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Why did the elephant cross the road? The complex response of wild elephants to a major road in Peninsular Malaysia

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ABSTRACT

Roads cause negative impacts on wildlife by directly and indirectly facilitating habitat destruction and wildlife mortality. We used GPS telemetry to study the movements of 17 wild Asian elephants (*Elephas maximus*) and a mechanistic modelling framework to analyse elephant response to a road bisecting their habitat in Belum-Temengor, northern Peninsular Malaysia. Our objectives were to (1) describe patterns of road crossing, (2) quantify road effects on movement patterns and habitat preference, and (3) quantify individual variation in elephant responses to the road. Elephants crossed the road on average 3.9 ± 0.6 times a month, mostly (81% of times) at night, and crossing was not evenly distributed in space. The road caused a strong and consistent barrier effect for elephants, reducing permeability an average of 79.5%. Elephants, however, were attracted to the proximity to the road, where secondary forest and open habitats are more abundant and contain more food resources for elephants. Although the road acts as a strong barrier to movement (a direct effect), local changes to vegetation communities near roads attract elephants (an indirect effect). Given that risk of mortality (from poaching and vehicle collisions) increases near roads, roads may, therefore, create attractive sinks for elephants. To mitigate the impact of this road we recommend avoiding further road expansion, reducing and enforcing speed limits, limiting traffic volume at night, managing habitat near the road and, importantly, enhancing patrolling and other anti-poaching efforts. Our results are relevant for landscapes throughout Asia and Africa, where existing or planned roads fragment elephant habitats.

1. Introduction

The world's terrestrial megafauna are rapidly declining due to anthropogenic pressure (Ripple et al., 2016). In an increasingly human-dominated world (e.g. Venter et al., 2016), there are few places where large animals can live without coming into contact with people and the human footprint (e.g. agriculture and infrastructure; Kareiva et al., 2007; Allan et al., 2017). Linear infrastructure, such as roads, are omnipresent features of human activity that are rapidly proliferating in the tropics (e.g. Chomitz et al., 2007; Laurance et al., 2009; Laurance et al., 2014; Ibisch et al., 2011). Roads have negative impacts on wildlife by directly and indirectly facilitating habitat destruction and wildlife mortality (Laurance et al., 2009; Clements et al., 2014). The effect of roads is particularly concerning for megafauna, animals that require large home ranges (Harestad and Bunnel, 1979; Jetz et al., 2004).

Animal behaviour, movement, and distribution can be affected by roads in several ways. Roads can affect habitat preference by modifying the environmental conditions near them (e.g. through edge effects; Benítez-López et al., 2010; Fortin et al., 2013). Roads can also affect movement behaviour (Dussault et al., 2007; Blake et al., 2008; Eftestøl et al., 2014), altering wildlife's ability to move between neighbouring areas and utilize resources within the available habitat (Johnson et al., 1992). At larger scales, roads can reduce landscape permeability and connectivity by acting as barriers that impede the movement of animals from habitat on one side of the road to the other side (Beyer et al., 2016; van Strien and Grêt-Regamey, 2016), which can eventually result in the fragmentation of populations (Dunson and Travis, 1991; Laurance et al., 2009; Said et al., 2016).

There is mounting evidence that roads act as barriers to movement and alter the distribution of elephants in space. In the Congo basin, for

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example, roadless wilderness is a strong determinant of forest elephant (*Loxodonta cyclotis*) home range area (Blake et al., 2008). Analysing the movement of 28 elephants, Blake et al. (2008) recorded only one road crossing outside a protected area and concluded that roads are a formidable barrier to forest elephant movements. Another study in central Africa found a similar response whereby two elephants exhibited no road crossings, while one individual never came within 11 km of the road and the second individual ranged 1–15 km away from the road (Granados et al., 2012). In India, however, Asian elephants (*Elephas maximus*) crossed a road in a wildlife sanctuary regularly, although elephants near the road showed high levels of agitation in response to large vehicles (Vidya and Thuppil, 2010). These variable effects of road crossing between central Africa and Asia suggest elephant responses to roads are complex and not well understood.

Southeast Asia is the region of the world with the largest number of threatened megafauna (Ripple et al., 2016, 2017). It is also a region of rapid economic growth (World Bank, 2016), experiencing a massive and unprecedented expansion of road coverage (World Bank, 2013). The expected infrastructure development over coming decades (Dulac, 2013) will likely further threaten the region's megafauna, including Asian elephants – the largest terrestrial animal in the region. Asian elephants are endangered due to the rapid decline of their populations, mostly as a consequence of habitat loss and the resulting human-elephant conflict in the form of crop raiding (Fernando and Pastorini, 2011; IUCN, 2017).

