THÈSE

To obtain the degree of

DOCTOR OF THE UNIVERSITÉ DE TOULOUSE

Issued by Université Toulouse III Paul Sabatier (UT3 Paul Sabatier)
Discipline: Behaviour, Ecology and Evolution

Presented and defended on 23/9/2016 by:

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New insights into ecology and conservation status of Bawean deer (*Axis kuhlii*) and red muntjac (*Muntiacus muntjak*) in Indonesian tropical rainforest

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Defended on 23 September 2016, in front of the jury :

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"The wildlife and it's habitat cannot speak,

so we must and we will"

(*Theodore Roosevelt*)

ACKNOWLEDGEMENTS

Although only one name appears on the cover as author, this thesis would not exist without all those who have given so generously of their time and energy over the last several years.

Postgraduate scholarships and funding was provided by Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, Republic of Indonesia. Primary funding for research was provided by Rufford Small Grant project No. 13957-1.

I would like to place on record my gratitude for the Ministry of Environment and Forestry, Repubic Indonesia, for not only permitting me to be part of the ongoing research work and carry out this research but also sanctioning leave which enabled me to complete the thesis. I would like to name certain Head of BBKSDA East Java, Suyatno Sukandar, M.Sc and Head of Ujung Kulon National Park, Dr. Mohammad Haryono in particular, then Head of Division FRC Area II/Gresik and Head of Management Section Area III/Sumur, who were particularly helpful in this regard.

Numerous individuals have been instrumental in making this work possible. I am grateful to my supervisor Stéphane Aulagnier, Prof and Head of the Behaviour and Ecology of Wildlife Laboratory (Comportement et Ecologie de la Fauna Sauvage), INRA Toulouse, for accepting me to supervise in his busy schedule, guidance and supervision throughout with positive appreciation. He has been instrumental in shaping up my interest in research and implementing the findings. I would like to thank co-supervisor Dr. Georges Gonzalez, Scientist CR1, for his great support in materializing and bibliography the Method by spending times, helping in administrative affairs, generating interest and for the beautiful words that build excitement when I tired. Many thank for you all, who gave me continued encouragement during this process and have mentored me along the way.

Another very important factor contributing to my work has been the numerous field assistants who have helped me to collect the field data. In particular, Intannia Ekanasty, Arifani Setya Rohim, Bayu Yogatama, and Cahya Wiratama, my research assistant, who worked diligently by my side for more than one years in Indonesia and who shares my interest in science, finding answers through difficulties in the fields. Also thankful to Mr. Daryan, Mr. Aom Muhtarom, Mr. Muhiban, Mr. Agung Suci Raharja, Mr. Asep Yayus Firdaus from Ujung Kulon National Park and Mr. Nursamsi, Mr. Rahim, Mr. Maskur, Mr. Taha from Bawean Island Nature Reserv and Wildlife Sanctuary for managing people in the fields and become forefront guard to protecting habitat and wildlife while I worked on this Thesis, and also to my friend Andi Nur Cahya, Dr. Matthew Linkie from University of Kent, and Mr. Hariyo T Wibisono from FFI Indonesia, event though we only meet three days in Bali for doing a small conference which facilitated by FFI Indonesia and Rufford Foundation, but your experience and knowledge sharing are very useful for me to finished this Thesis, and also in particular A.J. Mark Hewison, Cécile Vanpe, and Tanguy Daufresne, who spend time led me build an ideas in the first meeting before I return to Indonesia to do a research and also thanks for you willingness to be a part of refree in the selection of Rufford Grant.

I am very grateful to Joël Merlet , who provides a time in his busy schedule to assist the field activity in the first and third years of my research period, sorry for making injury your spine since we working together to collect the faecal of roe deer in Aurignac and Gardouch, a precious experience working with you. I also thankful to RMU team in Ujung Kulon National Park, in particular Mr.Sumardi, and Mr. Nasar for their valuable input. I'm grateful to Nadège Bonnot, and M. Yannick Chaval for their assistance and editorial comments, and my friends and colleagues at CEFS who made friendship, Julie Sevila, Chloé Monestier, Ophélie Couriot, Hélène Verheyden, Marie Line Maublanc, Pascal Dufour, Marianne Bayrou, Bruno Cargnelutti, Jean Joachim, Nicolas Cebe, Jean-François Gérard, Nicolas Morellet, Erwan Quéméré, and Jean-Luc Rames. Dominique Pantalacci (the secretaries of doctoral school of SEVAB) to have patiently solved my administrative problems.

On a more personal note, I owe my deep sense of gratitude to most important peoples in my life my mother Unay Yulia and Panca Dewi Manuhara Karti are the two but one who sincerely raised me with her caring and gentle love; my father Komarudin Effendy is the person who put the fundaments in my character, showed me the joy of intellectual pursuit ever since I was a child. You are teaching me that the world is an open door and one is only constrained to venture into the world by one's own fears. This thesis was her and his dream which I made fulfilled today. My sister and brother, Novita Anggraeni, Muhlis, Dicky Rizal Samsir Alam, Dewi Sondari, Lembahnandono Prasatya Mahatama, Zara Fitria Bramanthi, Kalimas Dwi Nandono, who always support anything that I want to be. They told me I could

do anything I put my mind to. Also for my friends from Indonesia, I am greatly value the care and confidence, though the life moment that we share: Dr. Puji Rianti, Dr. Afif Latif and family, Dr. Reggie Surya, Nuraziz Handika, Amie Pratiwi, Fito Beng Rahdianto, Okta Pramitya Pasaribu, Dwiyoga Yudhoyono and family, Nadya Noor Azalia, Ruby Lucyana Wihardi, Pratiwi Primatirta Widyaningrum for all the time, patient, tear and laughter become colored and spirited the journey. Your invaluable friendship has encourage me to keep moving on and stay focus through the years. Thankful also for my lecturer, senior, *co-parent*, Prof. Yanto Santosa, who has guided and become the best teacher ever since when I become undergraduate student until now. Your views inspire me, and your efforts to introduce French has changed all of my way. For all of this, I express my thanks and love for you all.

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ABSTRACT

The aim of this study was to investigate the ecology of two medium-sized tropical deer, the Bawean deer *Axis kuhlii* and the red muntjac *Muntiacus muntjac* in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park respectively, and to update their conservation status. We used for the first time a new monitoring technique, camera trapping, together with classical ecological field methods for estimating population size, investigating habitat use, predicting range, and identifying activity pattern. Results show that camera traps were initially expensive but they lightened the field work and provided much information for further analyses. Moreover, camera trapping provided a higher number of records and accurate species identification than other methods. For estimating population size we used a random encounter model (REM), a technique accurate for estimating density of elusive, rare and unmarked species contrary to photographic capture-recapture techniques which require both unique mark and good photographs for individual recognition, and compared the results with those obtained by faecal pellet group count. Both methods provided similar population density estimates, higher in the dry than in the wet season, and a population size of ca. 227-416 deer. The range of Bawean deer established dramatically narrower than previously reported, faecal pellet group count bringing additional data to camera trapping. Both deer species were mainly recorded in secondary forests; Analysis with Maximum entropy model (Maxent) showed that anthropogenic (for both species) and climatic (for red muntjac only) variables were the main predictors of habitat use. Finally, using time data recorded by camera traps, we investigated the activity pattern related to sex and environmental conditions. The believed nocturnal Bawean deer was predominantly photographed during the day, and its nocturnal activity was linked to luminosity. Red muntjac also showed some diurnal activity with higher peaks after sunrise and before sunset, and a nocturnal activity which was not influenced by luminosity. No difference was observed between males and females for both species. Whereas red muntjac is listed "Least concern" by IUCN even if local conservation measures should be undertaken in our study area, Bawean deer should remain "Critically endangered" as the population is still small and the main threats, habitat loss due to illegal logging and human disturbance by dogs and hunters, are ongoing.

Keywords: Bawean deer, red muntjac, tropical rainforest, camera trap, transect sampling, faecal pellet group count, population size, range, conservation status, habitat use, activity pattern.

INTRODUCTION

Male Bawean deer

Female Bawean deer

Male red muntjac

Female red muntjac

CHAPTER 1

INTRODUCTION

I. GENERAL INTRODUCTION: **CONTEXT OF THE STUDY**

I.1. Monitoring wildlife in the tropics

Incomplete knowledge of populations of wildlife species in tropical areas, should instigate population monitoring programmes in these areas (Danielsen et al., 2007; Walters, 2010). Without the support of good data, managers will have difficulty in setting limits of acceptable change for species and their habitats, including determining the priority areas for conservation of species (Buckland et al., 2005; Walters, 2010). How populations change over time, and how human activities, such as logging and hunting affect those populations, can only be answered by data from long-term monitoring programmes (Walters et al., 2010); which can in turn help managers in drawing up the planning process, of appropriate management decisions and evaluating the ongoing management activities for reducing threats (Stokes et al., 2010).

More than half of all conservation programmes have wildlife monitoring activities as their main component, and these also contribute to reserve management schemes (Wilson and Delahay, 2001; Dajun et al., 2006). Besides the above main issues, the lack of funding, (including support for proper equipment and capacity, in terms of staff education and the expertise to be able to design effective monitoring programmes independently (Danielsen et al., 2007; Gardner, 2010) is often blamed for the ineffective way protected areas are managed in several countries, including Indonesia (McCarthy et al., 2010). Budgeting and monitoring schemes are not effective due to errors in determining long-term investment, which often lead to large amounts of money being wasted (Balmford and Whitten, 2003; Balmford and Cowling, 2006; Gardner, 2010). For this reason, studies should seek to prioritize conservation initiatives that make use of limited resources with effective, up-to-date ecological information on species, and to produce more accurate data to improve management decisions. These obstacles, though significant, should not be allowed to prevent protected areas from being managed effectively.

For monitoring populations, techniques continues to improve over time, either directly on the targeted animals or indirectly on specific signs and marks. The suitability and effectiveness of a given method and its application will always be relative to the specific purpose and the resource constraints of the survey (Gaidet-Drapier et al., 2006). The resulting output data help in designing conservation actions appropriate to the target species, and in making inferences on many aspects, such as estimates of species richness (O'Brien et al., 2010, Meyer et al., 2015), estimates of community structure and diversity (Ahumada et al., 2011), or in simply detecting species presence (Giman et al., 2007; Tobler et al., 2008), studying activity patterns (Grassman et al., 2006) and abundance (Bennun et al., 2004; Marnewick et al., 2008). The use of technology in monitoring wildlife populations is known to help in reducing the level of effort and cost, while at the same time also in increasing the complexity of the resulting data (Silveira et al., 2003; Walters, 2010).

Potential biases in data collecting and the completeness of the outcomes of research will be primarily determined by the selection of wildlife monitoring methods used; this is an important aspect of successful project planning (Marshall et al., 2008). Furthermore, the selection of the most appropriate method will be determined according to the advantages and disadvantages of each method with regard to constraints on a particular survey, and it is very important to ensure the most beneficial technique is used to monitor wildlife populations (Walters, 2010). But in the end, when considering aspects of cost, the available budget can be the determining factor in deciding the method to use (Walters, 2010). Increasing the available resources will change the complexity of methods that can be used. Financial considerations aside, the ease of use by every member of the field team (even those with limited experience) and the ease of application in difficult field conditions, will be important in selecting the method. Selecting the correct monitoring methodology specific for research purposes, while able to produce accurate estimates of population parameters within budget would eventually drive appropriate project planning and successes of management activities (Walters, 2010).

I.2. Biological richness of, and threats to Indonesian tropical rainforests

In the past, forested areas covered more than 7 billion hectares, or close to half of the earth's land surface. Tropical forest was the largest with an area reaching 3 billion hectares (**Figure 1**). Still today, the forested area continues to decline; beginning with controlled burning activities for preparing agricultural land in the past, the long history of human conversion and modification of forests has radically reduced its range. Approximately 28% of forest has been completely lost to other use (40% and 46% respectively in temperate and sub-tropical regions and 20% in the tropics; **Table 1**).

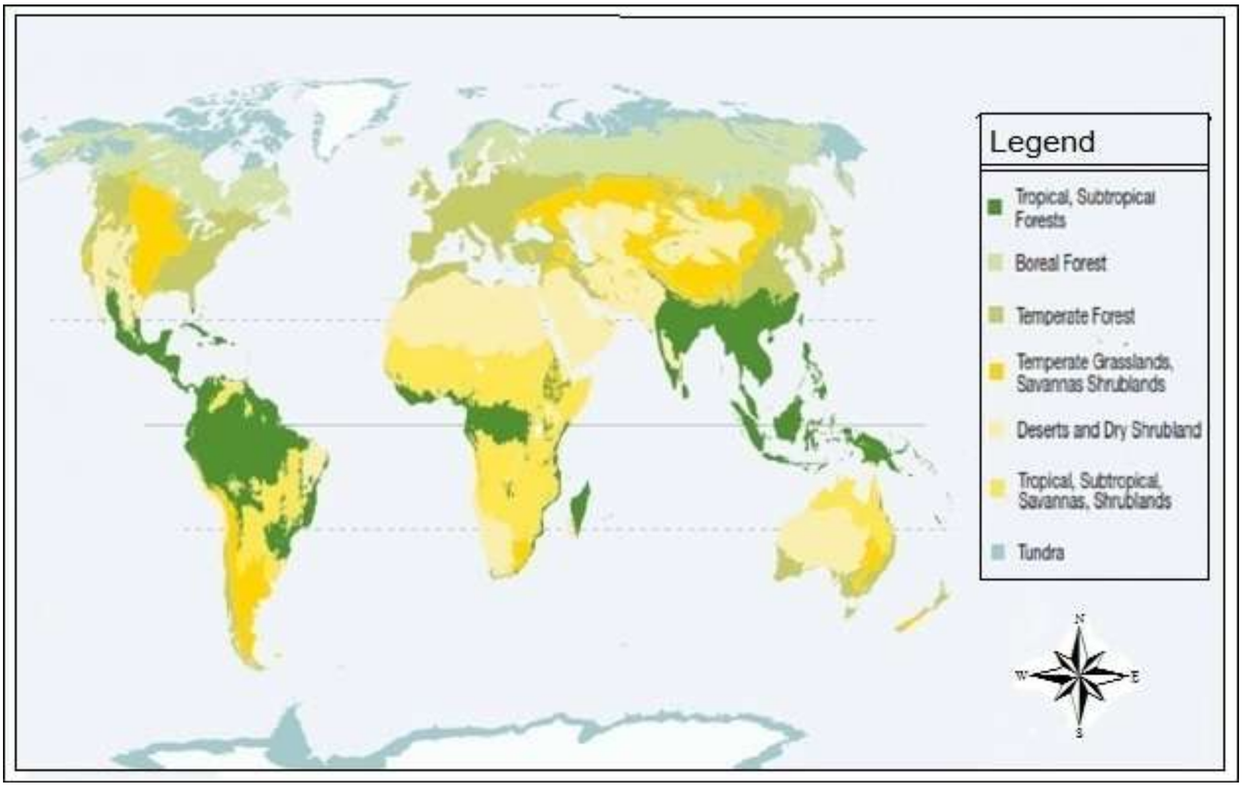

Figure 1. Distribution of forests and deserts based on ecoregions of the World (Source: Adapted from Olson, 2001; WCMC, 2009; Hofsvang, 2014).

Table 1. Past and current forest area per ecoregion (World Resources Institute, 2011)

Ecoregions	**Past area**	**Deforested**		**Current area**	
	x 1000 ha	**x 1000 ha**	**%**	**x 1000 ha**	**%**
Tropical	3,646	-1,055	-29	2,591	71
Boreal	1,425	-42	-3	1,383	97
Temperate	1,299	-518	-40	781	60
Desert and polar	64	-13	-20	51	80
Subtropical	984	-450	-46	534	54
Total	7,419	-2,078	-28	5,341	72

According to Oxford Dictionaries, tropical rainforest is "…a luxuriant, dense forest, rich in biodiversity, found typically in tropical areas with consistently heavy rainfall and located near the equator". Even though the world's tropical forests occupy only 7% of the land area, they house some 50 to 70 percent of all life forms and are the most productive and most complex ecosystems on Earth (Corlett and Primack, 2010). The majority of tropical rainforests are found in four biogeographic realms: the Afrotropical (mainland Africa, Madagascar, and scattered islands), the Australian (Australia, New Guinea, and the Pacific

Islands), the Indomalayan (India, Sri Lanka, mainland Asia, and Southeast Asia), and the Neotropical (South America, Central America, and the Caribbean islands).

Indonesia is a large archipelagic state including roughly 17,500 islands of extremely diverse size, shape, age and biological characteristics, situated on the equator. In broad terms, there are three categories of island size, namely:

a) the main islands (the Greater Sunda islands) of Kalimantan (574,194 km^2), Papua (443,336 km^2, on New Guinea), Sumatra (480,647 km^2), Sulawesi (191,671 km^2), and Java (127,569 km^2);

b) the much smaller islands of Nusa Tenggara (the Lesser Sunda islands) and Bali with a total area of 73,173 km^2;

c) the very small islands (under 29,000 km^2) for a total area of 1,919,443 km^2.

Biological diversity in Indonesia is the second greatest in the world, and Indonesia has the third largest area of tropical rainforest (after Brazil and the Democratic Republic of the Congo) with span 94.4 million ha forest (FAO, 2010; Parkesit et al., 2012). Indonesia is estimated to have 90 ecosystem types, from lowland rainforest to alpine, and from marine coastal to deep-sea ecosystems (The National Development Agency, 2003). This diversity as a result of diverse geographic, geological, and topographical conditions at the convergence of two biogeographic realms, Oriental and Australian (Mackinnon, 1974; **Figure 2**), makes the country’s forests home to a great diversity of flora and fauna, and Indonesia is one of only twelve nations on earth to be classified as 'megadiverse’ (Parkesit et al., 2012). Although Indonesia comprises only 1.3% of the earth’s land surface, it houses about 15% of the earth's species richness (MacKinnon, 1990; Parkesit et al., 2012).

The islands of Indonesia shelter 12% of mammal species of the world (670 species, including 35 species of primates; 36% of the mammal species are endemic), 17% of bird species (1,519 species, including 75 species of psittacine birds; 28% of the bird species are endemic), 7.2% of reptile species (511 species; 150 endemic), 270 species of amphibians, 1,400 species of freshwater fishes, and also the highest number of coral species in the world, with more than 77 genera and 450 identified species of scleractinian corals (Veron, 1995; Indonesian Ministry of Environment, 2009a). Indonesia is also estimated to house around 38,000 species of plants, of which 55% are endemic, and it is very rich in timber tree species belonging to the dipterocarp family: there are more than 350 species, 155 of which are endemic to Kalimantan (see also species richness on each Indonesian island in **Figure 2; Table 2**) (The

National Development Agency, 2003). Indonesia is ranked first in the world in terms of palm diversity (477 species; 225 endemic). In the last few decades this number has continued to rise as a result of several scientific expeditions: no fewer than 360 species of flora and fauna have been newly identified in Kalimantan's tropical rainforests (Parkesit et al., 2012).

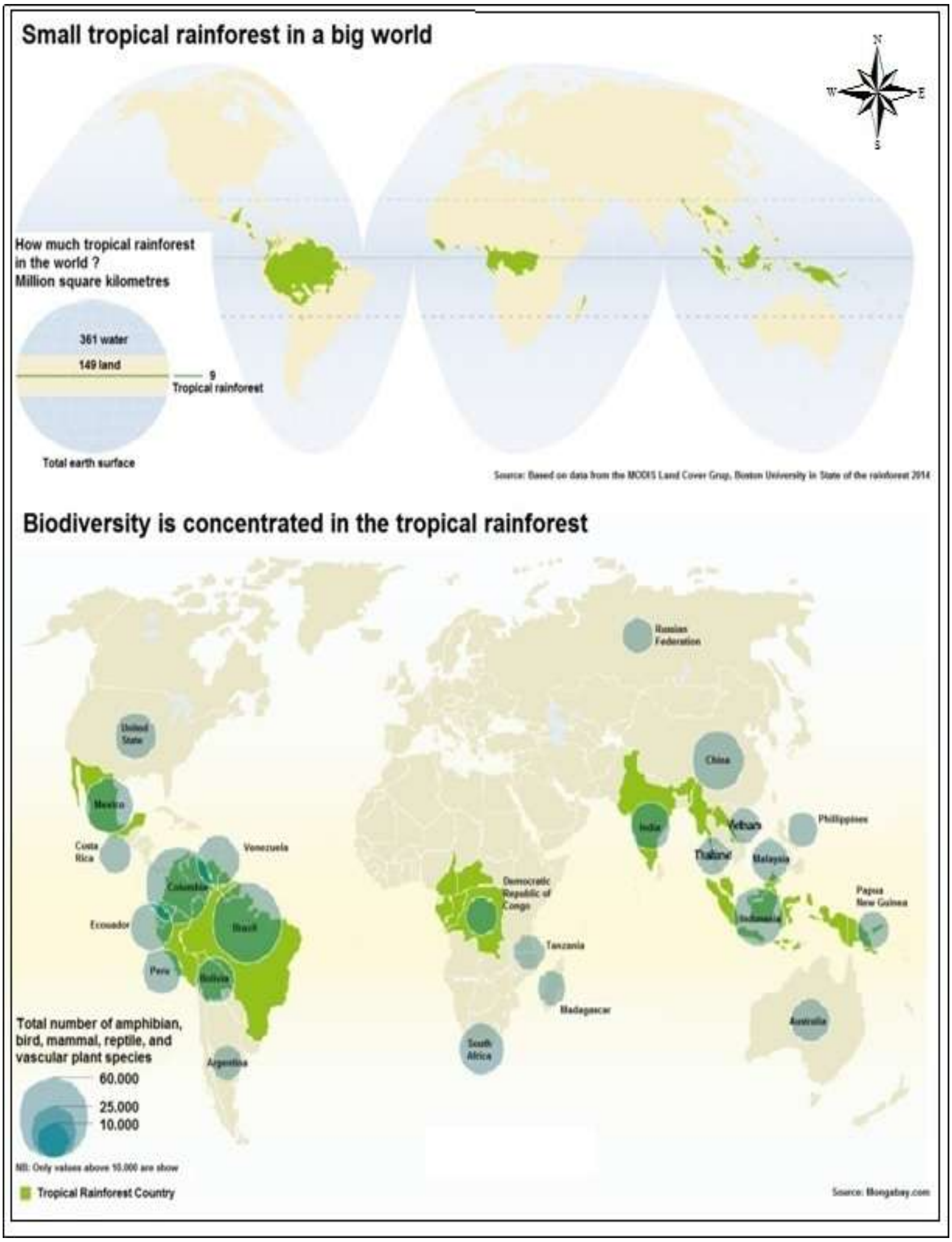

Figure 2. Distribution map of tropical rainforests and biodiversity richness are found predominantly in equatorial regions of America, Africa and Asia (Source: State of the rainforest 2014, based on data from the MODIS Land Cover Group, Boston University and Mongabay.com).

Table 2. Species richness on the major Indonesian islands

Species	Borneo*	Sumatra	Java	Sulawesi	New Guinea
Mammals	222	196	183	127	220
Resident birds	460	465	340	240	578
Snakes	166	150	7	64	98
Lizards	-	-	42	40	184
Freshwater turtles	-	8	-	-	8
Amphibians	100	70	36	29	197
Fish	394	272	132	68	282
Swallowtail butterflies	40	49	35	38	26
Plants	10,000-15,000	9,000	4,500	5,000	15,000-20,000

Note: *Borneo statistics (including Kalimantan)

As mentioned above, many of these species are endemic to Indonesia, where they are threatened by urbanization and deforestation due to the dramatic population growth; causing several species to be listed as endangered in the IUCN Red List [the World Conservation Union (IUCN, 2003) lists as endangered 147 mammals, 114 birds and 91 fishes]. According to the IUCN Red List, Indonesia is also the country with the highest number of threatened mammals in the world. Anthropization has destroyed many similar places across the earth, although exact figures are difficult to obtain. Most wildlife habitat has been destroyed where human population density is high (Corlett and Primack, 2008).

Globally, tropical rainforests account for nearly half of the 1.4 million species currently identified in the world, and scientists believe that their total number is likely to be far greater; probably 5–10 million (Gaston and Spicer, 2004). Approximately 2,000 new species of plant are found and classified each year. In Borneo, where the rainforests are relatively well-studied, only between 15% and 35% of the existing species are thought to have been described by scientists (Hofsvang, 2014). That new species are still being discovered in some of the world's tropical rainforests is indicative of the vast biodiversity that has not been well mapped and classified. However, these highly diverse ecosystems are threatened by escalating rates of forest conversion and degradation, even in the many ‘protected’ areas such as those in Indonesia (Brown and Lugo, 1990; FAO, 2005; Chapman et al., 2006).

According to the Food and Agriculture Organization (FAO, 2010), 130,000 km^2 of the world’s forests are lost every year; the majority from the tropics. The rate of deforestation per year varies by region (**Table 3**), two of the highest rates have occurred in Brazil and Indonesia in the 1990s, but they significantly decreased recently. Deforestation in the Brazilian Amazon, although varying a lot from year to year, has declined greatly over the past six years, by over 2/3 relative to the 1996-2005 average (INPE, 2011). The (relatively) much smaller region of Southeast Asia (Indonesia, Malaysia, Cambodia, Laos, Myanmar, Thailand, and Vietnam) lost nearly as much forest as the Brazilian Amazon converted to agriculture or cut for timber (Groombridge, 1992; Groom and Schumaker, 1993). Overall, however, Indonesia's deforestation rates appear to be slowing down; the rate between 1990 and 2000 was 1.75% per year, 0.31% per year between 2000 and 2005, and 0.71% per year between 2005 and 2010 (FAO, 2010).

Table 3. Forest loss in the main tropical rainforest countries

Country	**Annual change 1990-2000**		**Country**	**Annual change 2000-2010**	
	1000 ha/yr	**%**		**1000 ha/yr**	**%**
Brazil	-2,890	-0.51	Brazil	-2,642	-0.49
Indonesia	-1,914	-1.75	Australia	-562	-0.37
Sudan	-589	-0.80	Indonesia	-498	-0.51
Myanmar	-435	-1.17	Nigeria	-410	-3.67
Nigeria	-410	-2.68	United Republic of Tanzania	-403	-1.13
United Republic of Tanzania	-403	-1.02	Zimbabwe	-327	-1.88
Mexico	-354	-0.52	Democratic Republic of the Congo	-311	-0.20
Zimbabwe	-327	-1.58	Myanmar	-310	-0.93
Democratic Republic of the Congo	-311	-0.20	Bolivia	-290	-0.49
Argentina	-293	-0.88	Venezuela	-288	-0.60
Total	-7,926	-0.71	Total	-6,040	-0.53

Regarding tropical rainforests in Southeast Asia, 3.5% of the primary forest habitat has been lost in just one decade, decreasing from 66.3 million ha in 2000 to 64.0 million in 2010 (FAO, 2010). Primary forest, also known as intact forest, is a forest with a native species composition where the ecological processes have not been significantly disturbed by either natural phenomena or human activity. The FAO reported in 2011 that, between 2000 and 2010, 400,000 km^2 of primary forest was lost, or affected by human activity to the extent that it changed into secondary, or 'naturally-regenerated', forest. Today, about 36% of the total forest area in the world is primary forest; the remainder consisting of naturally-regenerated and plantation forests, whose status change is due to human interference and whose area continues to increase every year (Hofsvang, 2014). Nowadays, the most biologically-rich country in Asia, Indonesia, has less than half of its primary forest habitats (**Figure 3**).

Between 2000 and 2012, Indonesia loss more than 6 million ha of primary forest, giving an average annual loss of around 470,600 ha (Margono et al., 2014). In fact, in 2012 the annual loss of primary forests in Indonesia was estimated to be almost double that of Brazil (0.84 million ha and 0.46 million ha, respectively). However, there is no consensus on the areal extent and temporal trends of primary forest clearing in Indonesia. The Indonesian government issued a moratorium on deforestation in 2011 with the intention of reconciling economic, social and cultural development with environmental considerations, and encouraging the establishment of extensive protected areas.

Figure 3. Indonesian forests exploitation and degradation

1.3. Diversity and status of tropical deer

Human impact has raised the threat of extinction for almost three-quarters of the mammalian diversity worldwide, including ungulate species (Tsahar et al., 2009; Baillie et al., 2010). Low reproductive rates combined with low densities and the need for large habitats, makes the latter particularly sensitive to anthropogenic disturbance. The high demand for game hunting and animals for pets, increase the vulnerability of these species (Kelt and Vuren, 2001; Jerozolimski and Peres, 2003; Cardillo et al., 2005). Lack of knowledge of, and attention to, 'non-charismatic' species such as medium-to-large-sized ungulates, are critical limitations for assessing the conservation status of these species and for designing sound management strategies, particularly when faced with declining populations due to habitat fragmentation (Carbajal-Borges et al., 2014).

Over the last two decades, Indonesia has developed a national protection system for high-value conservation areas, with large protected areas in the various biogeographic regions. However, areas of high conservation value are not only found in protected areas (e.g. national parks, nature reserves, wildlife sanctuaries, etc.) but also in areas allocated for production or watersheds. Moreover, protection is often poorly applied in practice. Indonesian tropical rainforests are rich in biodiversity but unfortunately over the last two decades, much of these forests have been converted into some form of plantation forest through oil palm development or forest industries targetting acacia, teak, etc. Climate change as a result of land clearing for the development of plantations and harvesting of natural forest wood, would have caused disturbances to medium-to-large mammals such as orangutans, tigers, rhinos, elephants, anoas, deer, etc. In spite of the rapid depletion of wildlife during the present century, Indonesia still has a remarkable variety of large and small mammals. Ungulate species play a very central role in Indonesia, not only in terms of conservation of forest ecosystems, but also in Indonesian life generally. For example, the majority of animal protein consumed in most of Borneo's indigenous communities is derived from wild sources, particularly from vertebrates, including mainly ungulate species (e.g., Caldecott, 1988; Puri, 1997; Bennett et al., 1999; Rijksen and Meijaard, 1999). Furthermore, Kinnaird et al. (2003) suggest that the disappearance of ungulates from fragmented systems may have community-wide implications and may lead to the ecological reduction of top and meso-predators (O'Brien et al., 2003).

The decline of ungulates is a global concern. Smith et al. (1993) estimated that almost 79 % of the tropical deer species were at risk of extinction, making them the most endangered mammal group (**Table 4**). According to recent data in the IUCN Red List version 2015.4, deer are still one of the most threatened groups (**Appendix 1**; http://www.iucnredlist.org/about/summary-statistics). Recently, IUCN has published the conservation status of 53 deer species throughout the tropical regions: there are 12 species with status 'endangered', one species 'critically endangered', and one species has become extinct (see **Appendix 2**).

Table 4. Numbers of species threatened with extinction in the major groups of animals (from Primack, 1998)

Group	Approximate number of threatened species	Number of species threatened with extinction	Percentage of species threatened with extinction
Vertebrate animals			
Fishes	24,000	452	2
Amphibians	3,000	59	2
Reptiles	6,000	167	3
Boidae (constrictor snakes)	17[a]	9	53
Varanidae (monitor lizards)	29[a]	11	38
Iguanidae (iguanas)	25[a]	17	68
Birds	9,500	1,029	11
Anseriformes (waterfowl)	109[a]	36	33
Psittaciformes (parrots)	302[a]	118	39
Mammals	4,500	505	11
Marsupialia (marsupials)	179[a]	86	48
Canidae (wolves)	34[a]	13	38
Cervidae (deer)	14[a]	11	79

[a] Number of species for which information is available.

Indonesia houses nine deer species (Tragulidae and Cervidae): lesser mouse-deer (= lesser Indo-Malayan chevrotain), *Tragulus kanchil* (Raffles, 1821); greater mouse-deer (= greater Indo-Malayan chevrotain), *Tragulus napu* (F. Cuvier, 1822); Java mouse-deer (= Javan chevrotain), *Tragulus javanicus* (Osbeck, 1765); Bornean yellow muntjac, *Muntiacus atherodes* Groves and Grubb, 1982; red muntjac, *Muntiacus muntjak* (Zimmermann, 1780); Sumatran mountain muntjac, *Muntiacus montanus* Robinson and Kloss, 1918 (conservatively treated as a subspecies of the former one by Mattioli, 2011); Javan deer (= Javan rusa), *Rusa timorensis* (de Blainville, 1822); sambar, *Rusa unicolor* (Kerr, 1792); Bawean deer, *Axis kuhlii* (Temminck, 1836) (for more details related to the status, range and habitat of all of these species, see Appendix 2), over the 53 species of deer distributed throughout tropical areas (Wilson and Mittermeier, 2009).

Tragulus are the smallest deer species and hornless ungulate, found in mainland Asia and Africa. They are regarded as the most primitive ruminants according to their behaviour and paleontological records (Dubost, 1975; Ralls et al., 1975; Geist, 1998; Webb and Taylor, 1980). There are two sympatric species however, the degree of syntopy is less clear: *T. kanchil* and *T. napu*. Currently, distinctions between these species are primarily morphological differences (Groves and Grubb, 1982; Meijaard and Groves, 2004b). *T. napu* has the largest body size; it is widely distributed: from Indonesia (Kalimantan and Sumatra) to Brunei Darussalam, Malaysia (Peninsular Malaysia, Sabah, Sarawak), Myanmar, Singapore and Thailand. *T. kanchil* has a similar distribution from Indonesia to Brunei Darussalam, Cambodia; Lao People's Democratic Republic; Malaysia; Myanmar; Singapore; Thailand and Viet Nam. *T. javanicus* is restricted to Java island. All *Tragulus* species are associated with forests, but there is strong evidence that both *T. kanchil* and *T. napu* do not require old-growth forest or even particularly mature secondary forest. Hoogerwerf's (1970) description of favoured habitats suggests that *T. javanicus* might be an 'edge' species there; certainly seeming to prefer areas with thick understorey vegetation, such as that found along riverbanks. *T. kanchil* may be absent from highlands throughout much of its range, and seems to be an extreme lowland specialist in some areas; it is different from the two other species, both of which apparently range to higher altitudes - up to at least 1,000 m asl (Payne et al., 1985).

The red muntjac is the most common of the various muntjac species. Inhabiting a wide variety of habitats, it is widely distributed from Indonesia to the Thai-Malay Peninsula and also in India and Nepal (IUCN, 2008; **Figure 4A**). Two other muntjac species, the Bornean yellow muntjac and the Sumatran mountain muntjac, are found respectively only in Borneo and Sumatra. Apparently, the red muntjac is the most tolerant to disturbance. These three species are associated with forests but occur widely, ranging from protected to degraded forests due to the conversion of land into plantation and agricultural areas (Oka, 1998; Laidlaw, 2000; Azlan, 2006; G. Semiadi pers. comm. 2008). However these species have quite different ranges of altitude. *M. atherodes* and *M. muntjac* are usually found at low altitude (< 1,000 m asl.) whereas *M. montanus* is a common species in mountainous areas.

Two species of the genus *Rusa* and one species of the genus *Axis*, also originate from Indonesia. The Javan deer and the sambar are the largest deer in Indonesia, they are parapatric. The Javan deer is native only to Java and Bali in Indonesia (Corbet and Hill, 1992; Heinsohn, 2003; Grubb, 1993, 2005), while the sambar is distributed in many islands, such as in the Greater Sunda Islands (except Java, but including the Indonesian, Malaysian and Brunei parts of Borneo), as well as on Siberut, Sipora, Pagi and Nias islands (Grubb, 2005). Both deer seem to be extremely adaptable: the Javan deer is essentially a tropical and subtro-

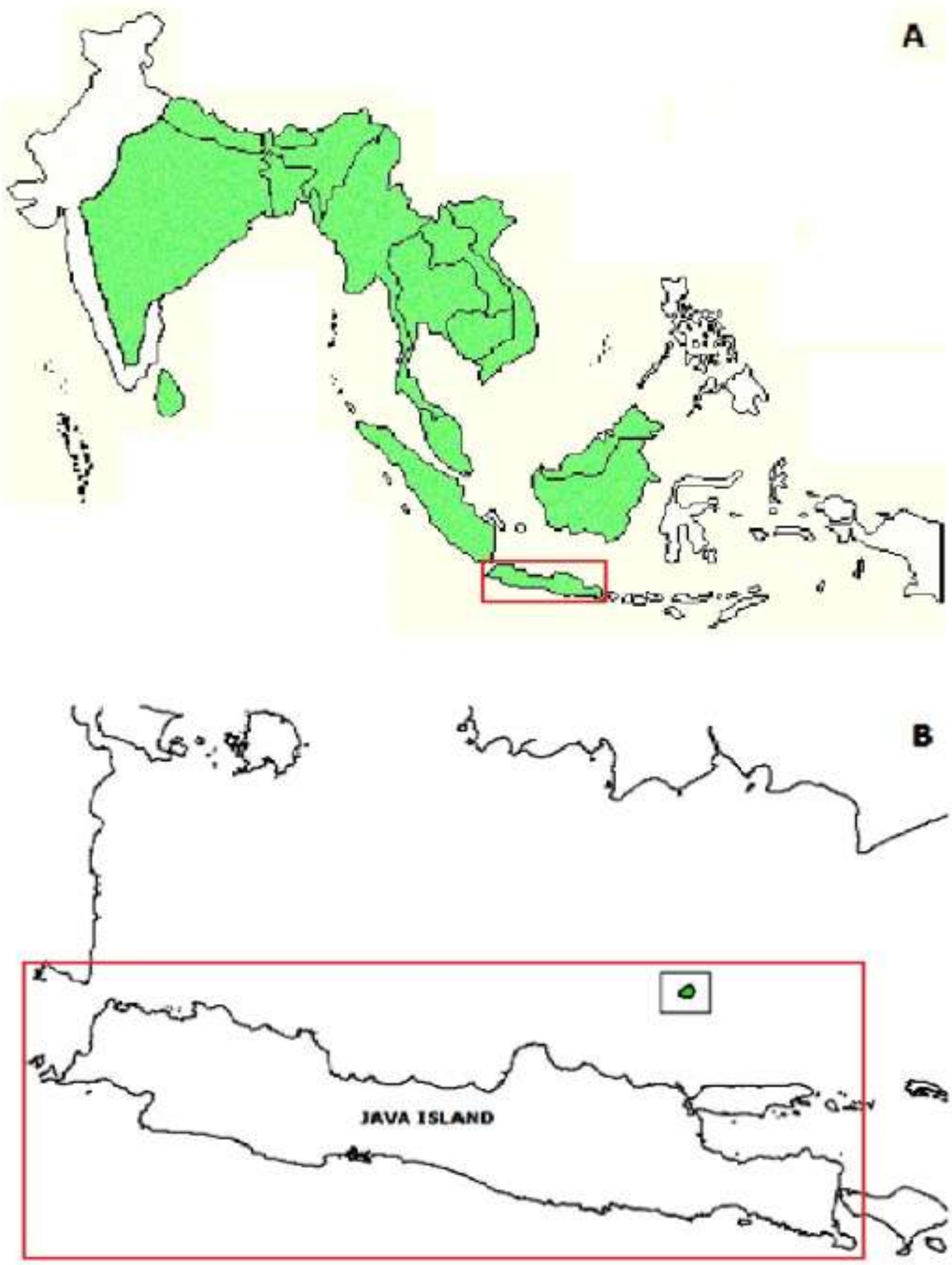

Figure 4. Distribution map of A) red muntjac, from Indonesia to the Thai-Malay peninsula, and B) Bawean deer, on Bawean Island (a 200 km^2, quite isolated island in Java Sea).

pical grassland species (Medway, 1977; Oka 1998) but is highly flexible, with successful populations in forests, mountains, shrublands and marshes (Whitehead, 1993; Oka 1998; Rouys and Theuerkauf, 2003; Keith and Pellow, 2005); the sambar is a large Indian ungulate adapted to a wide variety of forest types and environmental conditions. A difference between the two species is the fact that the sambar displays a high adaptability to areas with varying altitude. As an example, it occurs up to at least 3,825 m on Siouguluan Mountain, the highest peak of the Central Mountains in Taiwan; elsewhere on the island it ranges down to 150 m asl, but mostly lives at 2,000–3,500 m (Lin and Lee, pers. comm.). It occurs also up to 3.000 m on Gunung Kinabalu, Sabah, Borneo (Payne et al., 1985). And in Myanmar, recent camera-trap photographs caught evidence of a range of 0–2,150 m asl (Saw Htun, pers. comm.).

In contrast to the other eight species of deer in Indonesia, the Bawean deer, the most isolated deer in the world and the endemic deer species on the 200 km^2 Bawean island (Indonesia), is categorized as Critically Endangered (CR) on the IUCN red list (Semiadi et al., 2013), and listed in Appendix I of CITES (2009); additionally, this taxon is one of the 25 priority species legally protected by the Indonesian government. The Bawean deer is reported to range over a very small area, restricted to the Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), and a peninsula on the north-west side of the island (Tanjung Cina) (Lachenmeier and Melisch, 1996; Grubb, 2005; **Figure 4B**).

Van den Brink (1982) presumed that today's restriction to Bawean Island is a relic of the Bawean deer's occurrence across Java, probably during the Holocene; its extinction from Java was possibly caused by competition with the Javan deer and the red muntjac (Meijaard and Groves, 2004b). The species was supposedly discovered by Salomon Müller in 1836 in Tuban, on the northern coast of Java, and the native range was discovered only after the name was proposed (Sitwell, 1970). The species presumably evolved from a Pleistocene Javan *Axis* species (perhaps *Axis lydekkeri*) at a time when the Bawean Island was connected to Java via a land bridge (Blouch and Atmosoedirdjo, 1987; Meijaard and Groves, 2004a). The Bawean deer and the red muntjac, share similarities in terms of behaviour, ecology and body size. In addition, both species, have experienced similar threats due to substantial habitat destruction and poaching activity, particularly on Java island. Java is one of the most densely populated islands in the world, so it is not surprising that very little natural habitats remain there (MacKinnon and MacKinnon, 1986b). Anthropogenic fires are common, and over the centuries, burning has resulted in mono-species stands of fire-resistant trees, usually *Tectona grandis* (FAO/UNEP, 1981). In many annual cropping systems, soils are left exposed during critical periods, resulting in extensive erosion (IUCN, 1994). Illegal farming and felling, even within protected areas, are widespread, and an important timber tree, *Altingia excels*, has been nearly eliminated from lowland forests (Whitten et al., 1996). Despite the rate of loss being far lower in Java than in other Indonesian islands (such as Borneo, Sumatra and Sulawesi), forest-dwelling spacies are particularly threatened in Java because there is so little forest left.

The situation is made more complicated because the biology and ecology of Bawean deer and red muntjac are poorly investigated, and the species may be very rare and/or strongly influenced by current or past human activities. Methods for monitoring deer populations in tropical rainforests may need to be tested or validated before attempting the use of data. Furthermore, any validated method can become the reference method for later monitoring activities. In this manuscript, I discuss many of the challenges faced in monitoring the two deer populations. Information generated from this research is intended to assist in the planning process, to provide support for appropriate management decisions, and to assess the effectiveness of current management practices in mitigating threats and meeting objectives of conservation. Our results should certainly help assessing the level of population change and population status in the future, particularly for Bawean deer; as well as answering questions related to the impact of human activities such as logging and hunting, and how these activities influence population trends and ecology of both deer species. Furthermore, these results will be used to propose conservation actions that can best ensure sustainability of both deer species in their natural habitat.

II. TECHNIQUES FOR MONITORING UNGULATE POPULATIONS

II.1. Population growth and the needs for suitable methods for monitoring ungulates

In the last decade, improvement of habitat quality and good hunting management with reintroductions and restocking programmes, aimed at ensuring the preservation of wildlife populations in temperate regions like Europe, have implications for increasing the population numbers of wildlife such as deer (Meriggi et al. 2008; Gallo and Pejchar, 2016). The abandonment of historical agricultural systems in hill areas, and an increase of early succession from open habitat to forest, provide benefits for some ungulates species such as roe deer (*Capreolus capreolus* Linnaeus, 1758) that are very common in mainland Europe and some areas in East Asia (Gottardi, 2011). Moreover, the increasing abundance of ungulates has become a critical object for many communities, because they play a vital role in ecological processes, such as being seed dispersers, and are considered as an important prey for carnivores, e.g. roe deer – prey for grey wolf *Canis lupus* and boreal lynx *Lynx lynx*, but have also become an economic resource for humans, for example as meat sources, or in the ecotourism industry (Mattioli et al., 1995; Okarma, 1995; Meriggi and Lovari, 1996; Meriggi et al., 1996; Mattioli et al., 2004; Gazzola et al., 2005; Meriggi et al., 2008). The balance between utilization and conservation of species and habitats, while considering the harmony with human activity, is a necessity in any wildlife management. Species ecology and population trends in different habitats and ecosystems with unique climatic conditions that affect them underlie how the management strategy should be defined (Meriggi et al., 2008). Population censuses have become a priority to frame management plans of species that are not protected. Then, censuses will ensure the effectiveness and efficiency of any ongoing management plan, and can avoid the degeneration of the population into either overabundance or scarcity (Meriggi et al., 2008).

II.2. Evolution of deer census methods

Programmes to monitor terrestrial mammal populations have employed a large number of methods; some simple in execution, without requiring a lot of resources, and some complex and requiring setting in their implementation by researchers *in situ*; some which can only be applied to, and be suitable for, a single species, and some capable of being adopted for multiple species; some relevant only to a single site in the short term, and some widespread and operated in the long term (e.g., Caughley, 1977; Davis, 1982; Wilson et al., 1996; Plumptre, 2000; Stoner et al., 2007; Marsh and Trenham, 2008; Ogutu et al., 2008; Kindberg et al., 2009). Population monitoring methods generally fall into one of three main categories: 1) estimation of the total population of animals that can be performed directly, calculated by full census or censuses from sample plots; 2) estimation of a population index by collecting signs and marks in the field; and 3) estimation using a strategy of capture-mark-recapture or removal (Lancia et al., 1994). Each method has advantages and disadvantages, and its effectiveness will greatly depends on the target species and environmental or habitat conditions. Therefore, any potential method should be compared and/or validated to produce accurate density estimates or population size, as several studies conducted by the practitioners have attempted (Peterson and Thomas, 1998; Rowcliffe et al., 2008).

Population monitoring by direct observation and drive census were the first census methods used to support hunting activities and both methods were subsequently adopted for management needs and unlock new insight of scientific knowledge (Cederlund et al., 1984; Denis, 1985; Meriggi et al., 2008). These methods have been commonly used, especially in temperate regions and open areas such as meadows or savannahs. In practice they have produced varying degrees of results accuracy (Cederlund et al, 1998; Van Laere et al., 1998; Borkowski et al., 2011). Monitoring wildlife in tropical rainforest areas brings in additional difficulties, not only because some species are primarily shy, of drab coloration, secretive by habitat, and difficult to observe in the wild, but also because habitat conditions are often rugged with dense vegetation, and may be remote.

Practitioners in the last few decades have tried to address the problem of monitoring activities for the wildlife that is hard to study directly, monitoring strategies based on indirect encounters with a focus on tracks, footprints, faecal matter or dung, track stations, food removal, open or closed burrow-entrances or responses to audio calls (Bider, 1968), have been effective in overcoming these problems. In an effort to count wildlife numbers in a particular area, abundance indices can be produced (Rovero and Marshall, 2009; Imperioa et al., 2010); whereas answering questions about the proportion of time spent by the animals in their daily activities will involve activity indices (Ensing et al., 2014). The index value is considered comparable to actual density because the former is based on a constant proportion of the amount of searching relative to the total population of animals that occupies the area of interest, but it should be kept in mind that this value does not provide an actual estimate of the number of animals (Caughley, 1977; Witmer, 2005).

For instance some of the activities in estimating deer density by faecal and track count in both temperate and tropical regions have been well established and there are useful discussions by practitioners on such issues as how suitable these estimation methods are in overcoming difficulties due to low rates of detection (Mandujano and Gallina, 1995; Marques et al., 2001; Dellafiore et al. 2003; Rivero et al., 2004; Mandujano, 2005; Koster and Hart,2008; Periago and Leynaud, 2009; Camargo-Sanabria and Mandujano, 2011; Mandujano, 2014; Simcharoen et al., 2014; Torres et al., 2015). Faecal pellet group count is dependent on field conditions at sampling plots, substrate and vegetation type, and on climate, all of which can lead to a great variability in faecal decay rate (Skarin, 2007; Laing et al., 2003). This has been much studied in temperate areas where the technique works well in cold climates with snowy winters (Decalesta, 2013); frozen pellet-groups deteriorate less quickly than in warm and/or rainy climates (Tsaparis et al., 2009). In practice, implementing these indirect methods can be quite difficult. Such variables as the decay rates of indirect signs (for example, when used for faecal and nest counts) or misidentification of footprints of a species on flaccid substrate, or one covered with dense litter, make the accuracy of estimates questionable (Plumptre, 2000; Stephens et al., 2006; Keeping and Pelletier, 2014). In any event, correct identification of species from indirect signs can be very difficult, particularly for species with similar track or dung patterns.

