Class III–VII; however, these represent relatively small land coverages.

### 2.2. GPS telemetry

A total of 37 individual elephants were outfitted with GPS telemetry collars, with data from 29 individuals collected and utilized in this study. Individuals were tagged with units provided by Africa Wildlife Tracking (AWT, Pretoria, South Africa), weighing ~14 kg and representing < 1% of the total body weight of a three-ton adult individual (Alfred et al., 2012), regardless of sex. GPS units were calibrated to record locations bihourly, resulting in up to 12 fixes per day. Individuals satellite tagged more than six years (n = 2) prior to airborne LiDAR data collection were excluded from the analysis due to

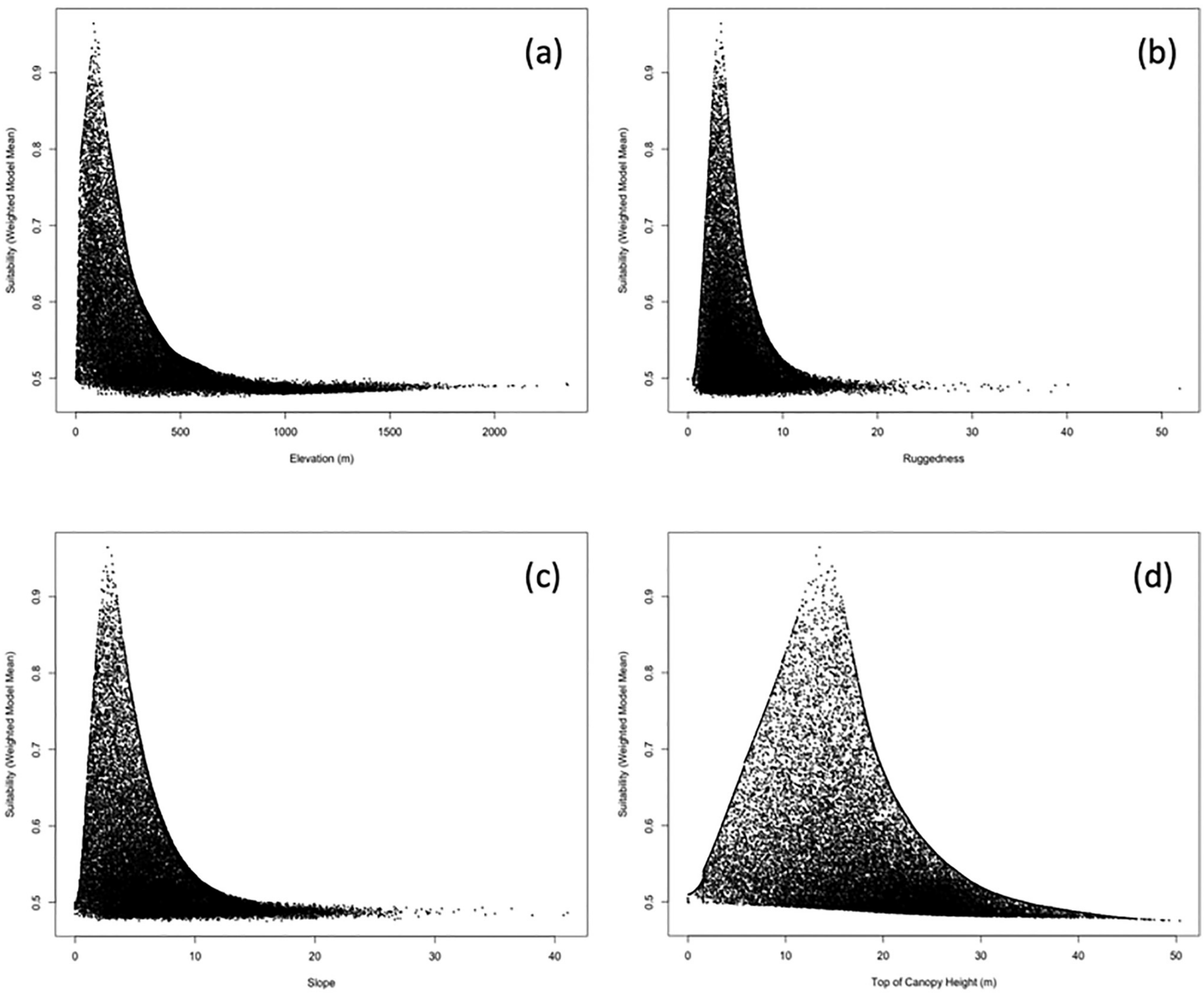


**Fig. 3.** Relationships with elephant suitability for environmental variables a) elevation, b) vector ruggedness measure (VRM), c) slope, and d) top of canopy height (TCH).