Within Southeast Asia, Peninsular Malaysia is an important stronghold for wildlife (Rostro-García et al., 2016), including Asian elephants (Saaban et al., 2011). In the past few decades Peninsular Malaysia has undergone a drastic transformation, passing from nearly 80% of forest cover in the 1940s (Aiken and State, 1994; FDPM, 2016) to < 37% in 2010 (Miettinen et al., 2011). Recognising the importance of the country's biodiversity (Mittermeier et al., 1997), Malaysia's government has developed legislation and policies to protect it (Nagulendran et al., 2016). The Central Forest Spine (CFS) is a national land-use master plan to maintain habitat connectivity for wildlife across the major habitat patches in Peninsular Malaysia (DTCP, 2009). The implementation of the CFS plan involves the protection of key wildlife corridors and the construction of several viaducts under existing highways to facilitate movement by wildlife. The National Elephant Conservation Action Plan (NECAP) is the official policy for Asian elephant conservation in Peninsular Malaysia (DWNP, 2013).

Little is understood about the impact of roads on elephants in Peninsular Malaysia. Here, we investigate and quantify how Asian elephants respond to the presence of a major road bisecting a key wildlife corridor. We used GPS telemetry data from forest elephants to (1) describe the spatial and temporal patterns in road-crossing behaviour. We also (2) quantify the effects of the road on forest elephant movement behaviour and distribution using a mechanistic movement modelling framework that includes both habitat preference and movement rates (Fortin et al., 2005; Forester et al., 2009; Avgar et al., 2016; Beyer et al., 2016; Raynor et al., 2017). Finally, we (3) explicitly evaluate individual variation in the response to roads in order to better understand the range of behavioural responses in the population of elephants. Our research, which is aligned with the objectives of Malaysia's CFS and NECAP policies, can inform management recommendations to reduce the impacts of roads on elephants and other large mammals.

2. Materials and methods

2.1. Study area

The study area (~4000 km^2) is located in northern Peninsular Malaysia (5°55′ N, 101°34′ E) and is known as the Belum-Temengor Landscape (BTL; Fig. 1a). BTL is a hilly and forested landscape dominated by dipterocarp and montane forests, with an altitudinal range of 260 to 2160 m above sea level. BTL consists of forest blocks under different management regimes: Royal Belum state park (Belum; 1246 km^2), a fully protected area that has never been commercially logged, and several forest reserves where some selective logging is permitted and ongoing (Fig. 1b).

In the 1970s there were some important infrastructural developments in BTL, including the construction of a ~125 km^2 reservoir and of the East-West Highway, a 120-km long road that bisects the study area (Fig. 1). The East-West Highway is fully asphalted, has a width of 2–3 lanes (~25 m), and often has additional structures such as steel and concrete barriers, and concrete drains on its sides (Fig. 1). Between 1970 and 1995, the forest reserve that runs parallel to the road (Fig. 1b) was heavily logged. Between 2005 and 2014, traffic volume in the East-West Highway increased at an average annual rate of 4.1%; and in 2014, traffic was 2.3 times denser during day-time (227 vehicles per hour from 0600 to 2200 h) than during the night (97 vehicles per hour from 2200 to 0600 h; Table S1; MoWM, 2014).

BTL is a key priority landscape for CFS and NECAP (DWNP, 2013). In 2015, a 200-m long and 11-m high viaduct was built to facilitate wildlife movement between the forests at both sides of the road (Fig. 1b & Fig. S1). Human density in BTL is low, with small villages of indigenous *orang asli* people living either inside or along the fringes of the forest. The *orang asli* practice subsistence and small-scale cash-crop agriculture (Kasim and Baskaran, 2014); there are no large-scale plantations within the study area.

2.2. Elephant tracking

We tracked "translocated" and "local" wild elephants. Translocated elephants were animals relocated from human-elephant conflict areas to BTL by the Department of Wildlife and National Parks (DWNP) to mitigate conflict (Saaban et al., 2011). Local elephants were individuals found in BTL and collared within 200 m from the East-West Highway. We used Inmarsat satellite GPS collars for elephants (Africa Wildlife Tracking, Pretoria, South Africa), programmed to record one location every 2 h. All elephants were immobilised by the DWNP as described in Daim (1995). We complied with research and ethics requirements by the Malaysian government (permit #JPHL%TN(IP): 80–4/2) and the Smithsonian National Zoological Park Institutional Animal Care and Use Committee (NZP-IACUC #10–32).

Our GPS collars provided a metric to quantify the accuracy of each location, called horizontal dilution of precision (HDOP). We removed 1) locations that reported HDOP values > 25 m, 2) duplicate records, and 3) obvious GPS errors; i.e. locations that implied animals travelled > 10 km within 1 h. For details for analyses on elephant tracking and road crossing behaviour see Appendix A1.

2.3. Describing patterns of road crossing

We tested whether there was an effect of the time of the day (daytime = 700 to 1900 and night-time = 1900 to 700) on the frequency of elephant road crossing by fitting a linear mixed effects model using the function lme (Pinheiro and Bates, 2000). The model included frequency of crossing events as the response variable, time of the day (day vs. night) as fixed factor, and the individual elephant as a random factor. Moreover, in order to understand the spatial patterns of road crossing, we divided the road into 90 1-km long segments and quantified the frequency of crossing in each of these segments.

2.4. Movement modelling

Habitat selection and animal movement were modelled based on the framework of Beyer et al. (2016), which defines a probability of a "step" between sequential telemetry location a to location b, and conditional on habitat covariates, X, at location b, to be:

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