Transect sampling has become more and more used for monitoring wildlife populations (Burnham et al., 1980, 1981; Seber, 1992; Buckland et al., 1993). This method is based on counting animals observed on both sides of a standardised transect of known length; for each individual or group of individuals detected the perpendicular distance from the transect must be measured. In order to obtain reliable population estimates and confidence intervals, certain assumptions must be fulfilled, for example that all the individuals on the transect will be observed, that the individuals are observed at their initial position, and that each observation is an independent event. Transect sampling is increasingly used by researchers, whilst managers still tend to be reluctant because not all assumptions can be verified and few observations are sometimes recorded. In addition, transect sampling, which requires heavy field work, relies on the surveyor's competence in identifying species, and confidently estimating animal-observer distances, which can be highly difficult through dense vegetation of tropical forests (Walsh and White 1999). Moreover, transect sampling can be problematic for monitoring rare species, as poor encounter rates can lead to sample sizes not being large enough for data analysis (Bennun et al., 2004). Following a precise path can make surveying problematic in difficult terrain, and clearing a pathway through dense vegetation could be a hard work and subsequently detrimental for data collection (Walsh and White, 1999).

In the recent decades the use of camera traps has increased rapidly; the detection shortcomings of some of the previous methods can often be overcome through this technique, particularly for remote species such as ungulates in tropical rainforests (Goswami et al., 2007).

II.3. Some practical considerations in monitoring deer populations

The fate of a species or a population can be strongly influenced by management decisions that are taken. Incomplete or imperfect information often becomes a problem in the planning or decision-making of management. Confidence in management decisions will increase with the understanding of how resources are changing over time in relation to the environmental conditions. This is a fundamental reason why a monitoring programme must be designed well enough for having a high probability of detecting any change in the population. Thorough and realistic goals in the design of deer monitoring, and collection of highly-accurate data by using appropriate methods that have been tested and are cost-effective, are absolutely necessary. The selection of these methods should be based on practical considerations: their advantages and disadvantages, how specialised the methods are in terms of the peculiarities of the species and habitats being monitored, the situations and conditions under which the methods can be used, and the extent to which they have been, or can be, tested or validated and duplicated with other species or habitats that have similar conditions (Lancia et al., 1994). At last, choosing the appropriate method will help to ensure that valid data on the biological conditions and habitat of a species can be obtained.

III. CAMERA TRAPPING FOR MONITORING DEER POPULATIONS

The previous section described how monitoring or population survey of medium- and large-sized mammals in tropical rainforests using classical sampling methods is very challenging (Thompson, 2004; De Souza Martins et al., 2007). Characteristics of animals that are hard to find directly, habitat conditions that disguise the existence of the animals and limited infrastructure in the study area, all make difficult the application of these methods.

Fortunately, technology has improved rapidly and increasingly offers benefits in surveying and monitoring populations. The use of camera-traps is often one of the best choices for obtaining information and knowledge about the population status and biology of wildlife, especially for species in tropical rainforests that are hard to find directly or may even actively avoid human presence. The use of camera-trapping and DNA analysis (from the collection of faeces, blood or hair) makes current monitoring strategies more precise and accurate, compared to some methods commonly used in the past. Additionally, data analysis technology using satellite imagery and ecological modelling techniques, increasingly helps to answer questions related to the changing conditions of the population due to pressure of environmental changes over time. Given all benefits, camera-trapping has become a popular tool for monitoring wildlife in the recent decades. Although expensive this is non-invasive, practical, and can be used for long-term monitoring, and allows the recording of a variety of information, such as presence, daily activities, reproductive success, etc. for many species; these are some of the many advantages of the use of camera-trapping (Witmer, 2005; Rosellini et al., 2008; Ancrenaz et al., 2012). The cost issues is especially important when the activity of interest occurs at multiple sites (e.g. Poole and Boag, 1988), or unpredictably (e.g. Foster and Humphrey, 1995). Additionally, remote photography is ideal for recording data at night, in inaccessible locations such as dens and nest cavities, or in terrain that is difficult to access (Mace et al., 1994; Huang, Z-P et al., 2014). Studies by Janečka et al. (2011) and Li et al. (2014), particularly show that detailed information on the status and abundance of the snow leopard in the Gobi Desert, and of four ungulates in mountain forests in southwest China, are limited because of the logistical challenges faced when working in the rugged terrain they occupy, along with their secretive nature; and how camera-trapping techniques have been used successfully to overcome these difficulties. Finally, because remote photography is less invasive than many other methods, it may be more appropriate to study rare, sensitive, or cryptic animals, such as many of those found in tropical rainforests (Tobler et al., 2008; Rovero et al., 2014).

III.1. A brief history of camera trapping in wildlife ecological research

It should be noted that the use of camera trapping is not new. The 1890s saw the first use of a camera to capture wild animals, free from human presence. The photographs were taken by a lawyer named George Shiras, who subsequently decided to dedicate his life to wildlife conservation. Shiras used trip wires and a flash bulb to catch animals on film; his photos were eventually published in National Geographic Magazine. Thereafter, the first purely scientific use of camera traps was in the 1920s by Frank Chapman. He surveyed large but poorly-known fauna, such as the tapirs on Barro Colorado Island in Panama, using trip-wire camera traps (Rovero et al., 2010).

Since its use in the 1890s, the technology of camera trapping has evolved in parallel of research on wildlife ecology (Kucera and Barrett, 1993). The use of this technology has been increasing over time, especially since the invention of infrared-triggered camera systems (Cutler and Swann, 1999; Koerth and Kroll, 2000). In the 30-year period that followed the study conducted by Chapman, other researchers like Gysel and Davis (1956), Pearson (1959, 1960), Dodge and Synder (1960), Abbott and Dodge (1961), Green and Anderson (1961), and Osterberg (1962), began using more modern camera trapping with movie camera systems for quantitative ecological research such as studies on feeding behaviour and habitat, for various species of small mammals and birds. A few years later, were developed camera traps with automatic systems, and several key parts of the camera were improved. Modifications were made to the settings for time-lapse photography and portable batteries were used by several researchers such as Abbott and Coombs (1964), Cowardin and Ashe (1965), Winkler and Adams (1968). Modifications in time-lapse photography systems brought progress in the study of animal behaviour in the next period. Arnold et al. (1989) for example, used one such system to study the effect of day length and weather on the time spent by western grey kangaroos (*Macropus fuliginosus*) on farmland; and Constantino (1974) studied ungulate species such as bighorn sheep (*Ovis canadensis*) in their use of waterholes. Modification of camera trapping in the form of boxes made by Rayoma (1970) to identify prey items brought to nests, was a forerunner of the birth of the camera trapping forms that are commonly found on the market today. However, this invention was not widely adopted in ecological research until the end of the 1970s, and then much refined thereafter. Continuing the development of time-lapse photography systems, two scientists, Savidge and Seibert (1998), successfully developed and used the technology of the time to identify predators at artificial nests. Their camera set-up was triggered by an infrared beam and utilized an automatic camera (Savidge and Seibert, 1988). This was the starting point for the automatic camera traps of today.

Sport hunting activities contributed to the increasing trend of using camera trapping. In the late 1990s, this tool was being used by sport lovers during their hunting activities to increase the chances of encounters with animals such as trophy deer. This had been the main reason they became commercially available with emerging technology (Kays and Slauson, 2008). A big jump occurred in the next 'development period', starting with the creation of durable portable batteries, the size of camera trap equipment became increasingly small, with water-proof plastic enclosures, and point-and-shoot film cameras being replaced by digital format cameras, triggered by passive infrared sensors (Rovero et al., 2010).

In the last two decades, the multi-purpose use of camera trapping has grown exponentially, and has become the subject of, as well as a tool of, many scientific studies involving wildlife as the primary object (Rowcliffe and Carbone, 2008; Rovero et al., 2010; O'Connell et al ., 2011b; McCallum, 2012). Being non-invasive and able to work all day, it has been a solution in many studies involved with wildlife which is difficult to find directly in nature or which occupies large home ranges (Trolliet et al., 2014); when combined with statistical analysis, this tool has become a perfect alternative for studying the interaction between wildlife and their habitat (Karanth and Nichols, 1998; Sollmann et al., 2013).

III.1.1. Camera trapping in tropical forests

The first camera trapping studies in tropical rainforests were conducted by Seydack (1984). He describes the use of a 35-mm camera system to calculate the density of large mammals in the tropical rainforests of South Africa. In his study, he recorded 14 species and successfully estimated population densities based on the identification of coat pattern and horn morphology in bushbuck (*Tragelaphus scriptus*), spot patterns for leopard (*Panthera pardus*), and differences in lateral white stripes on honey badger (*Mellivora capensis*). The first research using camera trapping in Asian tropical rainforests was conducted by Griffiths and Van Schaik (1993), they studied mammals found in Indonesian tropical rainforests. Thereafter, the most seminal study was conducted by Karanth and Nichols (1998), who successfully developed individual identification techniques to estimate tiger (*Panthera tigris*) abundance based on capture-recapture models. Their research became a theoretical basis and inspiration for researchers and practitioners around the world, promoting the use of camera trapping in wildlife monitoring activities, particularly for elusive species, and the development of statistical analysis that can be used with ecological data obtained from camera traps.

Studies by Karant and Nichols (1998) have significantly increased the use of camera traps in ecological studies of wildlife, particularly in tropical forests around the world. In recent decades, camera trapping has been widely used, with an annual increment of 50% (Rowcliffe and Carbone, 2008), and more than half of such use is in the monitoring of wildlife in tropical rainforests. The characteristics of animals with cryptic and elusive behaviour, and of those that live in remote areas which are difficult to access, and in habitat conditions that help hide them in tropical rainforests, all make camera traps an ideal tool for monitoring wildlife populations. The increasing use of camera traps has occurred not only in Asia and Africa but also in South America; in these regions, camera-traps are commonly used for surveying mammals in protected areas and forest fragments (Trolle, 2003; Kasper et al., 2007; Srbek-Araujo and Chiarello, 2007; Goulart et al., 2009; Jiménez et al., 2010), as well as for estimating single species abundance (e.g.of big cats and canids: Soisalo and Cavalcanti, 2006; Tobler et al., 2008; Di Bitetti et al., 2009; Harmsen et al., 2010). Recent studies that employ a standardised camera-trapping protocol, have been conducted in a wide range of habitats in 15 protected areas, spanning tropical regions in Central and South America, Africa and Southeast Asia. This overall study conducted to evaluate constituency trends for 511 populations of terrestrial mammals and birds, representing 244 species analyzed more than 2.5 million pictures captured by more than 1,000 camera traps and found that occupancy declined in 22% of populations, increased in 17%, and exhibited no change in 22% of populations during the last 3-8 years; while 39% of populations were detected too infrequently to assess constituent changes (Beaudrot et al., 2016). This long-term study has been able to identify the critical urgency of appropriate conservation actions, particularly in tropical rainforest regions.

III.1.2. Camera trap use in studies for species conservation

Conservation planning which target species or their habitats needs to be supported by accurate data sampling with techniques that have the best cost-effectiveness ratio. Camera traps working continuously for weeks are able to replace the necessary presence (with all their limitations) of humans in monitoring activities. This device does not cause any interference to wildlife being surveyed. In recent years, the use of camera traps has led to major findings, including revealing a new species of tapir, *Tapirus kabomani*, from the forests and open savannahs of Brazil and Colombia, proving that the forest elephant (*Loxodonta cyclotis*) and other rare species, are breeding in Sudan, and rediscovering the saola (*Pseudoryx nghetinhensis*), one of the rarest and most threatened mammals on the planet, which was photographed in Vietnam for the first time in 15 years.

Data obtained from surveys using camera traps have been able to show not only evidence of the presence of a target species (Tobler et al., 2008) but have also proved useful in: measuring the richness of species in various habitats (O'Brien et al., 2010), viewing community structure and diversity (e.g. terrestrial small-mammals by De Bondi et al., 2010), estimating the density of populations (e.g. cats by Bengsen, 2011a), and establishing patterns of activity (e.g. crab-eating fox (*Cerdocyon thous*) and pampas fox (*Pseudalopex gymnocercus*) by Di Bitetti et al., 2009), habitat use (e.g. bare-nosed wombats (*Vombatus ursinus*) by Borchard et al., 2012) and population changes, particularly after deforestation and habitat destruction (Ahumada et al., 2011; Beaudrot et al., 2016). For the first time, camera traps are enabling researchers to collect baseline population data on wildlife where only estimates (or often just guesses), were possible before.

Ultimately, camera traps have revolutionized wildlife research and conservation. Its use is relatively easy and cheap when considering the time, effort and results obtained. One important outcome is that today's camera traps have been used in many conservation campaigns that have significantly raised awareness and created a willingness by the public around the world to get involved in the conservation of wildlife and their habitats.

III.2. The need for studies of ungulates in tropical forests

Ungulate species are known to play a direct role in seed dispersal and serving as prey for predators, and camera traps have documented these interactions (e.g., Jenny and Zuberbühler, 2005; Babweteera and Brown, 2010; Nyiramana et al., 2011; Campos et al., 2012; Koike et al., 2012; Pender et al., 2013). This ecological role is exemplified by Ickes et al. (2001), who reported that species of ungulates were facilitating native and exotic plant spreading, such as the neotropical understorey shrub *Clidemia hirta*; Levels of Nepali hog plum *Choerospondias axillaris* seed dispersal and seedling abundance positively tracked mammal (muntjac and sambar deer) density (Brodie et al. 2009). He found that if illegal hunting of mammals in Khao Yai National Park were to increase to the levels seen, *C. axillaris* population growth rate would decline, though just slightly.

The interaction between ungulates and plants may also an influence on the conservation of other species. As an example Dinerstein et al. (2007) found that the positive conservation measures for predators such as tigers limited and depressed the abundance of some prey species. Thus, conservation activities aimed at restoring large predators are likely to change the composition of the mammal community, potentially eliminating rare but preferred prey species such as ungulates. The consequences of the loss of any wild ungulate guild are thus complex and cannot be effectively considered isolated from the responses to different trophic levels, or without reference to the environmental context (McNaughton, 1983; Davidson et al., 2010). This should certainly have a direct influence on the conservation of ungulates, in our case on the conservation of Bawean deer and red muntjac.

IV. THE STUDY: **MONITORING THE POPULATION AND ECOLOGY OF TWO REMOTE DEER IN INDONESIAN TROPICAL RAINFORESTS**

IV.1. The study species: the Bawean deer and red muntjac

The choice of the study organism, and more precisely the contradictory hypotheses and questions relating to a species, is a critical decision in ecological and evolutionary research. The Bawean deer and red muntjac are medium-sized cervids: adults weigh about 36-50 kg, with a body length of 105-115 cm for Bawean deer, 14-35 kg with a body length of 89-135 cm for red muntjac (**Table 5**). Both have low male-biased sexual size dimorphism and adult males and females are weakly territorial. Both species are considered to be flagship species of tropical forests (Blouch and Atmosoedirdjo, 1978; Oka, 1998; Mattioli, 2011). This makes both deer species ideal models for further comparisons.

Table 5. Reported measurements and bio-ecology of Bawean deer (*Axis kuhlii*) and red muntjac (*Muntiacus muntjak)*

	Bawean deer			Red muntjac		
	Size (cm)	Source	Bio-ecology	Size (cm)	Source	Bio-ecology
W	46-60	Kurt (1990), Whitehad (1993)	Bawean deer are primarily nocturnal, active intermittently through the night. They are very wary, and appear to avoid contact with people; where human activity is heavy, the deer spend the day in forests on steep slopes that are inaccessible to teak loggers. Individuals are occasionally seen on the beach in the southwest of the island, but otherwise are rarely seen directly (Blouch and Atmosoedirdjo 1978, 1987). It is typically solitary, although duos made up of a doe and fawn or a buck following a doe sometimes occur (Blouch and Atmosoedirdjo 1978).	20-35	Grzimek et al. (1990); Mattioli (2011)	In Taman Negara, Malaysia, camera-trapping showed red muntjac to be mostly diurnal (Kawanishi and Sunquist, 2004), whereas in Gunung Leuser, Sumatra, it was classed as cathemeral (i.e., sporadic and random intervals of activity during the day or night) (Van Schaik and Griffiths, 1996). It is a mostly solitary species that is capable of breeding through the year, and has been stated to be territorial (Kitchener et al. 1990; Oka 1998). However, Tyson (2007) found no evidence of territoriality in the radio-collared female muntjacs of Baluran National Park, Java. The diet is mostly fruits, buds, tender leaves, flowers, herbs and young grass (Kitchener et al. 1990; Oka 1998).
HBL	105-140	Blouch and Atmosoedirdjo (1987), Kurt (1990)		90-120	Grzimek et al. (1990); Mattioli (2011)	
SH	60-70	Lydekker (1915); Sitwell (1970); Blouch and Atmosoedirdjo (1987), Kurt (1990), Whitehad (1993), Geist (1998)		50-70	Grzimek et al. (1990); Rahman (2014)	
TL	17-20	Kurt (1990)		17-19	Grzimek et al. (1990); Rahman (2014)	

Note: W (Weight), HBL(Head and body length), SH (Shoulder height), TL (Tail length)

Bawean deer and red muntjac are good examples of medium size ungulates which live in Southeast Asian tropical forests. Little has been published on their ecology and role in the tropical rainforest ecosystem (**Table 5**). The reasons for such little conservation attention might result from their uncommonness, difficulty to observe as they mostly live in dense undergrowth (Blouch and Atmosoedirdjo, 1987; Sundell et al., 2004; Tyson, 2007), and locally challenging conditions with conservation interest targetted to more charismatic species such as the Javan rhinoceros *Rhinoceros sondaicus sondaicus*. Most previous studies of these two deer species, especially ecology and behaviour, have been conducted on captive individuals. In the wild, some studies have documented population trends of Bawean deer using different methods; mainly by direct and indirect surveys. Furthermore, some other studies have focused on the habitat and ecology of Bawean deer (Blouch and Atmosoedirdjo, 1978, 1987), and red muntjac in Gunung Halimun Salak National Park and Baluran National Park (Suyanto, 2003; Tyson, 2007). In any event, direct observation of the species in their natural habitat has been reported as being difficult.

IV.2. Subject of the study

With the recent development of monitoring techniques, and especially capture-recapture analyses from camera trapping, an alternative technique is now available for studying the ecology and behaviour of both deer. My study therefore aimed to use remotly triggered photographic camera units in combination with field surveys by transect sampling and faecal pellet-group count to provide data on the effectiveness of this combination technique for monitoring deer, and to collect data related to their population size and range, their habitat use and activity patterns. To ensure that the collected data from several sampling techniques were comparable, I tried to keep sampling parameters constant over the same period among techniques. From a conservation point of view, this study aimed to provide new insights into assessing conservation status and improving management tools.

To investigate these issues, I studied two deer populations living in Indonesian protected areas: Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS) and red muntjac in Ujung Kulon National Park (UKNP); see **Materials and methods**). Both deer populations under study are exceptional in the sense that they are threatened due to habitat change and poaching, with little attention being paid to their preservation.

IV.3. Background to the study

Indonesian rainforests still contain extensive habitat and play a significant role in deer conservation. However, the population status of these species is still unknown in most areas. The paucity of information is attributed to the fact that deer have received little conservation attention in the past decades, due to having to 'compete' locally with more charismatic species as these animals are not mascot species, nor of high "selling" value to some funding agency, and to the limited national capacity to undertake deer research and conservation. The limited knowledge of the ecology of deer and the absence of suitable protocols have led to a lack of reliable data that could be used in the planning of conservation of the species.

In my research, I tried to choose and apply more than one method, compare the results and decide which method will produce adequate results with the lowest commitment of staff and resources. I developed a standard design for monitoring deer at both study sites. This comparative approach can be used to determine whether a population index (such as faecal pellet-group count or transect sampling) correlates well with a more rigorous method of population estimation (such as total capture or capture-recapture) and can show the advantages and disadvantages of each method. The 'double sampling' or comparative approach also acknowledges the belief that different methods may be better or worse at different locations or under different circumstances.

The study was the first effort to assess deer abundance and the impact of human-deer interactions, recently initiated in national protected areas at the two study sites. In addition, this study provided baseline data on both deer species, information about their range, habitat use and activity patterns, as well as the threats they face, although they live in areas of global animal conservation importance. Further field research is important to assess the trend of the status of these deer, given management and conservation measures.

My study had the following objectives:

1. To investigate the feasibility of camera-trapping to monitor Bawean deer and compare it efficiency to two other survey methods, transect sampling and faecal pellet group count, both in terms of seasonal detection, financial and human costs.
2. To estimate the abundance and map the range of Bawean deer in BINR-WS, and assess its IUCN status using both Random Encounter Models (REM) on camera trapping data and faecal pellet group count.

3. To identify some environmental factors affecting the seasonal habitat use of Bawean deer and red muntjac, and modelled their predictive range using Maximum entropy modelling (Maxent).
4. To ascertained how season and lunar illumination affect Bawean deer and red muntjac activity.

My hypotheses were as follows:

1. Camera trapping provides valuable results and present the best trade-off between cost, effort and results for monitoring Bawean deer population.
2. REM may be an accurate for estimating density of elusive, rare and unmarked species such as Bawean deer rather than faecal pellet group count method.
3. (i) both deer species are highly dependent of primary forests versus other forest types, (ii) undisturbed protected forest areas are essential for their conservation.
4. Bawean deer and red muntjac will minimize their activity during the wet season and when moon illumination is brighter.

Finally, the new insight into ecology and population status of both deer addressed the 'major constraints' and had two ultimate goals related to conservation. The first was a site-specific motive to provide ecological information to direct conservation efforts for the Bawean deer and red muntjac populations. The second was to develop, from the results of this study and others, a series of generally applicable recommendations for improved management of tropical rainforest deer throughout their range.

IV.4. Structure of the study

Detailed investigation of the many topics introduced in this chapter is beyond the scope of a single dissertation, but the preceding overview provides context for my study of deer conservation in the particular Indonesian protected areas.

My study is divided into three chapters, comprising four papers. The first chapter (**Papers 1 and 2**) focusses on evaluating the efficiency of three survey methods, (camera trapping, transect sampling and faecal pellet-group count), both in terms of seasonal detection, and financial and human costs of supporting information-gathering practices for tropical deer; this was targetted to the Bawean deer population, and the aim was to estimate the abundance and update the distribution of Bawean deer in BINR-WS, and also to assess its IUCN status. **Paper 2**, using a Random Encounter Model (REM) that does not require individual recognition, presents an alternative analysis based on capture-recapture technique. I also aimed to test hypotheses about this species relative vulnerability to ‘local extinction’. In the second chapter (**Paper 3**), I investigated habitat use of both Bawean deer and red muntjac, applying a Maxent model to predict their range and test hypotheses that (i) these tropical deer are highly dependent on primary forests rather than other forest types, and (ii) undisturbed protected forest areas are essential for their conservation. The present research is to my knowledge, the first to apply range prediction for the two target deer species in Indonesian tropical rainforest, while also compiling a database of Bawean deer and red muntjac occurrences at different locations. In the third chapter (**Paper 4**), I specifically test the hypothesis that Bawean deer and red muntjac will adjust their activity to season and moon phases.

It should be noted that it has not been possible to include all data collected on the two studied populations in the four papers. Indeed, because of the lack of long-term studies and the urgent need for conservation, I used Bawean deer as the main example, representing the condition of deer in tropical rainforests with the uniqueness of their existential endangerment and their isolated survival status.

MATERIALS AND METHODS

CHAPTER 2

MATERIALS AND METHODS

This thesis was compiled and prepared from independent papers. Methods and techniques are therefore described in detail in the relevant chapters. This chapter thus only serves as a general overview of methods used in this study.

I. STUDY SITES

My study areas were Bawean island, mainly Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS) for Bawean deer, and Ujung Kulon National Park (UKNP) at the extreme northwest of Java island for red muntjac (see **Figure 5**). Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park are strongholds for large mammals within Indonesia and have been protected by the Indonesian Wildlife Authority since 1979 and 1958, respectively. While multiple censuses have been conducted in both protected areas, these typically used classical sampling techniques (Blouch and Atmosoedirdjo, 1978; Blouch, 1980; LIPI and IPB, 1999; Semiadi, 2004; Semiadi and Pudyatmoko pers. com.; BBKSDA East Java, 2009, UGM and BBKSDA East Java, 2003) and focused on specific taxa (e.g. Javan rhinoceros by Hoogerwerf, 1970; Shoshani and Eisenberg, 1982; Santiapillai et al., 1990). Monitoring cryptic wildlife species such as deer is often difficult or impossible using such techniques.

Bawean island is a relatively isolated, 200 km^2 island in the Java Sea *(*5°40'-5° 50'S; 112° 3'-112° 36'E). According to the classification of Schmidt and Ferguson (1951), Bawean Island's climate is categorized as type C (Semiadi, 2004). On the island, mean temperatures vary between 22°C and 32°C and relative humidity ranges between 50% and 100% (Semiadi, 2004). The mean annual rainfall is 2,298 to 2,531 mm, 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 BINR-WS (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 to 630 meters). Low coastal hills are separated by broad valleys, which are primarily cultivated lands. The centre of the island is mountainous with peaks at 400 to 630 m in elevation, and is mainly covered by forests (**Figure 6**).

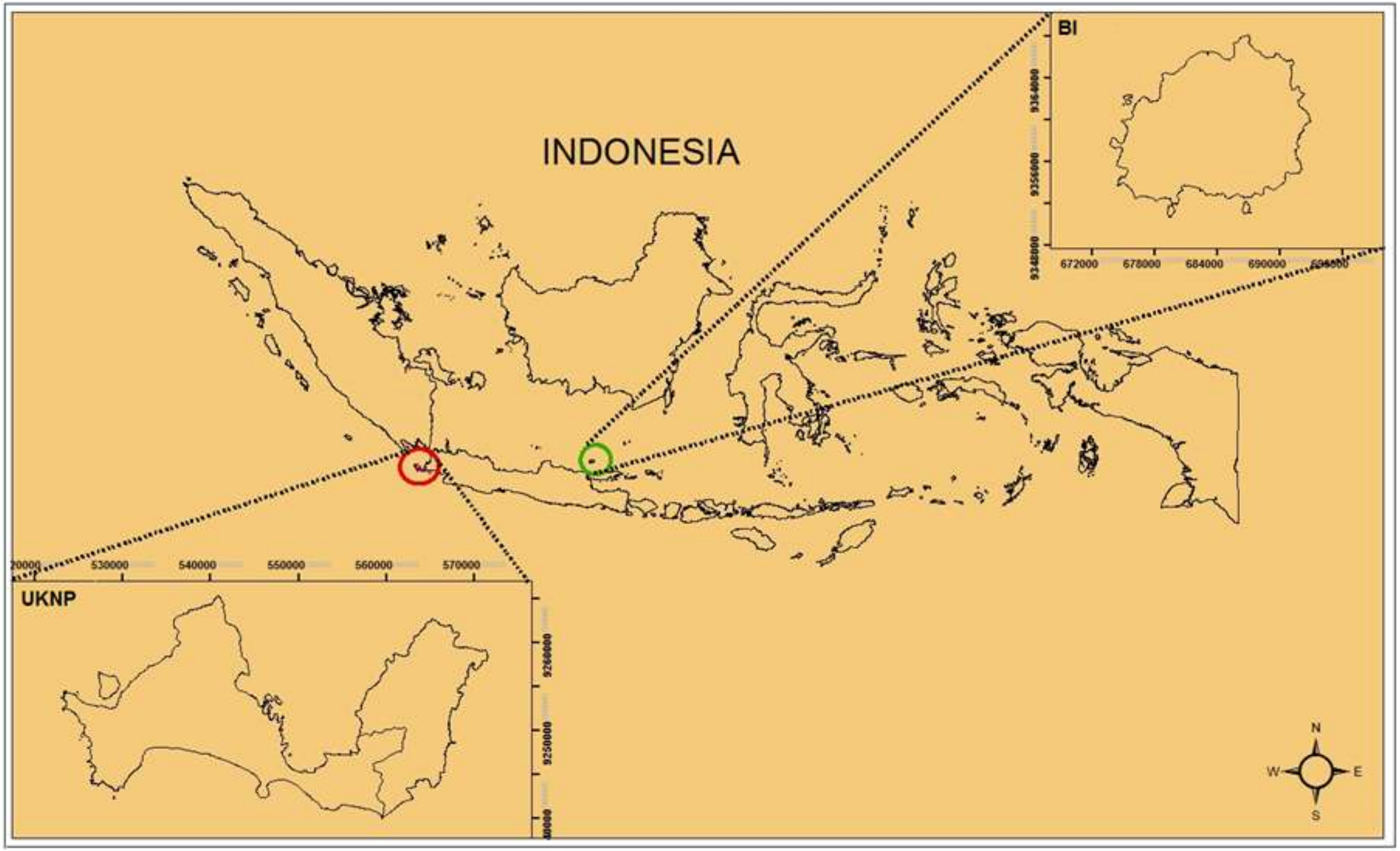

Figure 5. Study areas of (A) Bawean deer population on Bawean island, and (B) red muntjac population in Ujung Kulon National Park.

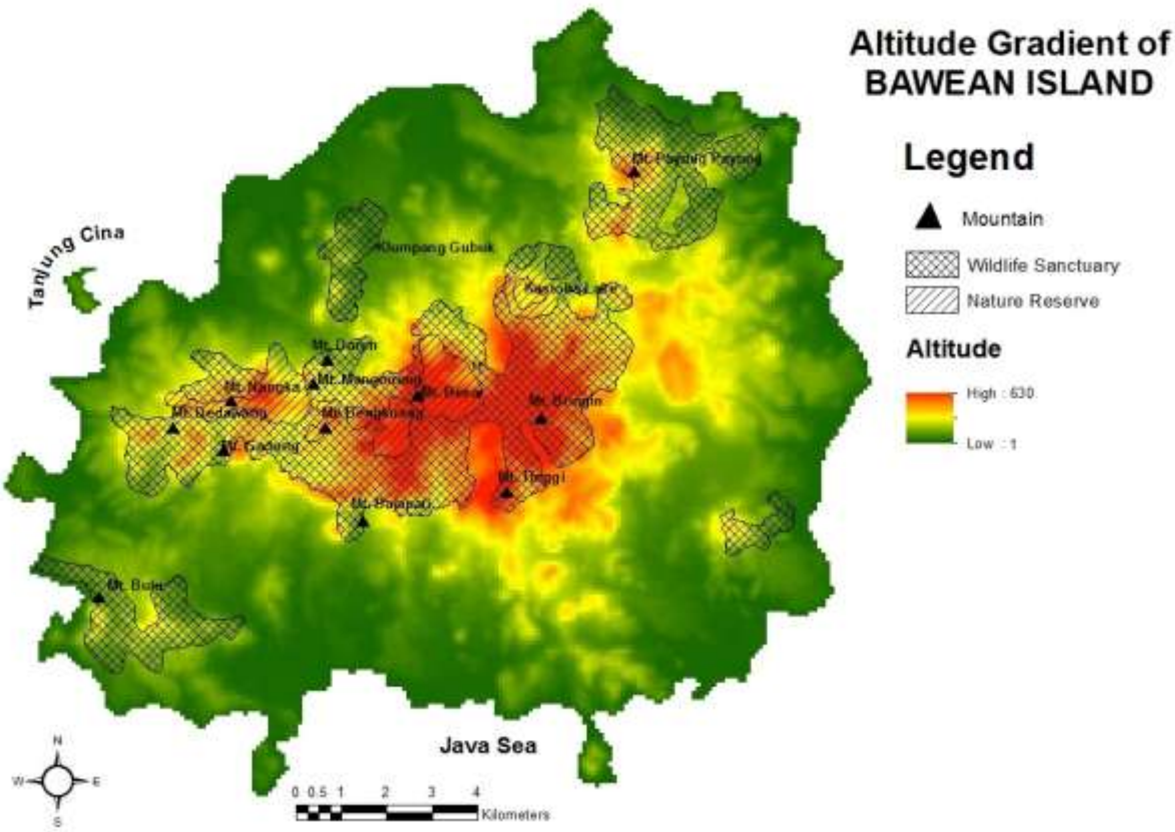

Figure 6. Distribution of altitudinal gradient on Bawean island.

The BINR-WS protects one of the small patches of tropical rainforest in Indonesia (ca 23% of the island), including teak plantations (60% of this area). The main vegetation type is a tropical rainforest and can be divided into four major forest types (Blouch and Atmosoedirdjo, 1987, for more details see **Figure 7**): primary forest, secondary forest, teak (*Tectona grandis*) forest, and shrub. Primary forests are old forests subject to only minor disturbance by human activities and generally not easily accessible. Both tree and understorey species vary greatly from one mountain to another. The most common trees include *Anthocephalus indicus, Ficus variegata, Radermachera gigantea, Symplocos adenophylla, Eugenia lepidocarpa, Dracontomelon mangiferum, Nauclea spp., Garcinia dioica, Canerium asperum, Irvingia malayana, Calophyllum inophyllum, Psychotria spp*. The understorey is mix of tree saplings and few species such as *Leea indica, Psychotria spp., Antidesma montanum, Memecylon floribundum, Petunga microcarpa* and *Guioa diplopetala*. Secondary forests, i.e.. forests that to varying degrees have been changed by human use or natural disaster, are composed of *Ficus variegata, Macaranga tanarius* and *Anthocephalus indicus*. The understorey is quite dense, and is made up of species such as *Leea indica, Ficus spp*., *Antidesma montanum* and *Garcinia celebica*.

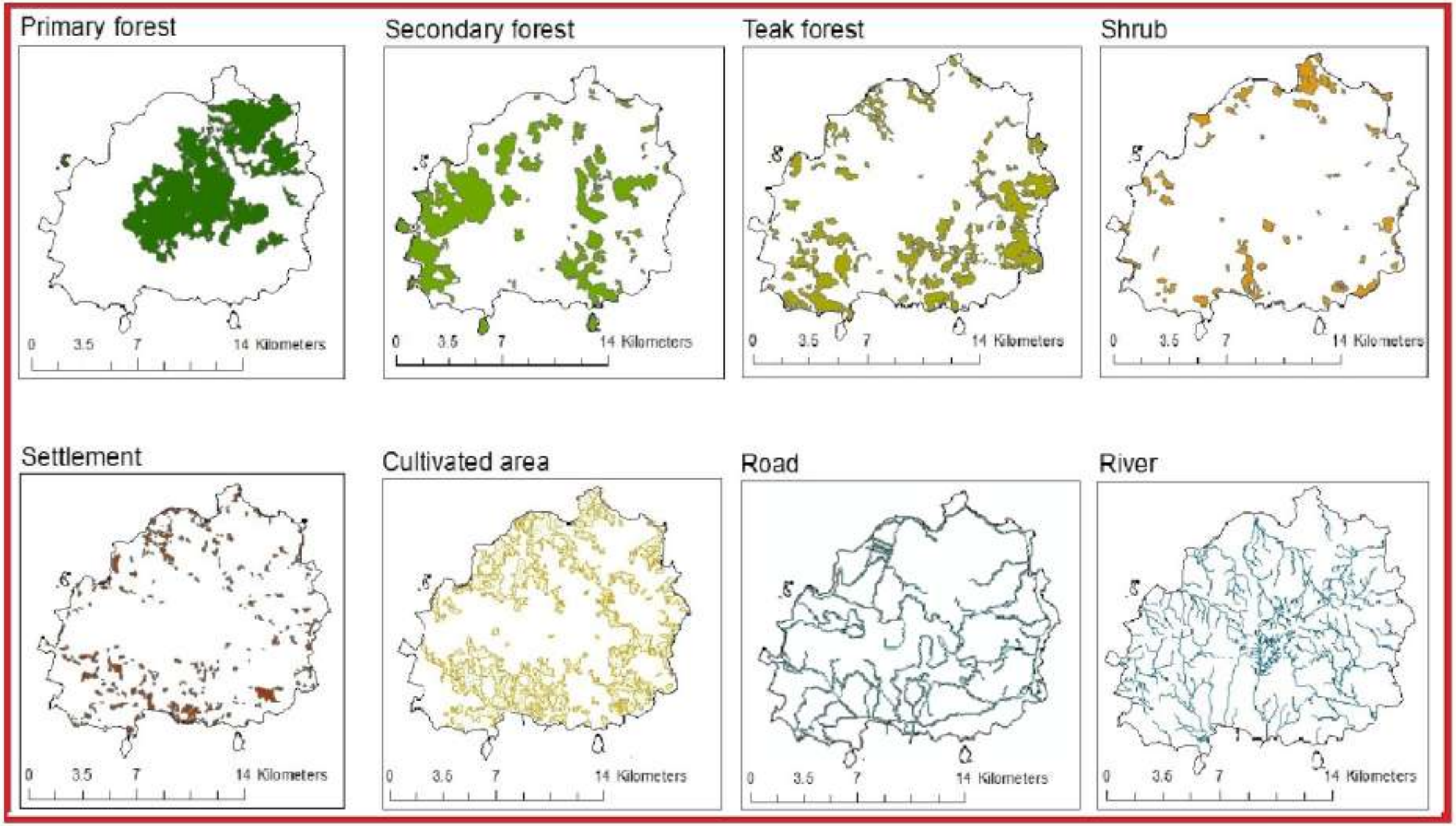

Figure 7. Land use and rivers in Bawean island.

Most of these forests occur patchily within teak plantations, mainly where planting failed. Teak plantations host the same species as secondary forests, but large trees are mainly teak and the understorey is generally less dense because of occasional fire. Shrubs are often found on poor, sandy soil and are characterized by small woody plants, mainly *Melastoma polyanthum* and *Eurya nitida*.

Generally, the habitat types in BINR-WS are globally endangered by deforestation and climate change. The remaining natural forests are confined to the steep sides and tops of the higher hills and mountains, often occurring as islands surrounded by teak. Moreover, the BINR-WS constitutes one of the last strongholds in the country for two endemic medium-large mammalian ungulates; the Bawean deer and the Bawean warty pig *Sus verrucosus blouchi* (Groves, 1981) and two endemic raptor birds, the Bawean serpent eagle *Spilornis cheela baweanus*, and spotted wood owl *Strix seloputo baweana*.

The second study site, Ujung Kulon National Park (UKNP) is a ca.120,551 ha: (terrestrial zone: ca.76,214 ha, marine zone, ca.44,337 ha) protected area of the Ujung Kulon National Park peninsula (6°45'S; 105°20'E). UKNP's climate is categorized as 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 maritime tropical, with a mean annual rainfall of ca. 3.250 mm. The heaviest rainfall between October and April occurs during the north-west monsoon (wet season), alternating with a noticeably drier period between May and September with ca.100 mm per month during the south-east monsoon (dry season). UKNP has varied topography (with terrain slopes steeper than 15°) and a wide altitudinal gradient 0 to 620 meters (**Figure 8**).

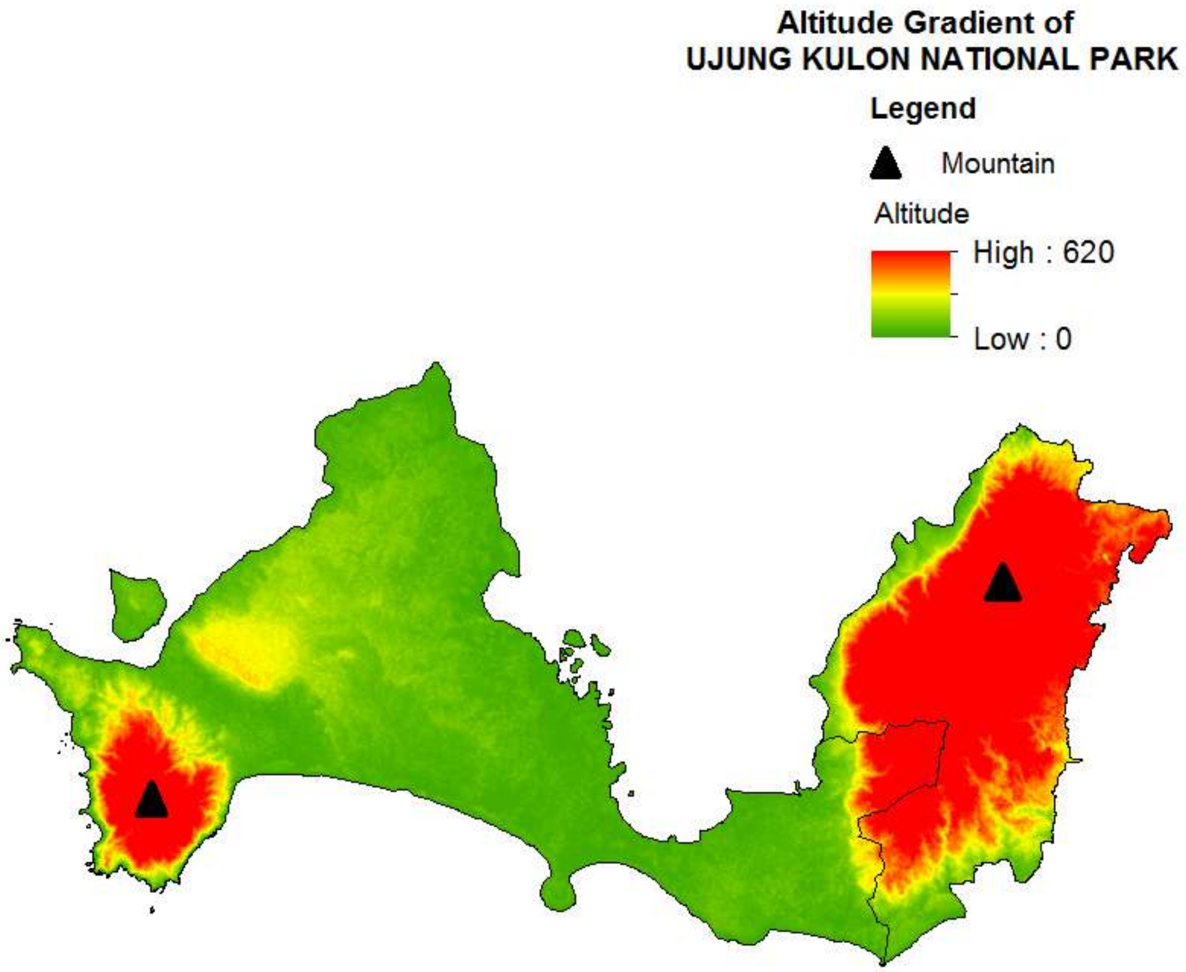

Figure 8. Distribution of altitudinal gradient in Ujung Kulon National Park.

The main vegetation is a tropical 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 (**Figure 9**). 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 (see **Paper 3**; **Figure 1**).

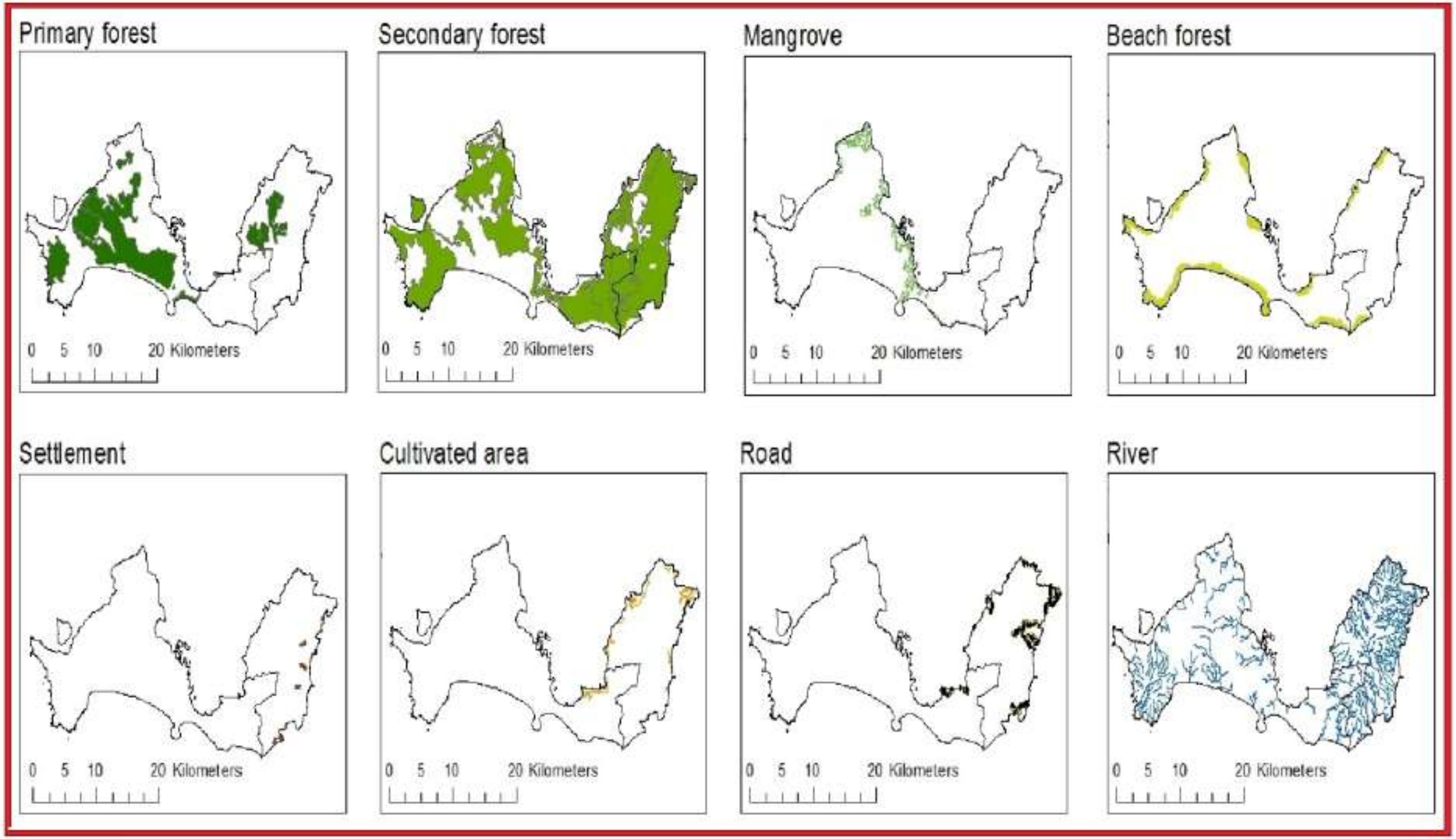

Figure 9. Land use and rivers in Ujung Kulon National Park.

At least 50 species of rare plants are present (MacKinnon, pers. comm.) in UKNP. A tall, closed-canopy primary forest grows on Gunung Payung, characterised by *Dillenia excelsa*, *Pentace polyantha* and *Syzygium* sp., with an understorey of low palms and herbs. Primary forest also occurs on Pulau Peucang with an open canopy and numerous emergents up to 40m high. Dominant tree species are *Parinari corymbosa*, *Lagerstroemia speciosa*, *Rinorea lanceolata*, *Pterospermum diversifolium*, *Intsia bijuga*, *Eugenia* sp., *Aglaia* sp., and *Diospyros* sp. Primary lowland forest of the Gunung Honje region includes *Pterospermum javanicum*, *Dipterocarpus gracilis*, *Intsia bijuga*, *Lagerstroemia speciosa*, *Ficus* sp. and *Eugenia* sp. The understorey includes palms such as *Arenga obtusifolia* and *Calamus* sp. (rattan).

The higher slopes are characterised by trees such as *Castanopsis* sp. which occur in a denser canopy dominated by *Podocarpus neriifolius*, *Turpinia sphaerocarpa*, *Fagraea racemosa*, *Dipterocarpus hasseltii*, *Aphanamixis* sp. and *Eurya* sp. The understorey is characterised by extensive moss growth both on the ground and on trees, as well as by the occurrence of epiphytic orchids such as *Asplenium nidus* and ferns such as *Freycinetia* sp. The vegetation of the Telanca plateau and central lowlands is a more open secondary forest, dominated by palms, such as *Arenga pinnata*, *Arenga obtusifolia* and *Caryota mitis*, which may occur in almost pure stands interspersed with taller canopy trees, such as *Lagerstroemia flosreginae*, *Diospyros macrophylla*, *Vitex pubescens*, *Ficus* sp., and *Planchonia valida*. Alternating with palm forest are dense stands of bamboo and Zingiberaceae, such as *Achasma* sp., *Nicolaia* sp., and *Lantana camara*. Some 64 hectares of artificially created grasslands are maintained as grazing for ungulates (Blower and Van der Zon, 1977; Hommel, 1987). Mangrove forest occurs in a broad belt along the northern side of the isthmus, extending northwards as far as the Cikalong River, as well as north of Pulau Handeuleum and on the north-east coast of Pulau Panaitan. Tree species include *Sonneratia alba*, *Lumnitzera racemosa*, *Nypa fruticans*, *Avicennia* sp., *Rhizophora* sp., and *Bruguiera* sp. Beach forest occurs on nutrient-poor sandy ridges on the north and north-west coasts of Ujung Kulon, and is typified by such species as *Calophyllum inophyllum*, *Barringtonia asiatica*, *Hernandia peltata*, *Guettarda speciosa*, *Terminalia catappa* and *Pongamia pinnata*. Other coastal vegetation includes pioneering formations along the upper edge of beaches, above the high tide mark. Characteristic species include *Ipomoea pescaprae*, *Spinifex littoreus* and *Canavalia maritima*. UKNP constitutes one of the last strongholds in the country for endemic large mammalian ungulates such as the Javan rhino *Rhinoceros sondaicus sondaicus* (Desmarest, 1822).

It should be noted that the dominant vegetation species in either study site are used to classify each habitat type at this site. The habitat types listed above are standard terms (Habitats Classification Scheme Version 3.1 by IUCN) used to describe the major habitat/s in which taxa occur.