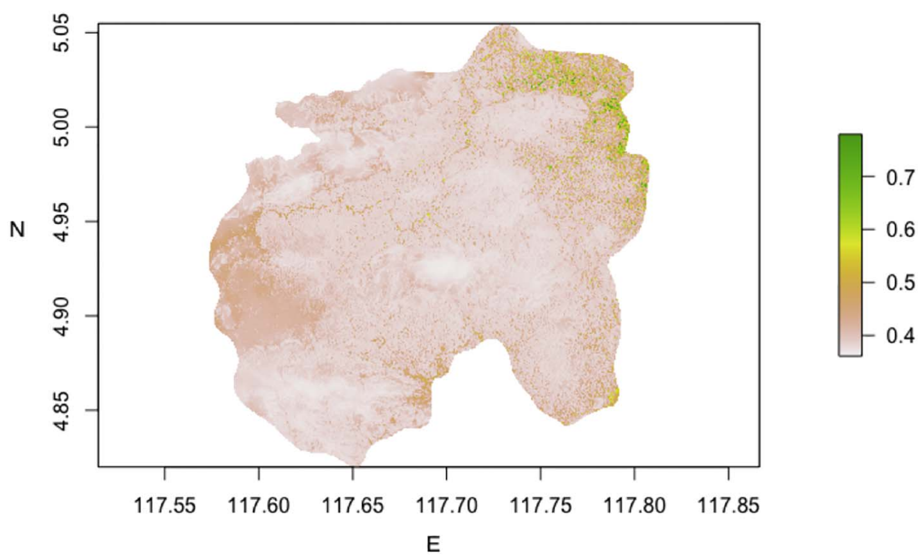


**Fig. 4.** Danum Valley Conservation Area, a large dominantly primary forest area found within Sabah's central forest block, shown to be largely unsuitable for elephants, with suitability restricted to the peripheries and major waterways. This figure highlights the importance of a range of habitat types within protected area networks.

