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Factors affecting seasonal habitat use, and predicted range of two tropical deer in Indonesian rainforest

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ABSTRACT

There is an urgent recognized need for conservation of tropical forest deer. In order to identify some environmental factors affecting conservation, we analyzed the seasonal habitat use of two Indonesian deer species, *Axis kuhlii* in Bawean Island and *Muntiacus muntjak* in south-western Java Island, in response to several physical, climatic, biological, and anthropogenic variables. Camera trapping was performed in different habitat types during both wet and dry season to record these elusive species. The highest number of photographs was recorded in secondary forest and during the dry season for both Bawean deer and red muntjac. In models, anthropogenic and climatic variables were the main predictors of habitat use. Distances to cultivated area and to settlement were the most important for *A. kuhlii* in the dry season. Distances to cultivated area and annual rainfall were significant for *M. muntjak* in both seasons. Then we modelled their predictive range using Maximum entropy modelling (Maxent). We concluded that forest landscape is the fundamental scale for deer management, and that secondary forests are potentially important landscape elements for deer conservation. Important areas for conservation were identified accounting of habitat transformation in both study areas.

1. Introduction

There can be little doubt that the lowland tropical forests, even though occupy only 7% of the land area, are the most species-rich of all terrestrial ecosystems and suffer the highest deforestation rates worldwide (Corlett and Primack, 2010; FAO, 2010; 2011; World Resources Institute, 2011; Hofsvang, 2014). Tropical forest degradation and fragmentation dramatically transform natural dynamics, potentially triggering species extinctions, decreasing survival, modifying habitat use and species distributions (Fahrig, 2003). Fragmentation impacts habitat availability and wildlife species, depending on their particular habitat requirements and their ability to move through the landscape (Ojasti, 2000; Turner et al., 2001). For example, habitat fragmentation caused by anthropogenic activities is the main factor that induces habitat use changing by ungulates (Tejeda-Cruz et al., 2009; García-Marmolejo et al., 2015), or constrain long-distance movement of Mongolian gazelles (*Procapra gutturosa*) and Asiatic wild asses (*Equus hemionus*) (Ito et al., 2013). Knowledge about the habitat and the range of species is crucial for designing sound management strategies of biodiversity conservation (Arzamendia et al., 2006; Kumar et al., 2010).

Information on which a range is occupied or avoided by organisms improves our understanding of how they meet their requirements for survival and reproduction (Manly et al., 2002). Habitat use by mammalian herbivores such as deer species is considered as an optimization process that involves factors such as body size, population density, competitors, predators, food availability, landscape, and microclimate (Morrison et al., 1992; Ofstad et al., 2016). For example the use of open habitats landscape by red brocket and white-tailed deer may be associated with its large body size and the structure of male antlers, which influence movement and feeding (Bolaños and Naranjo, 2001). While, the mule deer changed their habitat use after coyotes were introduced into the enclosure (O'Brien et al., 2010), and sika deer increased their relative use of habitat in lower quality during the high-density

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period (Borkowski, 2011). Furthermore, habitat use in dry season being most sensitive to competitive interactions within and between grazers species in an African savanna (Macandza et al., 2012). In red deer, neither habitat use nor home-range behaviour, especially those of males, was closely related to the pattern of spatial and seasonal variation in food resources (Lazo et al., 1994).

For predicting species habitat use and range several statistical models exist: general linear modelling/GLM (McCullagh and Nelder, 1989), algorithmic modelling (Ripley, 1996), beyond classical regression (Manly et al., 1993), genetic algorithm for rule set production/GARP (Stockwell and Peters, 1999), ecological niche factor analysis/ENFA (Hirzel et al., 2002), Bioclim (Beaumont et al., 2005), maximum entropy modelling/Maxent (Phillips et al., 2006), and multiple factor analysis/MFA (Calenge et al., 2008). Maxent, one of the most commonly used presence-only modelling for inferring species distribution, habitat use and environmental tolerances from occurrence data, allows users to fit models of arbitrary complexity (Warren and Seifert, 2011). Moreover, Maxent has been described as especially efficient to handle complex interactions between response and predictor variables (Elith et al., 2006, 2011). It is commonly used in studies in tropical regions (Cayuela et al., 2009), and is little sensitive to small sample sizes (Wisz et al., 2008).

Mammal fauna such as deer species have been proposed as good indicators of the integrity of natural communities because they integrate a number of resource attributes, and thus may show population declines quickly if one is missing (Escamilla et al., 2000). In addition, Smith et al. (1993) estimated that almost 79% of the tropical deer species are at risk of extinction and become the most endangered mammal group.