Hence, these two sites are quite similar, mainly with respect to climatic conditions, Bawean island being slightly milder in the wet season and hotter in the dry season. The sites differ in terms of sizes of protected area, habitat types, and levels of habitat fragmentation. Although the two protected areas are mainly covered by forests, these are more fragmented on Bawean island, and are surrounded by settlements, cultivated area and affected by illegal logging activities (**Figure 10**).

Figure 10. Illegal logging practice, here recorded by a ranger patrol, are still rampant in the protected area of Bawean island.

II. METHODS

II.1. Considerations regarding monitoring methods and camera traps

To assess wildlife population trends, scientifically based monitoring programmes must be carried out. For species that occur in very low densities, and/or that are nocturnal and shy, direct observations of animals are often not possible. The basic ecology of lesser deer makes their populations inherently difficult to monitor (Tobler et al., 2008). Moreover, the population trends of some small-medium deer are consequently difficult to monitor effectively.

Based on sightings, methodologies such as transect sampling (Rudran et al., 1996), are efficient and relatively inexpensive for many natural populations (Anderson et al., 1979; Burnham et al., 1980; Buckland et al., 1993). This method is commonly used for animals which are fairly easy to sight, such as large or medium-sized herbivores in relatively open habitats. In practice, this method requires some assumptions that are binding, the animals must be detected with certainty at their initial locations, and distance from the observer must be measured accurately (for details see Buckland et al., 1993). These assumptions are difficult to meet for species with low detection rates, either because they are rare and/or elusive, are nocturnal, live in tropical rainforest with dense vegetation, or they are heavily impacted by human activities (Griffiths and Van Schaik, 1993; Duckworth et al., 2006). The method is also less suitable for highly mobile mammals such as deer (Buckland et al., 2001; Fewster et al., 2008).

A new generation of camera traps and the use of well-developed capture-recapture models have led to an increase in the use of remote surveying and monitoring methodologies for terrestrial and remote species (Karanth, 1995; Jhala et al., 2008). Population estimates can now be made for individually identifiable species and relative abundance indices can be calculated for other species. Camera traps have also made possible more accurate estimates of species richness, species diversity, total mammalian biomass, spatial variation and population size of some mammals. With long-term use, camera traps enable researchers to monitor changes in populations over time. An earlier study that was carried out in BINR-WS on Bawean deer focused on their habitat and ecology (Blouch and Atmosoedirdjo, 1978, 1987; Semiadi and Pudyatmoko pers. com.), using mainly indirect surveys.

The present research, which was conducted in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, Indonesia from January 2013 to November 2014, aimed to study the populations in terms of techniques, abundance, habitat use and activity pattern using faecal pellet-group count, line transects, and the new tool of camera trapping for medium deer species such as Bawean deer (*Axis kuhlii*), and red muntjac (*Muntiacus muntjac*). In fact, very few studies have been conducted on medium and small sized deer in the Indonesia's tropical rainforests. This could be because both deer species have received little conservation attention, largely because they are uncommon, rarely seen, and have to compete locally for conservation interest with more charismatic species such as the Sumatran tiger (*Panthera tigris ssp. sumatrae* Pocock, 1929; see Linkie et al., 2003; Linkie et al., 2004; Linkie et al., 2006; Nyhus and Tilson, 2004; Wibisono et al., 2009), the Javan rhinoceros (*Rhinoceros sondaicus* Desmarest, 1822; see Griffiths, 1993; Schenkel and Schenkel-Hulliger, 1969; Hoogerwerf, 1970; Shoshani and Eisenberg, 1982; Santiapillai et al., 1990), Sumatran elephant (*Elephas maximus ssp. sumatranus* Temminck, 1847; see Oliver, 1978; Blouch and Haryanto, 1984; Sukumar, 2003; Leimgruber et al., 2003; Hedges et al., 2005; Hedges et al., 2006), and the Bornean orang-utan (*Pongo pygmaeus* Linnaeus, 1760; see Rijksen et al., 1995; Morrogh-Bernard et al., 2003).

The purpose of my Ph.D. study was therefore to use, for the first time, the technique of camera trapping to provide data on the ecology of Bawean deer and red muntjac and to evaluate the efficiency and effectiveness of three survey methods: camera trapping, transect sampling and faecal pellet-group count. For this purpose, I used a combination of direct observation and indirect tools such as using camera trapping for field ecology studies. I investigated in detail the use of camera trapping in terms of it's successful use in investigating and monitoring both remote species within the framework of an evolutionary method from classical to new method by sensory infrared trigger. In addition, line transects and faecal pellet-group count were utilized for comparison, and sporadic interviews with local people were used as auxiliaries to provide qualitative, background support. In this context, I was interested in studying the ecology of both deer species in respect of population size and status, distribution range, habitat use, and activity patterns; all aimed at trying to formulate conservation actions that could be taken based on the current status and ecological knowledge of both species, so that their very existence could be preserved.

II.2. Field studies

II.2.1. Camera trap surveys

Given the lack of information about the extent of home range or territory of either species from previous studies and according to the areas and habitat types to be surveyed, and the number of available camera-traps. The species' ranges were delineated using faecal surveys in UTM 2×2 km and 1×1 km squares in BINR-WS and UKNP, respectively, conducted throughout the month before the installation of camera traps. A square was considered positive if at least one faecal group was located, since that suggested the presence of individuals marking territory. A square was deemed negative when an accumulated effort of two man-hours failed to detect a faecal-group. This procedure was adopted because of the lack of information about the extent of home range or territory for either species in previous studies. In total , BINR-WS was gridded into 20× 4-km^2 trap stations, and UKNP was gridded into 329×1-km^2 trap stations (see **Paper 3, Figure 1**).

Camera-traps with heat-in-motion detectors were used to continuously record the activity of the target species in the two study areas, and were set to record date and time of all videos. In BINR-WS, camera traps were positioned 30-50 cm above the ground to record both small and large animals (**Figure 11A**). In UKNP, analog cameras were positioned 170 cm above the ground with a 10-20 degree angle lead to the ground (following the standard design of camera trapping used by the Rhino Monitoring Unit [RMU] teams to survey the Javan rhino) (**Figure 11B**). These differences in camera trapping might be affect the relative probability of photographic capture of the two deer species. However, the evidence of photographs in the field shows that muntjac are still capture even located in less than 1m from camera traps (**Figure 12**), this is possible due the camera not installed horizontally. Camera traps were deployed one per grid in rather open and accessible locations applying a buffer equivalent to half of the mean maximum distance moved (1/2MMDM) to reduce the likelihood of capturing the same individual twice (Karanth and Nichols, 1998; Soisalo and Cavalcanti, 2006). Before installation, I attempted to collect evidence of the presence of Bawean deer throughout the grid: either footprints, faeces, food remains or antler rubbing on trees. In practice, few camera traps were placed in areas with signs as it was difficult to find evidence of deer in the field.

A

B

Figure 11. Setting camera traps in: A) Bawean Island Nature Reserve and Wildlife Sanctuary, and B) Ujung Kulon National Park

).

Figure 12. Muntjac was photographed by camera trap in less than 1 m.

Although cameras were generally located in the same place during the study, we moved cameras by 300–500 m from the original location in the same grid when a camera did not capture deer in two or three periods of camera trap checking. In addition, we obtained information on the angle of the camera trap detection zone, directly from each camera via a manual procedure. Radii of the camera trap detection zones were obtained from videos by measuring the distance from each camera to the location of deer at the first triggering based upon marked locations in the field. The angle of each camera trap detection zone was obtained in the field by detecting a stick at six paired 4 m- distances perpendicular to the sensor beam and using a compass placed on a flat surface directly below the camera (**Figure 13**).

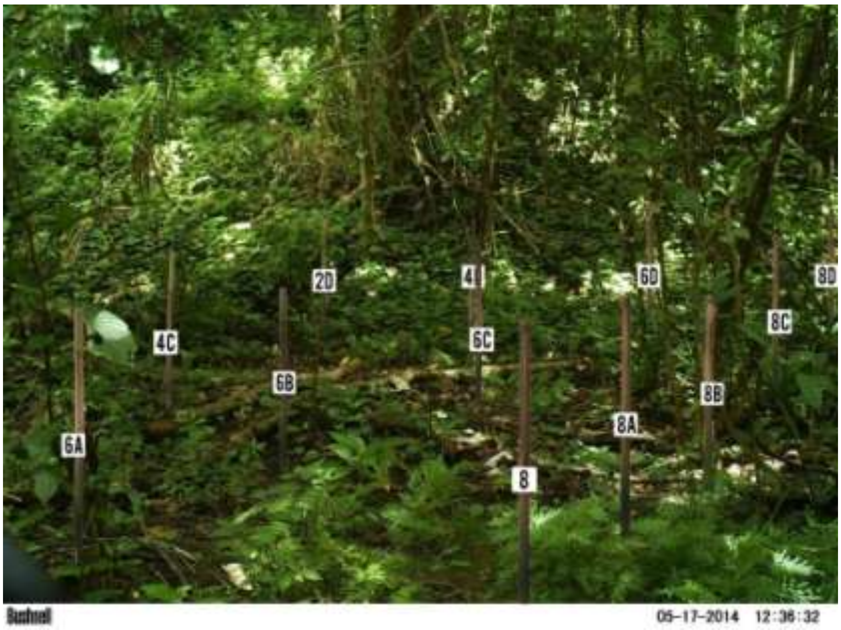

Figure 13. Placement of sticks in front of a camera trap, to record the angle of it's detection zone

II.2.2. Transect sampling

I performed intensive field-work from April to May and from June to July 2014 (representing wet and dry seasons) in both BINR-WS and UKNP. I placed 20 and 48 transects, respectively evenly spaced in 1-1.5 km transects every 2 km at both BINR-WS and UKNP, for total lengths of 108 km and 325 km respectively. (**Figure 14**). These transects were cut through the forest but removing vegetation only as necessary to allow for ease of movement. Extra care was taken not to cut lianas, and, when possible, saplings were bent rather than cut. By preserving saplings and lianas, I hoped to reduce potential browsing along these trails, and to speed forest recovery, so that our trails would not become hunting trails used by poachers. Each transect was walked four to six times, according to five day periods of 3 hours. The field-work was conducted during diurnal, crepuscular and nocturnal periods of potential animal activity. I counted each animal or group of animals. As per the planned methodology, I recorded the perpendicular distance from the observation to the centre line of the transect using a tape measure and range finder. I followed the recommendation of Raghatate et al. (2013) by using night-vision thermal imaging binoculars (**Figure 15**) that give the opportunity to continue observations after sunset, and the chance to see elusive creatures which are less active during the day (see **Paper 1, Methods [*Sampling design*])**. Treehouses sometimes were constructed when the location required us to stay overnight, and/or the observation area was adjacent to a wallow commonly used by wildlife, particularly in the dry season in Ujung Kulon National Park (**Figure 16**).

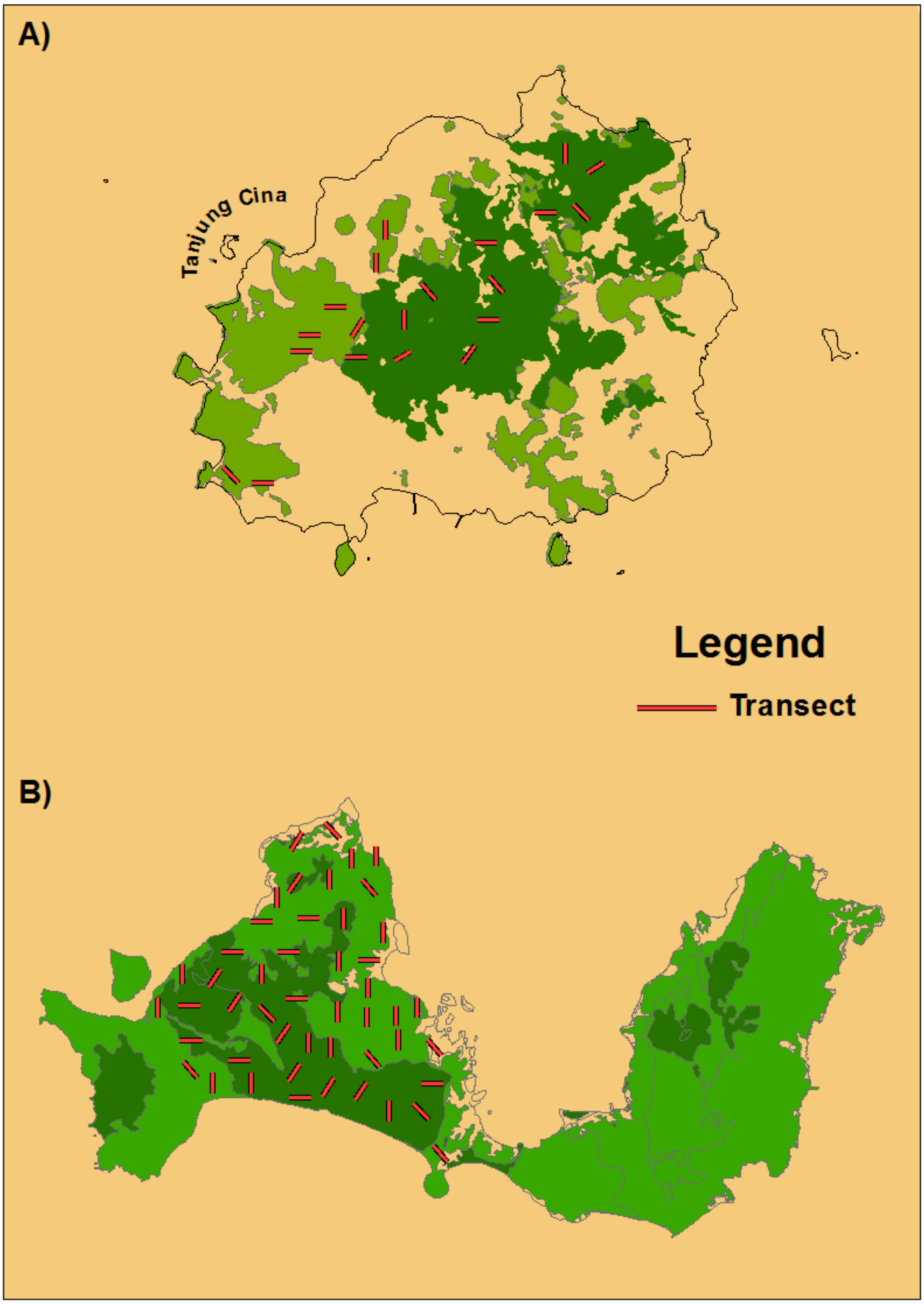

Figure 14. Transect sampling in A) Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), and B) Ujung Kulon National Park (UKNP), Indonesia.

Figure 15. Night observation in Bawean Isand Nature Reserve and Wildlife Sanctuary

II.2.3. Faecal pellet-group count

Four permanent square plots (7 m x 7 m; **Figure 17**), evenly 10 m-spaced were distributed within each grid: the plots were sited at each camera trap location. The number of sample plots included in the survey was approximately 300 square plots (4 plots per location×75 camera-traps location points) in BINR-WS and 548 square plots in UKNP (4 plots per location×137 camera-trap location points). Faecal pellet-group count surveys were conducted in 2014 at each study site. For the wet season, all sample plots were checked and cleaned for deer pellet groups in January, while the number of new pellet groups was counted in February to March. For the dry season, all sample plots were checked and cleaned in July and counted subsequently in August to September (see **Paper 1, Methods [*Sampling design*])**. In the absence of field data, due to the difficulty of finding individual Bawean deer directly, I used the observed defecation rate of captive Bawean deer (13 faecal groups/individual/day) in previous research by Blounch and Atmosoedirdjo (1987).

Figure 16. Treehouse in Ujung Kulon National Park.

Figure 17. A) faecal pellets, and B) design of permanent square plots in each camera trap point

II.3. Data processing

The first step in the processing the data from camera traps is to transfer field data to a computer or other device. The field researcher necessarily must ensure there is sufficient memory or storage space in the device, because the data generated from camera traps are generally large-sized format. The next step is prepare a spread sheet in Excel to give an overview of important information from camera trap data, such as location names or grid, UTM coordinates, type of habitat, dominant vegetation species, elevation, slope, start and stop dates and times for each camera, species name (if working with more than one species), date and time (hours, minutes and seconds) when the species were captured by the camera trap, number of photos or videos, sex (if this can be distinguished with certainty), and the behaviour exhibited at the time of camera trap capture. Recording start and stop dates and times for each camera is important, and is essential information to calculate the survey effort involved; it is also critical information for calculating the capture rate of each camera at a particular location. The information on start and stop date and time is also useful to record the total number of images taken and also the number of blank photographs during this period to give some indication of how well the camera has functioned. Some other information can be included in the spread sheet, for example in my study, I performed angle measurements that describe the detection zone and radius of each camera trap which is essential information for estimating Bawean deer density in BINR-WS. Additionally, moon phases can be added if studies are attempting to connect the activity pattern of the animals with each moon phase in one year.

Furthermore, after all the data has been recorded in an Excel file this file should be accurately named to reflect the name of survey area and species. In addition, if the video mode was selected during camera trap surveys, this can be processed using software such as GOM Player to make it easier to analyze. At the next stage, depending on available resources and the purpose of the survey, it may be necessary to simply extract the photographs of the species of interest and to log only these photos. If time is not restricted then those photos can be logged in an Excel spreadsheet, following a similar format to that suggested in **Appendix 4**.

In the process of organizing the data, I adapted the recommendations given by Ancrenaz et al. (2012) to assist with managing a high volume of pictures by using Camera Base (http://www.atrium-biodiversity.org/tools/camerabase).

II.4. Statistical analyses

Some basic data on camera traps, such as the number of cameras used, number of trap-nights, number of pictures obtained and the distribution of pictures between each site, are data which can be used to answer various hypotheses on the ecology and population status of both species of deer. Analyses were performed using statistical software such as R statistical environment, SPSS Version 20, Oriana V4.05 (Kovach Computing Services) and Microsoft Excel, as well as a range of other software adjusted for the main questions and hypotheses in each article. Data were aggregated by species and camera trap site, then summed to generate count data.

In **Paper 1,** I computed, from camera trapping data, seasonal relative abundance indices (RAIc). I also computed the relative abundance indices (RAIt) and faecal pellet indices (FPI) per season, for transect sampling and faecal pellet group count data respectively. Hereinafter, I compare the seasonal results and methods within seasons using chi-square tests in SPSS version 20. This comparison would seem to offer the most numerous and accurate methods for recording data on mammals, particularly for Bawean deer.

In **Paper 2**, I calculate the number of variables used to estimate population density, as developed by Rowcliffe et al. (2008). Some of the statistical analysis used in this calculation, as an example of the R package 'activity' by Rowcliffe, is used to calculate the proportion of time spent active. This value is critical for calculating the day range, i.e., the maximum distance moved per day (speed in m/s obtained from camera trap data expressed in km/24 hour period * proportion of time spent active). Furthermore, the standard error (SE) range of each variable was calculated using the delta method (Seber, 1982). The outcome densities per km^2 were extrapolated to the total protected area size on Bawean Island to provide estimations of population size. In addition, to ensure that the camera trap data taken in each period were sufficient to make reliable inferences, I also estimated a coefficient of variation for camera trap success rate per trapping period.

In addition, I tried to apply the capture-recapture method to estimate the population density of Bawean deer, since, even for species that lack natural unique markings, it is still possible to apply this method, which was developed by: Kelly et al., 2008, Soria-Díaz et al., 2010, for cougars; Oliveira-Santos et al., 2010, for tapirs; and Soria-Díaz and Monroy-Vilchis, 2015, for white-tailed deer. Analysis from this capture-recapture is not included in the discussion paper as published in the Oryx journal because it needs to be refined, especially in relation to the process of identifying each individual Bawean deer.

In **Paper 3**, I calculated photographic encounter rates (PER) per grid as: PER = number of photos * 100 / sampling effort (camera trap days). As the number of photographs significantly differed between seasons (chi-square tests), I compared the seasonal PER among habitat types in each study site, using Kruskal-Wallis tests adjusted for equal numbers and post hoc tests for multiple comparisons ($\alpha = 0.05$). Using many correlated variables may result in over-parameterization and reduce predictive power and interpretability (Morueta-Holme et al., 2010). For this reason, multicollinearity was checked for all combinations of environmental variables using Pearson's correlation coefficient. Then the selected variable was used to assess habitat use and a predicted range of both species, based on maximum entropy modelling (Maxent) developed by Philips et al. (2004).

Furthermore, in **Paper 4**, I used only the first deer photograph captured in each hour (subsequent deer photographs during the same hour were disregarded) and then grouped the number of Bawean deer and red muntjac events per hour of the day and tested the null hypothesis that activity for the two species was uniform throughout the day, applying the Rayleigh test (Batschelet, 1981; Zar, 2010). The Oriana V4.05 (Kovach Computing Services, 2012) program was used to apply this test. Differences in activity between sexes and times of day were evaluated using chi-square tests. Two-factor analysis of variance was used to test differences in levels of activity, both across the day and in seasonal terms. The seasonal analysis data were pooled into three-hour periods, to obtain a larger and more uniform number of activity fixes in each period. We used Tukey's honest significant difference test to evaluate variation differences in the frequency of events for each period. Results were considered significant if alpha < 0.05.

The details of the analysis for each article are described in the sections below:

II.4.1 Method selection and comparison

The efficiency of field techniques used for surveying Bawean deer and red muntjac respectively in BINR-WS and UKNP could be related to the available budget and human involvement. I explored the balance between positive and negative characteristics of camera trapping, transect sampling and faecal pellet group count, both in terms of seasonal detection and of financial and human costs. The cost of each method was evaluated for a 30-day survey and a four-month survey. For this purpose, I used only the data collected from the Bawean deer population as an example.

To evaluate the rigour of camera trapping in surveying Bawean deer and other animals in comparison to transect sampling and faecal pellet group count, a subset of the photographs obtained was used. Camera traps also obtained photos of non-target species; photographs of medium and large-sized mammals, domestic animals and birds were excluded. Exposures where the species was unidentifiable were also excluded from analysis. Individual subjects were identified to species level where possible using Suyanto et al. (2002) for mammals, MacKinnon et al. (1993) for birds and Iskandar (2002) for squamates and amphibians. As camera traps are continuous-time detectors, photographic events were considered to be independent if they a) contained different individuals or b) were separated by more than one hour. As we were interested in detection of deer species at the grid, data were pooled for cameras at each grid.

Three contemporary methods of estimating RAI for solitary species were compared against selection criteria to determine the most efficient. I used a sub-sampling technique to determine the relationship between the sampling intensity and the quality of outputs generated (Franco et al., 2007). The results from this comparison are specific to the study in question, but are also able to be extrapolated and applied in different situations to aid method selection (Franco et al., 2007).

II.4.2. Estimating abundance and density

My study focused on the urgency of estimating population size and status of Bawean deer. The most refined measure for wildlife monitoring is abundance or density (abundance per unit area). The ideal for any monitoring program would of course be to achieve total counts of all individuals in the population of interest. The first obvious problem is that in order to count individuals, we have to be able to distinguish one from another, which, without capturing and artificially marking them, can only be done for species with unique features such as spots or stripes. Moreover, our ability to detect individuals in a population is imperfect. There is no way to know for certain if the individuals detected by camera traps constitute the entire population or whether camera traps missed some; if so, there is no way to know what proportion this might be. Depending on whether individuals can be identified or not based on camera trap photographs, approaches to obtain measures of abundance and/or density differ. Related to that problem, I tried three methods and investigated how they were able to deal with these issues, while still fulfilling the requirements of each method.

II.4.2.1. Models from capture-recapture data

In this study, I tried to deal with a species whose individuals are possible to identify from pictures. I adapted previous studies by Soria-Díaz and Monroy-Vilchis (2015) for white-tailed deer, studies which assessed reliability in assigning individual identities to species that lack unique natural markings. It takes at least two independent researchers to study the photos and determine the identity of each individual; bias from observers must be evaluated (Soria-Diaz and Monroy-Vilchis, 2015). Based on these recommendations, I performed a double-blind exercise to increase the accuracy of individual Bawean deer identification and obtained 90% correspondence between independent evaluators; potential errors don't accounted in the identification of individual since any disagreements in these identifications were not considered for further analysis. Mark-recapture methods assume that individuals can be identified to determine whether data are ‘capture’ or ‘recapture’. Since the study uses a two-month period from the installation of the camera traps in the dry season to ensure the closed nature of the population, I was able to use some signs to distinguish individuals such as permanent scars (Jacobson et al., 1997), along with other secondary characteristics used for identification, such as neck thickness in proportion to body (González-Marín et al., 2008), the presence or absence of antlers (including the number of branches) or the presence of fawns (in the case of females), while also considering the location and date of the photograph

(Oliveira-Santos et al., 2010). Capture-recapture models estimate the probability of detecting an individual and use this probability in conjunction with the number of observed individuals to estimate actual abundance (Otis et al., 1978; Karanth and Nichols, 1998).

Accordingly, the study period was divided into two-month periods in dry seasons (the same periods used for REM) to fulfil the assumption of population closure using *CloseTest* (Stanley & Burnham,1999). Studies on mammals have used two month sampling periods for a closed population, arguing that in such short sampling times, the probability of observing a birth, death, migration, or immigration event is low (Karanth and Nichols, 1998; Silver et al., 2004; Soria-Díaz and Monroy-Vilchis, 2015). I developed individual capture histories for Bawean deer in a standard X matrix (Otis et al., 1978; Nichols, 1992). Constructing the capture history matrix, capture-recapture models are very similar to occupancy models in that they require data on presence to be structured, based on time of day or incidences. But instead of listing species detection/non-detection for each camera trap, I constructed a detection/non-detection matrix for each individual on each occasion, collapsing the data of the entire study area. So if, say, on occasion alpha, individual A was photographed n times on m different cameras, the matrix entry for individual A on occasion alpha was '1'. If individual A wasn't photographed anywhere, the entry was '0' (for an example, see **Appendix 4**).

This matrix was analysed using models developed for closed populations, in the CAPTURE program (Rexstad and Burnham, 1991). Each two-month period was composed of eight sampling occasions and each occasion covered a seven-day period. CAPTURE creates several capture-recapture models to estimate abundance and each model differs in assumptions about capture probabilities, which vary between individuals (M_h assumes that each individual has its own probability of being captured, independent of time and behaviour), through time (M_t accounts for variation in capture probabilities across occasions), based on behaviour model (M_b considers a differential response, trap-happy or trap-avoid, if the individual has been previously captured), null model (M_o when capture probabilities are assumed to be constant, with respect to time and individuals or in which no variations exists, Anile et al., 2012) or any combination there of (M_{bh}, M_{th}, M_{tb}, M_{tbh}) (Chao, 2001; Chao and Huggins, 2005; Anile et al., 2012). The model with the highest value (range between 0-1) is considered to be the one best fitting the sampled data (see Otis et al., 1978).

Density estimates were generated by dividing Bawean deer abundance by the effective sample area (Karanth and Nichols, 2002). The effective sample area included a minimum convex polygon around the traps and buffered that polygon with a belt whose width measures HMMDM among multiple captures of individual Bawean deers. We also used buffer areas around each camera trap equal to the minimum home range radius of 0.50 km defined for hog deer (Dhungel and O'Gara, 1991). With no data from the Bawean deer, we assumed home ranges of Bawean deer similar with hog deer *Axis porcinus* (Zimmermann, 1780) since they have similar body size and a close kinship. Previous research by Blouch and Atmosoedirdjo (1978) suppose that presence of Bawean deer in Bawean Island related with the ancestors of the present population were hog deer introduced by early European traders. Home ranges of stags hog deer varied from 0.16 km^2 to 2.23 km^2 (mean=0.8 km^2), and those of hinds (mean=0.60 km^2) varied from 0.11 km^2 to 2.05 km^2 (Dhungel and O'Gara, 1991).

II.4.2.2. Models to estimate densities of non-identifiable species

Increased use of camera traps in ecological research is currently accompanied by the development of a variety of methodologies, particularly those related to efforts for estimates of wildlife populations. Since the early 1990s, capture-recapture has become a common method used for this purpose, beginning with Karant et al. (1995). This method continues to evolve and is used for many thousands of wildlife surveys. The capture-recapture method requires individual recognition certainty to estimate population size. Natural signs such as a striped pattern, permanent scars left on the body or other marks, such as a ring or collar, are signs commonly used. In fact, not all animals have natural distinguishing marks that are distinct and permanent; a relevant example for deer species is that some natural signs appear only in certain periods, as when bucks are antlered.

Less than a decade ago, a method was developed to estimate population density for some animals that are difficult to identify with certainty. This method became known as a random encounter model (REM), which tries to connect the level of contact between moving animals and static camera traps in order to estimate species density from unmarked individuals. The models provide a factor that linearly scales encounter rate with density, depending on average animal group size and average speed of movement for the target species, together with characteristics of the camera detection zone (radius and angle within which it detects animals). For more detailed analysis, see (Rowcliffe et al., 2008).

REM has been successfully implemented by deploying cameras in systematic or fully randomized arrays for ungulate species (Rowcliffe et al., 2008; Rovero and Marshall, 2009; Zero et al., 2013; Carbajal-Borges et al., 2014). However, Foster and Harmsen (2012) suggest that the model's assumption of random placement of cameras with respect to animal movement will often be unsuitable for most species, including territorial animals. Relating this to the territorial behaviour of Bawean deer, I still have confidence that the Bawean deer species represents a suitable candidate to test REM, since Rowcliffe et al. (2013) found no reason to suppose that REM is fundamentally unsuitable for territorial species.

There are three assumptions that must be fulfilled in applying this model: (1) the animals move randomly and independently of each other with respect to cameras; meaning that the animals behave like particles of an ideal gas (**Figure 18**), (2) the object captured passing in front of camera traps, either in an image or on video, represents an independent contact between the animal and the cameras and (3) a closed population, meaning a population in a stable condition; there is no birth, death or immigration/emigration. For this purpose, I studied two-month periods in the dry season (June-July and August-September), on the basis that in such short sampling periods, the probability of birth, death, migration, or immigration events was low (Karanth and Nichols, 1998; Silver et al., 2004; Soria-Díaz and Monroy-Vilchis, 2015).

I used the following REM equation to obtain density estimates (D) from camera trap encounter rates (Rowcliffe et al., 2008):

$$gD = \frac{y}{t}\frac{\pi}{vr(2+\theta)}$$

where (y/t = trapping rate), v = animal's average daily speed of movement (km), r = radius of the camera trap detection zone (km) and θ = angle of the camera trap detection zone (radians). The outcome can then be multiplied by g (average group size) as the independent unit recorded by the camera is the group rather than the individual (Rowcliffe et al., 2008; Zero et al., 2013). Measurement of each variable in detail described in the first part of the manuscript (**Paper 2**).

II.4.2.3. Faecal pellet-group count

I used the faecal accumulation rate (FAR) by recording the monthly deposit of pellets after the initial removal of all pellets present in the plot. I counted faecal groups after 60 days of accumulation both in wet and dry seasons. Population density (D, individuals km-2) was estimated using the equation proposed by Eberhardt and Van Etten (1956): D = (NP*Dpg)/(T*dR), where NP = number of plots per km2, Dpg = mean pellet groups; T =

deposition time of fecal groups, and dR = defecation rate. In the absence of field data, I used the observed defecation rate of captive Bawean deer by Blounch and Atmosoedirdjo (1987). Finally the outcome densities per km2 were extrapolated to total protected area size on Bawean island to provide estimations of population size.

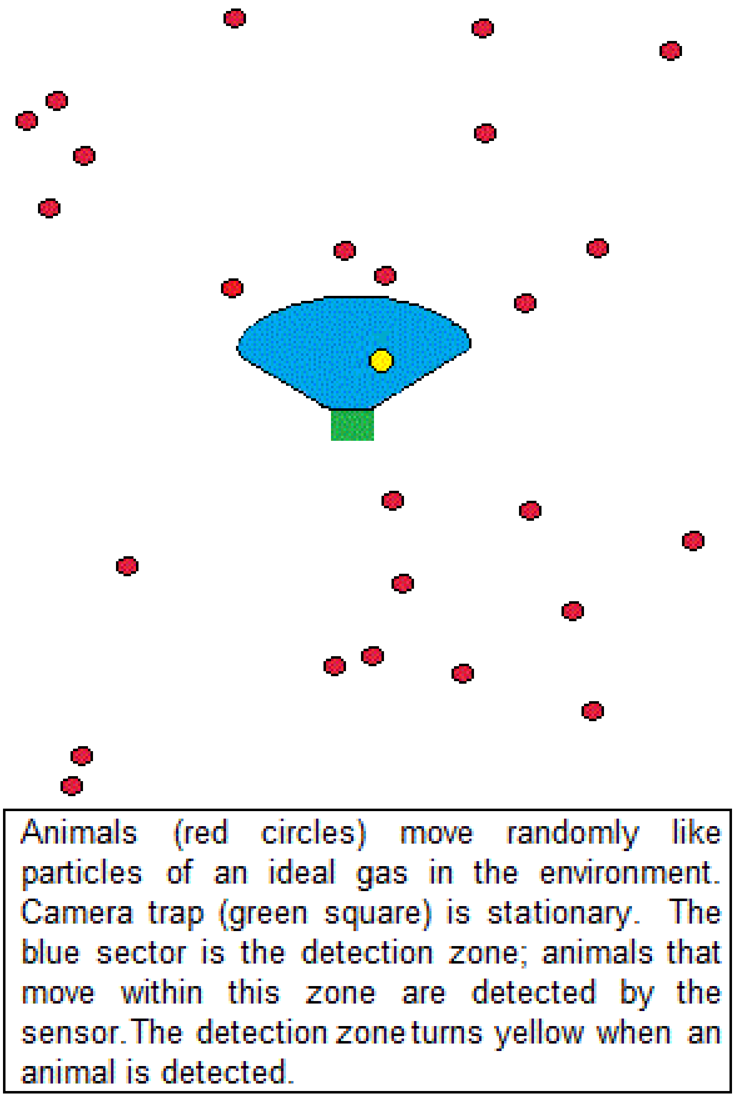

Figure 18. An illustrative animation of the REM

II.4.3. Assessing the habitat use and predicted range by Maximum entropy modelling (Maxent)

As camera traps were distributed in terms of space, I looked at the spatial distribution of the photographic records of deer (UTM coordinates of each location camera traps had recorded). First, I identified the different types of habitats that predominate in the study areas. Then, I compared the number of photographs among habitat types for each season (wet versus dry) in each study site to describe habitat use by deer.

I used information about the locations, such as habitat type, distance to river, distance to human settlement – anything that might be important to the species – to investigate whether any of these characteristics had an influence (either positive or negative) on both target species. Records of deer were the dependent variables of the models for each study area. Locations were fixed by latitude and longitude and converted into digital data and then into a GIS, using the ArcMap 10.2.2 program (ESRI, Redlands, California, USA).

II.4.3.1. Predictor variables

A geo-database for handling the explanatory variables was created in the same GIS environment. Environmental variables were subdivided into four classes: 1) physical variables such as elevation, slope and rivers (Debeljak et al., 2001; Patthey, 2003), 2) resources such as forest cover and productivity (Schutz et al., 2003), 3) anthropogenic effects such as impact of settlement, cultivated areas and roads (Patthey, 2003) and 4) climatic variables such as precipitation and temperature (Solberg et al., 2001; Hovens and Tungalaktuja, 2005). All variables were projected to the WGS 1984, UTM zone 49 S (Bawean Island) and WGS 1984 zone 48 S (Ujung Kulon National Park) geographic coordinate system. Variables were all clipped to the same extent of the study area and resampled to the same resolution (90 m) based on the ASTER Global Digital Elevation Model (DEM) used in the study. Finally, all predictors were converted to raster ASCII format in order to be imported into Maxent.

II.4.3.2. Maximum entropy modelling and model evaluation

The landscape of the study area and the behaviour of the deer makes formal, systematic biological surveys where presence and absence are recorded difficult to apply. Thus, only presence data were available.

The models were evaluated by various means in different steps. One of the criteria was the comparison of habitat suitability maps with different models, which was performed both visually between the individual outputs and by generating maps of prediction difference with map algebra in ArcGIS. These approaches highlighted the areas where one map predicted higher habitat suitability than another and expressed, with different values, each area's suitability. In addition, other criteria were drawn from various statistical analyses and measures, carried through in-built functions of the Maxent program. These included the AUC from the generated ROC curve, both for test and training data, accompanied by the omission rate and predicted area, tested better than a random model created from a one-tailed binomial test of omission (Phillips, 2006; Phillips and Dudík, 2008; Kuemmerle et al., 2011).

Area under the receiver operating characteristic (ROC) curve or AUC. The AUC values allow easy comparison of the performance models, proving useful in evaluating multiple MaxEnt models. An AUC value of 0.5 indicates that the performance of the model is no better than random, while values closer to 1.0 indicate better model performance (Philips et al., 2004). An ROC curve shows the performance of a classifier whose output depends on a threshold parameter. However, to use ROC curves with presence-only data, we must interpret as "negative examples" all grid cells with no occurrence localities, even if they support good environmental conditions for the species (Philips et al., 2004). The model gain (a model-fitting measure similar to deviance) was the measured factor of many of the analyses carried out by Maxent. I also used it as a comparison criterion by itself. Model entropy at different binarization thresholds was included as reference. The importance of each variable for the model was assessed by marginal and single-variable model response curves, as well as by contribution to the model gain per predictor. They were further supported by jackknife resampling procedures for AUC, test and training gain, which showed the performance of the models excluding and including each variable. The scheme of the methodological sequence can be seen in **Figure 19**.

II.4.4. Activity pattern

Camera trapping allows the time of day to be recorded and at least the sex of the individual deer to be identified for each photo. I used the camera location from each study site as a sample unit. Activity was defined as the proportion of photographs per hour, using only the first deer photograph taken each hour; subsequent deer photographs during the same hour were disregarded to avoid pseudoreplication. I tested the null hypothesis that activity was uniform throughout the day for both deer, applying the Rayleigh test (Batschelet, 1981; Zar, 2010). To complete this analysis, I grouped Bawean deer and red muntjac events into three periods: diurnal (one hour after sunrise to one hour before sunset), nocturnal (one hour after sunset to one hour before sunrise) and crepuscular (dawn – from one hour before to one hour after sunrise – and dusk – from one hour before to one hour after sunset) (Theuerkauf et al., 2003a). Two-factor analysis of variance was used to test differences in levels of activity between times of day and seasons. The seasonal analysis data were pooled into three-hour periods, to obtain a larger and more uniform number of activity fixes in each period. We used

Tukey's honest significant difference test to evaluate variation differences in the frequency of events for each period. Results were considered significant if alpha < 0.05.

The moon phase was enumerated for each calendar day of the sampling period using the software Quickphase Pro 3.3.4 (BlueMarmot.com). The effect of moonlight on activity was recorded by assigning one of the four moon phases to each day. Following Batschelet (1981), we used circular statistical analyses for temporal data that followed a cycle. The Rayleigh tests were used to test whether Bawean deer and red muntjac captures were randomly or uniformly distributed along the lunar cycle. We used Kuiper's test to discover whether the daily frequency distributions of captures of two different samples (new moon versus full moon) have the same distribution (Batschelet, 1981).

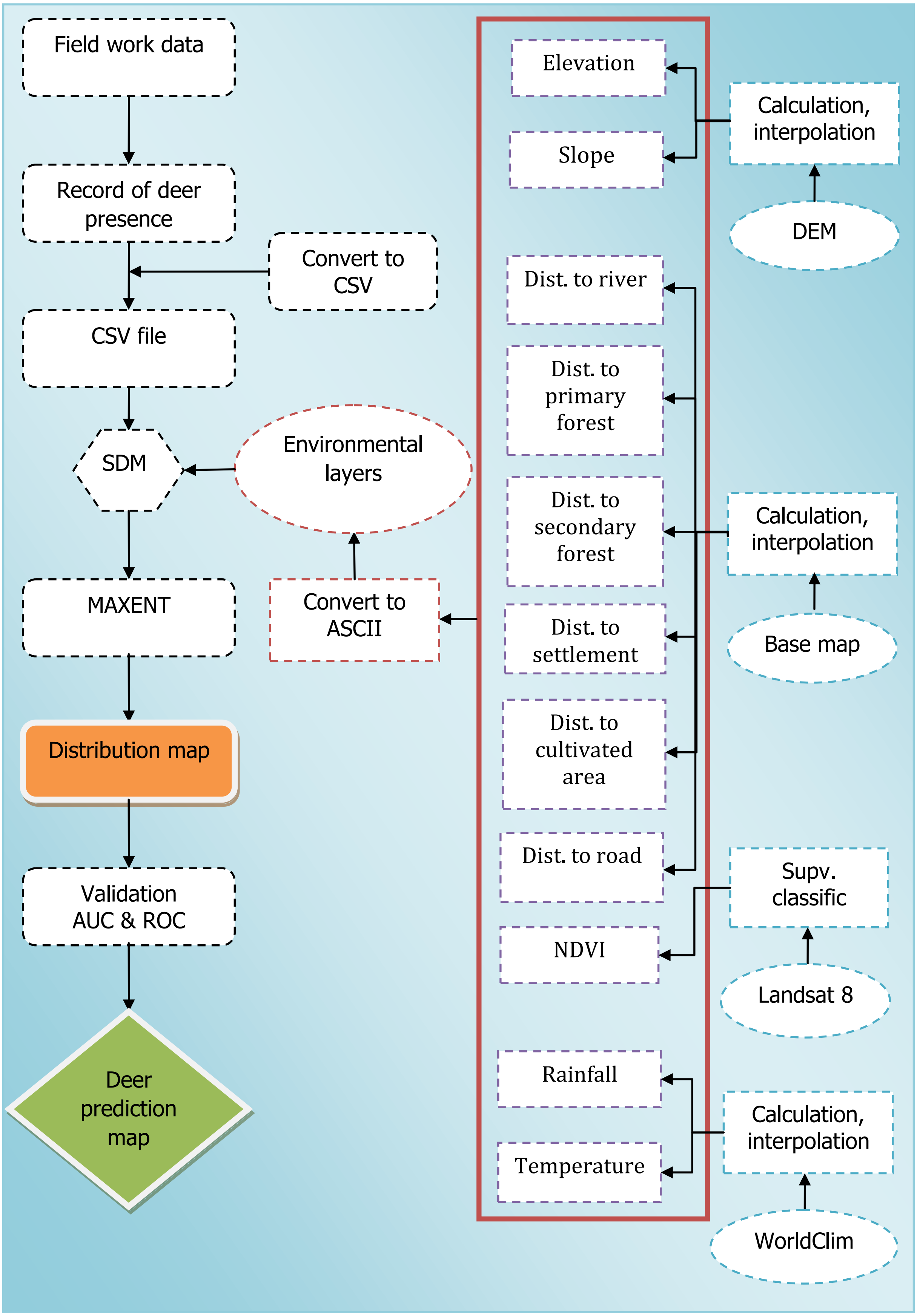

Figure 19. Flowchart for the sequences of Maxent to predict range of deer

CHAPTER 3

An evaluation of methods used to survey Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary

PAPER 1

Benefit of camera trapping for surveying the critically endangered Bawean deer (*Axis kuhlii* Temminck, 1826)*

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*** Rahman, D.A., Gonzalez, G., Aulagnier, S. 2016. Benefit of camera trapping for surveying the critically endangered Bawean deer (*Axis kuhlii* Temminck, 1826). Tropical Zoology, DOI. 10.1080/03946975.2016.1199763.**

Abstract

Despite being one of the rarest deer in the world, the critically endangered Bawean deer *Axis kuhlii* has received little conservation attention. Fauna monitoring is usually limited by lack of resource; therefore, the choice of a relevant methodology is fundamental to maximize the cost-benefit ratio. We compared the performance and cost of three direct and indirect methods to survey Bawean deer in protected areas of Bawean island. Camera trapping provided a high number of records of Bawean deer (118 for 5500 camera days) and ascertained identifications of several other species. The number of photographs increased with the dry season. Transect sampling was time consuming in the field for a poor result (2 records for 19.200 h). Faecal pellet group count was more successful (80 pellet groups for 9.600 h of fieldwork). Camera traps are expensive to buy but they lighten the field work and provide much data for further analyses.

Keywords: Cervidae; camera trapping; transect sampling; faecal pellet group count, cost

Introduction

Bawean deer, *Axis kuhlii* Müller, 1840 is categorized as Critically Endangered (CR) on the IUCN red list (Semiadi et al. 2013), and listed in Appendix I of CITES (2009); besides this taxon is one of the 25 priority species legally protected by Indonesian government. This species is endemic of the 200 km^2 Bawean Island where it ranges over a very small area restricted to the Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), and a peninsula on the north-west side of the island (Tanjung Cina) (Lachenmeir and Melisch 1996; Grubb 2005). Vulnerable to human activities it persists only at low density; this makes the Bawean deer to be one of the rarest and the most isolated deer in the World (Semiadi et al. 2013). However, this deer received little conservation attention, mainly because it is uncommon, rarely seen, and locally compete for conservation interest with more charismatic species such as Sumatran tiger *Panthera tigris sumatrae* Pocock, 1929 or Javan rhinoceros *Rhinoceros sondaicus sondaicus* Desmarest, 1822.

The Bawean Island is under conservation regimes and considered pristine but has not been adequately surveyed. The lack of long-term studies results in incomplete knowledge of the population and even the distribution of Bawean deer. However, some studies of Bawean deer documented population trends using different methods: faecal count (Blouch and Atmosoedirdjo 1978; Blouch 1980; LIPI & IPB 1999; Semiadi 2004; Semiadi and Pudyatmoko pers. com.; BBKSDA East Java 2009), footprints (UGM and BBKSDA East Java 2003), call counts (BBKSDA East Java 2009), and camera trap survey (UGM and BBKSDA East Java 2004). The later, conducted within three weeks, did not show any evidence of Bawean deer.

Some other studies focused on habitat and ecology of Bawean deer (Blouch and Atmosoedirdjo 1978, 1987; Semiadi and Pudyatmoko pers. com.), using mainly indirect surveys. Direct observation of the species in its natural habitat was reported difficult, probably due to its ecology. Blouch and Atmosoedirdjo (1978, 1987) found that Bawean deer are primarily nocturnal, active intermittently through the night, very shy, and typically solitary, although pairs can be sometimes recorded. Moreover, they avoid contact with humans, spending the day in forests on steep slopes which are inaccessible to loggers.

The selection of a method for monitoring mammals can influence the accuracy and comprehensiveness of research outcomes (Garden et al. 2007). Exploring the balance between positive and negative characteristics of all suitable methods in relation to specific survey constraints is crucial in order to ascertain the use of the most beneficial technique. In tropical rainforests, surveying populations of terrestrial medium- and large-sized mammals using classical sampling methods is particularly challenging (Thompson 2004; De Souza-Martins et al. 2007). Among observational techniques, transect sampling is efficient and relatively inexpensive for surveying many natural populations (Anderson et al. 1979; Burnham et al. 1980; Buckland et al. 1993; Rudran et al. 1996). In practice, this method requires some assumptions that are binding for estimating populations, the animals must be detected with certainty at their initial locations, and distance from the observer must be measured accurately (for details see Buckland et al. 1993). These assumptions are difficult to meet for species with low detection rate, either they are rare and/or elusive when they are nocturnal and live in tropical rainforest with dense vegetation (Griffiths and Van Schaik 1993; Duckworth et al. 2006). Indeed, Gopalaswamy et al. (2012) showed that visual detection was very low for ungulate species living in tropical forests where it is also difficult to capture animals. So, surveys of mammals such as deer most often implemented indirect methods (Mandujano and Gallina 1995; Villarreal-Espino 2006; López-Téllez et al. 2007; Koster and Hart 2008; Corona et al. 2010; Camargo-Sanabria and Mandujano, 2011; Ramos-Robles et al. 2013; Mandujano et al. 2013). Identification of footprints is the oldest indirect method (Bider 1968), but it requires a strong field knowledge. Identification and count of faeces initiated by Bennett et al. (1940) is easy to use and avoids the subjectivity of the observer, in the absence of similar species (see Acevedo et al. 2010; Alves et al. 2013). However this method becomes inaccurate when animal behaviour and variations of environmental factors influence deposit and decay of faeces.

Techniques using remote triggered photographic camera units have become popular in the last decade (Burton et al. 2015). The method is efficient for inventories, especially for cryptic and elusive animals in tropical rainforest (Tobler et al. 2008; Rovero et al. 2014), as well as for population studies of species when individuals can be individually recognized by marks, e.g. white-tailed deer *Odocoileus virginianus* (Soria-Díaz and Monroy-Vilchis 2015), Indian mouse deer *Moschiola indica* (Kumbhar et al. 2013), or not, e.g. Reeves' muntjac *Muntiacus reevesi* Ogilby, 1839 and Chinese water deer *Hydropotes inermis* Swinhoe, 1870 (Rowcliffe et al. 2008).

Despite the variety of field techniques that can be used for surveying terrestrial mammals such as Bawean deer, the efficiency of the method could also be related to the available budget and human involvement. In addition to establishing clear objectives, wildlife research must deal with reality of budget and time frame, the trade-off among these constraints must be considered and even tested, including extending the time and resources needed to complete the assigned task (Witmer 2005).

Thus, to support monitoring and conservation tools for Bawean deer we evaluated the efficiency of three survey methods, camera trapping, transect sampling and faecal pellet group count, both in terms of seasonal detection (1) and of financial and human costs (2). We hypothesize that camera trapping provides valuable results and present the best trade-off between cost, effort and results.