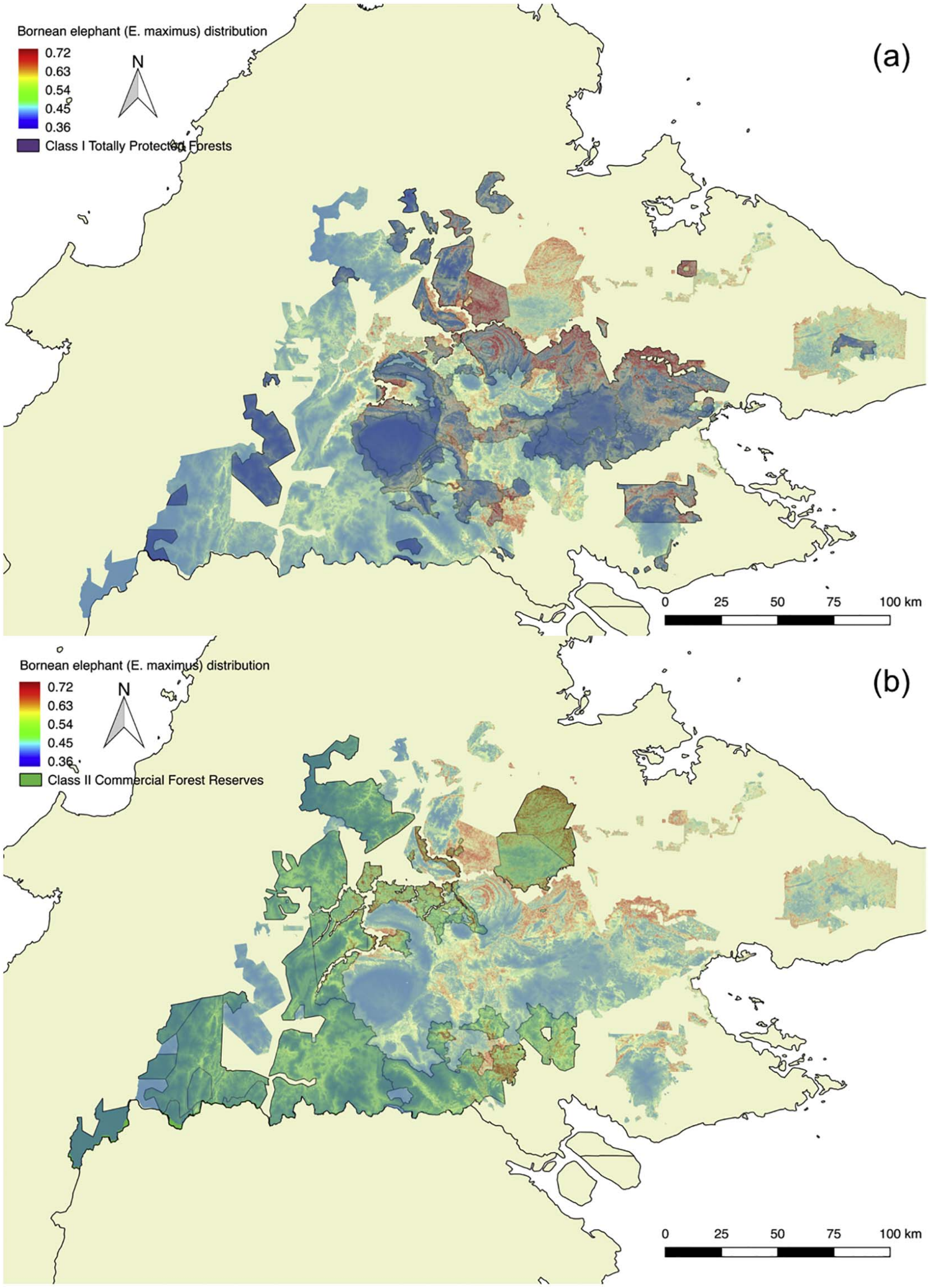


**Fig. 5.** Class I, totally protected areas, (a) and Class II, commercial forest reserves, protected area networks within the Bornean elephant range in Sabah. Displaying variations in suitability levels throughout network for both protected and commercial forest reserves.

potential significant canopy turnover between GPS and LiDAR data collections. Individuals were collared throughout their range, several individuals (n = 15) were darted and collared in oil palm and translocated to the nearest forest block to mitigate human-elephant conflict. Data from the first 14 days directly following release of each of the individuals were discarded due to the possibility of unnatural behaviors associated with recovery from the darting and tagging processes. This figure was selected after examination of mean movement rates of individuals during the first month of tagging. Two individuals were translocated large distances (> 50 km) from their home range and thus they were also excluded from the analysis due to potential discrepancies in movement patterns following release.

### 2.3. Airborne LiDAR mapping

The Northern Bornean state of Sabah, Malaysia, was aerially mapped in April 2016 using Light Detection and Ranging (LiDAR) by the Carnegie Airborne Observatory-3 (Asner et al., 2012). Precise