The "Critically Endangered" Bawean deer *Axis kuhlii* (Temminck, 1836) is one of the Indonesian ungulate species threatened by human activities (Semiadi et al., 2013). This deer lives only on the 200 km^2 Bawean Island (Lachenmeier and Melisch, 1996; Grubb, 2005) and is the most isolated deer in the World (Blouch and Atmosoedirdjo, 1987; Semiadi et al., 2013). It is listed in Appendix I of CITES (2009). On the contrary the "least concern" red muntjac *Muntiacus muntjak* (Zimmermann, 1780) is a locally common species (Davies et al., 2001) with varying levels of threat. Red muntjac is among the most widespread tropical cervids (Chasen, 1940; Groves, 2003; Meijaard, 2003), ranging from Pakistan to Indonesia, through all south-eastern Asia (Mattioli, 2011). In Indonesia populations of red muntjac persist in many areas where there is some forest cover (Whitten et al., 1996), on Bali, Java, southern Sumatra and Kalimantan Islands. Both species looks very similar in terms of body size and sexual dimorphism, and they are considered to be typical and flagship solitary species of tropical forests (Blouch and Atmosoedirdjo, 1978; Oka, 1998; Mattioli, 2011).

Like many other tropical forest cervids, Bawean deer and red muntjac are difficult to monitor because of their elusive behaviour. Recently, camera-traps have become an important tool for monitoring terrestrial rare and cryptic species which are difficult to observe in tropical rainforests (Karanth, 1995; Karanth and Nichols, 2002; Tobler et al., 2008). Camera trapping was also successful in determining abundance, habitat use and range of elusive ungulates (Bowkett et al., 2007; Rovero and Marshall, 2009; Krishna et al., 2009; Tobler et al., 2009). They proved to be useful for recording deer with high detection efficiency (Rovero et al., 2014).

In tropical rainforest, the lowland forest ecosystems are considered optimal habitats for deer species. Within these ecosystems primary forests are reported to be highly productive for a wide variety of vertebrates, particularly for mammalian species. Furthermore 'specialist' species associated with these forests are more vulnerable to disturbance and eradication (Rijksen, 1978; Yasuda et al., 2003; Meijaard et al., 2005) usually bestowing a higher conservation status upon them. We tested the hypotheses that (i) both deer species are highly dependent of primary forests versus other forest types, (ii) undisturbed protected forest areas are essential for their conservation. We used Maxent to model the habitat use and predict the range of Bawean deer for testing these hypotheses in Bawean Island Nature Reserve and Wildlife Sanctuary and red muntjac in Ujung Kulon National Park (Indonesia).

2. Material and methods

2.1. Study areas

We studied Bawean deer in Bawean Island, an isolated island in Java Sea (5°40′-5° 50′S; 112° 3′-112° 36′E, Fig. 1). According to the classification of Schmidt and Ferguson (1951), Bawean Island climate is categorized in type C (Semiadi, 2004). Within the island mean temperature varies between 22 °C and 32 °C, and relative humidity ranges between 50% and 100% (Semiadi, 2004). The mean annual rainfall reaches 2.298–2.531 mm on the southern coast; rainfall is more abundant during the north-west monsoon from the end of October until April (wet season) than during the south-east monsoon from May to October (dry season). The protected area of Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS) of ca. 725 ha (nature reserve) and ca. 3.832 ha (wildlife sanctuary) is characterized by a steep topography (with terrain slopes > 60°) and a wide altitudinal gradient (1–630 m). The BINR-WS constitutes one of the last strongholds in the country for endemic medium-large mammalian ungulates such as the Bawean deer and Bawean warty pig *Sus verrucosus blouchi* (Boie, 1832).

The main vegetation type is a tropical evergreen rainforest which can be divided into four major forest types: primary forest, secondary forest, teak (*Tectona grandis*) forest, and shrub (Table 1, Appendix 1A). The BINR-WS protects one of the small patches of evergreen rainforest in Indonesia (ca 23% of the Bawean Island), including teak plantations (60% of this area). This habitat type is globally endangered by deforestation and climate change (Semiadi, 2004; Rahman et al., 2017). The remaining natural forests are confined to the steep sides and top of the higher hills and mountains, often occurring as islands surrounded by teak.

We studied Red muntjac in Ujung Kulon National Park (UKNP), a peninsula of ca. 76.214 ha at the extreme southwestern tip of Java Island, Indonesia (6°45′S; 105°20′E). UKNP climate is categorized in type A (Hommel, 1987). The mean temperatures range between 25 °C and 30 °C and relative humidity ranges between 65% and 100% (Blower and Van Der Zon, 1977; Hommel, 1987). Conditions are tropical maritime, with a mean annual rainfall of ca. 3.250 mm. The heaviest rainfall occurs during the north-west monsoon (wet season) from October to April, preceding a noticeably drier period with ca. 100 mm per month during the south-east monsoon (dry season) from May to September. The Ujung Kulon National Park has varied topography (with terrain slopes > 15°) and a wide altitudinal gradient (0–620 m). The UKNP constitutes one of the last strongholds in the country for endemic large mammalian ungulates such as the Javan rhino *Rhinoceros sondaicus* (Desmarest, 1822).

The main vegetation is a tropical evergreen rainforest, which has suffered a number of anthropogenic and natural modifications. It is mainly secondary growth, following the destructive Krakatau eruption and tsunami of 1883. The main habitat types are primary forest, secondary forest, mangrove-swamp and beach forest (Table 1, Appendix 1B). The Arenga palms, which grow on thick ash, may be dominant as a result of long-past volcanic disturbance. As a result, the natural vegetation cover, now occupies only 50% of the total area, and is largely confined to the Mt. Payung and Mt. Honje massifs.