Material and methods

Study area

The Bawean Island (Indonesia) is a quite isolated island in Java sea (5^{o} 40’ - 5^{o} 50’S; 112^{o} 3’ - 112^{o} 36’E, Figure 1). Based on the classification of Schmidt & Ferguson (1951), climate is categorized in type C (Semiadi 2004). Rainfall is mostly abundant during the northwest monsoon lasting from the end of October until April, and reaches ca. 2.500 mm on the southern coast. Temperature conditions are almost uniform throughout the year, the average of maximum temperature is 32^{o}C and minimum temperature is 22^{o}C (Semiadi 2004).

The centre of the island is mountainous with peaks at 400 to 630 m in altitude, and is mainly covered by evergreen tropical forests (4700 ha, ca 23% of the island), including teak (Tectona grandis) plantations. The remaining natural forests are confined to the steep sides and top of the higher hills and mountains. Coastal low hills are separated by broad valleys, they are primarily cultivated lands. A mosaic of grassland, shrub, open and closed forest with understorey are found in the study area.

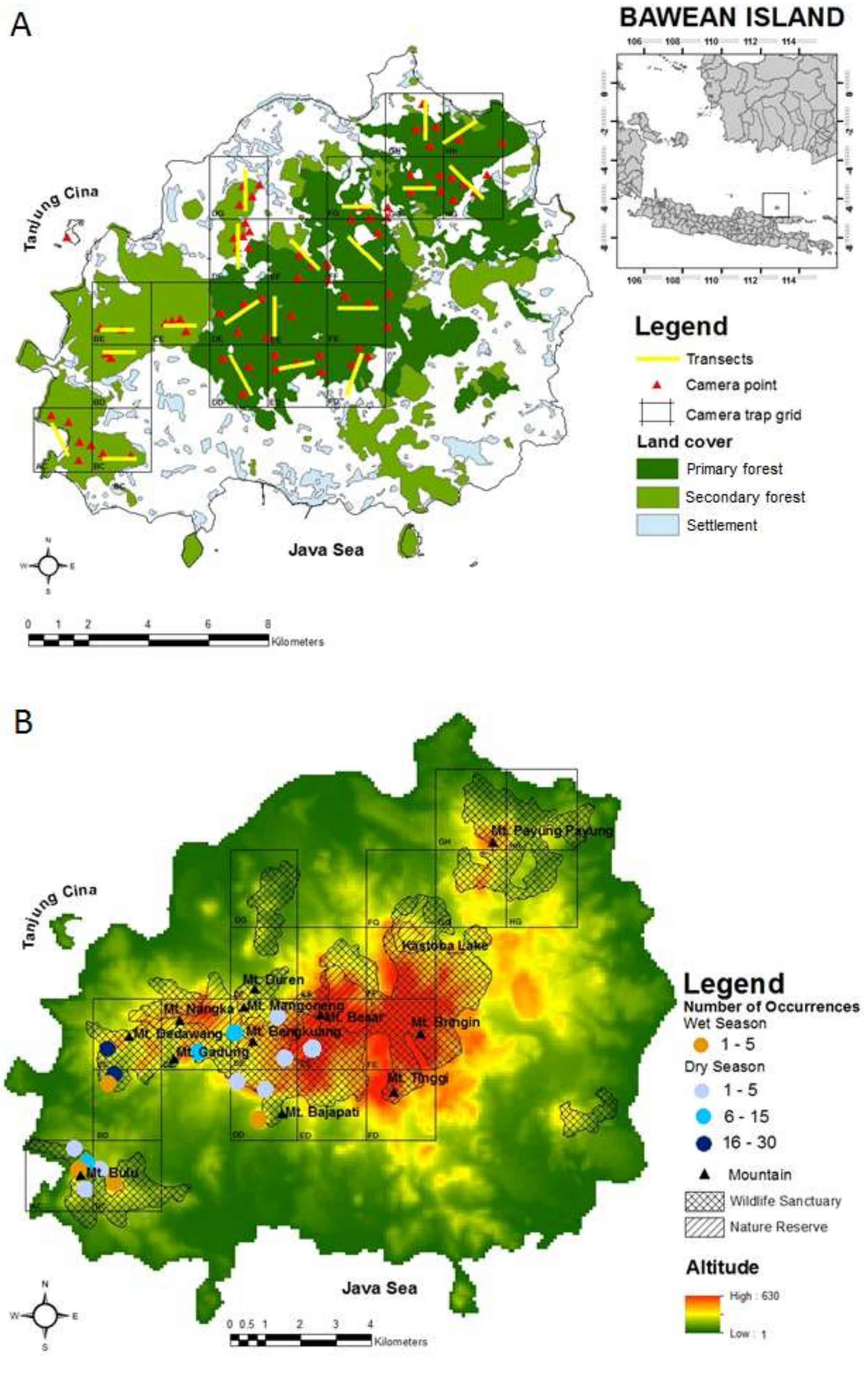

Figure 1. Camera trapping and transect sampling in the Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), Indonesia, (a) sampling sites within a 4-km2 grid (n = 75) and map of forests, (b) Bawean deer presence (118 photographs for 14 camera sites) and map of altitude (up to 630 m).

Sampling design

Study sites were selected on the basis of previous results regarding the presence/absence of Bawean deer in Bawean Island (Blouch and Atmosoedirdjo 1978; Semiadi 2004; BBKSDA East Java 2009) and by conducting interviews with local people. Over 100 interviewed people, only 13% reported records of Bawean deer for 2012–2014, and 87% told that they have not seen any deer or sign for many years or that Bawean deer do not exist in the area. Most records since 2012 originated from the northwest and southwest parts of the island, in the Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), and in Tanjung Cina, a peninsula (ca. 950 m x 300 m) where there is no resident human population on the northwest side of the island cut off from the main island by high tide. Therefore, surveys focused on the wildlife sanctuary (ca. 3832 ha) and nature reserve (ca. 725 ha), and additionally on Tanjung Cina.

The BINR-WS area was divided into 20 4-km^2 grids using a Geographic Information System (ArcGIS 10.2.2). From March to November 2014 twenty units of Bushnell Trophy Cam HD Max digital cameras working on passive infrared motion/heat sensors were installed, one per grid. These were set at one minute video mode with one minute interval and one minute video per trigger. Before installation we collected evidence of the presence of Bawean deer throughout the grid, either footprints, faeces, food remains or antler rubbing on trees. Because our goal was to monitor Bawean deer in the whole area of BINR-WS and to obtain as many photographs as possible in each grid, camera traps were deployed in the most promising locations of each grid and when a camera did not capture any animal (zero presence) after two or three checking visits, we changed its location in the same grid. Consequently, 75 locations of camera trapping were sampled during the study. To record both small and large animals, cameras were set up at 30-50 cm above the ground. Species recorded by camera trapping and transect sampling were identified using Suyanto et al. (2002) for mammals, MacKinnon et al. (1993) for birds, Iskandar (2002) for squamates and amphibians. Cameras were checked once every 21-28 days, including replacing battery and memory card, and even the camera trap in case of malfunction. To compare the efficiency with other methods we used only data collected during the same two months in both seasons: wet 1 = February-March; wet 2 = April-May; dry 1 = June-July; dry 2 = August-September. We counted the number of exposed photographs for Bawean deer and other species. Photographs with more than one individual in the frame were counted as one for each species.

Within each grid, we also defined one transect line 1-1.5 km long (Figure 1). Each transect has been walked four or six times in April-May and June-July 2014, according to five 3-hour periods: period I (morning) from 06:00 to 09:00; period II (midday) from 11:00 to 14:00; period III (evening) from 16:00 to 19:00; period IV (night) from 21:00 to 24:00 (using night-vision thermal imaging binoculars); and period V (early morning) from 02:00 to 05:00. This sampling design achieved a total of 20 transects. All wild animal sightings, tracks and signs were recorded simultaneously.

Within each grid, next to each camera trap location, we also sampled four permanent square plots (7 m x 7 m), evenly spaced 10 m, for performing faecal pellet group count according to previous studies (e.g. Acevedo et al. 2010; Alves et al. 2013). A total of 300 square plots (4 plots per location*75 camera-traps point location) were surveyed in February-March 2014 (wet season) and August-September 2014 (dry season). We used the faecal accumulation rate by recording the monthly deposit of pellets after the initial removal of all pellets present in the plot. This method is appropriate for rapid surveys and when it is quite difficult to find a new group of faecal pellets in the field (St-Laurent and Ferron 2008; Acevedo et al. 2010; Camargo-Sanabria and Mandujano 2011).

Surveys were carried out by two people to reduce observer bias, the surveyor himself and a ranger who has been working on wildlife in protected areas of Bawean Island for more than 10 years.

Data analyses

From camera trapping data, we computed seasonal relative abundance indices (RAIc) for Bawean deer according to Carbone et al. (2001):

$$\mathrm{RAIc} = \frac{\text{sum of all independent photographs} * 100}{\text{total number of camera days}}$$

To reduce the bias caused by multiple detections of the same species, data were considered independent if photographs were taken more than 0.5 hour apart (O'Brien et al. 2003). We also computed relative abundance indices (RAIt) per season for transect sampling data as:

$$\mathrm{RAIt} = \frac{\text{total number of sighted individuals} * 100}{\text{number of transects} * \text{repetitions}}$$

Faecal pellet indices were expressed following Forsyth (2005). We compared the seasonal results and methods within seasons using chi-square tests in SPSS version 20 (IBM, Armonk, NY, USA).

In addition, we evaluated the cost of each method for a 30-day survey (as this is the maximum time interval to replace memory card and batteries of camera traps) and for a 4-month survey (the duration of the study for transect sampling and faecal pellet group count). For camera trapping we considered 7 days per month of researcher's work, 3 days to set up camera traps, 4 days to interpret photographs and compile data, and 3 days of field assistant to help setting up and checking or removing cameras. Transect sampling and faecal pellet group count required 48 days and 52 days of researcher's work respectively, as the researcher was needed every day in the field to correctly identify the wild animals and faeces of Bawean deer, and 8 days of field assistant for both methods, to prepare transects and square plots. The cost of each method included additional fixed and variable expenses. Fixed expenses were those which did not change throughout the project, i.e. computer, global positioning system set, compass, etc. As they were identical for the three methods, they were discarded of the calculations. Variable expenses included: camera traps, batteries and memory cards for camera trapping; range finder and binocular (diurnal and night vision) for transect sampling; peg and meter roll for faecal pellet group count. Vehicle cost (rent and fuel), as well as daily allowance for researcher and field assistant were calculated on the basis of field days for each method. All costs were converted from the local currency (real) to American dollar (average exchange rate of April-July 2014: Rp 10.000 ≈ US$ 0.8).

Results

Overall, we accumulated a total of 132.000 h of camera trapping (5500 trap days), 19.200 h of transect sampling and 9.600 h of faecal pellet group count. During the whole study, we recorded 27 genera and 28 species of wild animals and humans. The identification at species level within the genus *Sus* was only possible through camera trapping.

Through camera trapping a total of 5406 photographs were exposed (270.3 per camera trap), showing 2961 wild and 25 domestic mammals (54.77% and 0.46%, respectively), 130 humans (2.40%), 1 bird (0.02%), 9 squamates (0.17%), and 1 insect (0.02%) (Table 1). A large number of photographs (42.29%) did not show any animal. Fourteen species were detected, the most frequent species was the long-tailed macaque *Macaca fascicularis* (n = 2013 photographs) and was the only species photographed at all sites. This primate was followed by wild boar *Sus scrofa* (n = 708), humans (n = 130), Bawean deer (n = 118) and Javan warty pig *Sus verrucosus* (n = 85). The other species, including feral domestic dog *Canis lupus familiaris,* were photographed less than 30 times (Figure 2), and nine species were photographed less than 15 times. The number of photographs showing animals was lower in the wet season than in the dry season (n = 913 vs 2199; $\chi^2 = 287.168$; df = 1; $p < 0.001$). For Bawean deer, the number of photographs was also lower in the wet season (n = 6 vs 112; $\chi^2 = 42.373$; df = 1; $p < 0.001$). RAIc were 0.41 and 3.93 for the wet and dry seasons respectively. After the initial period of installation the number of photographs increased from the end of the wet season (April), peaked in the middle of the dry season (August), and declined later to reach low values at the beginning of the next wet season (November) (Figure 3).

Through transect sampling a total of 21 species and 721 individuals were detected: mammals (n = 261; 36.20%) and humans (n = 44; 6.10%), birds (n = 326; 45.21%), squamates (n = 12; 1.66%) and insects (n = 78; 10.81%). Animals were less detected in the wet season than in the dry season (n = 110 vs 287; $\chi^2 = 45.038$; df = 1; $p < 0.001$). Bawean deer were sighted only twice along the 108 km walked during the dry season (Table 2). On five occasions during transect sampling we recorded vocalizations of deer, however individuals were difficult to find because of dense vegetation.

Through faecal pellet group count we could identify faeces belonging to long-tailed macaque, wild pigs (wild boar and Javan warty pig), and Bawean deer (Table 2). The number of deer pellet groups was not significantly higher during the dry season ($\chi^2 = 1.563$; df = 1; $p > 0.05$). Three locations of Bawean deer around Mt. Duren and Mt. Bajapati were only recorded by this method.

The detection of Bawean deer was significantly higher using camera trapping than faecal pellet group count during the wet season ($\chi^2 = 40.500$; df = 1; $p < 0.001$) but not during the dry season ($\chi^2 = 0.417$; df = 1; $p > 0.05$). Records of deer were too scarce with transect sampling for computing statistical analysis.

The daily costs of variable expenses estimated for a 30-day survey and the 4-month survey were respectively, US$ 145 and US$ 52 for camera trapping, US$ 233 and US$ 165 for transect sampling and US$ 150 and US$ 143 for faecal pellet group count (Table 3). For a quite similar result the later method is much more time consuming both for researcher and field assistant than camera trapping (52+32 days *vs* 16+12 days for the 4-month survey).

Figure 2. Main mammal species photographed by camera traps in Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), Indonesia. Images are sorted from left to right based on the number of photographs from the largest to the smallest (1) long-tailed macaque *Macaca fascicularis*, (2) wild boar *Sus scrofa*, (3) human *Homo sapiens*, (4) Bawean deer *Axis kuhlii*, (5) Javan warty pig *Sus verrucosus*, (6) feral dog *Canis lupus familiaris.*

Table 1. Species recorded by camera trapping in wet and dry seasons within each 4-km^2 grid of the Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia. References of grids are given in figure 1.

Species	Grid	∑ photographs	
		Wet	Dry
Mammalia			
Primates			
Cercopithecidae			
Long-tailed macaque	AC BC BD BE DD DF DG ED EE EF FD FE FF FG GG GH HG HH	491	1522
Hominidae			
Human	AC BC BD DD DF DG ED EE EF FD FE FF FG GG GH HG HH	62	68
Artiodactyla			
Suidae			
Wild boar	BD BE DD DF DG ED EE EF FD FE FF FG GG GH HG HH	195	513
Javan warty pig	AC BC BD BE DD DE DG ED EF FE FD FG GG HH	38	47
Cervidae			
Bawean deer	AC BC BD BE CE DD DE EE	6	112
Carnivora			
Canidae			
Feral dog	BE DD DF DG ED EF FE FF FG GG GH HG	15	9
Viverridae			
Common palm civet	HG FD FG GG	0	7
Felidae			
Domestic cat	HH	0	1
Rodentia			
Muridae			
Tanezumi rat	BC BD BE EF FF HG GH	7	5
Hystricidae			
Malayan porcupine	DF	1	0
Chiroptera			
Pteropodidae			
Lesser short-nosed fruit bat	BC	0	2
Aves			
Accipitriformes			
Accipitridae			
Crested serpent eagle	FF	0	1
Reptilia			
Squamata			
Varanidae			
Monitor lizard	AC DD DF FF FE	2	6
Scincidae			
East Indian brown mabuya	ED	0	1
Insecta			
Lepidoptera			

Papilionidae			
Great mormon	ED	0	1

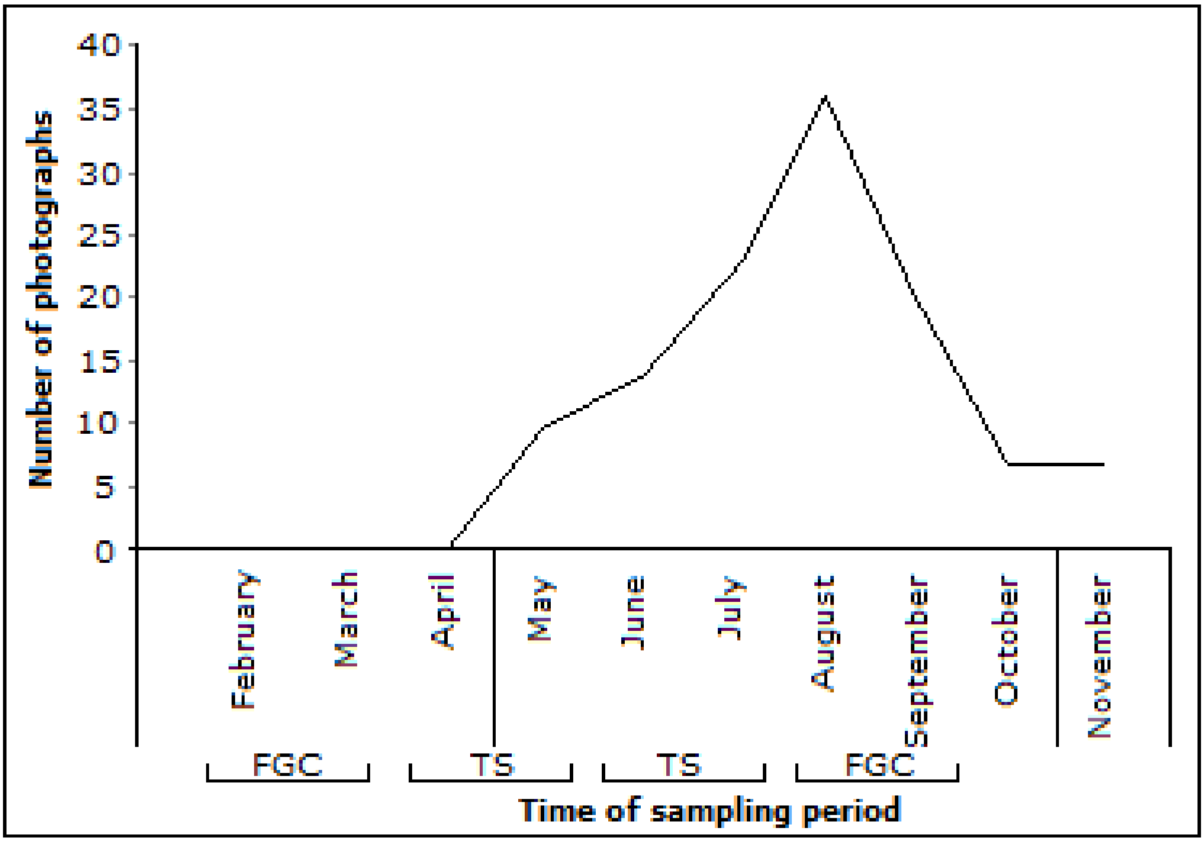

Figure 3. Monthly number of photographs taken by camera traps set for surveying Bawean deer in the Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS), Indonesia, and sampling periods for faecal pellet group count (FGC) and transect sampling (TS).

Table 2. Relative abundance of Bawean deer in wet and dry seasons by three survey methods at Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia. RAIc and RAIt: Relative abundance index for camera trapping and transect sampling respectively. FPI: Faecal pellet index.

Period of survey	Camera trapping		Transect sampling		Faecal pellet group count	
	Number of photographs	RAIc	Number of sightings	RAIt	Number of pellet groups	FPI
Wet 1 (February-March)	0	0	-	-	31	0.14
Wet 2 (April-May)	10	0.82	0	0	-	-
Dry 1 (June-July)	37	3.03	2	1.67	-	-
Dry 2 (August-September)	59	4.84	-	-	49	0.23

Table 3. Estimated costs (in US$) of variable expenses for three methods used for surveying Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia, considering a 30-day survey and a 4-month survey.

Method	Item	Variable expenses Unit value	30-day survey quantity	Total	4-month survey quantity	Total
Camera trapping	Camera traps	184	20	3680	20	3680
	Memory cards	4.8	20	9.6	20	9.6
	Batteries	0.35	160	56	640	224
	Vehicle rent and fuel	4.5	2 x 6	54	2 x 24	216
	Researcher's per diem	100	7 days	700	16 days	2800
	Field assistant's per diem	50	3 days	150	12 days	600
Total				*4649.6*		*7529.6*
Per-day cost				*155*		*61.7*
Transect sampling	Range finder	259	1	259	1	259
	Binocular monarch	330	1	330	1	330
	Night vision binocular scout	499	1	499	1	499
	Vehicle rent and fuel	4.5	2 x 12	108	2 x 48	432
	Researcher's per diem	100	12 days	1200	48 days	4800
	Field assistant's per diem	50	8 days	400	32 days	1600
Total				*2796*		*7920*
Per-day cost				*233*		*165*
Faecal pellet group count	Peg	0.4	300	120	300	120
	Meter roll	0.8	3	2.4	3	2.4
	Vehicle rent and fuel	4.5	2 x 13	117	2 x 52	468
	Researcher's per diem	100	13 days	1300	52 days	5200
	Field assistant's per diem	50	8 days	400	32 days	1600
Total				*1939.4*		*7390.4*
Per-day cost				*149.2*		*142.1*

Discussion

Comparative efficiency of camera trapping

Although camera traps were used for the second time in Bawean Island, we recorded the first automatic photographs of Bawean deer. In 2004, the study using camera traps by the Faculty of Forestry, University of Gadjah Mada, failed in obtaining any photographic evidence of the species (UGM and BBKSDA East Java 2004). This absence of detection of Bawean deer might result from: the smaller number of cameras, a worse camera location and a shorter duration of study. Indeed we used a double number of cameras and chose carefully their location, moving them within the same grid when they did not detect any animal after 41-61 days. Si et al. (2014) showed that moving cameras frequently gives more efficient detection and that camera traps should not be left at one site for more than ca. 40 days.

Moreover, we guess that in the previous study, which did target Bawean deer, some locations of camera traps were less relevant, as most of them were placed on river banks (e.g. Lampeci river and Tambelang river), even if the survey was conducted in the dry season. In our study camera traps which were installed on river banks did not photograph any Bawean deer contrary to camera traps placed deeper into forests. More, based on our results, it seems that Mt. Tinggi and Tanjung Putri do not host resident Bawean deer any longer. In addition, the sampling effort during the previous survey was only 200 camera days, whilst we accumulated 5.500 camera days. Computing a rarefaction analysis, Si et al. (2014) showed that a minimum of 931 camera days are needed to detect one resident species in a plot, and ca. 8700 camera days to detect all 10 resident species, including black muntjac *Muntiacus crinifrons* and Reeves' muntjac *M. reevesi,* at Gutianshan National Nature Reserve (China).

Camera trapping provided the most numerous and accurate records for mammals which could be identified at the species level, including cryptic and rare species, such as Bawean deer. Two studies comparing camera trapping to alternative monitoring methods, reported the efficiency of this method to accurately identify species and detecting rare and nocturnal deer in tropical forest, pampas deer *Ozotoceros bezoarticus* (Silveira et al. 2003) and brocket deer *Mazama* sp. (Lyra-Jorge et al. 2008). The ability to collect data on rare or secretive species that are generally difficult to observe directly can lead to great improvements in understanding community composition (Azlan and Lading 2006). Time recording permits to assess the presence of different individuals of the same species along the day (Lyra-Jorge et al. 2008) and their reproductive status, mainly when a doe is mare with her fawn (Srbek-Araújo and Chiarello 2005). This information is particularly relevant for studies of population dynamics, e.g. for estimating the size and trend of a population. Transect sampling or faecal pellet group count do not allow such a differentiation particularly in dense vegetation (Staines and Ratcliffe 1987). However, for most tropical mammals, including Bawean deer, absence of physical characteristics makes it not possible to identify individuals with confidence. Relying on scars or blemishes on the body should be risky because these signs disappear after some time (Kelly et al. 2008). At last, a major advantage of camera trapping is the long duration of field work in absence of researcher as cameras can be left for several days and weeks; more, any trained person is able to renew memory card and battery, and ensure that the camera trap is still operational.

On the contrary, transect sampling, which requires a heavy field work, relies on the surveyor competence for identifying species from signs and for surely estimating animal–

observer distances through dense vegetation (Walsh and White 1999). Then, there could be an observer bias if data are collected by inexperienced or inadequately trained people (Azlan and Sharma 2006; Rovero et al. 2006). Following a precise path can make surveying problematic in difficult terrain, such as in many areas of BINR-WS, and clearing a pathway through dense vegetation could be a hard work and come out detrimental for data collection (Walsh and White 1999). Transect sampling efficiency also depends on weather conditions since a strong rain or wind and hot temperature condition can disturb observation or cause animals to be inactive (Stelzner 1988). Bias is not just dependent on training of researchers and favourable field conditions, but also on the diurnal activity pattern and body size of species (Roberts 2011). At last, transects can be problematic for monitoring rare species, as poor encounter rates can lead to sample sizes not large enough for data analysis (Bennun and Howell 2002). This was the case in our study as we only detected Bawean deer twice in the dry season.

Faecal pellet group count could detect the presence of only some species in Bawean Island. This result can be explained by the species rarity, their small size or the defecating behaviour of animals, inside water, buried faeces in small holes or on branches of trees (Chame 2003; Mohapatra and Panda 2014). Faecal pellet group count is probably the most limiting of the three methods. It is dependent on field conditions at sampling plots, substrate and vegetation type, and on climate that induces a great variability in faecal decay rate (Skarin 2007; Laing et al. 2003). Faecal pellet group count has been much studied in temperate areas where the technique works well in cold climates with snowy winters (Decalesta 2013); frozen pellet-groups deteriorate less quickly than in warm and/or rainy climates (Tsaparis et al. 2009). One problem with faecal pellet group count in tropical forest is the accelerated decay of faeces during the wet season as a result of high rainfall levels and breakdown of pellet groups by insects and bacteria which biases the ‘standing crop procedure’. Very dry conditions during the aptly called dry season may lead to a better preservation of pellet (Jachmann and Bell 1979, 1984). Pellet-group counts during the dry season would give a better estimate of animal number in the area. More, our results showed that this technique can be additional to camera trapping as it recorded Bawean deer in three locations where no photograph was taken.

Limitations of camera trapping

Setting cameras for a long time at the same location can induce trap-shyness behaviour, as animals may be disturbed by the flashing lights (Meek et al. 2014). In our study, detection of Bawean deer increased from the installation of cameras until ca. 6 months when animals are supposed to increasingly avoid the areas covered by cameras. The subsequent decrease at the end of the study period could be related to the new wet season.

Camera traps are equipped with active and passive infrared detection, and detect heat or movement for taking photographs. So their performance reduces during hot days, when the air temperature becomes close to the animal body temperature or can be triggered by shaken or falling leaves and rain (Swann et al. 2011), which is an important issue in the tropics. This is a reason for higher detection at night, when the air temperature is fresher than the animal body (Srbek-Araújo and Chiarello 2005). In addition, Bawean deer was more photographed and recorded by faecal pellet group count during the dry than the wet season. Rowcliffe et al. (2011) found that the effective detection distance of tropical mammals by camera traps decreases from the dry to the end of the wet season, whereas the effect of season on effective detection angle was in the opposite direction.

Two cameras have been stolen, probably by poachers who did not want to get their images recorded. The risk of camera theft is typically higher when cameras are set up near settlements or along logging roads and ridgelines. In most cases an explanatory notice attached to each camera can alleviate theft, together with delivering information in local villages and at police officers. A padlock on the camera can also help, but ultimately if someone wants to remove the camera he will almost find a way to do so. In our case, to reduce the likelihood of theft we set cameras far from settlements or in areas more cluttered by vegetation. In any camera-trapping surveys it is mandatory to account for potential losses by having some additional cameras for securing the sampling design and obtaining good results (Meek et al. 2012).

Budget comparison

The cost of camera trapping is initially high, but this method automatically works during 24 hours per day without interruption and cameras can be set for a long time and/or re-used in other projects. In a medium-term project, the daily cost decreases with time because travel and human expenses are low. On the other hand, transect sampling and faecal pellet group count require daily field visits. For a 30-day survey, the daily cost is similar for camera trapping and the two other methods. For a 122-day survey, the daily cost is much more in favour of camera trapping with only US$ 62 per-day versus US$ 165-143 for transect sampling and faecal pellet group count respectively. Most researchers who evaluate costs and benefits of mammal recording methods agree that more expensive methods, if more accurate, are the best for long term studies and/or when different research groups share field equipment, and that the combination of two or more methods always result in better quality data, especially when surveying rare or secretive species (Barea-Azeón et al. 2007; Scheibe et al. 2008).

We believe, that in BINR-WS, camera trapping can provide reliable and standardised tools for the management of various mammal species, including Bawean deer. In this study, we successfully obtained the first automatic photographs of this rare, shy and elusive species which avoids contact with humans as it is supported by the absence of sighting during thousands of hours of fieldwork in BINR-WS. Moreover, camera trapping data would be used to investigate habitat use, daily activity pattern of deer and possibly population trend with an accuracy that was not possible with previous techniques, particularly in tropical rainforest. Such knowledge is crucial for designing sound management strategies for the conservation of this species.

Disclosure statement

No potential conflict of interest was reported by the authors.

Acknowledgments

We wish to thank Ariffani Setya Rohim, Bayu Yogatama, Cahya Wiratama, Mr. Nursamsi, Mr. Maskur, Mr. Rahim and all the team member that contributed with data collection. We are thankful to BBKSDA of East Java, Ministry of Environment and Forestry, Republic of Indonesia for providing research license in BINR-WS. Postgraduate scholarships and funding was provided by Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, Republic of Indonesia.

Funding

This work was supported by the Rufford Small Grants Foundation under Grant number 13957-1

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PAPER 2

Population size, distribution and status of the remote and Critically Endangered Bawean deer *Axis kuhlii**

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*** Rahman, D.A., Gonzalez, G., Aulagnier, S. 2016. Population size, distribution and status of the remote and Critically Endangered Bawean deer *Axis kuhlii*. Oryx, DOI. 10.1017/S0030605316000429.**

Abstract

Conservation of rare ungulates requires reliable population size estimates and distribution maps for prioritizing investments and assessing the effectiveness of conservation measures. We used both camera trapping and a random encounter model approach, and faecal pellet group counts, to update the range and population size of the Bawean deer *Axis kuhlii* in the Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia. We studied 2-month periods to fulfil the assumption of population closure. Both methods provided similar population density estimates (higher in the dry season) of c. 227–416 individuals. The estimated range of the species is significantly narrower than previously reported. The main threats (habitat loss as a result of illegal logging, and disturbance by dogs and hunters) are ongoing. Based on these results we suggest that the species should retain its Critically Endangered status on the IUCN Red List.

Keywords: *Axis kuhlii*, Bawean deer, camera trapping, Cervidae, conservation, faecal pellet count, random encounter model

Introduction

Reliable information on population size and range, and any trends in these parameters, is required to assess the conservation status of a species using the Red List criteria (IUCN, 2001). In the absence of such information, conservation management is often based on crude estimates, expert opinion or educated guesses, which may result in erroneous decisions that can be counter-productive (Akçakaya, 2002; Blake & Hedges, 2004; Murray et al., 2009). The Bawean deer *Axis kuhlii (Temminck, 1836)*, the most isolated deer in the world and the only endemic deer species in Indonesian tropical rainforest, is categorized as Critically Endangered on the IUCN Red List (Semiadi et al., 2013). The Bawean deer is reported to range over a very small area restricted to the Bawean Island Nature Reserve and Wildlife Sanctuary and a peninsula on the north-west side of the island (Tanjung Cina; Lachenmeier & Melisch, 1996; Grubb, 2005). The protected area is relatively close to human settlements, and illegal logging is not uncommon in the forest habitat. Listed in Appendix I of CITES (2016), this taxon is legally protected and is one of 25 species prioritized for conservation by the Indonesian government on the basis of their threatened status (decree SK.180/IV-KKH/2015; Ministry of Environment and Forestry, 2015). Despite this status, and threats across its range, surprisingly little is known about the Bawean deer and no long-term monitoring has been implemented, partly because this is not a charismatic species.

Several methods have previously been used to study population trends and distribution in this species: faecal sampling (Blouch & Atmosoedirdjo, 1978; Blouch, 1980; LIPI & IPB, 1999; Semiadi, 2004; BBKSDA East Java, 2009), footprint (UGM & BBKSDA East Java, 2003) and call counts (BBKSDA East Java, 2009), and camera trap surveys (UGM & BBKSDA East Java, 2004). The latter study, in which 10 camera traps were installed at seven locations (Lang Pelem river, Lampeci river, Tambelang river, Mt Tinggi, Angsana block, Tanjung Putri block and Tanjung Cina) during 20 days, recorded no evidence of the Bawean deer, although this may be attributable to the short study duration of the study and the placement of cameras in unsuitable locations.

Capture–recapture methods for estimating population size require individuals to be recognizable, either by rings or collars (e.g. Trolle et al., 2008; Oliveira-Santos et al., 2010) or by natural marks such as stripes, spots or scars (e.g. Kumbhar et al., 2013). They are not applicable to the many mammal species that lack distinctive marking, such as the Bawean deer, except when bucks are seasonally antlered.

The development of the random encounter model, a by-product of an ideal gas model (Hutchinson & Waser, 2007), has facilitated estimations of species densities from unmarked individuals with a known speed, and sensor detection parameters (Rowcliffe et al., 2008). The random encounter model has been implemented successfully for ungulate species by deploying cameras in systematic or fully randomized arrays (Rowcliffe et al., 2008; Rovero & Marshall, 2009; Zero et al., 2013; Carbajal-Borges et al., 2014).

In this study we used two methods to estimate the abundance and map the range of the Bawean deer in the Bawean Island Nature Reserve and Wildlife Sanctuary, and assess its IUCN status. Density was estimated using both the random encounter model on with camera trapping data and faecal pellet group counts; the latter technique that was the most commonly used in previous studies.

Study area

Indonesia’s Bawean Island (200 km^2) is relatively isolated in the Java Sea (Fig. 1). Based on the classification of Smith and Ferguson, its climate is categorized as type C (Semiadi, 2004). Rainfall is abundant during the north-west monsoon, from the end of October until April, and reaches c. 2,500 mm on the southern coast. Temperature is almost uniform throughout the year, with mean maximum and minimum temperatures of 32 and 22°C, respectively (Semiadi, 2004). The study area encompasses 46.6 km^2 of the Bawean Island Nature Reserve and Wildlife Sanctuary, which is characterized by steep topography (with slopes >60°) and a wide altitudinal gradient (up to 630 m). The main vegetation type is evergreen tropical forest, which covers 23% of the island. A mosaic of closed and open forest as well as permanently dry and seasonally flooded habitat types occur in the study area, including gallery forest, semi-deciduous forest with understorey, shrub and grassland, and teak *Tectona grandis* plantations (60% of the area), which are all globally threatened by deforestation and climate change. The remaining natural forests are confined to the steep sides and tops of the higher hills and mountains, often occurring as islands surrounded by teak (Semiadi, 2004).

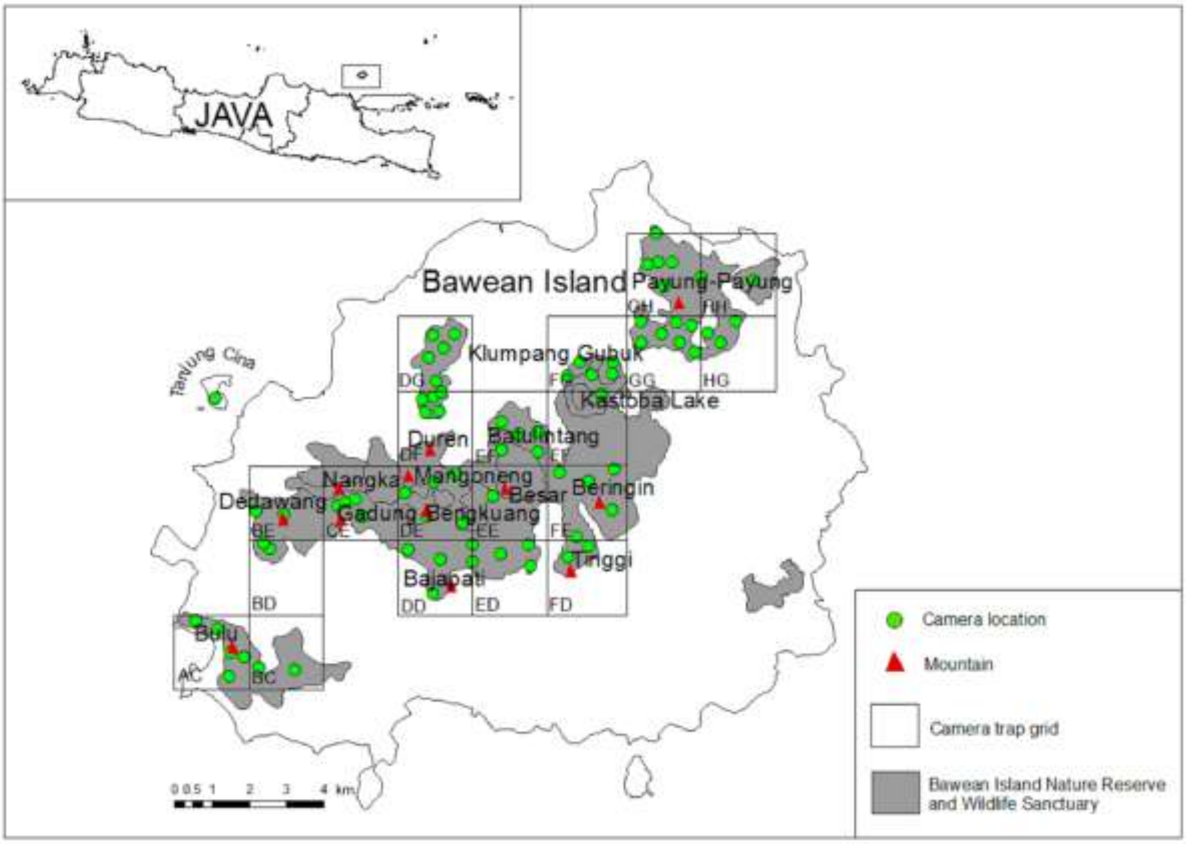

Figure. 1. Camera trap grid and camera locations in the Bawean Island Nature Reserve and Wildlife Sanctuary, Indonesia.

Methods

Camera trapping

The Bawean Island Nature Reserve and Wildlife Sanctuary was divided into 20 4-km^2 grid cells using the geographical information system *ArcGIS 10.2.2* (ESRI, Redlands, USA). The camera trapping survey was conducted during both the wet (March–April and November 2014) and dry seasons (May–October 2014). Twenty Trophy Cam HD Max digital cameras (Bushnell Outdoor Products, Overland Park, USA) operating on passive infrared motion sensors were installed 30–50 cm above the ground, perpendicular to the ground, to record both small and large animals. Herbaceous vegetation in the vicinity of the cameras was cleared to avoid interference (Tobler et al., 2008; Team Network, 2011; Rovero et al., 2013). The cameras were set at 1 minute video mode with 1 minute intervals. The total survey effort was 5,500 trap days. Sampling precision was assessed as the coefficient of variation of trap rates with cumulative trapping effort (cameras × days). The sampling precision for the Bawean deer increased up to an optimum trapping effort of 520–560 camera days (Fig. 2). One camera trap per grid cell was deployed, in open and accessible locations, applying a buffer equivalent to half of the mean maximum distance moved, (1/2MMDM) to reduce the likelihood of capturing the same individual twice (Karanth & Nichols, 1998; Soisalo & Cavalcanti, 2006).

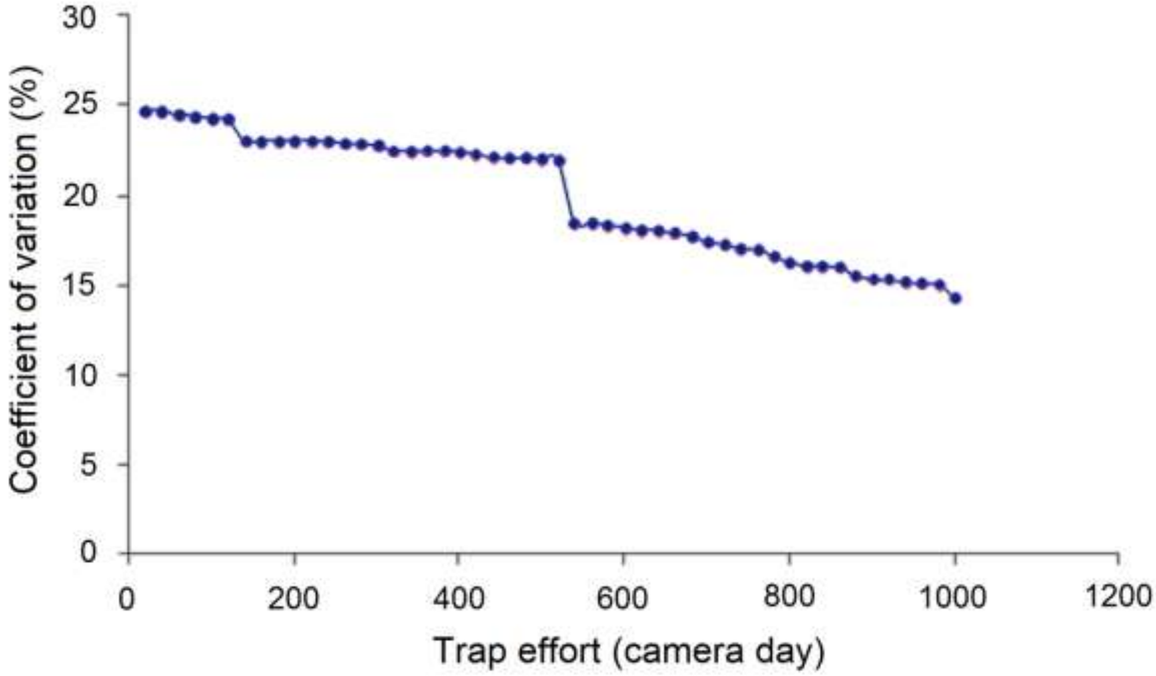

Figure. 2. Camera trap sampling precision expressed as the coefficient of variation of Bawean deer trapping rates with cumulative trap effort (number of cameras × trapping days).

Before installation we collected evidence of the presence of the Bawean deer (footprints, faeces, food remains, antler rubbing on trees) throughout the grid in the Bawean Island Nature Reserve and Wildlife Sanctuary *and also in Tanjung Cina*. We selected camera locations using the two following procedures. Firstly, we superimposed a grid of 100 x 100m cells over the study area using the Fishnet and Clip tools in ArcGIS 10.2.2 (ESRI, Redlands, USA). This generated 3,600 potential camera locations from which we randomly selected one for each 4-km2 grid cell in the field. In general, cameras were not moved during the study; however, if a camera did not capture any mammal in 2–3 periods of checking, we moved it 300–500 m from the original location within the same grid cell. Secondly, we selected locations where we found evidence of the presence of the Bawean deer. In practice, few camera traps were placed preferentially in this way (only 21 locations), as signs of the deer were difficult to find in the field. Moreover these cameras, which were expected to confirm the efficacy of the equipment, did not take significantly more photographs than randomly set cameras. In total, 75 locations were sampled during the survey period. Cameras were checked once every 28–31 days, and batteries and memory cards were replaced as necessary. Malfunctioning cameras were replaced to avoid loss of data.

Faecal pellet group count

Within each grid cell we counted faecal pellet groups in four plots (7×7 m) around the camera trap, spaced 10 m apart, according to Acevedo et al. (2010) and Alves et al. (2013). A total of 300 square plots (4×75 camera trap locations) were surveyed during the wet (February–March 2014) and dry seasons (August–September 2014). After the initial removal of all pellets present in each plot we calculated the faecal accumulation rate by recording the monthly deposition of pellets after the initial removal of all pellets present in the plot (deposition time of faecal groups). This method is appropriate for rapid surveys and when it is quite difficult to find a new group of faecal pellets in the field (Prugh & Krebs, 2004; St-Laurent & Ferron, 2008).

Random encounter model

The random encounter model uses the rate of contact between moving animals and static camera traps to estimate species density. It requires estimation of species-specific camera trap detection (Carbone et al., 2001), along with a camera trap detection specified by radius and angle, and an estimated day range based on speed of movement and activity data (Rowcliffe et al., 2011, 2014). The model is based on three main assumptions: (1) animals conform adequately to the model used to describe the detection process (i.e. they behave like particles of an ideal gas, moving randomly and independently of one another, (2) photographs represent independent contacts between animals and cameras, and (3) the population is closed (Rowcliffe et al., 2008). To fulfil these assumptions, camera traps were set at least 300 m apart to reduce the likelihood of capturing the same individual twice, and increase independence of locations (Kays et al., 2009). We studied 2-month periods in the dry season (June–July and August–September) on the basis that in such short sampling times the probability of birth, death, migration or immigration events is low (Karanth & Nichols, 1998; Silver et al., 2004; Soria-Díaz & Monroy-Vilchis, 2015).

We used the following equation to obtain density estimates from camera trap encounter rates (Rowcliffe et al., 2008):

$$gD = \frac{y}{t}\frac{\pi}{vr(2+\theta)}$$

where y/t = trapping rate (number of independent photographic events per camera trap day), v = a species' mean daily speed of movement (km day^{-1}), r = radius of the camera trap detection zone (km) and θ = angle of the camera trap detection zone (radians). The outcome can then be multiplied by g (mean group size), as the independent unit recorded by the camera is the group rather than the individual (Rowcliffe et al., 2008; Zero et al., 2013).

Independent photographic events were defined as individuals entering and exiting the field of view (Cusack et al., 2015). An individual's mean daily speed of movement was calculated as the speed recorded from camera trap videos multiplied by the proportion of time spent active (Rowcliffe et al., 2014). The radius of the camera trap detection zone was calculated by measuring the distance from the camera to the location of deer at the first trigger, based upon marked locations in the field. The angle of the camera trap detection zone was obtained in the field by detecting a stick in six paired approaches perpendicular to the sensor beam at a distance of 4 m and using a compass placed on a flat surface directly below the camera. The angle of maximal detection was then converted to radians for calculations. We used mean values of r and θ from all cameras in the calculations. The mean group size for this mostly solitary species was influenced mainly by does and their young.

Faecal accumulation rate

Population density (D, individuals per km^2) was estimated using the equation proposed by Eberhardt & Van Etten (1956): $D = (\text{NP}\times D\text{pg})/(T\times \text{d}R)$, where NP = number of plots per km^2, Dpg = mean number of faecal pellet groups, T = deposition time of faecal pellet groups, and dR = defecation rate. In the absence of field data we used the observed defecation rate of captive Bawean deer (13 faecal pellet groups per individual per day; Blouch & Atmosoedirdjo, 1987). We extrapolated the calculated densities to the total protected area on Bawean island to estimate the population size. The standard error of the estimates was computed using the delta method (Seber, 1982).

Distribution

We mapped the distribution and abundance based on the random encounter model and the faecal pellet count (map source: Bakosurtanal, 2002) using *ArcGIS*.

Results

Random encounter modelling

We recorded 118 photographs of Bawean deer (2.15 individuals per 100 trap-days), none during March–April, 10 in May (but only two independent photographic events), 19 in June, 23 in July, 32 in August, 22 in September, 6 in October and 6 in November. Random encounter modelling was performed bimonthly for June–July and August–September, with 32 and 50 independent photographic events, respectively. All variables and estimates for preferentially set, randomly set and all cameras are summarized in Table 1. Obtaining similar estimates for both sets of cameras, estimations for all cameras were 4.87± SE 1.05 individuals per km^2 in June–July and 8.92± SE 1.17 in August–September, yielding population estimates of 227± SE 33 and 416± SE 55, respectively.

Faecal accumulation rate

We counted 30 and 50 faecal pellet groups after 60 days of accumulation in the wet and dry seasons, respectively. We estimated a density of 3.48± SE 2.61 individuals per km^2 in the wet season (February–March) and 5.18± SE 3.61 in the dry season (August–September). The population size over the sampled area was estimated to be 162± SE 122 and 242± SE 168 in the wet and dry seasons, respectively.

Distribution and abundance of Bawean deer

The presence of Bawean deer was recorded in eight and 11 grid cells using camera traps and faecal pellet counts, respectively, including seven grid cells by both techniques (Fig. 3). The recorded range of the species was restricted to the south-western part of the Bawean Island Nature Reserve and Wildlife Sanctuary, from Mount Bulu to Mount Bengkuang, at 34-320 m elevation. Only old faecal pellets were found at Mount Tinggi and Mount Besar. No deer were recorded in Tanjung Cina or in the north-east of the island by these techniques, nor did we find any footprints or other sign of presence at Mount Tinggi, Mount Beringin, Kastoba Lake or Mount Payung-Payung. The highest estimated abundance was in the vicinity of Mount Dedawang (36.8 and 28.3 individuals per km^2 by random encounter modelling and faecal accumulation rate, respectively). Abundance was lower at Mount Duren (1.1 individuals per km^2 by faecal accumulation rate) and Mount Besar (3.4 and 3.3 individuals per km^2 by random encounter modelling and faecal accumulation rate, respectively), and also around Mount Bajapati (4.1 and 2.2 individuals per km^2). It was intermediate in the mixed secondary and teak forest of Mount Bulu (21.5 and 7.9 individuals per km^2).