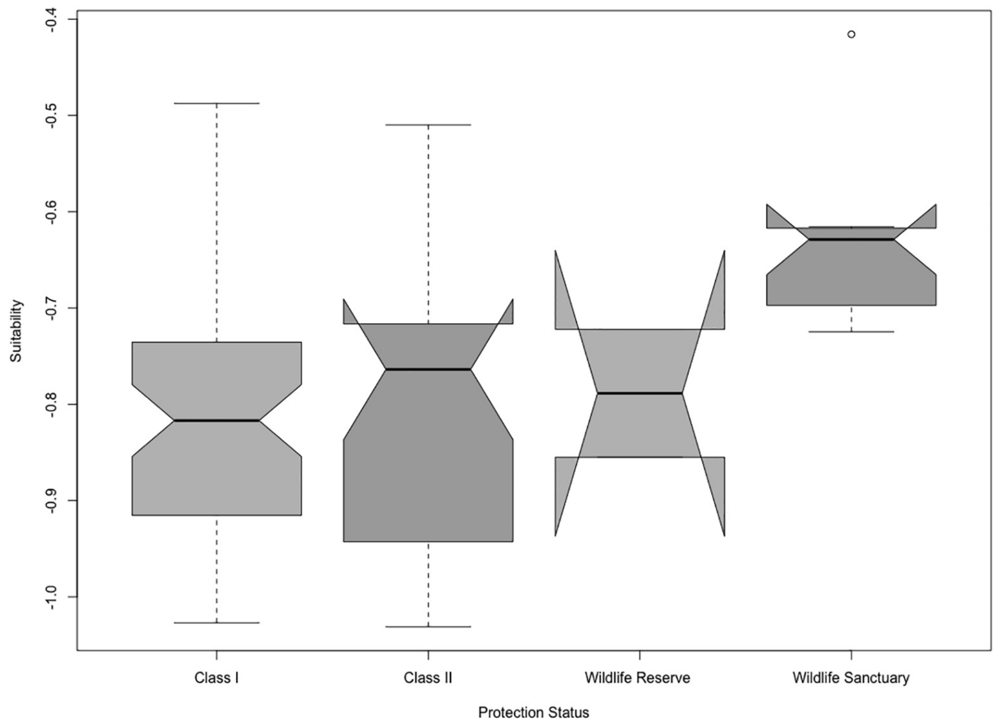


**Fig. 6.** Habitat suitability across different forest protection classifications, including totally protected forests (Class I, Wildlife Reserves, and Wildlife Sanctuaries) and commercial forest reserves (Class II).

ground-based LiDAR positions were ensured using a Global Positioning System-Inertial Measurement Unit (GPS-IMU), providing three-dimensional positions and orientations for CAO sensors. Data were collected at an average altitude of 3600 m above ground level, with a scan angle of 36° and a side overlap of 30%, for this study. Flights utilized a LiDAR pulse frequency of 150 kHz and were flown at a velocity of 150 knots. This resulted in a mean point density of 3.2 laser shots per m$^2$. Vertical and horizontal errors were estimated at 7 cm and 16 cm root square mean area (RSME), respectively.

LiDAR laser ranges and embedded GPS-IMU data were combined to produce a 'cloud' of LiDAR data (Asner et al., 2007), determining 3-D laser return locations. Where elevation is relative to a reference ellipsoid, the LiDAR data cloud was comprised of a series of geo-referenced point elevation estimates. LiDAR data points were processed using the 'lasground' tool packaged in the LAStools software package (Rapidlasso, Gilching, Germany), detecting laser pulses that penetrated the canopy volume and reached the ground.

These points were used to interpolate a raster digital terrain model (DTM). A further digital surface model (DSM) was created using interpolations of all first-return points, which included canopy top and, bare ground where only ground returns were detected. Disparities between DTM and DSM vertical difference yielded a digital canopy model (DCM). Spatial resolutions of 2 m for both ground elevation and woody canopy height models were derived.

### 2.4. Environmental variables

Top-of-canopy height (TCH) was created using the DTM created from the LiDAR point cloud. Terrain variables including elevation, slope and vector ruggedness measure (VRM) (Sappington et al., 2007). These data were acquired from Landsat imagery and analyzed at a 30 m$^2$ resolution. The LiDAR imagery was also analyzed at a resolution of 30 m$^2$. Rasterized data layers were manipulated in QGIS (v. 2.18.7) to produce slope and VRM measurements.

### 2.5. Species distribution modelling

Three different species distribution models (SDM), General Linear Model (GLM) (Stockwell and Peterson, 2002), Bioclimate variables (BIOCLIM) (Booth et al., 2014), and Support Vector Machine (SVM) (Guo et al., 2005), were utilized in the study. All SDM analyses were performed in R (v. 3.4.0), utilizing the package 'dismo' (Hijmans et al., 2017). These three modelling techniques were selected to provide a range of data interpretations in order to give a robust final model average, with the area under the curve (AUC) being utilized to create a final mean model across these three models (Fielding and Bell, 1997). AUC is widely utilized as a means of assessing model effectiveness, although there are inherent biases associated with its use (Lobo et al., 2008). Our models utilized Hijmans's (2012) removal of spatial sorting bias, at least partially accounting for a number of these concerns. The area modelling focused on non-agricultural areas within the known range of the Bornean elephant.

## 3. Results

A total of 29 collared individuals, were tracked between 2010 and 2017, throughout the state, with individuals from throughout the elephant's natural range represented in the data (Fig. 1a). Individuals were recorded at > 159,000 discrete locations throughout Sabah, from 2010 to 2017 (Fig. 1b). Individuals were tracked for a mean of 450.2 (± 307.4) days. Males (n = 13) had a mean tracking duration of 332 (± 228) days, with females (n = 16) a mean duration of 562 (± 336) days. Individuals were collared across central and eastern Sabah over a six-year period (Fig. 1b).