Table 1. Results of random encounter modelling to estimate the population of Bawean deer *Axis kuhlii* in the Bawean Island Nature Reserve and Wildlife Sanctuary (Fig. 1), for preferentially set (at locations with signs of deer), randomly set, and all cameras.

	REM with preferentially set cameras		REM with randomly set cameras		REM with all cameras	
Months	Jun - Jul	Aug - Sep	Jun - Jul	Aug - Sep	Jun - Jul	Aug - Sep
Trapping rate (captures per day)	0.0533	0.0984	0.0519	0.0686	0.0525	0.0820
Detection distance (km)	0.0083 ± 0.0005	0.0076 ± 0.0004	0.0081 ± 0.0005	0.0072 ± 0.0004	0.0082 ± 0.0003	0.0074 ± 0.0003
Detection arc (radians)	0.3410 ± 0.0088	0.3462 ± 0.0044	0.3332 ± 0.0070	0.3266 ± 0.0037	0.3366 ± 0.0054	0.3379 ± 0.0032
Group size (no. of individuals)	1.25 ± 0.11	1.24 ± 0.07	1.24 ± 0.10	1.11 ± 0.06	1.24 ± 0.07	1.17 ± 0.05
Speed (km day^{-1})	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484	1.425 ± 0.0484
Model estimate (95% CI)	4.83 (3.80-5.86)	9.80 (8.23-11.37)	4.88 (3.89-5.87)	8.12 (6.82-9.42)	4.87 (4.18-5.56)	8.92 (7.77-10.07)
Population Size	177-273	384-530	181-274	318-439	195-259	362-469

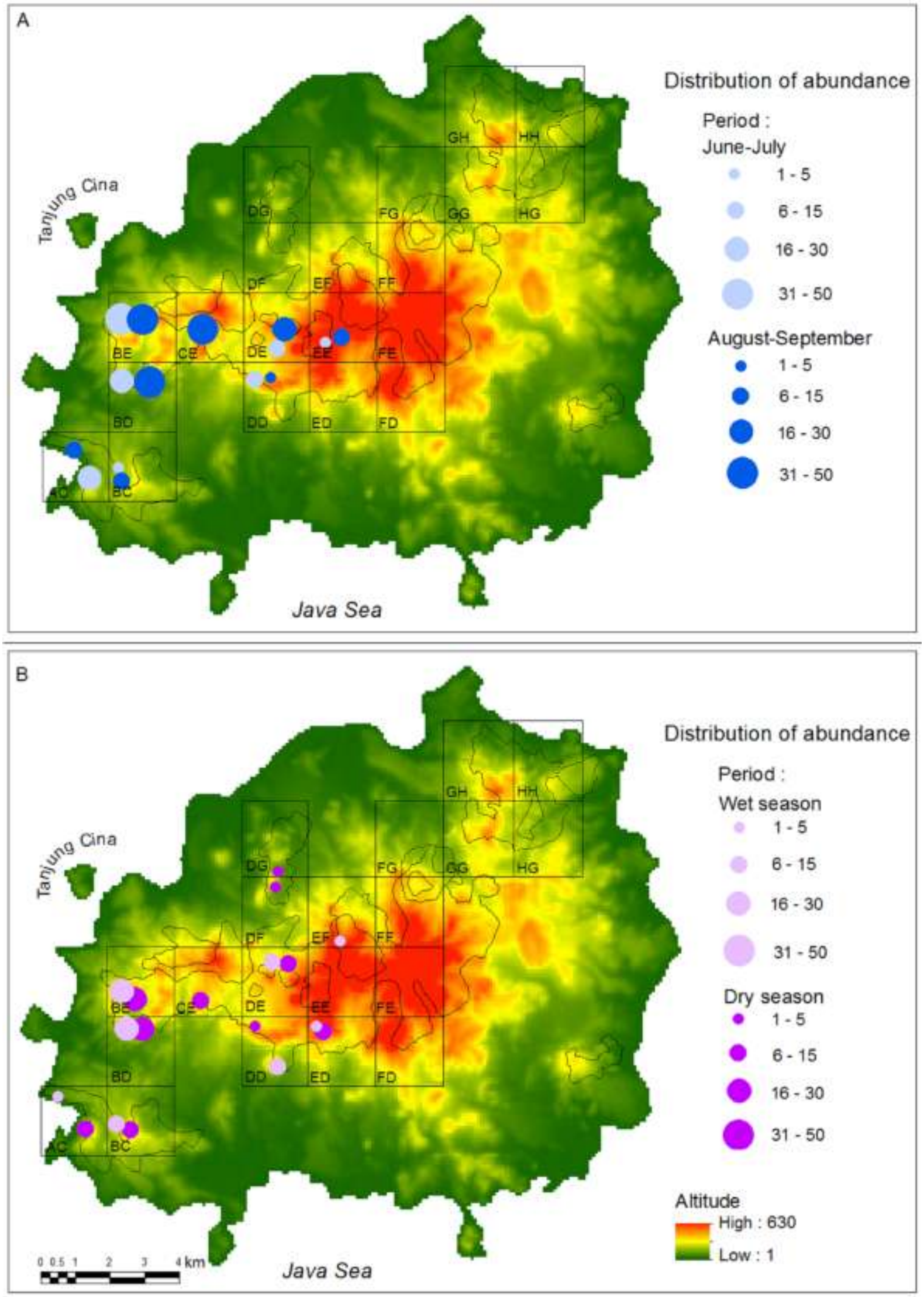

Figure. 3. Seasonal distribution of abundance (individuals km^{-2}) of Bawean deer in the Bawean Island Nature Reserve and Wildlife Sanctuary (Fig. 1) based on (a) camera trapping and random encounter modelling and (b) faecal pellet counts and faecal accumulation rates.

Discussion

Density estimates

We successfully tested the suitability of camera trapping and random encounter modelling for monitoring the status of the Bawean deer in its tropical forest habitat. The absence of photographs during the first 2 months (March-April) may be related to the presence of a high number of researchers at the beginning of the survey period, unsuitable locations of cameras, and lower activity of the species in the wet season. The trapping rate and density estimate increased during the dry season, peaking in August. As most deer were photographed when feeding, this could be related to the availability of food plants, which can become more scarce during the dry season, even in tropical habitats (Pontes & Chivers, 2007), leading to wider movements.

Estimates obtained with the random encounter model were more precise (narrower confidence intervals) and higher than those obtained using faecal pellet counts. This discrepancy may be attributable to the decay of faeces, and the approximate values of some parameters, such as the speed of deer movement, and the camera detection zone used in random encounter modelling. All parameters, even those that are hard to obtain (Rowcliffe et al., 2012), should be measured more accurately for the Bawean deer in the future. The combination of camera trapping and global positioning system telemetry could improve the accuracy of estimates, not only for performing random encounter modelling but also for analysing how species' home ranges can affect the required size of the area sampled. Such a study could also test the assumption of random distributions of cameras and wildlife (Cusack et al., 2015). The camera detection zone should also be investigated in different habitats and seasons; for example, we measured a lower detection radius in the wet season, although the difference was too weak to explain the absence of deer detection in that season.

Our findings suggest that random encounter modelling may yield accurate density estimates for elusive, rare and unmarked species, unlike photographic capture-recapture techniques, which require both unique markings and high-quality photographs for recognition of individuals (Soria-Díaz & Monroy-Vilchis, 2015). Moreover, random encounter modelling is continually being improved (Rowcliffe et al., 2011). Both methods estimated the highest density in the dry season, as previously reported (Blouch & Atmosoedirdjo, 1978), which supports the hypothesis that there is less movement in the wet season. The size of the Bawean deer population was estimated to be 242 individuals by the faecal pellet count method and

416 by random encounter modelling, which, compared to the previous estimate (250–300, by faecal pellet count; Semiadi, 2004), suggests stability.

Distribution and conservation status

O*ur records indicate that the range of the Bawean deer has* narrowed significantly. Camera trapping and faecal pellet counts proved to be complementary, with presence at Klumpang Gubuk recorded only by the latter technique. Unlike Blouch & Atmosoedirdjo (1987) *and* Semiadi (2004)*, we found Bawean deer only in the central mountain range and in the south-west of* the Bawean Island Nature Reserve and Wildlife Sanctuary, *around Mount Bulu. We* assume that the deer is no longer present in Tanjung Cina, where a density of 11.8 individuals per km^2 during the wet season was reported previously (Semiadi, 2004). No sign of presence was recorded at Mount Tinggi, Mount Beringin, Kastoba Lake or Mount Payung-Payung. Records by Sitwell (1970), Blower (1975), Blouch & Atmosoedirdjo (1978) and Blouch (1980) may indicate the existence of transient or survivor individuals rather than a stable population, possibly associated with increased habitat quality in some protected areas where routine patrol activities have reduced human disturbance and damage to vegetation.

The highest densities of Bawean deer were reported in secondary forests around Mount Dedawang, Mount Nangka, Mount Gadung, Mount Duren, Mount Mangoneng, Mount Bengkuang and Batulintang, a small area around Mount Bulu. The lowest densities were estimated in primary forests at Mount Besar, Mount Bajapati and Klumpang Gubuk. The population was centred around Mount Dedawang (cf. Blouch & Atmosoedirdjo, 1987), with activity concentrated at low altitudes (<300 m), where food and water are abundant.

Hunting activity was recorded at six of 20 camera trap locations (Rahman et al., 2016), and one snare was found in Batu Gebang block (the south-eastern part of Mount Dedawang), close to semi-open cultivated areas used by wild boar for foraging, and with the highest density of Bawean deer. Although wild boar were the poachers' main target, deer could also be trapped, and die from stress-related causes (BBKSDA East Java, 2009). Furthermore, the Bawean Island Nature Reserve and Wildlife Sanctuary is close to human settlements, and some areas have been damaged by illegal logging. The continued presence of Bawean deer in harvested forests suggests some degree of tolerance to selective logging. The deer are attracted to settlements by agricultural crops (Semiadi, 2004), which places them at risk from feral dogs (Blouch & Atmosoedirdjo, 1978). We photographed feral dogs in 12 grid cells (Rahman et al., 2016) and recorded two cases of Bawean deer killed by feral dogs close to settlements. Although such events are rarer now than previously (Blouch & Atmosoedirdjo, 1987), the threat should be taken seriously as feral dogs are the main predators of several deer species in South America (Weber & Gonzalez, 2003).

The Bawean deer has survived a decade of social turmoil, in which food scarcity triggered high levels of hunting and illegal logging (Semiadi, 2004). Despite a stable population size, the species should retain its Critically Endangered status under criterion B1ab(ii, iii) and not C2a(ii) (which suggests a population decline) as in the most recent assessment (Semiadi et al., 2015). The extent of occurrence is <100 km^2, the area of occupancy is declining and the habitat is fragmented. Further study is needed, including a long-term monitoring scheme. A captive-breeding programme was established in 2006 with a founder population of two stags and five hinds, and this population had increased to 35 individuals by 2014 (Meijaard et al., 2014).

Acknowledgments

We thank Balai Besar Konservasi Sumberdaya Alam of East Java and the Ministry of Environment and Forestry, Republic of Indonesia, for providing a licence to conduct research in Bawean Island Nature Reserve and Wildlife Sanctuary. Financial and logistical support was provided by the Rufford Small Grants Foundation. DAR received postgraduate scholarships and funding from the Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, Republic of Indonesia.

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Table S1. Previous population (or density) estimates for the Bawean deer *Axis kuhlii*, including the study area, method and source of data.

Study site[a]	Methods[b]	Estimation of population	Source of data
Data not available	Data not available	500 individuals	Sitwell (1970) Blower (1975)
Kolpo-kolpo area, Mount Mangoneng, Mount Gadung	Faecal pellet count	Secondary forest,19 individuals km^{-2}; primary forest, 5.6 individuals km^{-2}; brush, 2.2 individuals km^{-2}; rombok, 2.2 individuals km^{-2}; disturbed primary forest, 2.0 individuals km^{-2}; teak understorey, 0.9 individuals km^{-2}; teak without understorey, 7.4 individuals km^{-2}; teak with grass, 3.3 individuals km^{-2}. 200–400 individuals in total	Blouch & Atmosoedirdjo (1978)
Data not available	Data not available	200–400 individuals	Blouch (1980)
Data not available	Data not available	1,035 individuals	Sudarmadji (1985)
Bawean Island	Faecal pellet count	Aram-aram, 0.23 individuals ha^{-1}; Muntaha-muntaha, 0.28 individuals ha^{-1}; Kolpo-kolpo, 0.07 individuals ha^{-1}; Mount Bangkuang, 0.10 individuals ha^{-1}; Tanjung Cina, 1.18 individuals ha^{-1}	LIPI & IPB (1999)
Bawean Island & Tanjung Cina Island	Footprints	307–316 individuals	UGM & BBKSDA East Java (2003)
Bawean Island & Tanjung Cina Island	Faecal pellet count	250–300 individuals on Bawean Island & 11.8 individuals km^{-2} on Tanjung Cina	Semiadi (2004) Semiadi & Pudyatmoko (pers. comm 2006)
Data not available	No systematic survey	Maximum 500 individuals	Semiadi (pers. comm. 2008)
Mount Besar, Mount Mas, Tanjung Cina	Track count, call count	Track count: Mount Besar, 251 individuals; Mount Mas, 154 individuals; Tanjung Cina, 12 individuals) Call count: 405 individuals	BBKSDA East Java (2009)

CHAPTER 4

Habitat modelling for conservation of solitary deer species in protected tropical rainforest area

PAPER 3

Seasonal habitat use and predicted range of two tropical deer in Indonesian rainforest

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Submitted to Acta Oecologica

current status is under review

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.

Keywords**:** monsoon, camera trap, Maxent, Bawean deer, red muntjac

1. Introduction

There can be little doubt that the lowland tropical forests, 44% of the world's forests, are the most species-rich of all terrestrial ecosystems and suffer the highest deforestation rates worldwide (García-Marmolejo et al., 2013). Tropical forest degradation and fragmentation dramatically transform natural dynamics, potentially triggering species extinctions, decreasing survival, modifying habitat use and species distributions (Fahrig, 2003). 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).

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).

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). Therefore our primary objective was to identify the most relevant environmental variables for describing the habitat used seasonally by both deer and for predicting their range using spatial distribution models.

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).

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 (Philips 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; Elith et al., 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), which can be the case for Bawean deer. Here we used Maxent to model the habitat use and predict the range of Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary and red muntjac in Ujung Kulon National Park (Indonesia).

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.

2. Material and methods

2.1. Study areas

Bawean deer was studied in Bawean Island, a quite isolated island in Java Sea *(*5^{o}40'-5^{o} 50'S; 112^{o} 3'-112^{o} 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 to 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 to 630 meters).

The main vegetation type is a tropical rainforest which can be divided into four major forest types: primary forest, secondary forest, teak (*Tectona grandis*) forest, and shrub (Table 1). The BINR-WS protects one of the small patches of 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. 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. Moreover, 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* (Groves, 1981).

Red muntjac was studied 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 to 620 meters).

The main vegetation is a tropical 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). 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. The UKNP constitutes one of the last strongholds in the country for endemic large mammalian ungulates such as the Javan rhino *Rhinoceros sondaicus sondaicus* (Desmarest, 1822).

Table 1. Habitat types monitored for Bawean deer and red muntjac activity with camera trapping surveys, respectively from March to November 2014 in Bawean Island Nature Reserve and Wildlife Sanctuary and from January 2013 to July 2014 in Ujung Kulon National Park, Indonesia. Both of study site have a similary of categorical of habitat type, but with different composition.

Study site	Habitat	Description
Bawean Island Nature Reserve and Wildlife Sanctuary	Primary forest	Old forest subject weakly disturbed by human activities and generally not easily accessible; both tree and understorey species vary greatly from one mountain to another. Most two common trees include *Anthocephalus indicus*, *Ficus variegate* and the understorey is an assemblage of tree saplings and low species such as *Leea indica*, *Antidesma montanum*.
	Secondary forest	Most of forests are patchy within teak plantations, mainly where plainting failed. Most two tree composed included *Ficus variegata*, and *Macaranga tanarius* and understorey is quite dense, madde up species such as *Leea indica*, *Ficus spp.*
	Teak forest	Host the same species as secondary forests, but large trees are mainly teak and understorey is generally less dense because of occasional fire.
	Shrub	Poor, sandy soil and are characterized by small woody plants, mainly *Melastoma polyanthum* and *Eurya nitida*.
Ujung Kulon National Park	Primary forest	Occupies 50% of the total area, open canopy with numerous emergents up to 40m high. Dominant tree species are *Parinari corymbosa* and *Lagerstroemia speciosa* and understorey includes palms such as *Arenga obtusifolia* and *Calamus spp*.
	Secondary forest	Concentrated in central lowlands, dominated by palms, such as *Arenga pinata*, *Arenga obtusifolia*.
	Mangrove-Swamp	Occurs in a broad belt along the northern side of the isthmus, extending northwards as far as the Cikalong river, as well as north of Pulau Handeleum and northeast coast of Pulau Panaitan. Tree species include *Sonneratia alba* and *Lumnitzera racemosa*.
	Beach forest	Occurs on nutrient poor sandy ridges on the north and northwest coasts of Ujung Kulon, and is typified by such species as *Calophyllum inophyllum* and *Barringtonia asiatica*.

2.2. Survey methodology

According to the areas and habitat types to be surveyed, and the number of camera-traps, BINR-WS was gridded into 20 2-km^2 trap stations (10 in primary forest, 5 in secondary forest, 3 in teak forest and 4 in shrub) and UKNP was gridded into 329 1-km^2 trap stations (112 in primary forest, 84 in secondary forest, 54 in mangrove-swamp and 78 in beach forest). Camera-traps with heat-in-motion detectors were used to continuously record over the 24-hour activity of the target species and set to record date and time of all photos. In BINR-WS we mounted 20 units of Bushnell Trophy Cam HD Max analog cameras on trees, positioned 30-50 cm above the ground to record both small and large animals. In UKNP, we positioned 108 units Bushnell Tropy Cam 119467 and Bushnell Tropy Cam 119405 analog cameras 170 cm above the ground with a 10-20 degree angle lead to the ground (following the standard design of camera trapping by Rhino Monitoring Unit [RMU] team) to survey the Javan rhino. These differences in camera trapping might be affect the photographic capture probability of both deer species, particularly for red muntjac. However, the evidence of photographs in the field shows that red muntjac are still capture even located in less than 1m from camera traps.

Positioning camera-traps in each trap station or grid adopted the methodology of Karanth and Nichols (1998) in both study areas. Cameras were set up in a way to cover the whole study area by applying a buffer equivalent to half of the mean maximum distance moved (1/2MMDM). This means that any individual in the study area had a probability greater than zero to be photographed by at least one camera. Because our goal was to obtain as many photographs as possible in each grid, when a camera did not capture any object (zero presence), we changed its location in the same grid.

Field surveys were carried out during 9 months (March to November 2014) and 19 months (January 2013 to July 2014) in BINR-WS and UKNP, respectively. The sampling periods included both wet and dry seasons. Cameras were checked once every 21-30 days, including replacing battery and memory card, and even the camera-trap in case of malfunction in order to avoid loss of data. Each photograph of an animal was identified to species, and if the quality of the photograph did not allow absolute identification the photograph was excluded from the dataset. Sequential frames of the same species were counted as one photographic event, and unless individual identification was possible, any subsequent photograph of the same species taken within one hour was not considered a new photographic event. The location of each photograph was recorded by latitude and longitude and converted into digital data in GIS using ArcMap program. Sampling effort during the survey was 5.500 trap days in BINR-WS and 62.316 trap days in UKNP.

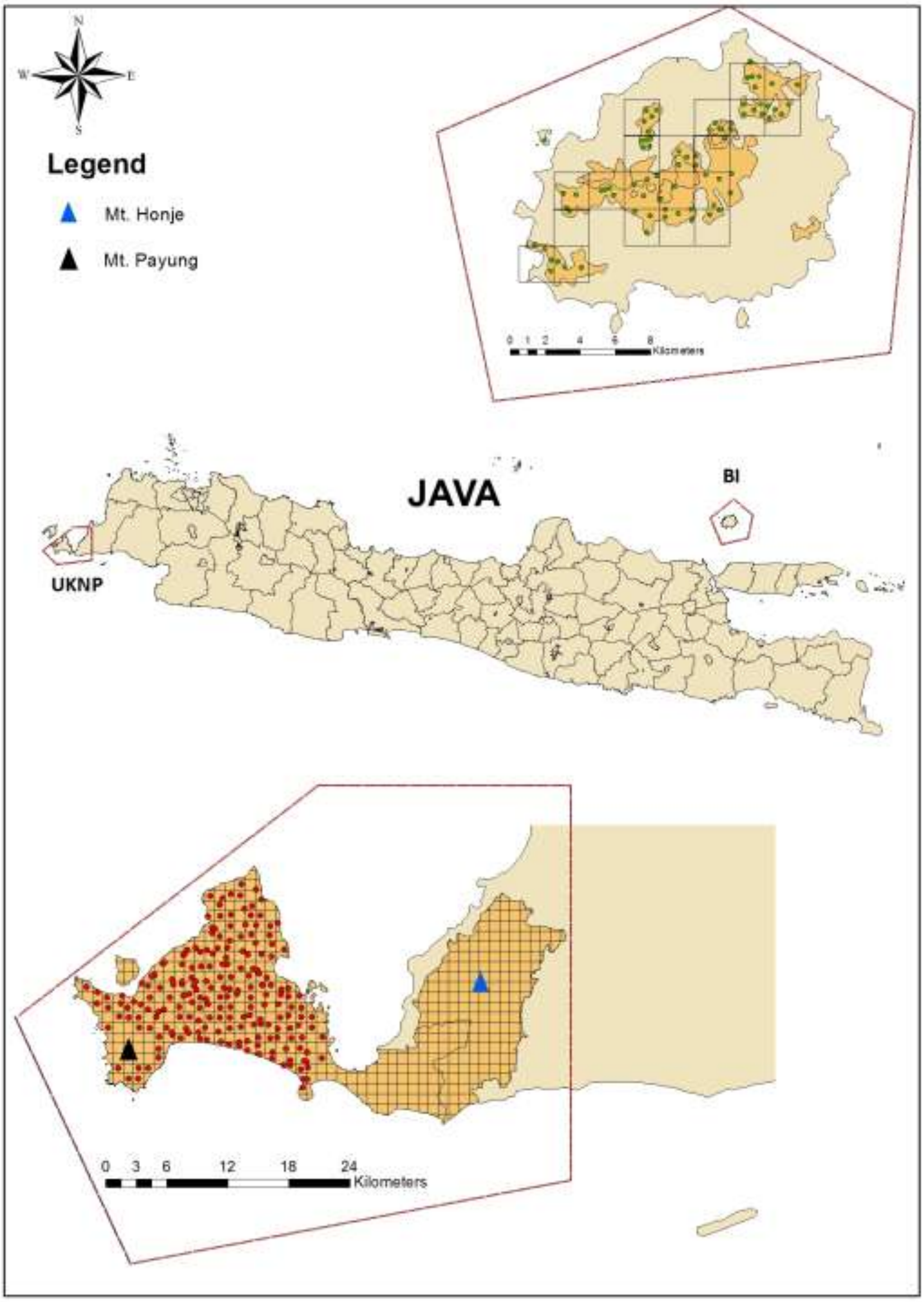

Figure 1. Camera trap locations within the two Indonesian study sites: Bawean Island (BI, green dots) and Ujung Kulon National Park in Java Island (UKNP, red dots). Mt. Honje and Mt. Payung are designated by bright blue and dark blue triangle, respectively.

2.3. Data analysis

2.3.1. Spatial patterns of habitat use

We calculated photographic encounter rates (PER) per grid as: PER = number of photos * 100 / sampling effort (camera-trap days). As the number of photographs significantly differed between seasons (Chi-square tests), we compared the seasonal PER among habitat types in each study site using Kruskal-Wallis tests adjusted for equal numbers and *post hoc* tests for multiple comparisons ($\alpha = 0.05$).

2.3.2. Species distribution modelling and validation

For modelling the distribution and habitat use of both deer species, we used presence records of deer as dependent variables. Then, we selected 15 environmental variables, which we considered to influence deer distribution based on literature. These variables were classified into 4 classes: 1) physical variables such as elevation, slope and distance to the nearest river (Debeljak et al. 2001; Patthey 2003), 2) resources such as land cover (distance to primary forest and secondary forest) and vegetation productivity (Schutz et al. 2003), 3) anthropogenic disturbance such as distance to settlement, cultivated area and road (Patthey 2003), and 4) climatic variables such as annual rainfall, rainfall of the wettest month, rainfall of the driest month, annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month (Solberg et al. 2001; Hovens and Tungalaktuja 2005).

Elevation data were downloaded as an ASTER global digital elevation model (DEM). A 90x90m digital elevation model was downloaded from Landsat 8 (http://earthexplorer.usgs.gov or http://srtm.csi.cgiar.org) from which slopes were generated using the slope function in ArcGIS (Jarvis et al., 2008). Data for rivers, land cover, roads were obtained from the Badan Kordinasi Survei dan Pemetaan Nasional (http://www.bakosurtanal.go.id/bakosurtanal/peta-rbi). Vegetation productivity was measured as the normalized difference vegetation index (NDVI, cf. Hansen et al., 2009). Since sample of climate data derived from research stations relatively similar with datasets from WorldClim (for example, the actual data of temperature range in the BINR-WS research station = 17 - 32 ^{0}C vs. WorldClim = 18 - 33 ^{0}C). Climatic variables were downloaded from the WorldClim database (http://worldclim.org/bioclim). The WorldClim dataset (Hijmans et al., 2005) gives an overview in terms of global environmental characterization as it provides high resolution (i.e. nearly 1km) climatic surfaces derived from historical records from a number of weather stations across the globe. WorldClim provides high resolution monthly maximum (tmax), minimum (tmin), and mean temperatures (tmean), and monthly precipitation (prec); and from those, a set of 19 bioclimatic variables can be derived. These data are derived from monthly temperature and rainfall values recorded between 1950 and 2000 from a global network of climate stations. All layers were projected into WGS 1984 Zone 49 South (Bawean Island) and WGS 1984 Zone 48 South (Ujung Kulon National Park). The WorldClim climatic variables are frequently used as the environmental variables for assessing habitat suitability to predict the potential distribution in many species and already bias corrected and spatially downscaled. With this reliability dataset, several analyses by means of GIS can be performed (e.g. to assessing the distribution Lao newt by Chunco et al., 2013; four felid species by McCarthy et al., 2015; cattle tick by De Clercqa et al., 2015).

We extracted distance values in ArcGIS 10.2.2 (ESRI, Redlands, California, USA) to create environmental layers used in Maxent software (Phillips, 2008). We created a distance raster using the Euclidean distance tool that measured the distance of each pixel to the forest edge. Distances to the nearest river, settlement, cultivated land area, and road were also extracted using the same tool. Values for the other environmental variables were automatically extracted from the raster at each location of deer occurrence. For any predicting Maxent, all rasters were resampled to a 100-m grid cell size and a mask layer was created from the park boundaries to restrict analysis to both study areas (Young et al., 2011).

Using many correlated variables may result in over-parameterization and reduce the predictive power and interpretability (Morueta-Holme et al., 2010). Multicollinearity was checked for all combinations of environmental variables using Pearson's correlation coefficient. There were strong negative correlations ($R^2 \geq 0.7$) between elevation, rainfall during the driest month and the maximum temperature of the warmest month; elevation, rainfall during the wettest month and minimum temperature of the coldest month. There were strong positive correlations between the maximum temperature of the warmest month, minimum temperature of the coldest month and annual mean temperature; rainfall of the wettest month, rainfall of the driest month and annual rainfall (Appendices 1A, 1B). Thus, only elevation, annual mean temperature and annual mean rainfall were considered in the model. Predictors used in the final model included one categorical variable (NDVI), and 10 continuous variables (elevation, slope, distance to river, distance to primary forest, distance to secondary forest, distance to settlement, distance to cultivated area, distance to road, annual rainfall and annual mean temperature).

We modelled the distribution of each deer species using Maxent v.3.3.3k (http://www.cs.princeton.edu/schapire/maxent/). The environmental layers consisted of all environmental variables, as well as a spatial mask layer that restricted the analysis to BINR-WS and UKNP (for more details see Phillips, 2008). We used the following settings of Maxent v.3.3.3k: automatic feature selection, regularization multiplier at unity, maximum of 500 iterations, 50 replicates and a convergence threshold 10-5. The output was in the logistic format for all analyses and the program was run with “auto features” checked (Philips and Dudik, 2008)

Accuracy assessment for each model was measured by the area under the curve (AUC) from the receiver operating characteristic curve (ROC, Woodward, 1999). The ROC curve is the relationship between the sensitivity and the false positive fraction. The AUC is the area under the ROC curve, with a value of 0.5 representing a random model, values between 0.8 and 0.9 representing models with a good fit and values over 0.9 being an excellent fit (Manel et al., 2001; Thuiller et al., 2003). We also develop distribution map of red muntjacs in consecutive years, We used presence data from January to April 2013-2014 that represent the wet season and May to July 2013-2014 for the dry season.

2.3.3. Variable contribution and response curve

There are two methods to assess the contributions of environmental variables to models: 1) relative contribution and permutation importance and 2) Jackknife test (Phillips and Dudik, 2008). The relative contribution and the permutation importance of each variable were calculated in Maxent as an average over 50 replicate runs. Values were normalized to give the total percent contribution. To get alternative estimates of variable importance, we also ran a Jackknife test. This test generates a model with each variable separately and also creates another set of models, which excludes one of the variables.

3. Results

We recorded 118 photographs of Bawean deer, 6 in wet season (PER = 0.33) and 112 in dry season (PER = 3.04), and 4363 photographs of red muntjac, 1614 in wet season (PER = 4.96) and 2749 in dry season (PER = 9.22). Differences between seasons were significant for both species (Bawean deer: $\chi^2 = 41.80$, df = 1, $p < 0.001$; red muntjac: $\chi^2 = 658.15$, df = 1, $p < 0.001$). These differences and the number of data will condition seasonal analyses that will be restricted to the dry season for Bawean deer.

3.1. Habitat use

Bawean deer and red muntjac were found in all sampled habitats, although they were recorded in 8 of the 20 sampled grids and in 156 of the 329 sampled grids, respectively.

Bawean deer encounter rate differed among habitat types in the dry season ($H = 7.80$, $df = 3$, $p = 0.050$). The highest encounter rates were recorded in secondary forest and the lowest in teak forest and shrub (Fig. 2A). Most of camera traps in primary forest did not photograph any deer.

Red muntjac encounter rates differed among habitat types in both seasons: dry $H = 68.16$, $df = 3$, $p < 0.001$; wet $H = 60.50$, $df = 3$, $p < 0.001$. The highest encounter rates were also recorded in secondary forest (Fig. 2B, 2C) and differed significantly from all other habitats in both seasons (dry mean rank = 223.4, wet mean rank = 227.7). The lowest encounter rates were recorded in mangrove-swamp (dry mean rank = 126.4, wet mean rank = 111.0) but they did not differ from encounter rates in primary forest (dry mean rank = 141.0, wet mean rank = 147.9). Encounter rates in beach forest did not differ from the former ones in dry season only (dry mean rank = 162.5, wet mean rank = 158.6).

3.2. Species distribution modelling and validation

Distribution models for both species and seasons performed well except for Bawean deer in wet season, when recorded data were scarce. All AUC values were greater than 0.796 (Table 2; Appendix 2). Models identified areas of high probability of presence within both study sites. For Bawean deer in dry season, areas of high predicted suitable conditions are located in the western and central part of the protected area (Fig. 3A). For red muntjac, high probability of suitable conditions included almost the whole area of the park, except the high mountain at the southwest in both seasons (Fig. 3B, 3C). Red muntjacs occupied the same environmental system in consecutive years, either on wet season (Fig. 4A, 4B) or on dry season (Fig 4C, 4D).

Table 2. The AUC and standard deviation for each species model in two season at Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park

Species	Season	Number of photographs	AUC	Standard deviation
Bawean deer *Axis kuhlii*	Dry	112	0.796	0.204
Red muntjac *Muntiacus muntjac*	Wet	1692	0.844	0.068
	Dry	2711	0.824	0.058

3.3. Significant explanatory variables

For Bawean deer, distance to cultivated area had the most relative contribution followed by distance to settlement (56.0% and 24.4%, respectively, Table 3). Based on permutation importance distance to settlement was the most significant variable (42.5%) followed by distance to cultivated area (17.8%). Response curves were logistic for both variables (Appendix 2A). Distance to cultivated area had the greatest relative contribution both in wet and dry seasons for red muntjac, (56.0% and 57.8%, respectively) followed by annual rainfall (19.3% and 18.2%, respectively). Based on permutation importance, distance to cultivated area was the most significant both in wet and dry seasons (50.2% and 49.6%, respectively) followed by elevation (11.1% and 12.9%, respectively). Response curves were roughly unimodal for distance to cultivated area and bimodal for annual rainfall in both seasons (Appendix 2B).

Jackknife test in Bawean deer suitability model showed the highest gain when "distance to cultivated area" was used alone, while "distance to secondary forest edge" most increased the gain when it was omitted (Fig. 4A). Jackknife tests in red muntjac suitability models showed the highest gain when "distance to cultivated area" was used alone (Fig. 4B, 4C).

Table 3. The relative contribution (RC) and permutation importance (PI) of each environmental variable for each species as an average over the 50 replicates. Values are normalized to give percentages.

Environmental variable	Bawean deer		Red muntjac			
	Dry season		Wet season		Dry season	
	RC	PI	RC	PI	RC	PI
NDVI	5.9	4.7	5.5	6.1	2.3	1.7
Elevation	1.7	1.3	7.7	**11.1**	6.5	**12.9**
Slope	0.1	0.2	2.6	3.8	2.6	2.8
Distance to nearest river	2.8	6.6	0.3	1.5	0.5	3.4
Distance to primary forest edge	5.9	4.7	0.1	0.1	0.1	1.3
Distance to secondary forest edge	0.6	1.6	0.1	0.3	0.3	0.3
Distance to nearest settlement	**24.4**	**42.5**	0.5	7.0	7.1	4.7
Distance to nearest cultivated area	**56.0**	**17.8**	**56.0**	**50.2**	**57.8**	**49.6**
Distance to nearest road	1.2	8.8	6.7	8.8	3.6	9.9
Annual mean temperature	0	0	1.1	6.2	0.9	7.7
Annual rainfall	1.6	11.8	**19.3**	4.8	**18.2**	5.7

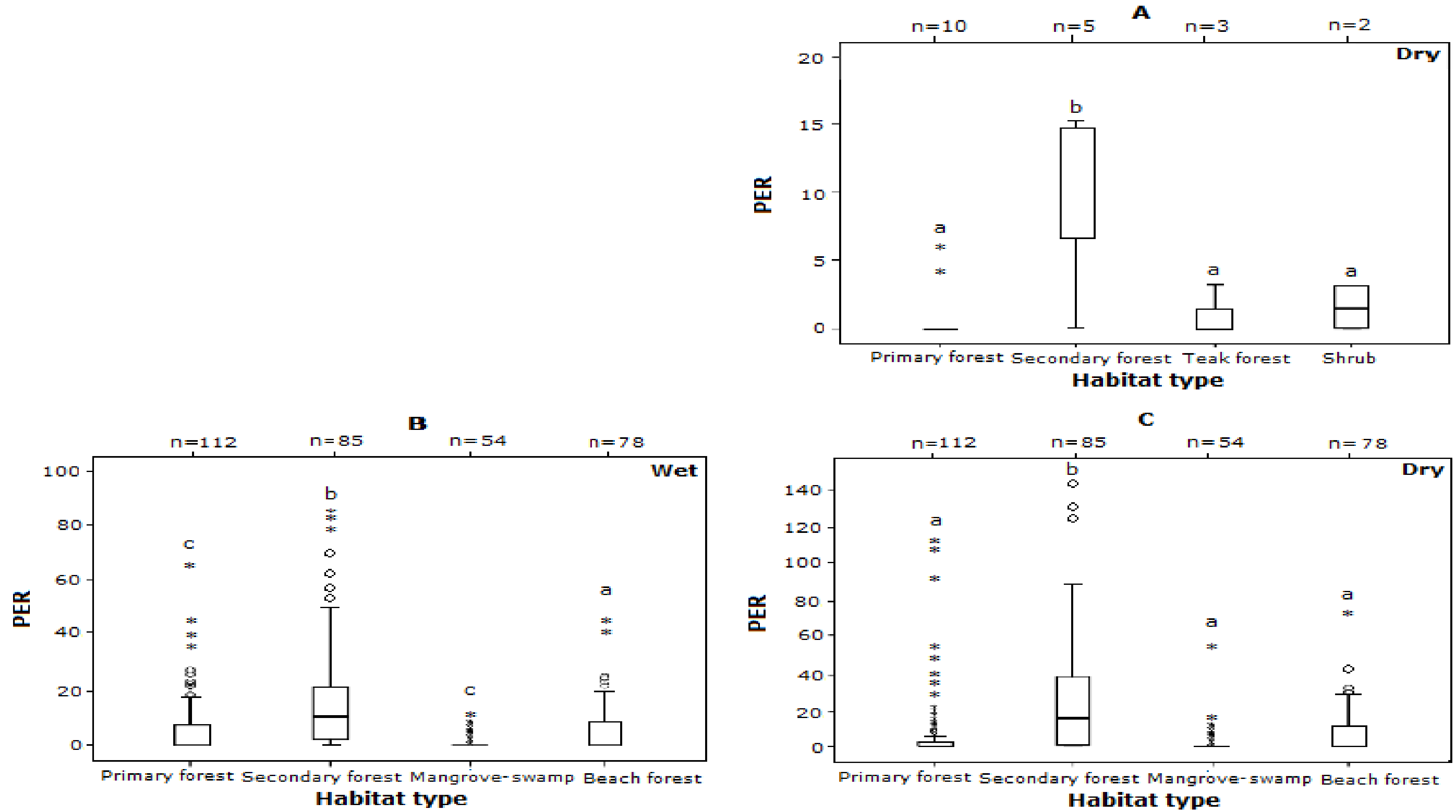

Figure 2. Photographic encounter rates recorded by camera traps in each habitat type in different seasons, from May to October 2014, in Bawean Island Nature Reserve and Wildlife Sanctuary for Bawean deer (A) and from January 2013 to July 2014, in Ujung Kulon National Park for red muntjac (B,C). Different letters indicate significant differences at the 0.05 probability level (with Bonferroni correction), n= number of camera traps.

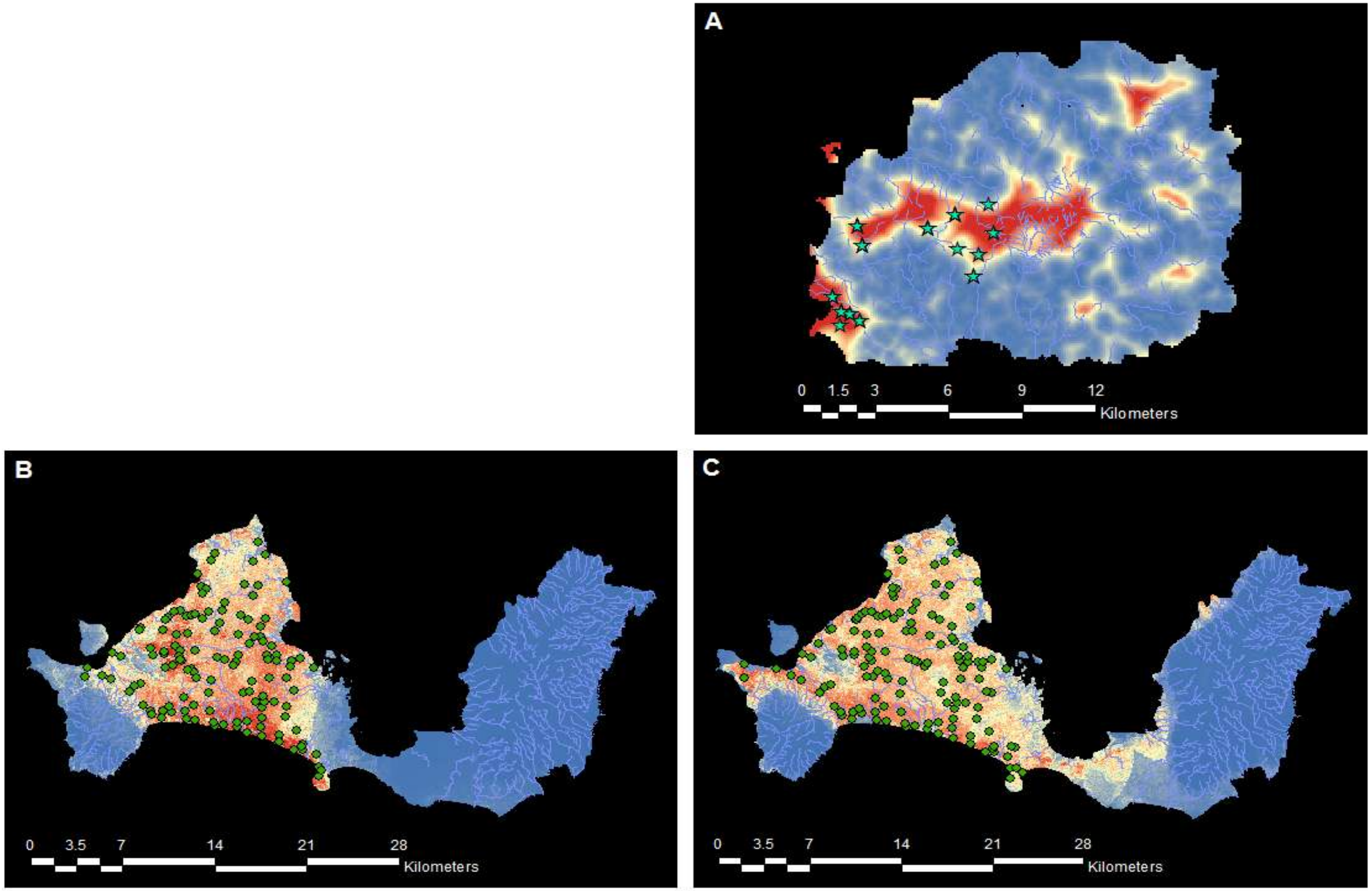

Figure 3. Distribution map in dry season for (A) the Bawean deer and (B,C) red muntjac, respectively in wet and dry seasons. Probability of presence is displayed from high (red) to low (blue). Recorded with camera trapping for Bawean deer presences are indicated by blue stars, as well as the red muntjac presences are indicated by green dots.

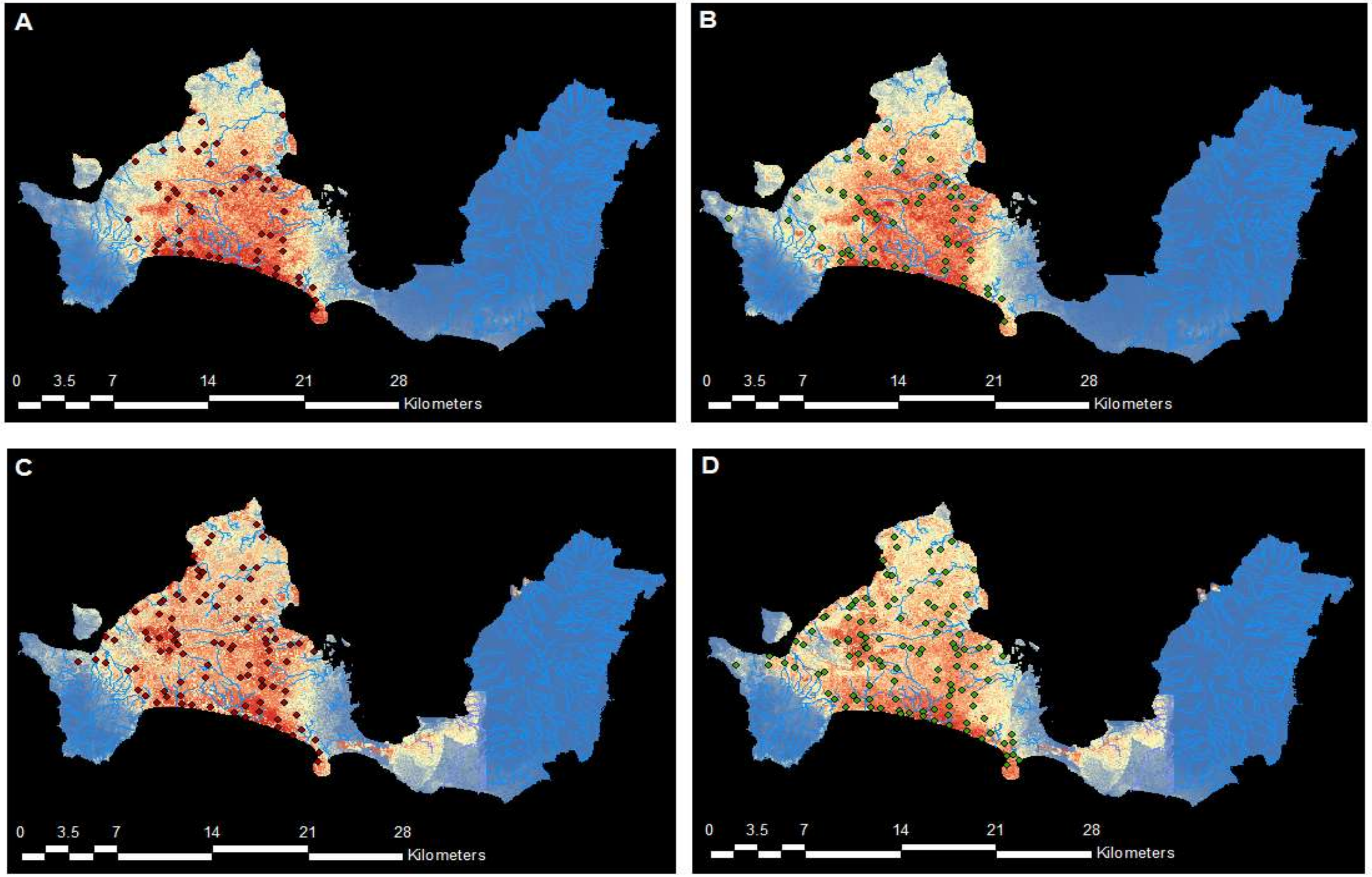

Figure 4. Distribution map for the red muntjac in wet season (A,B) and dry season (C,D), respectively in 2013 and 2014. Probability of presence is displayed from high (red) to low (blue). Presences recorded by camera trapping are indicated by red dots for presences in 2013, as well as the presences in 2014 are indicated by green dots.

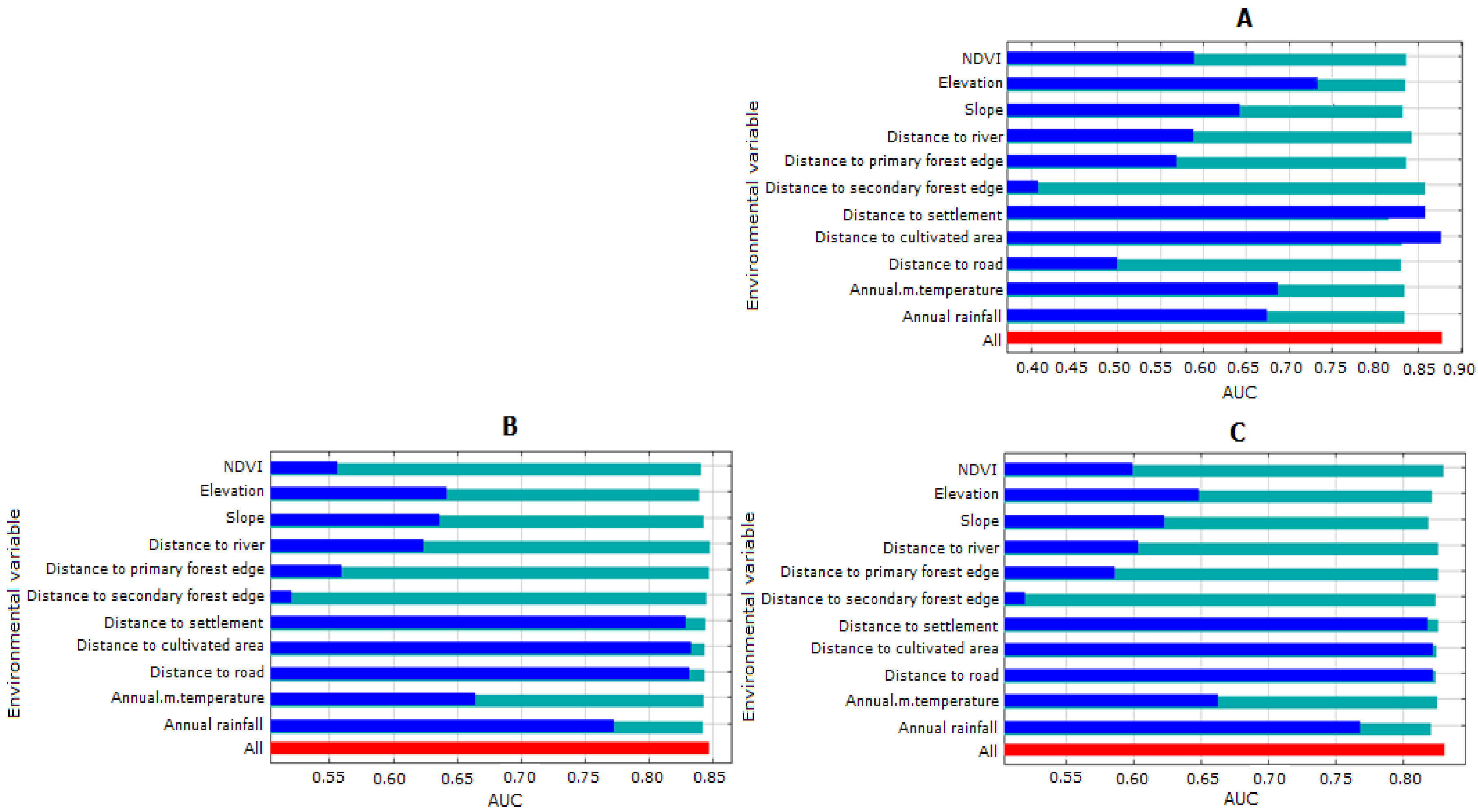

Figure 5. Jackknife tests of AUC values of the Maxent models applied to Bawean deer in (A) dry seasons and to red muntjac in (B) wet and (C) dry seasons. For each variable the dark blue bars correspond to models generated with only this variable. The light blue bars correspond to model generated without this variable and red bars correspond to model generate with all variable.