Species distribution models highlighted notable areas of higher suitability (Fig. 2). These areas are largely located on the peripheries of currently forested areas. Much of the remnant contiguous forest in Sabah is largely unsuitable, with remaining primary forest conservation areas such as Danum Valley, Imbak Canyon, and Maliau Basin proving to be among the least suitable areas within their range. A large percentage of the highly suitable areas border the Kinabatangan and

Segama floodplains (Fig. 2). These areas have undergone among the highest agricultural conversion rates in Sabah and this evidence suggests that a large proportion of the most highly suitable elephant habitat in Sabah has already been lost.

Both the terrain and habitat variables utilized to create the species distribution models all displayed highly significant relationships with elephant presence ($p < 0.001$), with an AUC weighted mean of 0.70 ( ± 0.20), across models. Terrain variables (elevation, slope and VRM) all displayed a similar pattern with regards to elephant presence, with low lying, flat and non-rugged terrain vastly more preferential to elephants (Fig. 3a–c). Elephants were scarcely predicted to occur above 2000 m elevation and on slopes > 30° (Fig. 3a–c). In addition to the strong correlative effects of terrain, habitat structure was found to heavily influence habitat suitability among elephants, with optimal forest stature of ~13 m (Fig. 3d). This is compared to a mean TCH of 19.94 m across Class I (totally protected) and 18.70 m throughout Class II (commercial reserve) forests, and lower quartile statures of 15.09 and 14.06 m, respectively. This indicates that less than a quarter of forest within the Bornean elephant range is of suitable stature.

Current totally protected areas in Sabah total ~26% of the state land area, with varying degrees of connectivity. How different protection statuses benefit elephant populations is key to the future prosperity of the species. Class I, or totally protected areas, include a range of suitability levels, given the range of habitat types and degradation levels. Traditionally celebrated, high TCH, high carbon storage, primary forest conservation areas such as Danum Valley Conservation Area (DVCA) (mean TCH = 32.77 m) were found to be areas of low preference for elephants (Fig. 4), with a mean suitability of 0.40 ( ± 0.001) throughout the DVCA. Areas found to be the most suitable within the DVCA were largely found in the peripheries, although waterways visible in Fig. 4 show that major rivers are likely to be the main sources of movement within the DVCA.

Conversely, Class II, active commercial forest reserves such as Segaliud Lokan or Deramakot were found to have a mean suitability of 0.569 ( ± 0.1) and 0.474 ( ± 0.12), respectively. With higher peripheral suitability, particularly in forests of eastern Sabah, there is increased susceptibility to logging and hunting encroachment. An overview of current totally protected areas (Class I, Fig. 5a) and commercial forest reserves (Class II, Fig. 5b) display high variability in suitability. However, Class I protected forest represents the lowest mean suitability for when examined as a whole (Fig. 6). The Lower Kinabatangan Wildlife Sanctuary (LKWS) had the highest mean suitability due to the degraded nature of the remnant forest, as well as the largely flat, low elevation nature of the floodplain (Fig. 6).

Current forests that are under Class II forest protection that would represent the greatest impact value through their conversion to totally protected would include Segaliud-Lokan Forest Reserve (576.9 $km^2$), and section of Sungai Pinangah (73.5 $km^2$) and Kalumpang (179.8 $km^2$) Forest Reserves. Upgrading of these current Class II protected areas (830.2 $km^2$) to Class I would represent a vast increase in protection of critical elephant habitat, particularly for Kalabakan in the south where little high-quality elephant habitat exists.

## 4. Discussion

In a world of declining primary forest cover, a biodiversity conservation management strategy solely focusing on primary forest is likely to miss opportunities for much-needed biodiversity protection. In this study, we showed that a focus on protection of remnant primary forest is detrimental to the future of the Bornean elephant. Such a primary forest-centric approach means that habitat judged to be of low quality may be more readily sanctioned for agricultural conversion or clearance for other means. The importance of low-stature, scrub forest is key to the future of Bornean elephants, with these habitats at high risk of conversion. Flat, low elevation, land has also been shown to be of crucial importance habitat suitability, and with these areas providing the most productive agricultural regions (Murtilaksono et al., 2011), it is crucially important that remaining low-stature forest in these areas are protected. The combination of both short-stature forest and low-lying flatlands produce a high-suitability, energetically low, habitat with plenty of feeding opportunities (Figs. 2, 3a–d).