4. Discussion

Although this study likely represents the largest camera trapping dataset for Bawean deer and red muntjac, the number of photographs was fairly low for Bawean deer in the most favourable areas of the range. This is reflective of the rarity of this species and echoes its current status of “critically endangered” (Semiadi et al., 2013). In a previous camera trapping study, UGM and BBKSDA East Java (2004) did not record any photograph of Bawean deer inside BINR-WS, even during the dry season (September to October). The number of photographs was lower in the wet season for both species, possibly related to a lower level of activity or more probably to a greater availability of food. It is known that the time dedicated by animals for searching and obtaining food is inversely proportional to its abundance (Chappell, 1980). In most tropic habitats, food availability is assumed to be uniform throughout the year (Foster, 1973; Frankie et al., 1974), but can become scarcer during the dry season (Pontes and Chivers, 2007), leading to broader movements.

The hypothesis that both deer species mostly use areas with primary forest-type was not supported by our results. More than 50 % of Bawean deer and red muntjac were detected in secondary forest, which cover respectively 25.0 and 25.8 % of the grids and are mainly located at low elevation in both study sites. Although Teng et al. (2004) suggested that deer of the genus *Muntiacus* are habitat generalists, including varied elevations, Steinmetz *et al.* (2008) found that signs, and presumably *Muntiacus vaginalis*, were significantly more common in lower than higher-lying areas of the Tenasserim-Dawna mountains, Thailand.

The encounter rate was significantly higher in secondary forest than in all other habitat types for both species. Blouch and Atmosoedirdjo (1987) also found that Bawean deer was significantly more recorded in secondary forest than in three of four other habitat types. According to Brown and Lugo (1990) secondary forests have higher productivity than primary ecosystems. Ground cover in the secondary forest habitat is relatively sparse and dominated mostly by fruit trees canopy in both of study sites. This structure may be conducive to Bawean deer and red muntjac, which routinely forages on fruits, buds, tender leaves, flowers, herbs and young grass (Blouch and Atmosoedirdjo, 1987; Kitchener *et al*., 1990; Oka, 1998). Indeed, most animals were photographed when feeding. In UKNP fruits of sugar palms, *Arenga obtusifolia,* offer an abundant source of food for muntjac, a high consumption of these fruits was recorded on photographs. On the contrary, previous studies (Supriatin, 2000; Santosa et al., 2013) indicate that the dominance of this rapidly spreading palm species reduces the availability of food plants for rhinos. Habitat use can also be associated with relatively safer habitats from predator risk (Arceo et al., 2005). For Bawean deer in the absence of natural predators, humans and feral dogs could affect their habitat use.

Encounter rates in primary forest was higher than in teak forest and shrub for Bawean deer, and lower than in beach forest for red muntjac. The food offered by this habitat to deer species seems good but scarcer than in secondary forest (Blouch and Atmosoedirdjo, 1987). Nevertheless, it is likely that both deer require nearby areas of primary forest as refuge for resting (Blounch and Atmosoedirdjo, 1987; Seagel, 2003). Teak forest of BINR-WS regularly burns naturally in dry season and a brushy understorey of grasses and small shrubs develops, offering food at certain periods to Bawean deer.

Presence of red muntjac in beach forest may be related with food and mineral requirements. Mineral licks have long been recognized as areas to which wild animals, particularly ungulates, are attracted (Schultz and Johnson, 1992; Montenegro, 2004; Ayotte et al., 2008; Poole et al., 2010; Matsubayashi and Lagan 2014). As an example, sodium (Na), which is available in large quantities on vegetation around the beach, is the mineral most sought by white-tailed deer when using mineral licks (Kennedy et al., 1998).

Low encounter rates of Bawean deer in shrub and red muntjac in mangrove-swamp were expected because food is scarce, and also because the cover, although dense, is usually too hot during the day to be comfortable for deer (Blouch and Atmosoedirdjo, 1987).

According to our Maxent models the distribution of red muntjac did not differ between seasons even if, as well as for Bawean deer, the number of photographs was lower in the wet season. Both species selected mostly forests far from cultivated areas. Many studies on ungulate species already reported the influence of human infrastructures and activity on habitat use (e.g. Wolfe et al., 2000; Nellemann et al., 2001; Setsaas et al., 2007). However, red muntjac occur in plantations of coffee, rubber, sugarcane, cassava, coconut and teak adjacent to forest (Laidlaw, 2000; Azlan, 2006), and may also benefit from agricultural conversion at forest edge (M. Tysoon pers. comm.). More, Bawean deer were recorded in fields bordering forests by night where they ate young leaves of corn and cassava particularly in the dry season, retreating to relatively safer habitats during daytime. Indeed ungulates seem to be able to tolerate human activity to a higher extent during periods of food shortage (Strand et al., 2006).

The impact of human settlements is highly significant for Bawean deer and not for red muntjac. Bawean deer were not recorded closer than 2500 m to the nearest settlement. This is likely the result of avoiding human disturbance and feral dog conflicts, as part of an anti-predator behaviour that increased travel costs to move away from disturbance (Formaniwicz and Bobka, 1988), and perhaps more importantly, reduced opportunity to forage in optimal habitat when humans are most active (Creel et al., 2005). Based on the distribution map, red muntjac were mostly located near crop lands, particularly in the dry season. This flexible species which is known to live sometimes in such habitat close to the forest edge (Mattioli, 2011) likely responds more to the availability of food than to tolerance to human disturbance.

The influence of annual rainfall on habitat use by red muntjac only could be related to habitat availability. This deer was more recorded in the south than in the north of UKNP, namely where rainfall is the highest (3000-3500 mm/year) and habitat dominated by secondary and primary forests. These are the main biotopes of red muntjac (Mattioli, 2011), unlike the mangrove forests which dominate in the north of the park. Conversely, in BINR-WS rainfall is almost uniform over the island and is not related to any habitat type. Temperature did not significantly affect the distribution of deer which is not surprising given the small differences in mean monthly temperatures in both sites (17-32 °C in BINR-WS, 17-30 °C in UKNP). Moreover, both deer tend to live in areas where the range of temperature is smaller, 22-26 °C for Bawean deer, 21-25 °C for red muntjac according to http://www.landsat.usgs.gov. However this variable could become relevant in the scope of the global as small changes in temperature can have drastic effects on tropical species and thus on their distribution patterns (IPCC, 2007a; Wright, 2009; 2010). Other variables such as elevation, slope, NDVI, distances to secondary forest and to road were not significant, likely because their variation were too small in both sites and/or fall within the usual range for the species. This is the case with elevation and slope in UKNP for red muntjac which can reach 800 m in Java (S. Hedges, pers. comm.). The positive influence of NDVI suggested that both species prefer forest to open areas but, with ca. 70 % of all forest habitat types in the areas, secondary forests were highly dominant and always close for deer. Although roads infer human disturbance for both deer, distance to road was not significant. This could result from a trade-off between sense risk and movement ease in fragmented habitat, particularly for Bawean deer which can travel long distances in the dry season (Blouch and Atmosudirdjo, 1987). In our study Bawean deer locations were closer to urban and cultivated area, where road connected forest patches. This should be investigated further by setting cameras along roads.

Conclusion

Our study revealed the prevalence of Bawean deer and red muntjac in secondary forest versus other habitat types. Both species can use habitats at the edge of forest where they are at greater risk of conflict with humans, using forest as a refuge and exploiting agricultural landscapes for getting additional food (Blouch and Atmosoedirdjo, 1987; O'Brien *et al*., 2003). This highlights the importance of protected areas. Up to now, conservation initiatives for deer have been extremely limited in Indonesia due to a lack of knowledge on the ecology of these species, particularly for Bawean deer. Both deer received little conservation attention, mainly because they are uncommon, rarely seen, and locally compete for conservation interest with more charismatic species such as Sumatran tiger *Panthera tigris sumatrae* (Pocock, 1929), Sumatran elephant *Elephas maximus sumatranus* (Temminck 1847) or Javan rhino.

Habitat degradation and loss are ongoing threats to deer in Indonesia. Protected areas have become islands of habitat within a mosaic of agriculture and urbanization, and they suffer illegal logging and deforestation (Meijaard et al. 2005). With an appropriate degree of caution, we feel that our results are a basis of knowledge for other areas and are essential for implementing conservation initiatives including identifying areas of conservation priority, developing anti-poaching efforts, and even initiating anti-encroachment operations.

Acknowledgments

We wish to thank the team of Rhino Monitoring Unit (RMU) in Ujung Kulon National Park and all members of Bawean Island Nature Reserve and Wildlife Sanctuary who contributed to data collection. We are thankful to BBTNUK and BBKSDA of East Java, Ministry of Environment and Forestry, Republic of Indonesia for providing research license in UKNP and BINR-WS. Financial and logistical support was provided by Rufford Small Grants Foundation under Grant number 13957-1. Postgraduate scholarships and funding of DAR was provided by Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, Republic of Indonesia.

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CHAPTER 5

Activity pattern of remote medium-size deer in protected tropical rainforest areas

PAPER 4

Seasonal activity pattern and daily activity levels of two tropical deer in relation to the lunar cycle

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Manuscript in preparation.

Abstract

The activity pattern of mammalian ungulates are regarded as being primarily influenced by several factors, including sex and reproductive status, environmental conditions, predation, and behavioural thermoregulation. Facing change of environmental conditions the activity rhythm of animals may habituate. We used remote cameras to quantify Bawean deer and red muntjac activity patterns and examined differences by season, sex and lunar cycle, respectively in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, Indonesia. We used 118 photographs of Bawean deers taken during March-November 2014 and 4142 photographs of red muntjacs taken during January 2013-July 2014. Male and female Bawean deer were active throughout the day and night during all season, with several peaks in activity during the 24-h period. While, male and female of red muntjacs show diurnal activity levels with higher peaks during more less one hour after sunrise until one hour before sunset. There were no significant differences between males and females for both deer. In fact that the number of capture by camera trapping were found to be less for both sex of Bawean deer and red muntjac in wet season. Bawean deers presented variations in the amount of nocturnal activity corresponding to differences in nocturnal luminosity, but not for the red muntjac. We guess that this amount of differences between two similar-sized species are closely related to reduced of predation risk and foraging success.

Keywords: Seasonal, activity, lunar cycle, Cervidae, tropical rainforest

Introduction

Animal behaviour changes throughout the day, thus the temporal aspect of activity is an important dimension of an individual's ecological niche, and patterns of diel behaviour can directly influence individual fitness (Kronfeld-Schor and Dayan, 2003). Understanding what influences the timing of activity is therefore relevant to understanding how species can survive, adapt to and persist in their habitat (Buchholz, 2007; Krop-Benesch et al., 2012). Many factors affect the activity of animals, including the sex and reproductive status of the animal (Kolbe and Squires, 2007) and environmental factors such as season (Donati and Borgognini-Tarli, 2006; Manfredi et al., 2011), lunar luminosity (Schwitzer et al., 2007; Lucherini et al., 2009), predation (Sundell et al., 2004; Griffin et al., 2005), habitat fragmentation (Norris et al., 2010) and anthropogenic disturbance (Di Bitetti et al., 2008).

Especially in regard of seasonal changes, there are predictable variations in activity pattern related to the physiological state of the animal, e.g. the reproductive stage, and the environment, notably food resources and climatic conditions (Scheibe et al., 2001). In addition, connection with lunar cycle, in example at nocturnally active animals alter their behaviour and activity with changing light conditions. In most cases two major selective forces explain these responses; either change in predation risk or in prey availability. However, the moon phase can affect animals differently depending on whether they are predators, prey, or both. Visually orienting nocturnally active predators may benefit from bright moonlight because their prey is easier to detect. This, in turn, would cause prey to adopt a more cryptic lifestyle through reduction in activity. This assertion is supported by observations of white-tailed deers (*Odocoileus virginianus*), which individual vigilance was least during diurnal and moonlit nocturnal hours, presumably to avoid visually hunting coyotes, bobcats or human (Lashley et al., 2014). For ungulate that lived in tropical ecosystem such as the mountain tapir (*Tapirus pinchaque*), night-time activity was higher during full moon than during quarter and new moons (Lizcano and Cavalier, 2000).

Bawean deer and red muntjac are good example for medium, hornless ungulates that live in Southeast Asian tropical forests. Little has been published on their ecology and role in the tropical forest ecosystem. Most previous studies particularly in tropical rainforest of Indonesia, however, particularly studies on their ecology and behaviour including activity pattern, have been conducted on captive individuals; studies on wild both of deer in natural habitat have been limited. This outcome may be the result of both of species being thought to be cryptic, living in dense undergrowth (Blouch and Atmosoedirdjo, 1987; Sundell et al., 2004; Tyson, 2007). In previous studies, activity pattern of Bawean deer are often reported to be solitary nocturnal, active intermittently through the night (Blouch and Atmosoedirdjo, 1987), while red muntjac to be mostly diurnal (Kawanishi and Sunquist, 2004) and in several area was classed as cathemeral (i.e., sporadic and random intervals of activity during the day or night) (Van Schaik and Griffiths, 1996).

Indeed, the challenges of studying cryptic species is one of the reasons why even the most basic natural history data is lacking for the majority of species in tropical region. Simple automed photography systems have been used for inventories cryptic animals in tropical rainforest (Tobler et al., 2008; Rovero et al., 2014). Hence, camera trapping provides new opportunities for assessing range, habitat use and activity pattern of elusive species with limited knowledge, and improving conservation tools. Through analysis of data from a 9 and 19 month camera trapping campaign, respectively in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, we ascertained how season and lunar illumination affect *A. kuhlii* and *M. muntjak* activity. We specifically tested the hypothesis that Bawean deer and red muntjac will minimize their activity during the one of the season and moon phases when illumination is brighter.

Material and methods

Study areas

The activity of Bawean deer *Axis kuhlii* and red muntjac *Muntiacus muntjak* were monitored respectively in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park (Fig. 1):

1. Bawean deer was studied in Bawean Island, a quite isolated 200 km^2 island in Java Sea (5^{o}40'-5^{o} 50'S; 112^{o} 3'-112^{o} 36'E). 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 and 32°C (Semiadi, 2004), and the mean annual rainfall is 2.298 to 2.531 mm on the southern coast, rainfall is mostly abundant during the northwest monsoon lasting from the end of October until March**.** The protected area of Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS) [of ca. 3.832 ha (wildlife sanctuary) and ca. 725 ha (nature reserve)] is characterized by steep topography (with terrain slopes > 60°) and a wide altitudinal gradient (-11 to 630 meters).
   The main vegetation type is tropical rainforest which can be devided into four major forest types: primary forests, secondary forests, teak (*Tectona grandis*) forests, and shrubs. The

BINR-WS protects the small patch of rainforest in Indonesia (c.a 23% of the Bawean Island**),** including teak plantations (60% of this area), habitat type which is globally endangered due to deforestation and climate change. 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. Moreover, the BINR-WS constitutes one of the last strongholds in the country for endemic medium-large mammalian ungulates such as the Bawean deer *Axis kuhlii* (Temminck, 1836) and Bawean warty pig *Sus blouchi* (Groves, 1981). Although only a tiny island, the Bawean Island, particularly the BINR-WS plays a key role in conservation of medium-large mammals in Indonesia. Unfortunately, land cover change, and more recently, illegal logging an increasing threat to the integrity of the reserve.

2. Red muntjac was studied in Ujung Kulon National Park (UKNP), a peninsula at the extreme southwestern tip of Java Island, Indonesia (6°45'S; 105°20'E). UKNP climate is categorized in type A (Hommel, 1987) within 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 approximately ca.3.250 mm. The heaviest rainfall is between October and April during the north-west monsoon. A noticeably drier period occurs between May and September with ca.100 mm per month during the south-east monsoon. The Ujung Kulon National Park have varied topography (with terrain slopes strepper than 15°) and a wide altitudinal gradient (0 to 620 meters) with large approximately *ca.*120.551 ha: (terrestrial zone: ca.76.214 ha, marine zone, ca.44.337 ha).

   Park's vegetation is a tropical rainforest, which has suffered a number of anthropogenic and natural modifications. It is mainly secondary growth, following the destructive tsunami of 1883. The main habitat types are primary forest, seconday forest, mangrove-swamp and beach forest. 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, primary lowland rain forest, now occupies only 50% of the total area, and is largely confined to the Mt. Payung and Mt. Honje massifs. The UKNP constitutes one of the last strongholds in the country for endemic large mammalian ungulates such as the Javan rhino *Rhinoceros sondaicus sondaicus* (Desmarest, 1822).

Gridding methodology

Field surveys were carried out during 9 months (March to November 2014) and 19 months (January 2013-July 2014) in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park respectively. The sampling periods corresponded to two consecutive season cycles, during wet and dry season. Sampling effort during the survey was 5.500 trap days in BINR-WS and 62.316 trap days in UKNP.

In both study area, positioning of camera-traps adopted the methodology of Karanth and Nichols (1998). We positioned cameras in a way to cover the whole study area by applying a buffer equivalent to half of the mean maximum distance moved (1/2MMDM). This means that any individual in the study area had a probability greater than zero to be photographed by at least one camera. Because our goal was the monitoring of both of species in the whole area of each study area and obtain as many photographs as possible in each grid, when a camera did not capture any object (zero presence), we changed its location in the same grid. According to the proportion of large areas and representation of major of forest types, BINR-WS area was divided into 20 trap stations 2-km^2 and UKNP area was divided into 329 trap stations 1-km^2 (Figure 1). Cameras were checked once every 21-30 days, including replacing battery and memory card, and even the camera trap in case of malfunction in order to avoid loss of data. Each photograph of an animal was identified to species, and if the quality of the photograph did not allow absolute identification the photograph was excluded from the dataset. Sequental frames of the same spesies were counted as one photographic event, and unless individual identification was possible, any subsequent photograph of the same species taken within one hour of the first was not considered a new photographic event.

Camera traps with heat-in-motion detectors were used to continuously record the activity of the target species and set to record date and time of all photos, working continuously over the 24-hour. We deployed 20 units of Bushnell Trophy Cam HD Max analog cameras in BINR-WS, cameras were mounted on tree, positioned 30-50 cm above the forest floor to record both small-large animals. While in UKNP, we deployed 108 units Bushnell Tropy Cam 119467 and Bushnell Tropy Cam 119405 analog cameras. Cameras were positioned at 170 cm above the ground with an angle 10-20 degree lead to the ground (followed standard design of camera trapping by Rhino Monitoring Unit [RMU] team) to survey the Javan rhino *Rhinoceros sondaicus sondaicus*. Although there are differences of placement of camera trapping in both of study areas, we believe it does not affected to the captures probability. However, camera-trapping capture showed the presence of all the species that exist in BINR-WS and UKNP, particularly for small-large sized mammals. All camera trap locations were under closed canopy forest which enables us to assume that the minimum variation in light penetration did not effectively influence our results.

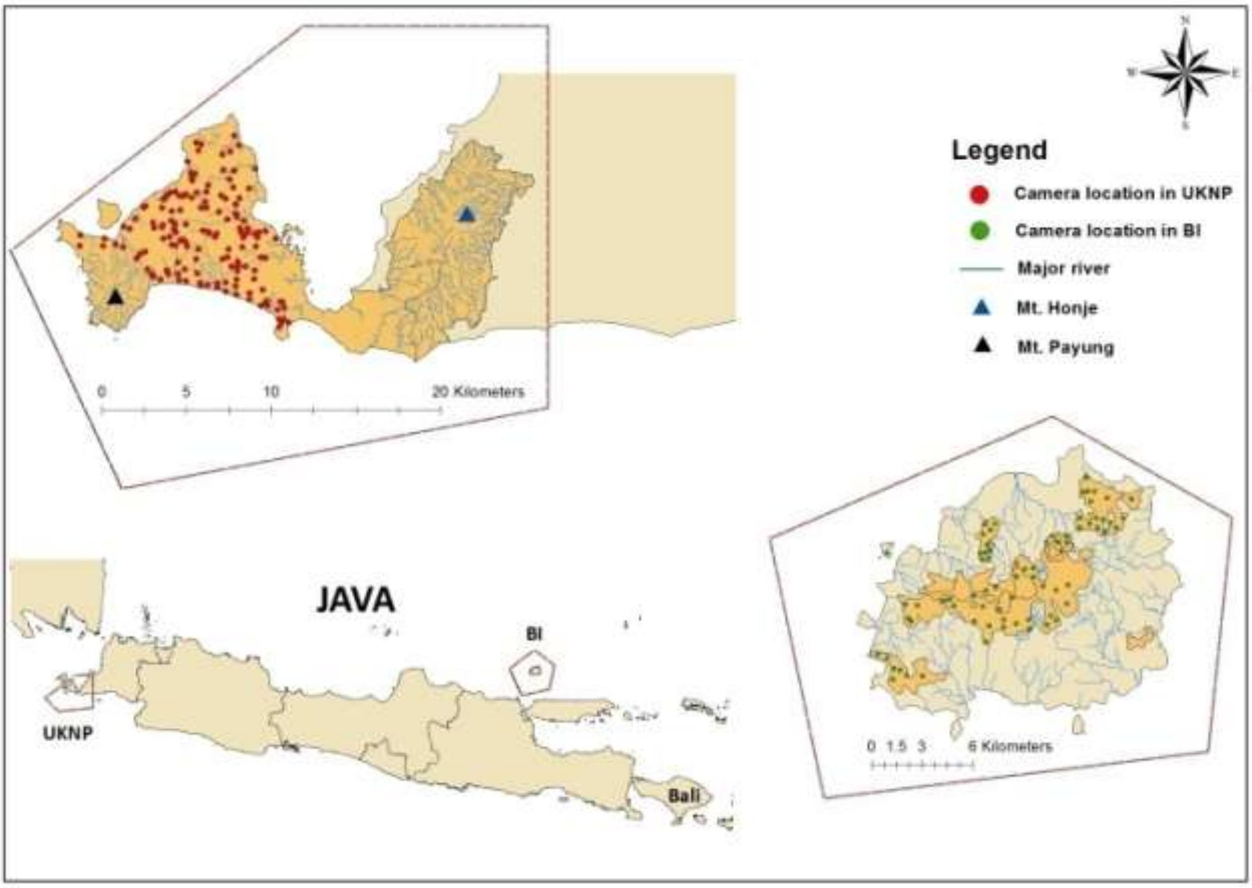


Figure 1. Location of the two areas (BI: Bawean Island; UKNP: Ujung Kulon National Park) in Java, Indonesia where we studied the activity patterns of Bawean deer and red muntjac, respectively.

Data analysis

Temporal patterns of activity

Since it is possible to record the time and distinguish sex when each photo is taken to describe daily activity pattern with a level of detail. We used every camera location from each species site as an individual sample unit. Activity was defined as the proportion of number photographs per hour. We used only the first deer photograph captured in each hour; subsequent deer photographs during the same hour were disregarded and then grouped the number of Bawean deer and red muntjac events per hour of the day and tested the null hypothesis that both deer activity was uniform throughout the day, applying the Rayleigh test (Batschelet, 1981; Zar, 2010). The program Oriana V4.05 (Kovach Computing Services, 2012) was used to apply this test. To complete this analysis we grouped Bawean deer and red muntjac events in three periods: diurnal, nocturnal, and crepuscular (dawn and dusk). Diurnal (one hour after sunrise to one hour before sunset), nocturnal (one hour after sunset to one hour before sunrise), dawn (from one hour before to one hour after sunrise), and dusk (from one hour before to one hour after sunset) (Theuerkauf et al., 2003). Differences in the activity between sexes and times of the day were evaluated using Chi-square tests. Two-factor analysis of variance were using to tested differences in levels of activity among daily time periods and seasons. For the seasonal analysis data were pooled into 3-hours periods, to obtain a larger an more uniform number of activity fixes in each period. We used Tukey's honestly significant difference test to evaluate variation differences in the frequency of events for each periode. Results were considered significant if alpha < 0.05.

Moon phase and activity

Moon phase was enumerated for each calendar day of the sampling period using the software Quickphase Pro 3.3.4 (BlueMarmot.com). The effect of moonlight on activity was obtained by assigning 1 of the 4 moon phases to each day. Following Batschelet (1981), we used circular statistical analyses for temporal data that follow a cycle. The Rayleight tests were used to test whether Bawean deer and red muntjac captures were randomly or uniformly distributed along lunar cycle. We used Kuiper’s test to test whether the daily frequency distributions of captures of two different samples (new moon vs full moon) have the same distribution (Batschelet, 1981).

Results

Temporal pattern of activity

We recorded 118 photographs of Bawean deer in wet and dry season, respectively (6 vs 112 photographs) and 4363 photographs of red muntjac in both season (wet = 1614 photographs vs dry =2749 photographs) (Table 1). Bawean deer and red muntjac were captured in different events. Bawean deer captures was uniform, while red muntjac was not uniform or random during two season. The percentage of total photographic events occurring during each hour of a 24 hour day was considered a proxy to the activity patterns of both species and indicates resource partitioning between two deer species (Figure 2). Bawean deer activity pattern not varied significantly with time of day (F= 0.197, $df.$ = 2, P > 0.05) and also did not vary among seasons (F = 0.644, $df.$ = 1, P = 0.425; Figure 3A). There was no interaction between time of day and season in all activity levels (diurnal F = 1.179, $df.$ = 2, P = 0.281; nocturnal F = 0.095, $df.$ = 2, P = 0.759; crepuscular F = 0.047, $df.$ = 2, P = 0.828). Based on the Rayleigh test, we approved the null hypothesis that Bawean deer activity was distributed uniformly throught the day (Z=2.22; P> 0.106). Bawean deers were active throught most of the day. Although males of Bawean deer tended to show higher of uniformly throught the day than females at Bawean Island Nature Reserve and Widlife Sanctuary (Figure 4A), we detected no significant differences in activity patterns (χ^2=19.72, d.f.=23, p=0.476). Most montly activity occurred in June and August (Figure 5A)

Table 1. Total number of Bawean deer *A. kuhlii* and red muntjac *M. muntjak* records, respectively from March to November 2014 in Bawean Island Nature Reserve and Wildlife Sanctuary and from January 2013 to July 2014 in Ujung Kulon National Park, Indonesia.

Species	Trap days	Number of photographs				Sex ratio[a]
		Males	Females	Fawn	Unsexed	
Axis kuhlii	5.500	76	29	23	10	2.62:1
Muntiacus muntjak	62.316	2279	1663	84	116	1.37:1

[a]Adult sex ratio (M/F)

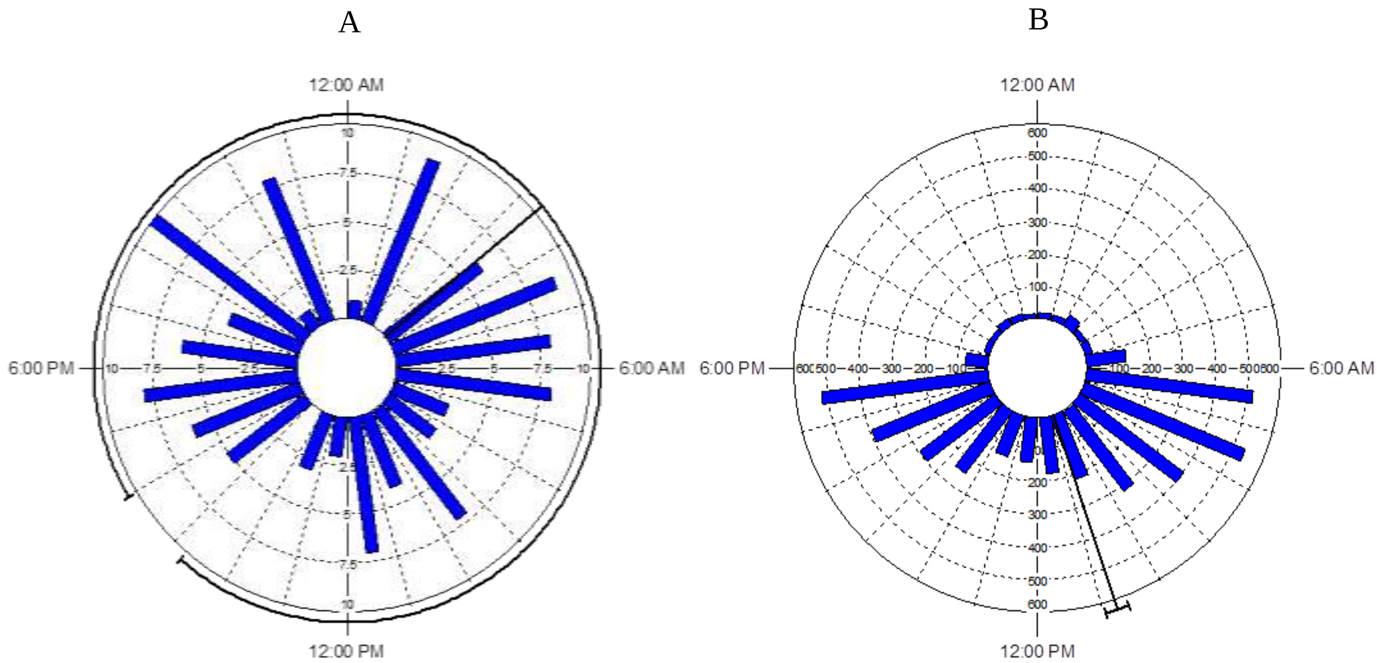


Figure 2. Circular histogram illustrating the distribution of deer activity by camera traps throughout the day. Lighter blue bars indicate levels of activity of A) Bawean deer, and B) red muntjac. Radius and arc indicate, respectively, location of average hour of activity and its 95% confidence interval.

While, for red muntjac, activity varied significantly with time of day *(F*= 344.92, *df.* = 2, *P* < 0.01) and also did vary among seasons *(F* = 13.33, *df.* = 1, *P* = 0.00281; Figure 3B). There was interaction between time of day and season in diurnal activity levels (*F* = 54.48, *df.* = 2, *P* = 0.00), but no for nocturnal and crepuscular activity levels *(*respectively: *F* = 0.317, *df.* = 2, *P* = 0.57; *F* = 0.991, *df.* = 2, *P* = 0.319). Tukey post hoc comparisons (at *P* < 0.05) indicated that diurnal *(M* = 4.745) was significantly greater than nocturnal *(M* =1.445) and crepuscular *(M* = 2.112) activity levels *(P* < 0.01). Based on the Rayleigh test, we rejected the null hypothesis that red muntjac activity was distributed uniformly throught the day (*Z*=756.85; *P*< 0.01). Male and female of red muntjacs show diurnal activity levels with higher peaks during more less one hour after sunrise until one hour before sunset (Figure 4B), we detected no significant differences in activity patterns (χ^2=31, d.f.=23, p=0.948) and mostly activity occurred during August and September for both sex (Figure 5B).

Moon phase and activity

The frequency of Bawean deer captures was not uniform or random during the lunar cycle and increased during full moon lunar phase for Bawean deer when lights is at maximum on the forest floor. Contrary, the frequency of red muntjac captures was distributed uniformly (Rayleigh test, Bawean deer: *Z*=51.21, *P*< 0.05; red muntjac *Z*=6.57, *P*> 0.253; Fig. 6). Bawean deers tend to be more active during the day and start their activity later on days with a full moon, but the frequency distribution of daily captures is not statistically different from the one observed on days with a new moon for both of species (Kuiper's test, Bawean deer: *k*=154, n_1= 47, n_2 = 23 *P*> 0.28; Fig. 7A and red muntjac *k*=1318, n_1= 714, n_2 = 861 *P*> 0.68; Fig. 7B).

Discussion

Several authors have previously noted the activity pattern of Bawean deer and red muntjac. Blouch and Atmosoedirdjo (1979; 1987) noted that Bawean deer is primarily nocturnal, emerging from dense cover just after dark (around 18:00 hours) and being active intermittently throughout the night. Peaks of activity occur approximately every two hours, usually separated by retreats into cover. As the night progresses, foraging periods become shorter and rests become longer, until the animals retire back into dense cover at sunrise. At night they move into more open forest areas or grasslands and cultivated area. These result are also similar to those recorded by Semiadi (2004), individuals are occasionally seen on the beach in the southwest of the island or along the river at dusk until night period, but otherwise are rarely seen directly, as well as the observations by Semiadi (2004) on captive animals. While activity patterns of red muntjacs vary considerably, in Taman Negara, Malaysia, studies by Kawanishi and Sunquist (2004) using camera-trapping noted that red muntjac to be diurnal. They show cathemeral activity (sporadic and random intervals of activity during the day or night) peaks in Gunung Leuseur, Sumatra (Van Schaik and Griffiths, 1996) and also in East Java (S. Hedges pers.comm. 2008), there some variation between localities in balance of day and night activity.

A

B

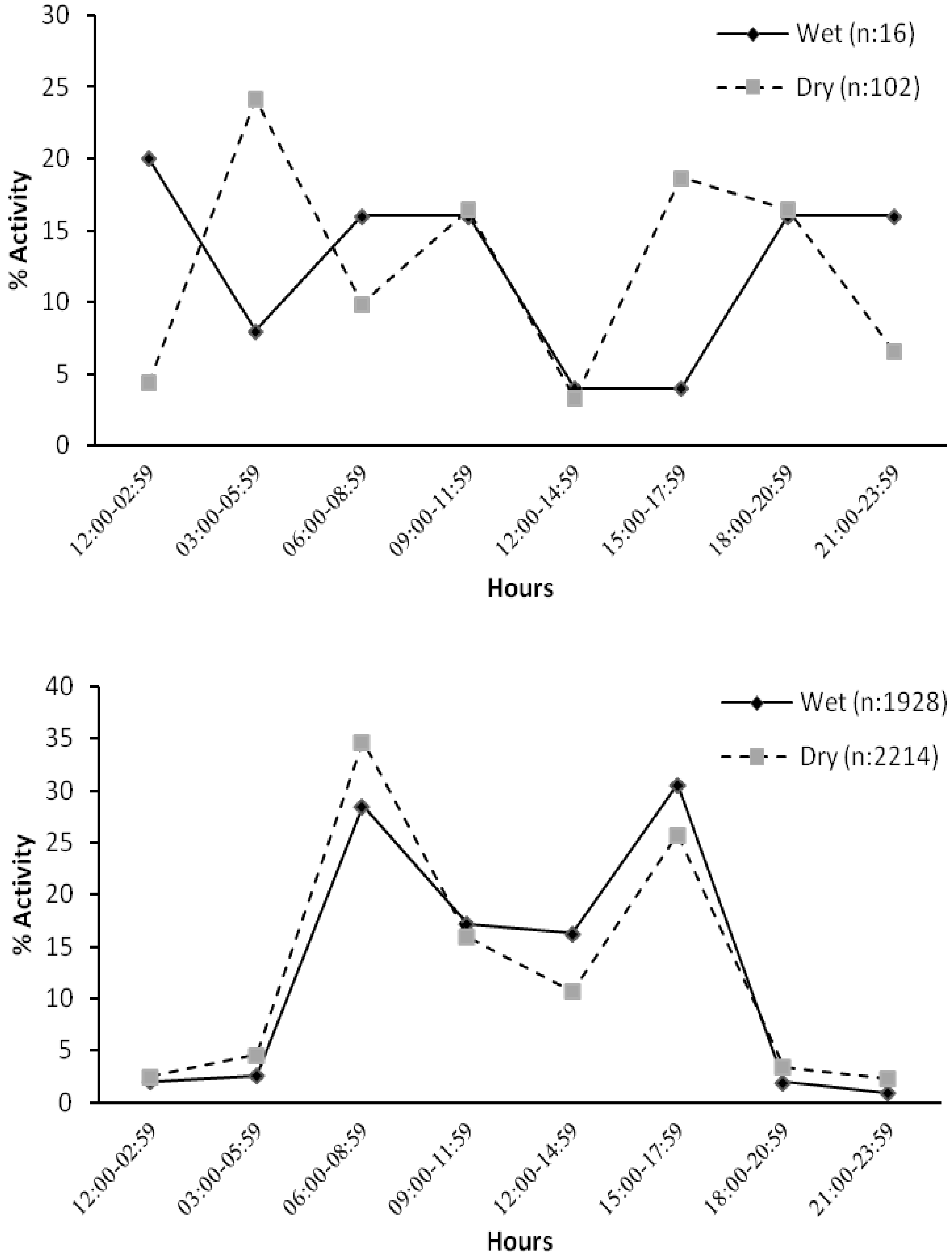
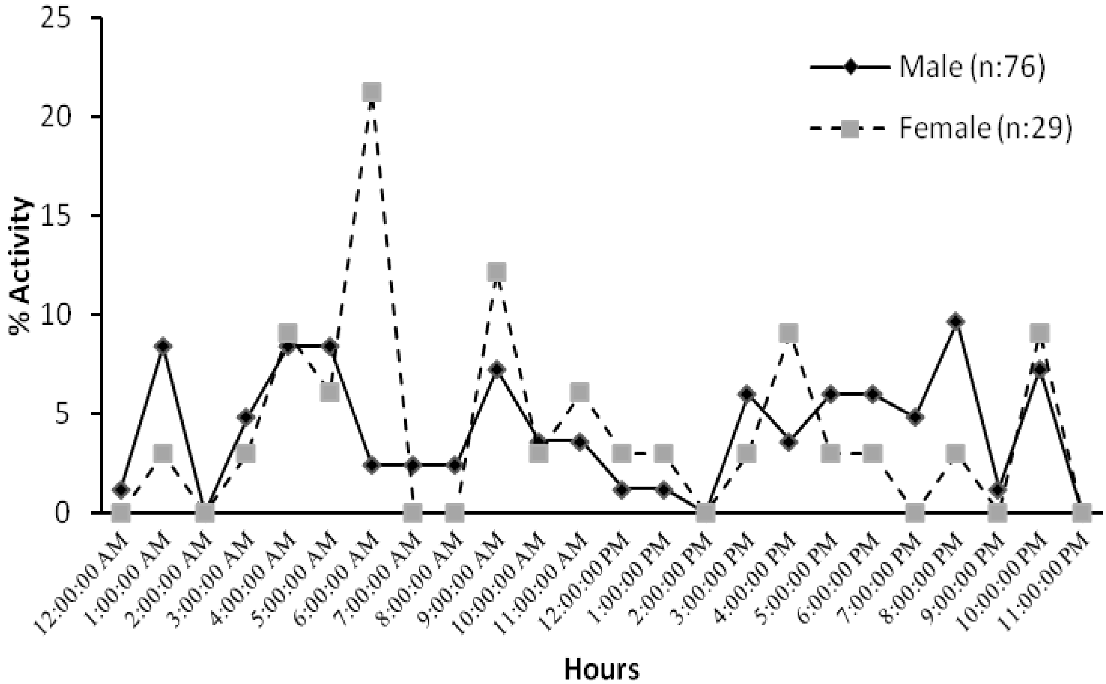


Figure 3. Pattern of seasonal activity of A) Bawean deer and B) red muntjac in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, respectively. *n*: total number of captures.

A



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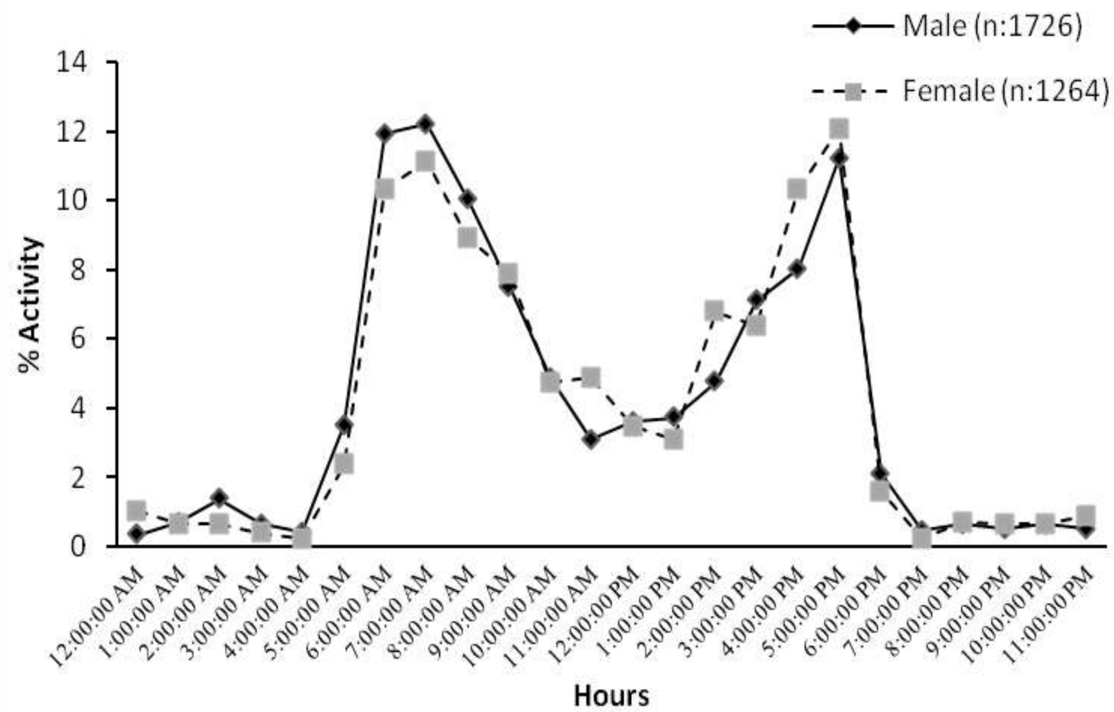


Figure 4. Pattern of intersexual daily activity of A) Bawean deer and B) red muntjac in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, respectively. *n*: total number of captures.

A

B

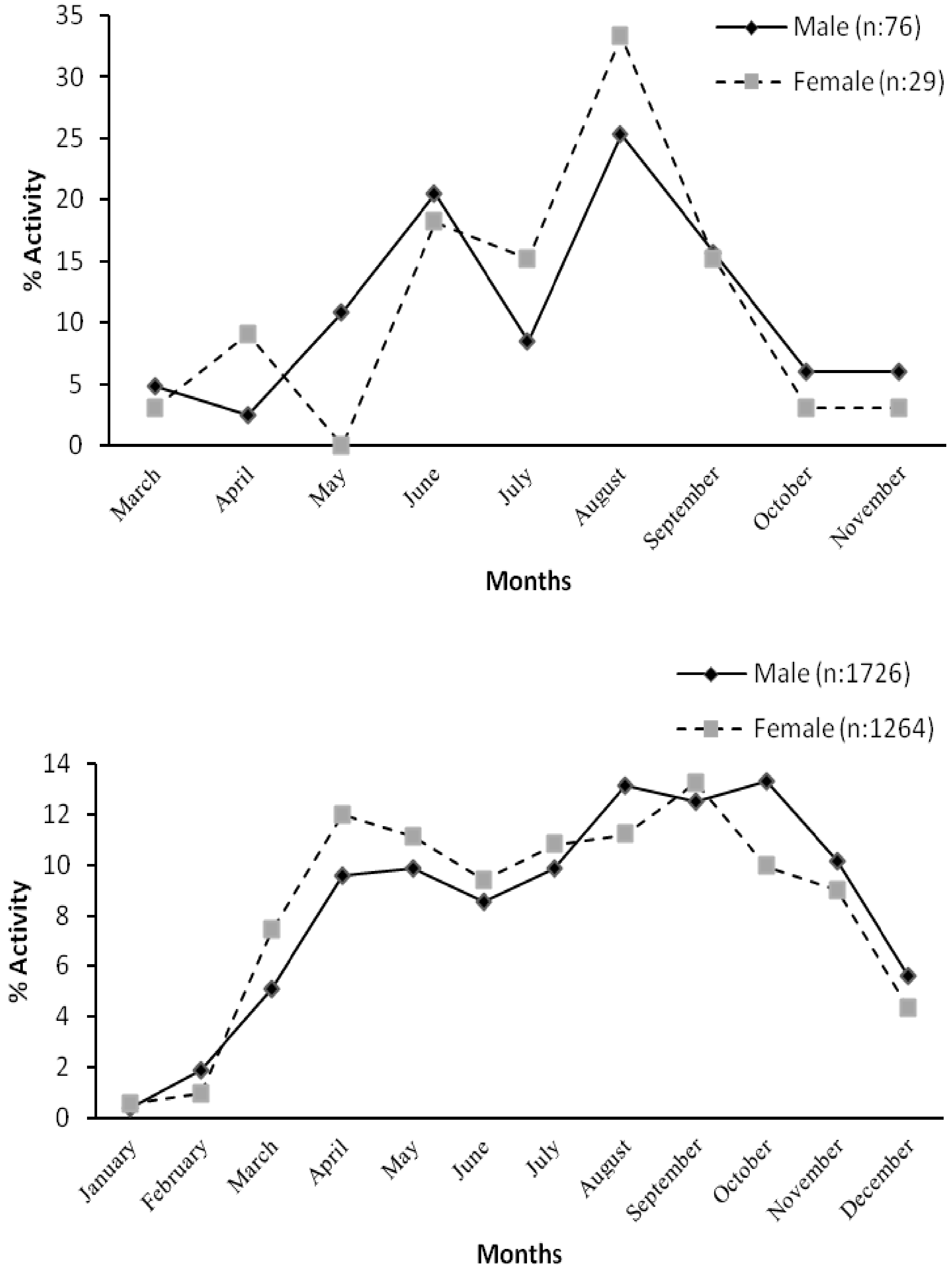


Figure 5. Pattern of intersexual monthly activity of A) Bawean deer and B) red muntjac in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, respectively. *n*: total number of captures.

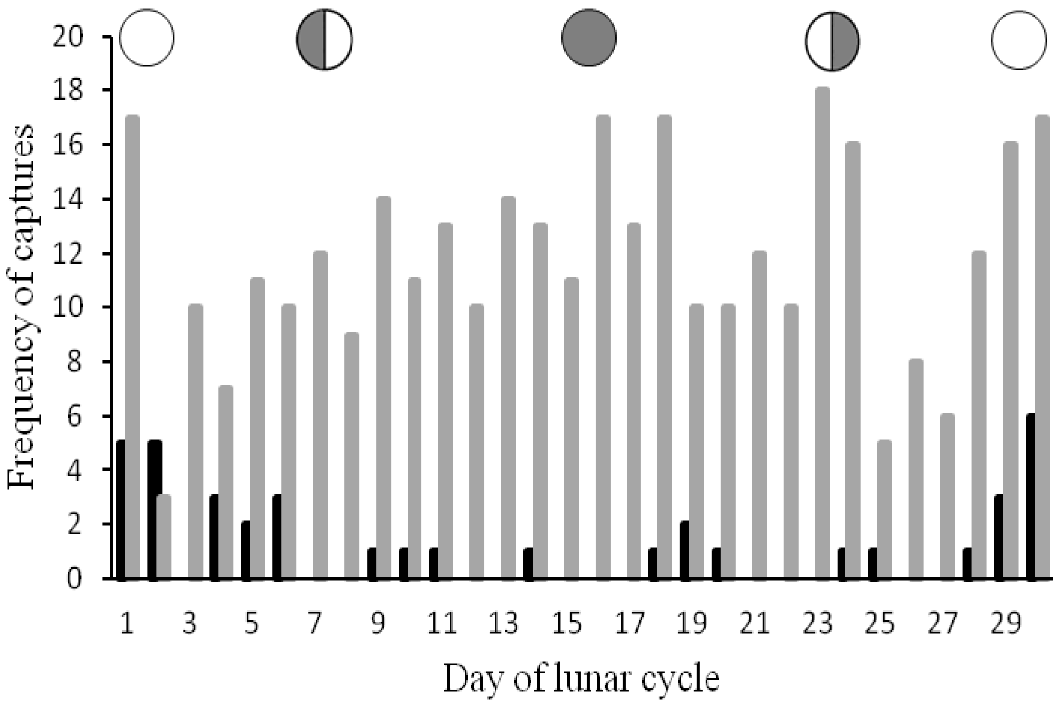
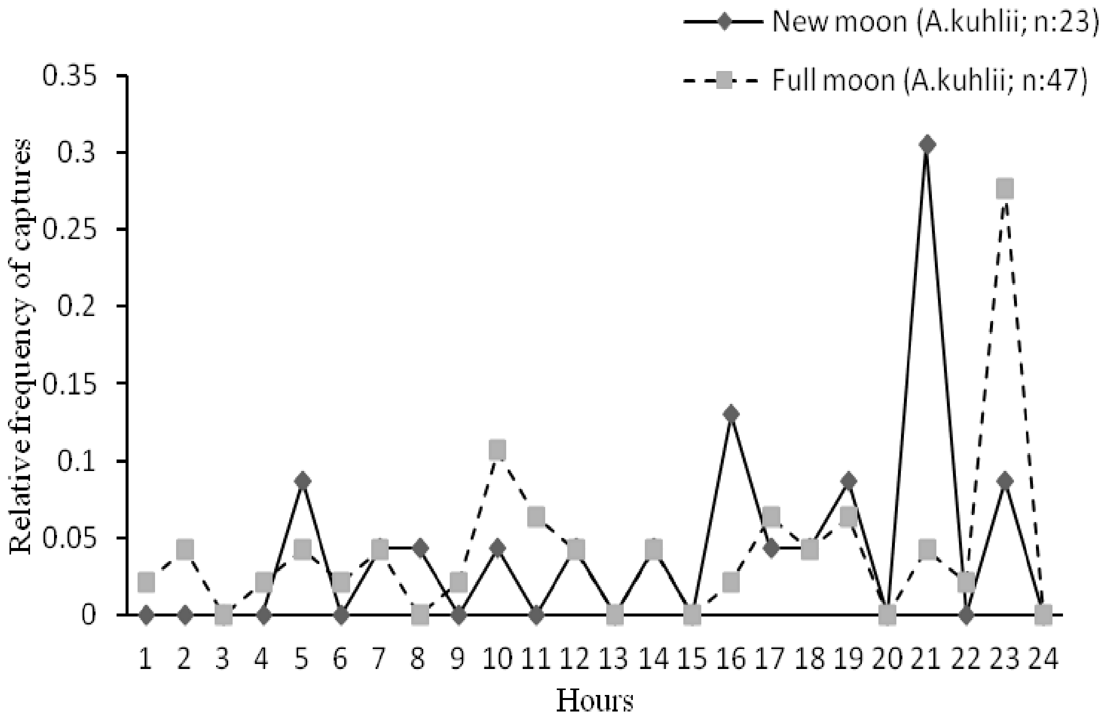


Figure 6. The frequency of Bawean deer (black bars) and red muntjac (grey bars) captures varies along the lunar cycle during the higher peaks of photographs number period (11 August to 9 September 2014 for Bawean deer and 23 July to 21 August 2013 for red muntjac).

A



B

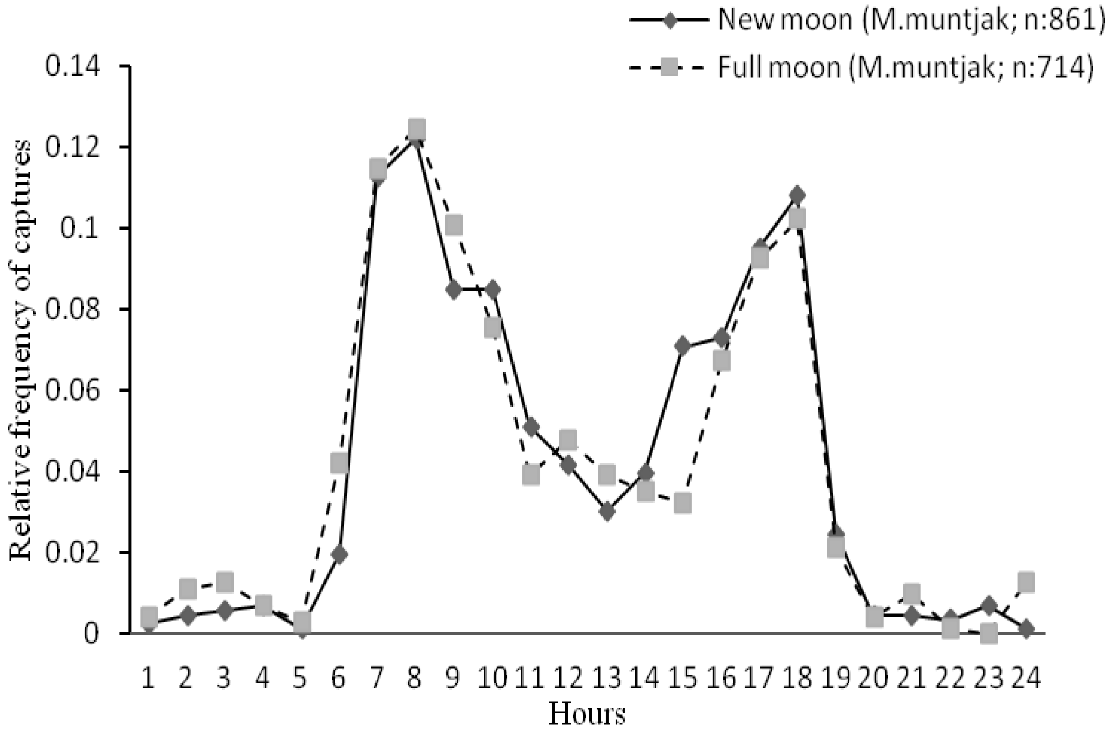


Figure 7. Daily activity patterns of A) Bawean deer and B) red muntjac in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, respectively on new moon and full moon nights.

Contrary to our prediction, the patterns of activity were discrepant result with previous research by Blouch and Atmosoedirdjo (1979; 1987) and Semiadi (2004), we found that Bawean deers were significantly active uniform throughout the day with peak activity in 6-7 am and 8-9 pm. We suggest that the strict resemblance in the activity patterns of Bawean deer may be to due the absent of natural predators except large reticulated pythons (*Python reticulates*). However, pythons are not common and likely have little impact on the deer population (Blouch and Atmosoedirdjo, 1987). Killing a young fawn may have occurred by wild boar or macaques in our study, but no evidence has been found to support this (Blouch and Atmosoedirdjo, 1987). Feral dogs are currently the greatest cause of mortality to this species, being responsible for 9 out of the 11 deaths examined by Blouch and Atmosoedirdjo (1987) during October 1977 and May 1979.

In fact, human-wildlife conflicts, fragmented landscape and predation by feral dogs across our study in BINR-WS region are responsible for mortality of Bawean deer. However, most of the deaths occurred in area between the edge of protected areas and settlements or cultivated area. Between the time of study, we found more less two case of death of Bawean deer cause by feral dogs, but these case of deaths is much lower when compared with the era before 1990, hunting has led to high population declines in the past. As a consequence, we guessed based on the result of camera trapping, Bawean deers may be adopting a more flexible behaviour, with absence of natural predator and hunting activity by human from the limiting effects of predator risk. In addition, This finding might suggest that the presence of Bawean deer throught the day in some areas in BINR-WS where forest was harvested until now suggests some degree of tolerance of this species to selective logging. Recently, our study found that there is a tendency that Bawean deer distribution becomes closer to settlements. However, a definitive testing of this assumption requires documenting Bawean deer activity patterns in other areas more exposed to human impact, such as those located outside and on the border of the Bawean Island Nature Reserve and Wildlife Sanctuary. Therefore, reduced predator risk enables Bawean deer to be active across the entire lunar cycle, without the need to avoid strongly illuminated nights.

In Ujung Kulon National Park, activity pattern of red muntjacs are seems to be more related to the activity of predation by leopard and dhole than hunting or habitat disturbance. In this study, activity of red muntjacs opposited with periods when their main predator forage in terrestrial. We found that the activity peaks for the red muntjac is to be mostly diurnal, whilst leopard *Panthera pardus* as a main predator being widely known as a nocturnal animal, the leopard is also active during the day and should be reclassified as diurnal. We found there were several images taken of the leopard during the day. In our study this would indicate that the leopard's travelling activity pattern for hunting was during early morning to mid-day and declined in the evening hours. As a carnivore, it is advantageous for the leopard to be most active during the hours when its prey is most active. It is similar with dholes were almost exclusively diurnal. Poaching levels are lower than in the last 20 years ago seems to provide an opportunity for the population to survive and continue to grow. During the study, we not found poaching activity except for bird. However, there is no strong evidence that either hunting or habitat disruption are actually threats to the survival of populations except in the case of islands such as Singapore, where it is now extinct (Baker and Lim, 2008). Peak densities are not in pristine forest (see habitat and ecology), and in Danum Valley (Sabah, Borneo), an area with negligible hunting, *Muntiacus muntjak* strongly increased in densities after logging (Davies et al., 2001); a weaker increase was found by Duff et al. (1984). Eventhough, even quite severe habitat disruption can increase ecological carrying capacity for this muntjac, but need to be aware, it seems possibly only temporarily.

It is know that the time dedicated by animals to searching for and obtaining food is inversely proportional to its abundance (Chappel, 1980). If this type of behaviour was the principle factor affecting the quantity of time spent active by Bawean deer and red muntjac, the lower activity level in wet season at each study site might be related to greater availability of food. In most tropic habitats, food are assumed to be uniform throughout the year (Foster, 1973; Frankie et al., 1974), but become scarce over the dry season (Pontes and Chivers, 2007). Study by Esparza-Carlos et al. (2011) might explain that, during the wetter year, food resources became unimportant while cover and visibility explained deer habitat use. The fact that the number of capture by camera trapping were found to be less for males and females of both deer in wet season is likely to be associated to the finding that food are become to be abundant, consequently deer reduced their activity and moved to be less. Alternatively, the maximum activity in dry season at both of study site, could also reflect the different reproductive tactics in males and females of solitary deer (Blouch and Atmosoedirdjo, 1978; Kitchener et al., 1990). Whereas the increased activity of females may be the effect of greater energetic requirements to feed their weaned young (the birth season for both deer occurs from February to June; Blouch and Atmosoedirdjo, 1978; Kurt, 1990), males may be induced to increase their level of activity to devote more time in activities related to the marking and maintenance of territory in response to the presence of dispersing juveniles (Oka, 1998; Kitchener et al., 1990).

We finding that Bawean deers tended to be more active in bright nocturnal periods than when the night was dark at BINR-WS was contrary to our hypothesis. In contrast to the hypothesis we adopted, some authors have reported that moonlight may act indirectly on the behaviour of ungulates by increasing their rate of movements in brighter nights increased difficulty to obtain food (Beier, 1990; Birkett et al., 2012). An alternative explanation is associated to the trade-offs between food and safety that the risk of predation. The absence of natural predation may be influenced to movement increasingly in above of moon light to obtain food, even though when the night was dark. Unlike Bawean deer, red muntjac activity did not vary with the level of moonlight, to be more inactive in bright nocturnal periods and when the night was dark at UKNP because they may become more visible and detected by predator species, this is likely a strategy to avoid leopards and dholes. Harmsen et al. (2011) showed that armadillos and pacas appear to further reduce predation risk by lowering their activity during bright moonlight nights, as has been observed in many smaller rodent species (Daly et al., 1992; Kotler et al., 2004).

We believe that this amount of differences between two similar-sized species, Bawean deer and red muntjac, can be explained by a difference in the exploitation of resources, habitat disturbance and behaviour to avoidance of predator. Daily activity patterns can have consequences for an animal’s predation risk (Kronfeld-Schor and Dayan, 2003) and foraging success (Rijnsdorp et al., 1981). Predators are believed to have higher hunting success when prey are mobile (Avgar et al., 2011), so increased ungulate activity at dawn and dusk could provide predators with a useful means of enhancing predation success by investing hunting effort during periods of increased prey activity.

Acknowledgments

We wish to thank team of Rhino Monitoring Unit (RMU) in Ujung Kulon National Park and all team member in Bawean Island Nature Reserve and Wildlife Sanctuary that contributed with data collection. We are thankful to BBTNUK and BBKSDA of East Java, Ministry of Environment and Forestry, Republic of Indonesia for providing research license in UKNP and BINR-WS. Financial and logistical support was provided by Rufford Small Grants Foundation. Postgraduate scholarships and funding was provided by Directorate General of Higher Education, Ministry of Research, Technology and Higher Education, Republic of Indonesia.

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GENERAL DISCUSSION

CHAPTER 6

GENERAL DISCUSSION

I. SYNTHESIS OF MAIN RESULTS

The main topic of this study concerns the collection of basic information on the ecology and population status of the Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park, one of the last refuges for this and other medium-large mammal species in the island tropical rainforest. The originality of this work is based on the compared use of camera trapping and classical field work to estimate population density and investigate habitat use, predicted range and activity patterns. Our results give clues about environmental conditions and key resources which need to be protected for the persistence of this remote and enigmatic species of deer. They also provide support for the application of novel approaches to handling small, sparse and incomplete data sets that are commonly obtained for mammals inhabiting tropical areas. This support was reinforced by testing the same methods on another medium-sized deer, the red muntjac, in a similar nearby context, within insular rainforest. To my knowledge, this is the first camera-trapping-based analysis on two species of tropical cervids.

My main results are summarized below.

• **PAPER 1:** As expected, camera traps are expensive but they lighten the load of field work and provide a great deal of information for further analyses. Camera trapping delvered a high number of records and accurate species identifications, including Bawean deer, whereas transect sampling and faecal pellet group count were time consuming in the field, for limited results. Transect sampling revealed to be poor efficient when applied to a remote species living in the tropical rainforest. Faecal pellet group count is probably the most limiting of the three methods. It is dependent on field conditions at sampling plots, substrate and vegetation type, as well as on climate, which induces a great variability in faecal decay rate. However, this technique can be used alongside camera trapping, as it recorded Bawean deer in three locations where no photograph was taken. The budget analysis showed that after a heavy initial investment, camera trapping is cheaper than the other techniques.

• **PAPER 2:** Random encounter model **(**REM) proved to be effective for estimating density of elusive, rare and unmarked species contrary to photographic capture-recapture techniques, which require both unique markings and good photographs for individual recognition. In addition, estimations by REM were more precise (narrower confidence intervals) than those obtained using faecal pellet count. Both methods provided similar population density estimates for Bawean deer: highest in the dry season, with a population size of ca. 227-416 deer. The range of Bawean deer proved to be dramatically narrower than previously reported. The main threats, habitat loss due to illegal logging and human disturbance by dogs and hunters, are ongoing. Based on these results, we suggest that the IUCN Red List status should remain "Critically Endangered".

• **PAPER 3:** Camera trapping was performed in different habitat types during both wet and dry seasons to record Bawean deer and red muntjac. The highest number of photographs (and highest photograph encounter rate) was recorded in secondary forests and during the dry season. In models, anthropogenic and climatic variables were the main predictors of habitat use for both species. Distances to cultivated area and to settlements were the most important variables for Bawean deer. Distance to cultivated areas and annual rainfall were significant for red muntjac. Important areas for conservation were identified, accounting for habitat transformation in both study areas.

• **PAPER 4:** The activity pattern of mammalian ungulates is regarded as being primarily influenced by sex and reproductive status, environmental conditions, predation and behavioural thermoregulation. Male and female Bawean deer were active throughout the day and night whatever the season, with several peaks of activity during the 24-h period. Their amount of nocturnal activity was related to nocturnal luminosity. Male and female red muntjac show diurnal activity levels peaking during ca. one hour after sunrise and one hour before sunset. No difference was recorded between males and females for either deer species. For both sexes and species, the number of photographs was higher in the dry season. The activity pattern of both species can be closely related to predation risk and foraging success.

II. DISCUSSION AND PERSPECTIVES

II.1. Methodological considerations – field methods

This study provides the first data on the comparison of three monitoring techniques applied to investigate a wild population of Bawean deer, based on cost-effectiveness analyses.

I could not include the results of the red muntjac analyses in **Paper 1**, due to the urgency in assessing Bawean deer populations with a 'critically endangered' status. There is no doubt that the 4,363 records of red muntjac collected during the 19 months (versus 118 records of Bawean deer collected over nine months) could support an accurate population estimate of this deer species in UKNP. Additional analyses showed that there is a similarity between the data generated by each method in both populations, which is better shown through camera trapping than through the other techniques. Nevertheless, the failure rate in capturing the object by camera traps was quite high in BINR-WS: 5406 photographs in 5500 day traps. These photopraphs mostly showed objects such as leaves or twigs that are moving due to wind or rain. Capture rate was low, particularly in the wet season. However, camera trapping performed well relative to other methods which have been used to derive absolute Bawean deer densities in the past. Estimates were more precise (i.e., narrower confidence intervals) than those obtained faecal pellet count (**Paper 2**). Besides, the limited amount of data available for the Bawean deer population makes it a good example for assessing the appropriate method.

This study has demonstrated that camera trapping is a successful method for recording evidence of elusive species which were previously thought to be difficult to study. Following a precise path for a transect sampling survey can be problematic in difficult terrain, as in many areas of BINR-WS, while clearing pathways through dense vegetation could be hard work and prove detrimental for data collection (Walsh and White, 1999). Moreover, transect sampling yielded very limited data. Faecal pellet count was more successful and collecting faecal pellets allows investigation of aspects other than occurrence and abundance, such as genetics, diet, hormone status, or diseases (Kohn and Wayne, 1997). Studies that intend to investigate these aspects in a very rare animal should consider the effort required to obtain a large enough sample to answer specific research questions.

In this way, camera trapping also provides auxiliary information for the study of deer behaviour, habitat use and space partitioning between deer and other mammal species. Camera trapping proved, therefore, to be a very effective method to investigate a range of aspects of deer ecology and more effective than even multi-year faecal collection. However, while the number of presence detections per unit effort may be higher for faecal pellet counts than for camera trapping in some instances, many simultaneously operational camera traps accumulate a larger amount of effort more rapidly. It is this characteristic that makes camera traps more suitable to investigate occurrence or population parameters of species at very low densities, such as in the case of the Bawean deer population.

Considering the effectiveness of surveys, the dry season was the most productive and appears to be the best season to perform surveys with camera traps (see **Paper 2, 3 and 4**). In most tropical habitats, food availability is assumed to be uniform throughout the year (Foster, 1973; Frankie et al., 1974), but can become scarcer during the dry season (Pontes and Chivers, 2007), leading to broader movements. Increased food availability has been shown to reduce movements, distributions and home range sizes in deer (Jerina and Krofel, 2012) and early successional forests in dry season undoubtedly offered preferable, higher quality grazing to deer in our study area.

In conclusion, while camera trapping and faecal pellet collecting yielded complementary information, the former seems more effective for studying several aspects of ecology in animals occurring at very low population density. Indeed, faecal pellets can provide a range of valuable information; however, in very rare species, the effort to collect an adequate number of samples to perform statistical analyses may be considerable, both logistically and financially. As faecal pellet counts have repeatedly been advocated as the most effective method to study elusive deer (Forsyth et al., 2007), researchers should keep the limitations of this method in mind. Both methods assessed the highest densities in the dry season, a result that was already reported by Blouch and Atmosoedirdjo (1978) and which supports the hypothesis of a lower movement activity in the wet season.

II.2. Assessing population size and distribution of Bawean deer using three approaches

II.2.1. Capture-recapture techniques coupled with camera trapping: a possible approach for species without conspicuous individual markings

In my study, one of the main objectives of camera trapping was to estimate the size and/or density of deer population in a given area (**Paper 2**). This study provides the first attempt and some recommendations to determine population size and status conservation of Bawean deer using camera traps coupled with faecal pellet count. In the last decade, camera trapping, in combination with capture-recapture (CR) models, has proven useful not only for large carnivores with conspicuous individual marks, such as tiger (*Panthera tigris*; Karanth, 1995; Karanth and Nichols, 1998; O'Brien et al., 2003), jaguar (*Panthera onca*; Silver et al., 2004), leopard (*Panthera pardus*; Balme et al., 2010) and Sunda clouded leopard (*Neofelis diardi*; Wilting et al., 2012), but also for smaller carnivores like ocelot (*Leopardus pardalis*; Dillon and Kelly, 2007), leopard cat (*Prionailurus bengalensis*; Mohamed et al., 2013), ringtail (*Bassariscus astutus*; Gerber, 2010) and species without immediately conspicuous individual markings such as cougar (*Puma concolor*; Kelly et al., 2008; Negrões et al., 2010) or maned wolf (*Chrysocyon brachyurus*; Trolle et al., 2007). Tapir (*Tapirus terrestris*) and white-tailed deer (*Odocoileus virginianus*) are two ungulate species which do not have natural markings; however Olivera-Santos et al. (2010) and Soría-Diaz and Monroy-Vilchis (2015) have been successfully able to assess reliability in determining the individual identity of both species.

The survey area was calculated based upon the polygon sampled by a camera trap by applying the buffer area covering Half Mean Maximum Distance Moved (HMMDM), as developed by Karanth and Nichols (2002) and O'Brien and Kinnaird (2011). The density was converted based on the size of the survey area, since the program CAPTURE only calculated abundance, not density values. Buffers are usually estimated using the distance between the outermost camera trap station that captures the same individual (Silver, 2004). Hereinafter, I applied another approach to estimate the size of the buffer area, including HMMDM-based telemetry data (Soisalo and Cavalcanti, 2006) or the use of literature information related to the home range of hog deer (*Axis porcinus*; Dhungel and O'Gara, 1991), which is commonly used in the calculation of density using the capture-recapture method. I used home range data from hog deer, which were previously available (obtained from telemetry), to construct the sampling area, because these data are not available for Bawean deer. Lacking data for Bawean deer, the hog deer was selected because 1) the hog deer's body size and behaviour are similar to those of its congeneric and 2) data on the latter species were accurately obtained using GPS radio-collars. It is important to consider this variation in order to make appropriate decisions in management programs. However, in future studies, it would be necessary to obtain the home range of Bawean deer, to improve the accuracy of results.

The number of individuals identified different within two-month periods, ranged from 7 to 11, with a sex ratio of 1:1 and a female:fawn ratio of 3:1. Otis's test (1978) supported the closure assumption in all two-month periods (dry 1 (June-July): z = -0.983, p = 0.072; dry 2 (August-September): z = -1.314, p = 0.125). For the standard closed capture estimates a null and heterogeneity model was the highest values (M_h= 1), and the abundance obtained was from 9.45 ± 1.30 to 15.86 ± 3.24 individuals with an interval of capture probability from 0.08 to 0.25.

My data indicate a wide variation in the number of deer observed, using different sample areas, from 16 km^2 in June-July; 10.25 km^2 in August-September; and 15.70 km^2 based on the home range of hog deer. CR estimated a density of 1.45 individuals per km^2 (SE = 0.14) in June-July, 3.87 individuals per km^2 (SE = 0.09) in August-September. With the buffer areas based on home range radius, I obtained densities of 1.05 individuals per km^{-2} (SE = 0.11) in June-July, 4.24 individuals per km^{-2} (SE = 0.28) in August-September (**Table 6**).

Table 6. Recommended model [(M_o), (M_h)] to estimate abundance and standard error (Ň±SE), capture probabilitity (p), and density (individuals km^{-2}).

Month	Number of identified individuals	Model and value	Ň±SE	p-value	Density in each two-month dry period	Density ± SE (sampling area 15.70 km^2)
Dry 1	7 (4♂, 2♀, 1 fawn))	M(h)=1.0	9.45±1.30	0.08	1.45±0.14	1.05±0.11
Dry 2	11 (6♂, 3♀, 2 fawn)	M(h)=1.0	15.86±3.24	0.25	3.87±0.09	4.24±0.28

I consider these results of deer density to be quite good but overestimate, capable of giving an overview of the Bawean deer's population status. Nevertheless, I believe there is a potential bias due to errors in viewing the photographs. The likely error is related to the quality of photographs (non-evolving natural tags) and associated with a change in natural marks (evolving natural tags). An underlying problem for all deer camera trap surveys is that we do not actually know the true densities of the target population and therefore cannot judge whether we are underestimating or overestimating densities. Calibrating the camera trapping technique would require a camera survey to be conducted in an area with known densities. Increasing the capture probability is also necessary to obtain enough recaptures to conduct capture-recapture surveys. So, monitoring populations of Bawean deer should require an increased sampling effort in future surveys; double camera trapping placement in each site may improve recognition of deer individuals through identification of both right-side and left-side images and get the home range of deer, to ensure this is a robust conclusion.

II.2.2. Camera trapping and random encounter model (REM)

Capture-recapture models provide abundance estimates that are reliable statistically, but show bias in estimates of density due to errors in determining the size of the buffer area. On the other hand, the other approach, based on the rate of contacts between moving animals and static camera traps for unmarked animals, may not be suitable for species with a strong tendency to use landscape features that are rare or under conditions with rare populations (Rowcliffe et al., 2013). Countering this assessment, my study has shown that restricting REM estimation to periods and habitats in which animal movement is more likely to be random with respect to cameras can help to reduce bias in estimating the density of the rare Bawean deer population. The results of both preferentially and randomly set cameras are now shown in Table 1 (**Paper 2**). In June-July the estimate is almost the same. In August-September, both estimates fall within the confidence interval of each other. Nevertheless, I emphasize that, despite this result, our estimates remain biased, highlighting the need for truly random placement with respect to animal movement, as well as reliable estimates of average speed of animal movement and camera detection zone areas.

All parameters related to the estimate by REM, even those hard to obtain (Rowcliffe et al., 2012), should be measured more accurately for Bawean deer in the future. The combination of camera trapping and GPS-telemetry could improve the accuracy of estimates, not only for performing REM, but also for analysing how animal home ranges can affect the size of the sampled area. The camera detection zone should also be investigated in different habitats and seasons, as we measured a lower detection radius in the wet season than in the dry season, which could have affected REM estimates, given that density is directly proportional to this parameter.

There is a big difference in REM results between the two periods (either preferentially or randomly set cameras). I suspect that the increase of trapping rate is related to the availability of edible food plants and the fact that deer might move more during the dry season. Chappell (1980) reported that the time dedicated by animals to searching for and obtaining food is inversely proportional to its abundance.

Our study suggests that REM may be an accurate measure for estimating density of elusive, rare and unmarked species, unlike photographic capture-recapture techniques, which require both unique markings and good photographs for individual recognition. Moreover, REM is a method under continuous improvement (Rowcliffe et al., 2011).

II.2.3. Faecal pellet group (FPG) count

Faecal pellet counts have been widely used and assessed reliably to estimate population sizes of both old and new world ungulates (Wallmo et al., 1962; Franzman et al., 1976; Jordan et al., 1993; Murray et al., 2005; Acevedo et al., 2010; Camargo-Sanabria and Mandujano, 2011; Alves et al., 2013), including Bawean deer in BINR-WS. In the first study conducted by Blouch and Atmosoedirdjo (1978), eight habitats were defined by using permanent study plots and the intensity of deer use (abundance) of each type was estimated (**Figure 20**).

Further studies conducted between 1996-1998 by LIPI [Indonesia Institute of Sciences] and IPB [Bogor Agricultural University] (1999) in several sites across BINR-WS estimated the following densities for each site: Aram-aram 23 ind. /km^2; Muntaha-muntaha 28 ind. /km^2; Kolpo-kolpo 7 ind. /km^2; Mt. Bangkuang 10 ind. /km^2 and Tanjung Cina 118 ind. /km^2. In addition, Semiadi (2004) estimates that the population size is 250–300 individuals on the whole Bawean Island and 11.8 ind. /km^2 in Tanjung Cina, while BBKDA East Java (2009) showed that Mt. Besar has 251 deer, Mt. Mas 155 deer and Tanjung Cina 12 deer. In my study, I counted 30 and 50 faecal groups after 60 days of accumulation, both in wet and dry seasons. I estimated a density of 3.48 individuals km^{-2} (SE = 2.61) in the wet season and 5.18 individuals km^{-2} (SE= 3.61) in the dry season. Population size over the sampled area was estimated at 162 (SE = 122) or 242 (SE = 168) deer in wet and dry seasons respectively. This estimate suggests population stability according to the last estimate.

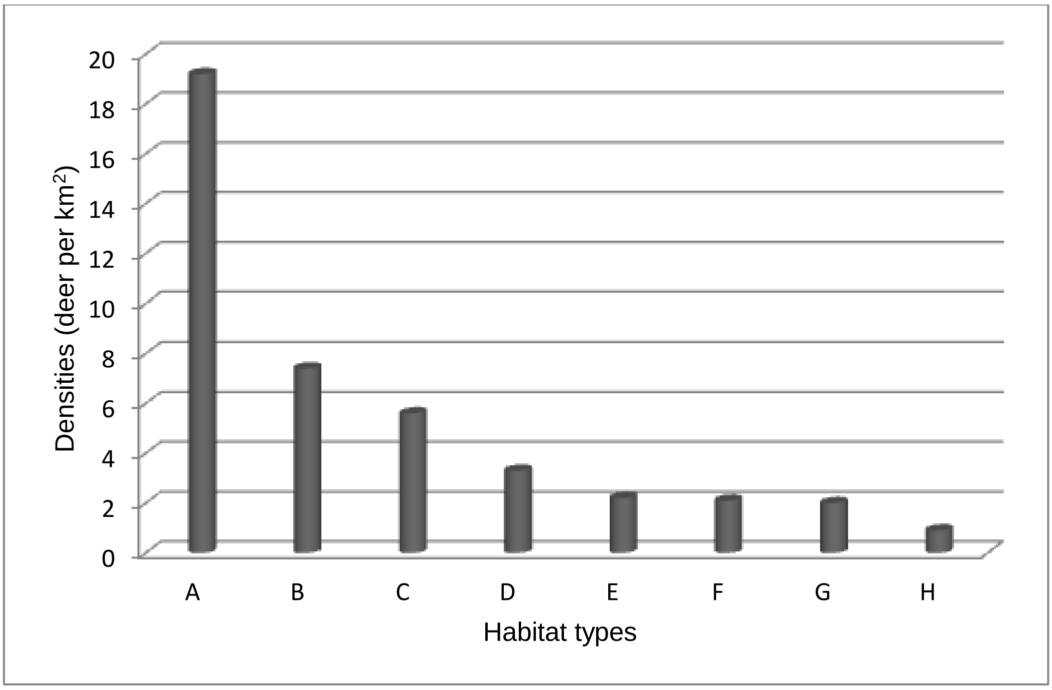

Figure 20. Densities of Bawean deer in various habitats according to the study by Blouch and Atmosoedirdjo (1978), A: secondary forest (19.2 deer per km^2); B: teak with understorey (7.4); C: primary forest (5.6); D: teak with grass (3.3); E: brush (2.2); F: rombok (2.1); G: disturbed primary forest (2.0); H: teak without understorey (0.9).

In most of the previous studies, there was no complete information as to: how many sample sites? How were they distributed over the island? When did this distribution take place? How long were they? A complete record of the information came from a survey conducted by Blouch and Atmosoedirdjo (1978). A total of 323 permanent circular plots of 20 m^2 each were randomly located, from 10 to 50 m apart at three sites. Every month during a year, all plots were searched for faecal pellets of deer; estimation of densities was ccalculated per habitat type. Since pellets tended to be washed away by heavy rain, only those counts made during months preceded by a month with less than 100 mm of precipitation were used. Thus, deer density estimates presented there were typical of habitat use during the dry season. The study by BKSDA and UGM (2009) was conducted by recording the total marks (footprints, ex feeding, antler rubbing in plants, faeces and direct encounter) found on the tracks. The survey was conducted for ten days in the dry season, 12-21 June 2009. The results of these estimates allow a high bias, due to both the questionable protocol being used and the short duration of the survey. As a consequence, I can only use the results of Blouch and Atmosoedirdjo (1978) as a comparison, although there are differences in technical application in the field, but the protocol was properly implemented each time.

FAR population numbers differ considerably between the wet and dry seasons (162 ± 122 and 242 ± 168). As mentioned in **Paper 1**, this difference can be related to the decay rate. Variable decay rate significantly affects the population density and the estimated value of this variable is related to the environmental conditions in the plot sampling. I found that the number of faeces was lower in the wet season than in the dry season. I suspect this is related to the accelerated decay of faeces during the wet season as a result of high rainfall levels and breakdown of faeces by insects and bacteria. Besides, forest floor litter is increased during the wet season, which can potentially reduce detection. I conclude that the best time to carry out a survey by pellet count is in the dry season, when conditions lead to better pellet preservation.

There is quite a big difference between REM and FAR estimates. The possible reasons are given in the second paragraph of the discussion in **Paper 2**. This has been developed in the former answer. I also wrote that we believe the REM estimate should be retained, as it was more precise than the pellet-group count (CV is smaller). Moreover, REM has higher equipment start-up costs but, because it requires little field work, it is cheaper in the long-term than the pellet-group (this is developed in **Paper 1**). Finally, in our study, camera trapping and faecal pellet count proved to be complementary; particularly when discussing distribution, detection through camera traps is not always 100%, so it is useful that faecal pellet count can indicate deer presence. Therefore, in the future, there is a need to develop the standard survey protocol for the faecal pellet count method in BINR-WS.

II.3. Population size, distribution and conservation status of Bawean deer

Bawean deer ranks as one of the rarest animals in the world and is an endemic species to Bawean Island. Historically, there is no strong evidence for the origin of this species or for how the species originally came to Bawean Island. Blouch and Atmosoedirdjo (1987) guess that hog deer are the ancestors of this species, originally brought over by European traders. But since the discovery of fossil *Axis oppenoorthi* and *Axis lydekkeri* dating from the Upper Pleistocene in Java, many scientists consider there to be a kinship between the two extinct species and Bawean deer, believing they might be its ancestors. At that time, during periods of low sea levels, Bawean and Java were connected by land. The closest surviving relatives of the Bawean deer are the hog deer of mainland Southeast Asia and the Calamian deer, *Axis calamianensis*, found on Calamian Island in the Philippines (Groves and Grubb, 1987). Recently a phylogenetic study confirmed the closeness between Bawean deer and hog deer

(Fautley et al., 2012; **Figure 21**), unfortunately *A. calamianensis* was not included in the analysis.

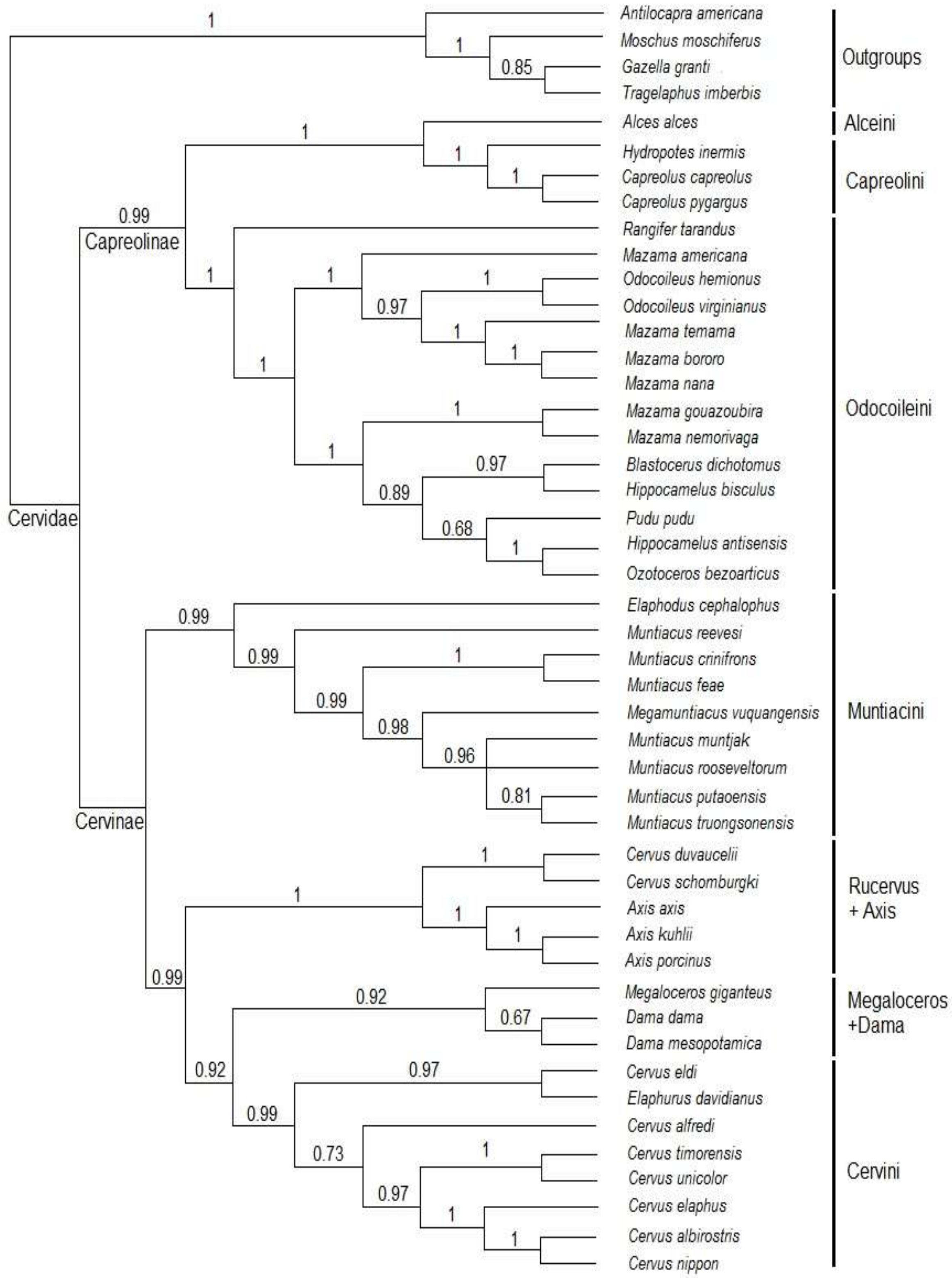

Figure 21. Bayesian phylogenetic analysis of deer using six molecular markers: cytb, COII, 12S, 16S, aLAlb, PRKCI. Values above branches are posterior probabilities

Large numbers of deer have never been reported on Bawean Island, although accounts from the nineteenth century indicate they were then fairly plentiful (Semiadi, 2004). This situation follows the general trend on Java, where deer numbers had drastically reduced by 1900 because of the increasing human population, the increasing needs of agricultural land and the availability of modern weapons. Since its first report by researchers, there has never been a detailed paper on the population size of Bawean deer. The oldest record that discusses the condition of deer populations was a report published in 1953. Written in 1928, whereas the research was conducted in the deer's natural habitat, researchers could not find any deer, except antlers brought there by local people (Van Bemmel, 1953). The researcher argued that the preservation of Bawean deer had been disturbed since 1948, when there was a famine on Bawean Island. The people who usually worked as fisherman started intensive hunting activities to meet their protein requirements.

In addition, there has been a severe impairment of the Bawean deer's habitat due to the process of deforestation; the forest began to be converted to a teak forest in 1943. Disturbance of native habitats occurred again around 1960; there was an expansion of the teak forests (Halimi pers. comm.). Unfortunately, there was no estimate of density at that time. A survey over the period from 1970 to the 2010s guesses that the Bawean deer population has remained relatively unchanged and stable (300-500 individuals), since the establishment of Bawean Island as a protected area (Sitwell, 1970; Blouch and Atmosoedirdjo, 1978; Blouch, 1980; UGM and BBKSDA East Java, 2003; Semiadi, 2004; BBKSDA East Java, 2009), which seems to provide efficient protection to Bawean deer in their natural habitat. Nonetheless, it is important to realize that this designation does not necessarily ensure the preservation of the Bawean deer population. Our study provided similar population density of 3.48 to 8.92 individuals per km^{-2} and a population size of ca. 162-416 deer. Continuous, long-term conservation efforts are necessary to ensure not only the stability but increase of the population, and also the preservation and even improvement of deer main habitat.

In the past, Blouch and Atmosoedirdjo (1987) showed that most deer were found in the natural forests of the western half of the island's mountainous central region (**Figure 22**). An isolated part of the population remained quite well in 25-30-year-old teak plantations near the village of Kumalasa, in the southwest corner of the island. Occasionally, a deer was sighted on the beach in the Kumalasa area or on the main road west of Mt. Dedawang, but the vast majority of Bawean islanders had never seen a Bawean deer (Blounch and Atmosoedirdjo, 1987). Today, the situation looks bleaker; my records indicate that the Bawean deer range has dramatically narrowed and is threatened by fragmentation and destruction through illegal logging, mainly in areas far from ranger patrols. I saw that the population condition tended to be stable, with densities relatively similar to those in the previous surveys conducted by Blouch and Atmosoedirdjo (1987) and Semiadi (2004). However, as mentioned earlier, it seems that the population tends to grow and is concentrated in the centre of the protected area (around Mt. Dedawang, Mt. Nangka, Mt. Gadung, Mt. Duren, Mt. Mangoneng, Mt. Bengkuang and Batulintang) and in a small area around Mt. Bulu, located in the southwest of BINR-WS. We assume that Bawean deer are no longer living on Tanjung Cina peninsula, where Semiadi (2004) reported a density of 11.8 animals per km^2 during the wet season. No sign of deer presence has been recorded at Mt. Tinggi, Mt. Beringin, Kastoba Lake or Mt. Payung-Payung. These ancient records may indicate the existence of transient or surviving individuals rather than a stable population. Camera trapping and faecal pellet count proved to be complementary with a presence at Klumpang Gubuk which was only recorded by the second technique.

The Bawean deer is listed as critically endangered under criterion C2a(ii) of the IUCN Red List (Semiadi et al., 2015) and it is therefore “considered to be facing a very high risk of extinction in the wild” (IUCN, 2001). In line with this, I argue that it faces a very high risk of extinction, particularly in the long-term, its expected continued decline due to a deterioration in habitat quality through disturbance, hunting and habitat destruction. To qualify for the critically endangered category under criterion C2a(ii), a species has to have a declining global population of <250 mature individuals, with at least 90% confined to one subpopulation (IUCN, 2001). Semiadi (2013) stated that the species lives in >1 subpopulation, the largest of which contains 250-300 individuals. Hunting, invasive predators, grazing livestock animals and illegal logging are still rampant in the protected area; all of these issues are certainly very harmful to the survival and existence of Bawean deer. The fact that the extent of occurrence (EOO) < 100 km^2 with number of locations = 1 and a continuing decline has been observed, particularly as the area occupied by Bawean deer was only ~19.12 km^2 of the 46.60 km^2 of the potential Bawean deer habitat in BINR-WS (iii), shows that the quality of habitat may be declining due to human activities such as illegal logging. Based on several criteria, it seems that the status of Bawean deer must remain ‘critically endangered’, but under criterion B1ab(ii, iii) although the size of the population is stable.

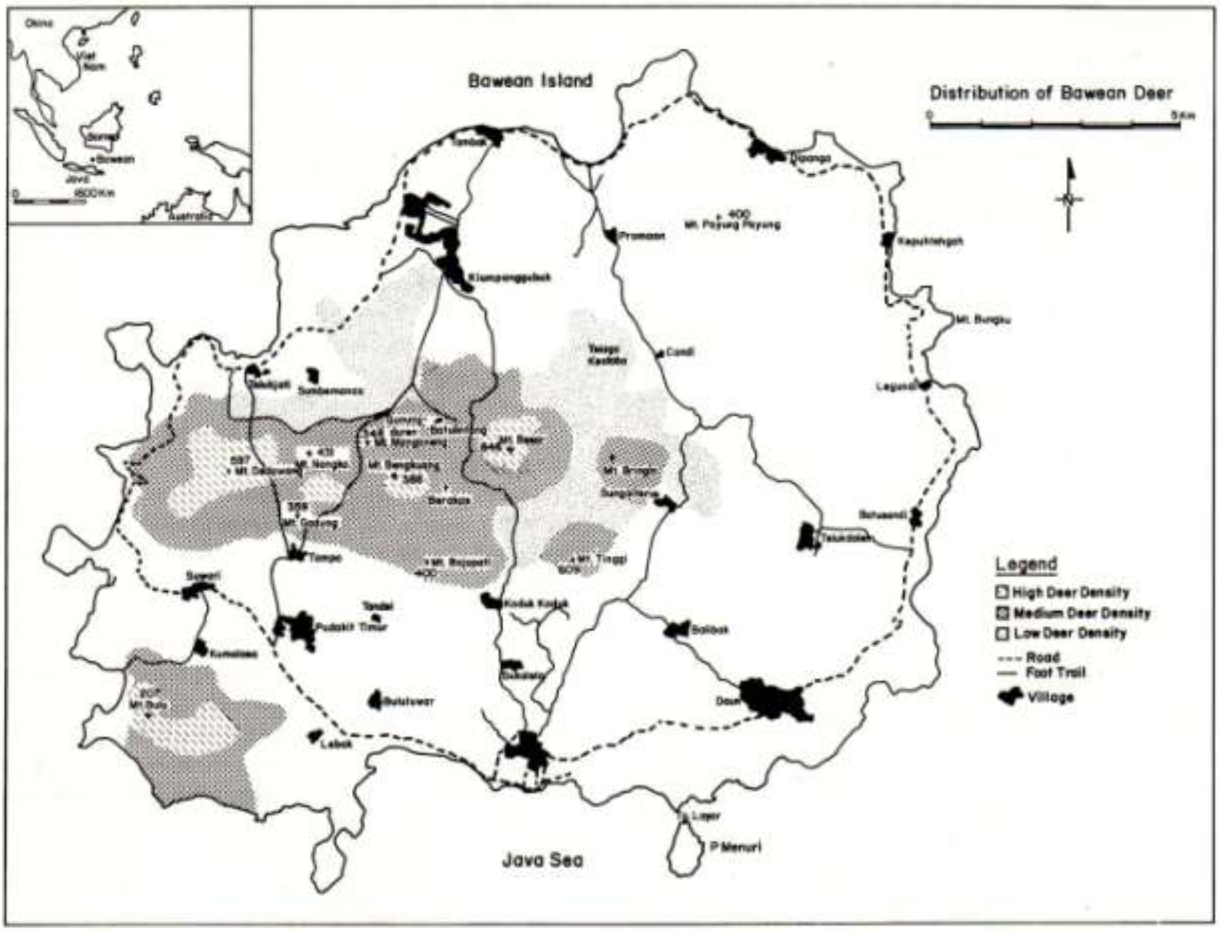

Figure 22. Distribution of Bawean deer according to Blounch and Atmosoedirdjo (1987).

II.4. Seasonal habitat use and predicted range modelling of Bawean deer and red muntjac

II.4.1 Daily and seasonal habitat use

In the plantation-forest mosaic of BINR-WS and UKNP, Bawean deer and red muntjac respectively used rainforest fragments and vegetation in lowland areas. Some degraded rainforest fragments containing secondary vegetation provided a favourable habitat in which to forage, for both species of deer. The association of deer species with forest edges has been broadly documented in many regions (e.g. Aung et al., 2001; McShea et al., 2001). Tree canopies, along with secondary vegetation and grass growth, appeared to provide cover and fodder for deer. The presence of fruits, buds, tender leaves, flowers, herbs and young grass along forest fragments also encouraged the use of secondary forest by deer (Blouch and Atmosoedirdjo, 1987; Kitchener et al., 1990; Oka, 1998).

Habitat use was also influenced by the time of the day for both species of deer, with secondary forest areas being associated with daytime, primary forests being more visited at night. This pattern may be attributed to longer periods spent on feeding and other activities in areas which provide fodder and cover during the day, while primary forest could be mainly used for movements between foraging areas at night.

Deer possibly switch from browsing to grazing between dry and wet seasons, changing their movement patterns based on seasonal availability in tropical rainforests (Esparza-Carlos et al., 2011). There is a tendency for Bawean deer to move closer to settlements, as farm products in dedicated land become attractive for this species, mostly when the dry season has come. A study by Esparza-Carlos et al. (2011) might explain why; under drier conditions, deer habitat use was explained primarily by food resource variables, while during the wetter parts of the year, food resources became unimportant.

Red muntjacs are non-specialists and seem to use all successive stages of secondary forest; this species was mostly recorded consuming fruits of palm trees, which dominated in the secondary forest area. Similarly, Arceo et al. (2005) showed that deer diet included 40%-50% of fruits in tropical ecosystems during the dry season, a period of low plant growth. A study by Brown and Lugo (1990) found that secondary forests have higher productivity than primary ecosystems; secondary forests are potentially important landscape elements for ungulate conservation (García-Marmolejo et al., 2015). This may explain why the encounter rate was higher in secondary forests than in other habitat types, for both species of deer. The hypothesis that both mostly use primary forests was rejected by my results (**Paper 3**).

II.4.2. Determinant variables in habitat use and range

Identifying the determinant environmental variables is essential for understanding how deer select each habitat type. Physical variables such as elevation, slope and distance to the nearest river (Debeljak et al., 2001; Patthey, 2003), resources such as land cover (distance to primary forest and secondary forest) and vegetation productivity (Schutz et al., 2003), anthropogenic disturbance such as distance to settlement, cultivated area and road (Patthey, 2003) and climatic variables such as annual rainfall, rainfall of the wettest month, rainfall of the driest month, annual mean temperature, maximum temperature of the warmest month, minimum temperature of the coldest month (Solberg et al., 2001; Hovens and Tungalaktuja, 2005) revealed to be differently relevant for both species of deer. However, I emphasize that not all the variables mentioned significantly affected the distribution and habitat use by both species of deer. For Bawean deer, distance to cultivated area and distance to settlement were the most significant variables in the dry season. Meanwhile, distance to cultivated areas, followed by annual rainfall and elevation, had the most significant effect on the distribution and habitat use of red muntjac, both in wet and dry seasons.