Low stature forest is often associated with highly degraded, selectively logged forests (Berenguer et al., 2014). These forests are much more likely to have disturbed and discontinuous canopies, with this habitat structure lending itself to far higher levels of understory vegetation. Elephants, as understory vegetation feeders appear to habituate better to these “low-quality” habitats (English et al., 2014). Primary forests, with little sunlight penetrating to the forest floor, lack the necessary levels of understory vegetation for effective elephant grazing. Furthermore, the girth of trees found in these primary forests mean that elephants are unable to push over trees, such as with African elephants, in order to access leafy vegetation (Guy, 1976). This theory explains why in areas of existing primary habitat such as DVCA, it is peripheral areas, which are more likely to experience encroachment logging, which provide increased sunlight through the removal of larger trees (Fig. 4). Larger watercourses throughout the range were found to be more suitable, this is likely due to a requirement for fresh water as well as the abundance of fast growing, palatable species, such as *Phragmites karka*, an important food source for elephants (English et al., 2014).

Furthermore, forests displaying the highest suitability were largely found in peripheral regions, often directly bordering oil palm plantations. This suggests that there is substantial overlap between preferential habitat for elephants, and those sites which produce the highest agricultural yields. Oil palm plantations also provide a source of food, although feeding opportunities are largely restricted to younger palms, with softer leaves providing greater nutrition, this results in the loss of around 300–500 ha of crops per month (Alfred et al., 2010). Elephant incursion into agricultural lands could also be related to historical memories of once present feeding locations, mineral presence or salt licks, that at one time was productive for the matriarch. All of these factors lead to increasing levels of human-elephant conflict, with additional losses of forests exacerbating the issue.

The fact low stature forests provide the most suitable habitat suggests that elephant focal habitat regeneration projects may be effective over short-medium time frames. These findings are corroborated by Evans et al. (2017), which found that regrowth forests were increasingly likely to be utilized by elephants as TCH approached the 13-m stature found here to be of highest suitability. This suggests that, given the regrowth rates reported by Evans et al. (2017), cleared land can reach optimal stature for elephants in just 17 years. This provides important restoration, and corridor re-establishment, impetus and, given the global interest in elephant conservation, could help in the acquisition of funding for habitat connectivity studies. Additionally, a large proportion of oil palm plantations which are currently underproductive could provide valuable habitat within this timeframe (Abram et al., 2014). An optimum TCH of 13 m (Fig. 3d) suggests that, given a mean TCH of 19.94 m across Class I protected areas, the protection of relatively small, localized forest fragments could have a large contribution to habitat quality throughout the range.

Given the extensive range and variability of habitat types throughout both Class I and Class II protected forests in Sabah (Figs. 5–6), it is difficult to make generalizations regarding suitability throughout Sabah. Rather, large increases in high habitat suitability areas can be achieved with the targeted protection of small areas of forest. These forests will also often be of low economic timber value and will in the future likely be slated for conversion to oil palm plantations as land requirements for the crop expand. As such, a large proportion of remaining high-quality habitat could be lost over the next 5–10 years without the knowledge of these areas of importance.

There has been a marked increase in elephant poaching in Sabah over the last several years, with the discovery of a number of dead elephants and multiple seizures of ivory in Kalimantan, Indonesia (The

Star, 2017). The suitability of peripheral forests and elephants' willingness to enter oil palm plantations create opportunities for poachers. This, together with habitat loss, is the greatest threat posed to the fragile extant populations of the Bornean elephant. With just ~2000 individuals in the world, the loss of breeding males threatens the breeding stability of the entire population and threatens to send the elephant the way of the Sumatran rhinoceros (*Dicerorhinus sumatrensis*), now declared extinct in the wild in Sabah.

Our study represents the most detailed examination of how this species utilizes the forests of Sabah. However, our models are based solely on presence data obtained through animal GPS telemetry tracking. The study would be strengthened by characterizing areas of known elephant absence within the region. The issue of inaccuracies of GPS data (< 20 m) also means that some of the habitat variables were misaligned with the actual locations of the animals in question. However, given that this study examined > 159,000 discrete locations, the overall error of the model is negligible (Hernandez et al., 2006).

Understanding of how large, enigmatic mammals utilize habitat is of paramount importance for conservation planning strategy. We aimed to examine factors affecting Bornean elephant prevalence by assessing the impacts of forest quality and terrain on habitat suitability. In turn, we sought to redefine conservation planning priorities based on wide-scale, high resolution digital renderings of habitat data. In doing so, we provide the most complete examination of Bornean elephants to date. Through the use of targeted forest protection, it is hoped that the future of this iconic species can be assured.

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