II.4.2.1. Elevation and slope

I found that Bawean deer and red muntjac deer mainly lived at elevations lower than 300 m. This seems to be related to vegetation cover and land use. Slopes also affected habitat use by Bawean deer and red muntjac. Generally, both deer used gentle (< 20°), undulating slopes, but this varied seasonally, probably according to food availability and temperature. However, the effect of temperature, if it is associated with altitude and slopes, is not very clear for species which live in lowlands, because the temperature is within a narrow range. Altitude affects the time required for grazing in herbivores, higher altitudes increasing the rest periods (Aldezabal et al., 1999). The effect of slopes is similar to that of altitude, with more grazing on flat surfaces and more rest on steep hillsides. Plant specific richness decreased sharply with altitude, due mainly to the decrease of herbs and, to a lesser extent, shrubs and vines (Vázquez and Givnish, 1998). Apparently, this gradient is not preferred by herbivores in tropical forests. Simcharoen et al. (2014) found that sambar deer (*Rusa unicolor*) preferred flat areas, presumably due to the quality of vegetation available and greater visibility for detecting predators. However, it seems that the effect of altitude and slope are important at the local scale, but irrelevant at the regional scale and varies between species living in tropical regions (García-Marmolejo et al., 2013).

II.4.2.2. River

As suggested by the contribution in the Maxent model, rivers are important habitat parameters for Bawean deer and red muntjac, particularly in the dry season. The lack of rivers may restrict the presence of deer. As a result of the high density of water sources in our study area, it was difficult to determine the importance of this resource for either species of deer; more than 60% of both protected areas were within 500 m of a water source. One interesting result was that the distribution of Bawean deer and red muntjac became closer to the river in the dry season, when some water sources ran dry. Similarly, Bello et al. (2001) and Fullbright and Ortega-Santos (2006) reported that water was an essential habitat component for white-tailed deer (*Odocoileus virginianus*) in arid ecosystems and under conditions where water sources are limited, for example, artificial water holes determine grouping patterns, habitat segregation and habitat use in four sympatric ungulates in the Shivalik ecosystem in India (Dar et al., 2012). On Bawean Island, the manager of the protected area set up an artificial pool and some animals visit this area when the nearby river runs dry. I documented the fact that deer frequently visited water pools after a low rainfall period during the dry season.

II.4.2.3. Forest cover

Bawean deer and red muntjac used mostly forested landscapes, with only moderate proportions of cultivated areas, as it was previously reported for Bawean deer by Blouch and Atmosoedirdjo (1987). This result supports the hypothesis that both species of deer require forest patches, although in different proportions. Bawean deer use forests for rest and avoid the presence of humans in protected areas, while overall forests are important for both species of deer to satisfy their food requirement. Most of the presences recorded through camera trapping were associated with feeding activity. In both study areas, some pastures may provide food for both species of deer, but no evidence of their presence was recorded. Avoidance of pastures is possibly the result of predation risk by leopards (*Panthera pardus melas*) and dholes (*Cuon alpinus*) in large open areas at Ujung Kulon National Park and/or human activity and feral dogs in Bawean Island Nature Reserve and Wildlife Sanctuary. The highly preferential use of forested landscapes is contrasted with the tolerance of both species to anthropogenic disturbances by agricultural expansion, intensification and forest logging. In the Sarawak planted forests, muntjacs are among the most common species camera trapped in young acacia plantations and have been seen grazing on young acacia shoots (Belden Giman pers. comm.). The area around teak plantations in BINR-WS are regularly naturally burned in the dry season and therefore a brushy understorey is allowed to develop, composed mainly of grasses and small shrubs. It seems that visits by Bawean deer of this habitat type takes place at a certain period when grasses and other understorey are abundant.

Many studies on the relationship of the chemical properties of natural salt-licks and ungulates have been conducted and the roles of natural salt-licks and species diversity of visiting ungulates were reported (Montenegro, 2004; Ayotte et al., 2008; Poole et al., 2010; Matsubayashi and Lagan, 2014). The presence of red muntjac in beach forests may be related to mineral content and food required by most ungulates. Natural salt-licks in Ujung Kulon National Park can be found in mud, salt springs and from the sea. Although the need for natural salt is high, it seems this does not necessarily ensure a high frequency of visits to the beach forest. The availability of natural salt in some kinds of plants and mud in the inland terrestrial ecosystems may affect deer visits to this habitat type. Furthermore, the low encounter rate of Bawean deer in the shrub was expected, as it was for red muntjac in mangrove-swamp forests, since both species of deer generally use areas which have a high abundance of herbs, grasses, young leaves and twigs. Blouch and Atmosoedirdjo (1987) found that Bawean deer densities in shrubs are low not only because food species are scarce, but also because the cover afforded, although dense, is usually too hot during the day to be comfortable for deer.

II.4.2.4. Vegetation productivity

Food is a major factor limiting the presence of ungulates; and plant productivity may be closely related to the presence of ungulates. Several studies have suggested that herbivores should increase plant diversity in high-productivity conditions and decrease it in low productivity conditions (Olff and Ritchie, 1998; Proulx and Mazumder, 1998; Bakker, et al., 2006). For example, plant species with fruits or other structures attractive to ungulate seed dispersers often have high invasive potential (Rejmánek and Richardson, 1996; Daehler et al., 2004; Richardson and Rejmánek, 2011). I found that the normalized difference vegetation index (NDVI) correlated with the presence of deer in both study sites. NDVI is highly correlated with plant productivity (Garbulsky et al., 2010), which in turn is often driven by rainfall (Pettorelli et al., 2005). High NDVI values can be correlated with taller, more mature and less nutritious grasses (Kawamura et al. 2005; Mueller et al. 2008), certainly influenced by the distribution of herbivores that are highly dependent on the availability of forage. For example, some small and medium-sized herbivores avoid areas with high NDVI during the wet season in the Mara region of Kenya, an area associated with low-quality high grass (Georgiadis and McNaughton, 1990) and an higher risk of predation due to dense vegetation cover (Riginos and Grace, 2008). These herbivores are generally concentrated in areas with low NDVI, with short grasses of better forage quality and lower risk of predation (Bhola et al., 2012). Although both regions receive heavy rainfall, BINR-WS experiences a much more pronounced dry season than UKNP and vegetative growth is mainly confined to forest areas during the dry season. As a consequence, NDVI was able to track all the different parameters of vegetation structures (such as temporal patterns of canopy structure) within the study area of the BINR-WS but not in UKNP, where the differences between the wet and dry seasons are sometimes vague.

II.4.2.5. Anthropogenic disturbance

Human pressure variables, such as distance to settlements and roads, have a significantly negative effect on the presence of Bawean deer, though not for red muntjac. It is well known that habitat fragmentation negatively affects populations of most wild species, while the easy access provided by roads does the same, by increasing poaching of game species (Laurance et al., 2005). Our results revealed that the distance to settlements has a heavy effect on the presence of Bawean deer in the dry season, but the influence of distance to roads is not obvious; roads represent hidden effects of human disturbance and we can infer that this disturbance has an indirect negative impact on the Bawean deer population due to human access to their habitat (Kilgo et al., 1998). Illegal human activities mostly occur near by roads, favoured by accessibility. In Africa and the Amazon rainforest, roads have the greatest impact on large and small ungulates, with the magnitude of road avoidance increasing with local hunting pressure (Laurance et al., 2006; Nascimento et al., 2006). However, it seems that Bawean deer also benefit from the presence of the road, using roads to save energy and rapidly travel long distances in the dry season, although it would be necessary to prove this pattern with targeted studies, setting up cameras around the road. Moreover, roads can provide benefits for deer when certain crops are abundant along the road (Hoenes and Bender, 2010). In our study, we found Bawean deer locations to be closer to urban and cultivated areas, where roads connected both. Nevertheless, they still avoided the possibility of direct encounters with humans, including, of course, encounters with the nearby settlement. It seems that this behaviour is an attempt to avoid human interference and conflicts with feral dogs, as part of an anti-predator behaviour that increased the time spent travelling away from distractions (Formaniwicz and Bobka, 1988; Creel et al., 2005).

The effect of human pressure variables is also visible for red muntjacs in our study, though this appears more closely related to the presence of food. The distribution of cultivated areas is no greater closer to the settlement, which is different from the distribution pattern in BINR-WS. Based on the distribution map of red muntjac in Maxent, deer distribution is mostly located near crop land, particularly in the dry season. Although red muntjac is the more generalist species of the two, it seems that their tolerance for disturbance is greater, due to the wider presence of food and the smaller human presence. According to Laidlaw (2000) and Azlan (2006), red muntjac occur widely even in heavily degraded forest, as well as in areas adjacent to forests and in plantations for coffee, rubber, sugarcane, cassava, coconut and teak;

this species may even benefit from agricultural conversion at the forest edge (M. Tysoon pers. comm.).

II.4.2.6. Climate

Climate showed the second strong influence on species habitat use and range. The influence of rainfall on habitat use seems related to the availability of food. During the wet season, habitat use was explained by a compounded effect of several variables unrelated to food. A study by Esparza-Carlos et al. (2011) might explain why, during the wet season, food resources became secondary, while cover and visibility explained deer habitat use. After heavy rainfall, forbs are abundant and deer shift their diet as grazers. In contrast, in the dry season, when rainfall was lower, these forbs were absent. I believe that red muntjac responded to this abundance by extending their area of use, thus increasing photographic rates in many areas and moving closer to cultivated areas. However, I found evidence of their presence in the same habitat during both the wet and dry seasons over two different years: 2013-2014. I cannot conclude that rainfall has an influence on Bawean deer population, due to the limitations of the data in the wet season in this population. Long-term studies in the future need to be performed to investigate how rainfall affects these deer.

Bawean deer and red muntjac exhibited similar responses to temperature throughout the year, but seemed to move increasingly during warm periods of the dry season, as can be seen from the higher capture rates during the dry season. In the lowland tropics, mean annual temperature ranges only from 24 to 27^{o}C and seasonal monthly temperature variation is < 4^{o}C (Wright et al., 2009). Small changes in temperature may have drastic effects on tropical species and thus on their distribution patterns (Wright, 2010) as many of these species are adapted to low temperature variation and lack populations inhabiting a wider range of temperatures (Colwell et al., 2008). For example, the IPCC (2007) predicts that the temperature in Western Africa will soon increase 1.8 to 4.7°C. Models suggest a change in precipitation anywhere from -9% to +13% (IPCC, 2007). As a result of climate change, Thuiller et al. (2006a) predicted high species loss in tropical central Africa, mostly in the Congo Basin. The already limited range of the okapi (*Okapia johnstoni*) will become even more constricted. Unlike other species, okapi cannot easily shift to cooler areas.

Finally, our modelling approach could enable the identification of suitable areas where anticipation of conservation measures is of huge importance. Both studied species appeared to be closely associated with anthropogenic activities and climatic conditions. This allows managers to preserve sufficient suitable habitat in order to sustain their populations in the near future, through field management practices. It is feared that over the years, climatic shifts might lead to rampant conversion of forests and reduction of dense evergreen forests in and around the Indonesian landscape, as it happened in Sumatra due to forest clearing activities for mining and plantation. Besides, it is possible that a long-term occupancy of deer in disturbed forests or in areas with high human impact alters their interactive effects/relationships with environmental factors, affecting their sensitivity, behaviour and tolerance to habitat disturbance.

The identification of environmental conditions associated with fine-scaled habitat variables unlikely to be captured at a landscape level, such as predation, den-site selection, food abundance and refuge habitat, could be used to generate predictive spatial models by incorporating intermediate factors (such as inter/intraspecies competition, etc.) essential in future studies on small, ranging ungulates, particularly deer species.

II.5. Daily and seasonal activity pattern

Van Schaik and Griffiths (1996) reported a relation between body size and activity pattern for Indonesian mammals, where small species tend to be nocturnal as an anti-predation strategy and large ones (over 10 kg) are expected to be cathemeral and diurnal (**Table 7**). My results indicate that both deer species have a diurnal pattern of activity. Before this study (**Paper 4**), Bawean deer were believed to be nocturnal (Blounch and Atmosoedirdjo, 1978, 1987; Semiadi, 2004), but most of our photographs of this species were taken during the day. More precisely Bawean deer were active throughout the day with peaks at 6-7 am and 8-9 pm, while red muntjac showed higher daily activity peaks one hour before and after sunrise, until one hour before sunset; however, this activity pattern might be local or related to daily time.

In the past, it has been suggested that Bawean deer tend to become more nocturnal in response to human threats, for example heavy hunting or forest encroachment (Blouch and Atmosoedirdjo, 1987). Changes in the pattern of their activity may be because the level of interference is now relatively low when compared to that of a few years ago, although it is still relevant. For example, most Bawean deer activity was recorded in BINR-WS areas with the smallest interference level. In areas with the highest levels of disturbance, around Mt. Payung-Payung, camera traps failed to capture any deer. This is a good example of how individuals or populations react to new conditions that may change the selection pressures acting on them (Sih et al., 2011). For example, the return of wolves to the Greater Yellowstone ecosystems directly and indirectly changes the population dynamics of elk (*Cervus canadensis*), which begins with changes in habitat use and vigilance, which in turn affects feeding behaviour, nutrition and disorders of the progesterone levels that lead to a decline in fawn production (Creel et al., 2007). Equally, the absence of predators is known to alter the abundance of prey, increase population (Holt et al., 2008) and cause changes in patterns of behaviour (Bonnot et al., 2016). My study shows the same trend as the results of studies conducted by Bonnot et al. (2016), where I observed a higher activity during the day than at night in the Bawean deer population, as expected for non-hunted populations or populations with reduced predation pressure.

Daily activity of red muntjac appears to be more strongly associated with the relationship between predator-prey than hunting or habitat disturbance. In this study, the activity of red muntjacs was opposite to those periods when their main predators were actively foraging. A strict crepuscular pattern of activity has been linked to the presence of predators in the environment (Leuthold, 1977) and crepuscular activity peaks, which are commonly interpreted as an anti-predator response in ungulates (Monterroso et al., 2013; Swinnen et al., 2015; Bonnot et al., 2016).

Table 7. Relation between activity pattern and body size in mammals, using average weight of the species in the highest possible taxonomic unit within the order

	Nocturnal	Diurnal	Cathermal
10 – 100g	*Ptilocercus* – Chiroptera	-	Insectivora
100g – 1kg	Prosimii – Non-sciurid Rodentia – Petauristinae	Sciurinae – *Tupaia*	-
1 – 10kg	*Cynocephalus* – *Manis* – Viverridae – Small *Felis*	Anthropoidea	Mustelidae – *Arctictis*
10 – 100kg	-	-	*Helarctos* – Large Felidae – Artiodactyla
> 100kg	-	-	Proboscidea – Perissodactyla

As expected, deer activity varied seasonally, proving lower in the wet season than in the dry season. This result is consistent with the common pattern observed for other ungulate species such as wild Asian water buffalo *Bubalus arnee* and African Elephant (*Loxodonta africana*)

(Eisenberg and Ticker, 1976; McCullough et al., 2000; Birkett et al., 2012). I already related the lower activity level (encounter rate) of both species of deer and both sexes within each species to a greater availability of food in the wet season. Alternatively, the peak activity in the dry season could also reflect reproductive tactics of males and females (Blouch and Atmosoedirdjo, 1978; Kitchener et al., 1990).

The increased activity level of females over males in the wet season may be the consequence of greater energetic requirements during the lactation period (the birth season for both deer species occurs from February to June; Blouch and Atmosoedirdjo, 1978; Kurt, 1990). The birth period is a crucial stage of the annual biological cycle in species of mammal (increase of the mother's energetic requirements: ca. 40% during late gestation and 150% during lactation; Loudon, 1985). Lactating females showed greater activity levels due to their need to meet greater energetic demands for lactation (Ciuti et al., 2009). Males may be induced to increase their level of activity to devote more time to marking and maintenance of territory in response to the presence of dispersing juveniles during the rutting period (for Bawean deer in July to November, while red muntjac have no seasonal rut and mating can take place at any time of year; see in Kitchener et al., 1990; Oka, 1998). During rut, males spent less time lying and more time standing, moving and performing other active behaviours than during non-rut periods, which suggests that males were more active during rut than non-rut periods, as has been reported for a number of ungulate species (Kitchen, 1974; Georgii and Schroder, 1983). The obvious increase in standing and moving during rut indicates the importance of gaining access to females, as well as chasing and avoiding opponents (Relyea and Demarais, 1994).

II.6. Major threats and degree of pressure

It seems that both deer species receive major threats and a different pressure level, either directly on their populations or indirectly on their habitat. Both species are disturbed by people living around protected areas. Currently, the most important perceived threats are illegal hunting and the loss and fragmentation of habitat caused by ongoing human population expansion.

II.6.1. Direct threats

It has long been known that hunting activities have threatened the existence of wildlife in tropical regions. Globally, hunting activity takes place on a massive scale in many countries; for example in the early 1990s, each year approximately six million animals were hunted in

Borneo, Malaysia (Bennett et al., 2000) and four million metric tons of meat from hunted animals were taken from the Congo basin (Fa and Brown, 2009). My findings clearly confirm that wildlife in BINR-WS and UKNP is under more pressure from hunting than any other threat. During my study I recorded hunters who hunt to maintain their crop land from interference from pest animals, such as wild boar (*Sus scrofa*), using snares or feral dogs in BINR-WS, and poachers using snares to catch mainly Javan rhinoceros in UKNP, even though no hunting for meat refers to both species of deer.

High levels of hunting in BINR-WS seem to affect the distribution of Bawean deer (**Paper 2**, **Paper 3**) and their activity pattern (**Paper 4**). Parry et al. (2009) mentioned that the abundance of wildlife in tropical forests is generally positively correlated to hunting activity compared with the forest type or its protected status. In Borneo, for example, a small forest patch directly adjacent to the settlement of fishermen has a higher abundance of wildlife than the large remote protected areas (McConkey and Chivers, 2004). Along the Amazon Basin, the abundance of wildlife is a marker of poor accessibility of an area for hunters (Peres and Palacios, 2007; Ramirez-Gomez et al., 2015), while in West Africa, the scale of hunting of wild animals is associated with the availability of alternative protein resources (Brashares et al., 2004).

II.6.2. Indirect threats

Agriculture and illegal logging cause different degrees of impact on the wildlife in the protected areas, overall the highest in the BINR-WS. In fact, these two types of land use are the most common, not only in Indonesia but also in developing countries such as in West Africa, followed by Central and East Africa (Tranquilli et al., 2014). The activities of this illegal land use have long been noted as causes of deforestation and forest degradation, reducing the effective size of protected wildlife areas and increasing the animals' decline by providing hunters access to remote areas. Thus, changes in the distribution, dispersal and loss of small to large-sized mammals due to hunting and habitat degradation, also known as defaunation, have become a critical issue and may have important effects on ecosystem functions in the future (Galetti and Dirzo, 2013; Dirzo et al., 2014). Determination of the status of an area seems to have a considerable influence on efforts and management in these areas; despite the fact that various forms of interference frequently occur in both study sites, ranger patrols have proven quite effective at reducing interference by the public in the area of UKNP. Easiness to access or entered into both protected area is limited, of course, it helps the manager to restrict a traffic of community to get into area. However, ultimately if someone want to remain get into area and wreak their havoc to wildlife and their habitat, he will almost find a way to do so. Indeed, it should be kept in mind that restricting public access or movement within the protected area and land conversion become agricultural area or illegal logging needs still to be performed so that the interference can be reduced

II.7. Ecological conclusions from this study relevant to conservation

The most important conclusion for management concerns the critical population size and distribution of Bawean deer, particularly as described in **Paper 2** and in the extent of the area over which both species of deer range (**Paper 3**). The population size was estimated to be between 242 and 416 Bawean deer, suggesting population stability according to the last estimate, but its range dramatically narrowed and is now threatened by fragmentation, due to human disturbance and destruction through illegal logging. The small population size and its relative isolation predispose Bawean deer to inbreeding and to a great risk of extinction by stochastic events, such as large fires. Fires are a traditional management method on Bawean Island for preparing land for cattle (Blouch and Atmosoedirdjo, 1987). They should be strictly managed at locations directly adjacent to the protected area to avoid serious damage to flora and fauna. At the end of the dry season, the fire risk increases, not only because of land burning (which is often uncontrollable) by communities, but also as a result of natural fires. Lower hygrometry levels during the dry season causes high foliage mortality, increasing the fuel load for late dry season fires (Brando et al., 2014). These fires have been shown to develop higher temperatures and cause greater damage to soil, vegetation and shrub ecosystems than early dry season fires on Bawean Island (Semiadi, 2004).

With its range surrounded by mostly cultivated areas, the situation of Bawean deer is critical; population size is very low and the cultivated areas have little potential to hold additional resident individuals. The degree of connectedness among reported units of populations and the dispersal potential of deer across a corridor connecting these units separated by human activities (such as roads, development or logging) are focussed by ongoing studies. This should allow an exchange of individuals between populations, which may help prevent the negative effects of inbreeding and reduced genetic diversity (via genetic drift) that often occur within isolated populations (Frankham et al, 2004; Frankham et al, 2009; Buckland et al., 2014).

Meanwhile, red muntjacs are found in many protected areas over their range (GMA Indonesia Workshop). Much of Java's remaining forest is officially protected, including the Ujung Kulon National Park area. Moreover, Indonesian forestry law protects all species of muntjac. The red muntjac population in Ujung Kulon National Park is relatively better preserved than in any region of Sumatra or Kalimantan. Species protection laws related to ungulates have not been widely publicized in many areas of Sumatra. In addition, though a significant percentage of Sumatra's forests are protected, the authorities responsible for conservation of forests and protected areas are often under-funded and almost all are grossly understaffed, so that there is only a small ranger presence in the field. Where they are field ranger teams generally focus on flagship species such as the Asian elephant, *Elephas maximus*, Sumatran rhinoceros, *Dicerorhinus sumatrensis*, or the tiger although tiger protection rangers do also conduct ungulate protection activities.

Quite similarly, for the red muntjac population in UKNP, protection is more focused on the Javan rhinoceros. Nonetheless, protection of this iconic species directly benefits the protection of other species, including the red muntjac. The ranger presence in UKNP was able to reduce hunting pressure, comparatively to the past. Although red muntjac is a species having a high tolerance and plentiful resources, efforts to protect it must still be made.

II.8. Implications for deer conservation in the Indonesian tropical rainforest

Conservation of wide-roaming animals has largely shifted towards a landscape scale approach (Angermeier and Karr, 1994), recognizing that for many of these species, reserves are not sufficient to hold viable populations and that the area that can be set aside for additional reserves is becoming increasingly limited (West et al., 2006). Moreover, in an ever-changing and developing cultural landscape, protected areas continue to be one of the most important tools for conservation and should continue to be cornerstones for regional conservation planning (Noss et al., 1996; Oates, 1999; Margules and Pressey, 2000; Terborgh et al., 2002). In an assessment of the potential of Indonesia's protected areas to ensure the long-term survival of deer, there are at least 473 protected areas, which cover more than 22 million hectares (Ministry of Forestry, 2014; **Table 8**).

Table 8. Terrestrial conservation areas in Indonesia up to 2013 (Source: Direktorat Kawasan Konservasi dan Bina Hutan Lindung, Direktorat Jenderal PHKA Tahun 2013).

Protected areas	Number	Size (ha)
Nature Reserve	222	3.957.691,66
Wildlife Sanctuary	71	5.024.138,29
National Park	43	12.328.523,34
Nature Recreation Park	101	257.323,85
Grand Forest Park	23	351.680,41
Game Hunting Park	13	220.951,44
Sanctuary Reserve Area-Nature Conservation Area	18	275.190,30

National parks and other fully protected areas now cover over 18% of tropical rainforests in the world but many of these legally protected areas are still subjected to illegal human activities (Brooks, 2004), which is exemplified by Bawean Island Nature Reserve and Wildlife Sanctuary. Accordingly, wildlife monitoring is critical in developing plans for protected area management and management of the surrounding areas (Kremen et al., 1994).

Bawean Island Nature Reserve and Wildlife Sanctuary and Ujung Kulon National Park represent key elements for the conservation of Bawean deer and red muntjac (along with many other species) locally. As long as the wildlife in the protected areas is well-protected, it is reasonable to feel confident that current conservation may succeed in preserving most of the abundance of wildlife contained therein. These deer species are almost entirely restricted to the parks. Although protected-area systems in the BINR-WS and UKNP have been somewhat successful in reducing habitat clearance, as with other protected areas in the tropical region, they have been much less effective at preventing more insidious types of habitat degradation (Wright et al., 2007a), enhanced accessibility meaning poachers can enter and leave with impunity. However, documented reproduction and the existence of the species in the park over the past decades indicate that the park holds some potential for the long-term conservation of Bawean deer and red muntjac. Several factors contribute to this:

- good park management, especially the low human population pressure in the park's surroundings due to the system of protected areas leading to the absence of or very low poaching pressure on local wildlife, as well as a low deer-crop field rancher conflict potential, although threats to the Bawean deer population still remain, due to illegal logging and poaching of wild boar by humans using feral dogs;

- perception of the species in local community is predominantly positive. Moreover some people realize the importance of deer for the stability of forest ecosystems. In fact, Bawean deer are regarded as iconic animals on Bawean Island;
- location of the Agency of Protected Area base in the immediate vicinity of the park and the consequent direct contact between rangers, researchers and the local community contributes to awareness of conservation issues amongst the local population.

Small protected populations such as those in the BINR-WS area would not represent as much of a conservation problem if they were embedded in larger regional populations or interconnected with other populations. A set of interconnected populations (also termed a meta-population) has an increased overall population size, protecting the species from negative effects of demographic, genetic and environmental stochasticity and allowing for re-colonization of extinct patches (Hanski, 1998; Hanski and Ovaskainen, 2000). Whereas, as an example, about 50% of the protected area on Bawean Island is still covered by natural vegetation, 60% is more or less under human influence and the biome is characterized by a fragmented landscape (Blouch and Atmosoedirdjo, 1978). Large-scale crop plantations and natural barriers such as the ocean most likely prevent or at least render difficult and rare Bawean deer dispersal. Consequently, the major threat to the species in the BINR-WS is the isolation of populations too small to be viable over the long-term.

Addressing the primary conservation challenges of deer species in tropical forests requires effective design of protected areas, as well as sustainable management practices. In the last decade, there has been a growing need for biological assessment and conservation of these species, primarily from increased levels of disturbance to their natural habitat (Boddicker et al., 2002). Therefore, appropriate methodological approaches are required to manage these elusive animals (Rodriguez, 2003).

Monitoring wildlife populations and habitats is an important way to assess the impacts of human activities on nature and understand the natural rates of wildlife changes (Balmford et al., 2003). A systematic analysis of population trends and habitats is needed to mitigate the decline of biodiversity and document extinction rates (Balmford et al., 2003; Kühl et al., 2008). Survey and monitoring programmes permit evaluation of the sources and impacts of potential threats including: habitat degradation and fragmentation (Debinski and Holt, 1999), wildlife poaching and natural disasters (Hocking et al., 2000) such as hurricanes, fires and disease (Kühl et al., 2008).

Recommended conservation actions should proceed through appropriate revisions of management plans and be based on the results of monitoring in the field. Some recommendations include the enhancement of populations and if possible the expansion of areas used by deer. The small size of some species and their insular nature leave them susceptible to hazard events (e.g., weather-related disasters, earthquakes or diseases), and to any resumption of hunting, and probably to inbreeding and genetic diversity loss. In addition, protection laws related to ungulates have not been widely publicized in many areas of Indonesia. Furthermore, their poor enforcement has increased the hunting pressure and other illegal activities in protected areas. Records for punished poachers or illegal loggers are often poor, because the protection of wildlife and its habitat is rarely a national or even local priority, especially when facing big corporations or migrant communities claiming indigenous rights, as is common in Africa (Mubalama, 2010). Decisive action, such as confiscation or destruction of firearms, snares, pit-saws and camping materials, along with the prevention of bushmeat, timber or other resources being extracted from the protected area must be upheld. Corruption can often be a big issue causing additional temptation to ignore the law, thereby undermining effective conservation programs (Sutherland, 2009). Even though much of Java's remaining forest is officially protected, frequent hunting with shotguns was found to be a severe problem for larger mammals and birds across some places.

There seem to be no species-specific conservation measures in need of implementation, above turning existing laws on protected areas and protected wildlife into reality, with a particular focus on eradicating illegal logging, wildlife trade and deforestation, initiating a co-ordinated breeding programme to evaluate and if necessary address possible inbreeding deficiencies in the captive population. I hope this study will encourage researchers and conservationists to carry out similar research in other protected areas, fragmented forests, reserved forests, plantations and urban landscapes in the country, as a basis for recording rigorous distributional data on lesser deer and updating their natural history and population status. Furthermore, it can be the basis for policy makers to formulate policies related to the conservation of deer in Indonesia.

II.9. Conclusion

Camera trapping was the most effective methodology used to study the rare Bawean deer and the more common red muntjac, even if deer was not the target species for the latter. The method also yielded large amounts of data on non-target species that could be used to investigate aspects of spatial interactions among species. Camera traps have an enormous potential for monitoring and consequently managing deer. Their use in tropical rainforests can alleviate the challenging conditions of surveying for enigmatic and elusive species. However, the use of camera traps is not a panacea. Careful planning must precede any camera trap project; the aim must be well-defined and the available resources considered. However, a successful camera trap project is very rewarding and may return results that no other survey method would provide.

BINR-WS and UKNP house one of the last Indonesian protected populations of Bawean deer and red muntjac, respectively. Both species have persisted in BINR-WS and UKNP in spite of the rapid and large-scale conversion of the regions for crop cultivation over the last decades. The Bawean deer population has been particularly threatened, due to illegal logging and poaching using feral dogs. Parks seem to accommodate the basic needs of both species of deer, in terms of availability of food and shelter mainly. However, the small population size and high degree of isolation in BINR-WS leave the Bawean deer population in critical danger of extinction if not managed properly. The distribution of Bawean deer and red muntjac within each park is restricted by anthropogenic factors such as settlements and cultivated areas. Yet the local situation for deer is probably stable, particularly for the Bawean deer population, as deer can also benefit from the surrounding cultivated areas. This trend is a good news for their conservation, nevertheless an increase of populations should be pursued in the future. While having no information about the population of red muntjac during the previous years, the high camera-trap capture rates suggest the population is in good condition; moreover, I saw disruptions due to hunting activity in UKNP diminish over time, as affected by the rangers. For many other protected areas in the Indonesian tropical rainforest, the situation is probably similar, mostly due to disturbance from settlements, roads, cultivated areas and plantations of non-native tree species. Conservation efforts for deer should focus on landscape connectivity to limit the hazard of small population size and isolation. Consequently, research should address questions on the range of unprotected deer populations and how the species could move through anthropogenically altered landscapes.

II.10. Perspectives

This thesis opens up new horizons for studies on remote deer in tropical rainforests and will be useful for setting up future observational and experimental studies, as well as for improving conservation plans and efforts in tropical areas such as Indonesia. I already alluded to several perspectives in the discussion of my papers and in the general discussion. Below, I summarize several of these perspectives and add new suggestions for future research on Bawean deer and red muntjac.

Concerning the variance in methodology in estimating the population size of Bawean deer and red muntjac, it could be interesting:

- to use non-invasive genetic analyses for identifying individuals and for providing a better estimate of population size; combining camera trapping and non-invasive genetic data in a spatial capture-recapture framework and occupancy modelling would improve density estimates;
- to use radio-collars, or better GPS collars, for investigating home range and movement patterns, which are valuable for estimating population size with capture-recapture and random encounter models. In addition, studies using these tools might be useful to investigate the size of males' territory, the mating system, social behaviour and habitat preferences;
- to continue intensive camera trapping to get more data in both wet and dry seasons, particularly for Bawean deer and to set up double camera trapping to reduce bias in identification of individuals in capture-recapture modelling.

Concerning the estimation of population size, studies on Bawean deer and red muntjac, as well as, more broadly, other low sexual size dimorphic ungulates, should benefit the improvement of special techniques for recognizing individuals from picture analysis (e.g., Jacobson et al, 1997; González-Marín et al., 2008).

Concerning habitat use, preferences and range, it would be interesting:

- to investigate the effects of other variables (e.g., population density, operational sex ratio, predation risk, food availability, etc.);
- to monitor the red muntjac population in different locations, to determine their response to environmental variables at those locations.

Concerning the genetic polymorphism and disease hazard for isolated deer populations, future research should perform investigations on faeces for:

- assessing the genetic diversity and evaluating the effects of genetic drift and population isolation within species range;
- quantifying the immunogenetic variability useful for resisting pathogen exposure;
- investigating pathogens and parasites, as well as level of stress in relation to human influence.

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APPENDIX

APPENDIX ….

Appendix 1: Red List Category summary for all animal in mammalia classes and orders

Order	EX	EW	CR(PE)*	CR(PEW)*	CR	EN	VU	Subtotal (threatened spp.)	NT	LR/cd	DD	LC	Total
Afrosoricida	0	0	1	0	1	8	8	17	3	0	4	31	55
Carnivora	6	0	0	0	5	31	38	74	29	0	12	167	288
Cetartiodactyla	7	2	2	0	14	44	53	111	25	0	61	123	329
Chiroptera	5	0	8	0	25	48	97	170	83	0	200	684	1.142
Cingulata	0	0	0	0	0	0	3	3	5	0	5	8	21
Dasyuromorphia	1	0	0	0	1	6	5	12	10	0	4	47	74
Dermoptera	0	0	0	0	0	0	0	0	0	0	0	2	2
Didelphimorphia	1	0	1	0	2	0	7	9	3	0	17	69	99
Diprotodonita	7	0	2	0	13	16	16	45	16	0	2	76	146
Eulipotyphla	7	0	2	0	12	41	31	84	13	0	77	269	450
Hyracoidea	0	0	0	0	0	0	0	0	1	0	0	4	5
Lagomorpha	1	0	0	0	3	10	5	18	5	0	8	61	93
Macroscelidea	0	0	0	0	0	1	2	3	1	0	4	11	19
Microbiotheria	0	0	0	0	0	0	0	0	1	0	0	0	1
Monotremata	0	0	0	0	3	0	0	3	0	0	0	2	5
Notoryctemorphia	0	0	0	0	0	0	0	0	0	0	2	0	2
Paucituberculata	0	0	0	0	0	0	2	2	2	0	0	2	6
Peramelemorphia	3	0	0	0	0	4	2	6	1	0	3	9	22
Perissodactyla	0	0	0	0	4	5	3	12	2	0	0	2	16
Pholidota	0	0	0	0	2	2	4	8	0	0	0	0	8
Pilosa	0	0	0	0	1	0	2	3	0	0	0	7	10
Primates	2	0	0	0	59	117	83	259	22	0	21	121	425
Proboscidea	0	0	0	0	0	1	1	2	0	0	0	0	2
Rodentia	37	0	14	0	64	145	141	350	102	0	367	1.400	2.256
Scandentia	0	0	0	0	0	0	2	2	0	0	3	15	20
Sirenia	1	0	0	0	0	0	0	4	0	0	0	0	5

Tubulidentata	0	0	0	0	0	0	0	0	0	0	0	1	1
Subtotal	78	2	30	0	209	481	507	1.197	324	0	790	3.111	5.502

Notes: IUCN Red List Categories: EX- Extinct, EW- Extinct in the Wild, CR- Critically Endangered (includes CR(PE) and CR(PEW)), EN- Endangered, VU- Vulnerable, NT- Near Threatened (includes LR/nt - Lower Risk/near threatened), LR/cd -Lower Risk/conservation dependent, DD- Data Deficient, LC- Least Concern (includes LR/lc - Lower Risk, least concern).

* CR(PE) & CR(PEW): The tags 'Possibly Extinct' and 'Possibly Extinct in the Wild' have been developed to identify CR species that are likely already extinct (or extinct in the wild), but require more investigation to confirm this. NOTE that these are not IUCN Red List Categories; they are tags that can be attached to the CR category to highlight those taxa that are possibly extinct. They are included in the above table to indicate a plausible upper estimate for number of recently extinct species on The IUCN Red List.
For the full list of CR(PE) and CR(PEW) species in the current IUCN Red List, see Table 9 (http://www.iucnredlist.org/about/summary-statistics).

Appendix 2: **Deer in tropical regions**

Genus	Status	Population trend
Axis		
Axis axis (chital)	LC ver 3.1	Unknown
Axis calamianensis (calamian deer)	EN B1ab(i,iii,v) ver 3.1	Decreasing
Axis kuhlii (Bawean deer)	CR C2a(ii) ver 3.1	Stable
Axis porcinus (hog deer)	EN A2bcd ver 3.1	Decreasing
Blastocerus		
Blastocerus dichotomus (marsh deer)	VU A4acde ver 3.1	Decreasing
Cervus		
Cervus elaphus (red deer)	LC ver 3.1	Increasing
Hippocamelus		
Hippocamelus antisensis (taruca)	VU C2a(i); E ver 3.1	Decreasing
Hippocamelus bisulcus (Patagonian huemul)	EN B2ab(i,ii,iii,iv,v); C2a(i) ver 3.1	Decreasing
Mazama		
Mazama americana (red brocket)	DD ver 3.1	Unknown
Mazama bororo (small red brocket)	VU C2a(ii) ver 3.1	Decreasing
Mazama bricenii (mérida brocket)	VU A4c ver 3.1	Decreasing
Mazama chunyi (Peruvian dwarf Brocket)	VU A4c; B2ab(iii) ver 3.1	Decreasing
Mazama gouazoubira (gray brocket)	LC ver 3.1	Decreasing
Mazama nana (Brazilian dwarf Brocket)	VU A3cde ver 3.1	Unknown
Mazama nemorivaga (Amazonian brown brocket)	LC ver 3.1	Decreasing
Mazama pandora (Yucatan brown Brocket)	VU A2c ver 3.1	Decreasing
Mazama rufina (dwarf red brocket)	VU A4c; C1 ver 3.1	Decreasing
Mazama temama (Central American red brocket)	DD ver 3.1	Decreasing
Moschiola		
Moschiola indica (Indian chevrotain)	LC ver 3.1	Unknown
Moschiola meminna (white-spotted chevrotain)	LC ver 3.1	Unknown

Moschus		
Moschus berezovskii (forest musk deer)	EN A2cd ver 3.1	Decreasing
Moschus chrysogaster (alpine musk deer)	EN A2cd ver 3.1	Decreasing
Moschus cupreus (Kashmir musk deer)	EN A2d ver 3.1	Decreasing
Moschus fuscus (black musk deer)	EN A2cd ver 3.1	Decreasing
Moschus leucogaster (Himalayan musk deer)	EN A2d ver 3.1	Decreasing
Muntiacus		
Muntiacus atherodes (Bornean yellow muntjac)	LC ver 3.1	Decreasing
Muntiacus feae (fea's muntjac)	DD ver 3.1	Unknown
Muntiacus gongshanensis (Gongshan muntjac)	DD ver 3.1	Decreasing
Muntiacus montanus (Sumatran mountain muntjac)	DD ver 3.1	Unknown
Muntiacus muntjak (southern red muntjac)	LC ver 3.1	Decreasing
Muntiacus puhoatensis (Puhoat muntjac)	DD ver 3.1	Unknown
Muntiacus putaoensis (leaf muntjac)	DD ver 3.1	Decreasing
Muntiacus rooseveltorum (Roosevelts' muntjac)	DD ver 3.1	Decreasing
Muntiacus truongsonensis (Annamite muntjac)	DD ver 3.1	Decreasing
Muntiacus vaginalis (northern red muntjac)	LC ver 3.1	Decreasing
Muntiacus vuquangensis (large-antlered muntjac)	EN A2cd+3cd+4cd ver 3.1	Decreasing
Odocoileus		
Odocoileus hemionus (mule deer)	LC ver 3.1	Stable
Odocoileus virginianus (white-tailed deer)	LC ver 3.1	Stable
Osgoodomys		
Osgoodomys banderanus (michoacan deer mouse)	LC ver 3.1	Unknown
Ozotoceros		
Ozotoceros bezoarticus (pampas deer)	NT ver 3.1	Decreasing
Pudu		
Pudu puda (southern pudu)	VU A2cd+3cd ver 3.1	Decreasing
Rucervus		
Rucervus duvaucelii (barasingha)	VU C1 ver 3.1	Decreasing
Rucervus eldii (eld's deer)	EN A2cd+3cd+4cd ver 3.1	Decreasing
Rucervus schomburgki (Schomburgk's deer)	EX ver 3.1	

Rusa		
Rusa alfredi (Phillipine spotted deer)	EN C2a(i) ver 3.1	Decreasing
Rusa marianna (Philippine deer)	VU A2cd ver 3.1	Decreasing
Rusa timorensis (Javan deer)	VU C1 ver 3.1	Decreasing
Rusa unicolor (sambar deer)	VU A2cd+3cd+4cd ver 3.1	Decreasing
Tragulus		
Tragulus javanicus (Java mouse deer)	DD ver 3.1	Unknow
Tragulus kanchil (lesser mouse deer)	LC ver 3.1	Unknow
Tragulus napu (greater mouse deer)	LC ver 3.1	Decreasing
Tragulus nigricans (Balabac mouse deer)	EN B1ab(iii,v) ver 3.1	Decreasing
Tragulus versicolor (silver-backed chevrotain)	DD ver 3.1	Decreasing
Tragulus williamsoni (Williamson's chevrotain)	DD ver 3.1	Decreasing

Appendix 3: Status, range and habitat of deer in Indonesia tropical rainforest (the information cited from IUCN website 2015)

Spesies	Status	Range	Habitat
Axis kuhlii (Bawean deer)	CR C2a(ii) ver 3.1	Endemic to Bawean Island (= Pulau Bawean), in the Javan Sea off the northern coast of Java, Indonesia	Bawean deer is found in primary and secondary forest, reaching higher densities in the latter (Blouch & Atmosoedirdjo, 1978; G. Semiadi & S. Pudyatmoko pers. comm. 2006). The species occurs up to 500 m (G. Semiadi & S. Pudyatmoko pers. comm. 2006), typically in hill forests rather than the marshy grasslands (Blouch & Atmosoedirdjo, 1987 It enters croplands, feeding on corn and cassava leaves, as well as grasses among the crops (Blouch & Atmosoedirdjo 1987, G. Semiadi & Boeadi pers. comm. 2006).
Muntiacus atherodes (Bornean yellow muntjac)	LC ver 3.1	Occurs only on Borneo, and lives throughout the island (Payne *et al*. 1985). It is present in both Indonesia (Kalimantan) and Malaysia (Sabah and Sarawak).	It uses both primary and secondary forest (Matsubayashi and Sukor 2005; Belden Giman pers. comm. 2008). Predominates over the red muntjac in low hill ranges and coastal regions (Payne et al.,1985), whilst Meijaard & Sheil (2008) pointed out that still “no robust quantitative data exist to support that pattern. There is, however, an opinion by many field observers that this species is genuinely absent from mountains. *M. atherodes* also seems to be the predominant species in Sarawak planted forests, Bintulu Division, a mix of *Acacia mangium* plantation and natural forest, where it uses mature and immature plantation, freshly logged forest and relict tall forest; nearby it has also been found in oil palm (Belden et al., 2007; Belden Giman pers. comm. 2008).

Muntiacus montanus (Sumatran muntjac)	DD ver 3.1	The distribution of *M. montanus* is uncertain. It is known only from specimens collected from western Sumatra, Indonesia. The known localities are Kerinci district, Jambi province; Pesisir Selatan district of West Sumatra province; Gunung Leuser, Aceh Province, in the north of Sumatra; lowlands of Deli, east Sumatra.	The specimens collected by Robinson & Kloss (1918) came from altitudes of 7.300 and 4.700 feet (2.225 m and 1.430 m asl), and that reported on by Miller (1942) was obtained at 9.300 feet (2.830 m asl); all were presumably in montane forest. The two recent records of the species came from 1.900–1.925 m asl. The species may thus be primarily montane.
Muntiacus muntjak (southern red muntjac)	LC ver 3.1	Southern red muntjac, as defined here, occupy part of the southern Thai–Malay peninsula including southern Myanmar and Brunei Darussalam and occurs on the main islands of the Greater Sundas (Borneo, Java, Bali and Sumatra) (Chasen, 1940; Groves, 2003; Meijaard, 2003; Baker & Lim, 2008).	Southern red muntjac are associated with forest, but occur widely even in heavily degraded forest and, in areas adjacent to forest, in plantations of coffee, rubber, sugarcane, cassava, coconut, and teak (Oka 1998; Laidlaw 2000; Azlan 2006; G. Semiadi pers. comm. 2008). Most of its range is dominated by evergreen vegetation, but it readily uses deciduous forests and mosaics of grassland, scrub, and forest (e.g. on Java; Tyson 2007); on Bali and Java, *M. muntjak* routinely uses woodland savanna as a feeding ground (Oka 1998; S. Hedges pers. comm. 2008). This muntjac has a wide altitudinal range, but the highest in altitude up to at least 1.000 m asl such as those found in Usun Apau plateau (Payne *et al*. 1985).

Rusa timorensis (Javan deer)	VU C1 ver 3.1	Native only to Java and Bali in Indonesia. Over the last twenty years it has been introduced to many other islands of the Indo-Pacific region (Corbet and Hill 1992, Heinsohn 2003, Grubb 2005, Groves and Grubb 2011). And also introductions apparently took place in antiquity within present-day Indonesia, to the Lesser Sunda islands, Maluku islands (including Buru and Seram), Sulawesi, Papua, and Timor.	Rusa deer is essentially a tropical and subtropical grassland species (Medway 1977; Oka 1998) but is highly flexible, with successful populations in forests, mountains, shrublands and marshes (Whitehead 1993, Oka 1998, Rouys and Theuerkauf 2003, Keith and Pellow 2005). It is found from sea-level to 900 m asl (G. Semiadi pers. comm., S. Hedges pers. comm. 2008).
Rusa unicolor (sambar deer)	VU A2cd+3cd+4cd ver 3.1	The Sambar extends from India and Sri Lanka east along the southern Himalayas (including Nepal and Bhutan) through much of south China (including Hainan Island) to Taiwan (where it occurs in the central and eastern parts; Lin, C.-Y. and Lee, L.-L. pers. comms. 2008). Further south it occurs in Bangladesh, throughout mainland Southeast Asia (Myanmar, Thailand, Lao PDR, Cambodia, Viet Nam, West Malaysia) and many of the main islands of the Greater Sundas	No large Indian ungulate has adapted itself to a wider variety of forest types and environmental conditions than has Sambar deer (Schaller, 1967). Within India, Sambar occurs in the thorn and arid forests of Gujarat and Rajasthan, in the moist and dry deciduous forests throughout peninsular India, in the pine and oak forests at the Himalayan foothills, and in the evergreen and semi-evergreen forests of northeastern India and the Western Ghats (Sankar & Acharya, 2004, N.S. Kumar pers. comm. 2008). Outside India it extends into temperate-latitude and alpine-zone woodlands of Taiwan (Lin, C.-Y. & Lee, L.-L. pers. comm. 2008). In Borneo, while Payne et al. (1985) considered Sambar “most common in secondary forests of gently-sloping terrain” they also knew of occurrence in “tall

	(excepting Java): Sumatra, Siberut, Sipora, Pagi and Nias islands (all Indonesia), and Borneo (Malaysia, Indonesia, and Brunei) (Grubb 2005). Same as rusa deer, this species successfully introduced in many region such as Australia, New Zealand, South Africa (Western Cape), United States (California, Florida, Texas)	dipterocarp forests on steep terrain and in swamp forests". In Thung Yai, Thailand, Sambar signs were twice as abundant in lowland forest as in montane forest. Sambar was found to live in much higher densities in moist than in dry deciduous forests of Nagarahole National Park (Karanth & Sunquist, 1992). The Sambar occurs up to at least 3.825 m on Siouguluan Mountain, the highest peak of the Central Mountains in Taiwan; elsewhere on the island it ranges down to 150 m asl, mostly living at 2.000–3.500 m (Lin, C.-Y. & Lee, L.-L. pers. comm. 2008). It occurs up to 3.000 m on Gunung Kinabalu, Sabah, Borneo (Payne *et al*. 1985). In Myanmar, recent camera-trap photographs spanned the range of 0–2.150 m asl (Saw Htun pers. comm. 2008). Sambar is largely restricted to hilly terrain in the Terai Arc Landscape (Johnsingh *et al*. 2004). More widely in India, there does seem to be a marked preference for undulating terrain (N.S. Kumar pers. comm. 2008). Kushwaha et al., (2004) found that in Kumaon Himalaya (India), Sambar usage was greater of the higher than the lower altitude area. In Southeast Asian regions of dense evergreen closed-canopy forest, Sambar is highly tolerant of forest degradation: indeed, much higher numbers are found in encroached stands than in pristine forests, if hunting is under control (Rijksen 1978, Heydon 1994, Stuebing 1995, Davies *et al*. 2001).

Tragulus javanicus (Java mouse deer)	DD [ver 3.1]	*Tragulus javanicus* as here defined is endemic to the island of Java, Indonesia, according to Meijaard and Groves (2004a). The latter authors did not mention the island of Bali, but a sighting was reported from Bali Barat National Park, Bali, in a bird watching trip report (Birdquest 2006).	Hoogerwerf (1970) wrote of *T. javanicus* on Java occurring "from sea-level to high in the mountains". In the Dieng plateau area, V. Nijman (pers. comm. 2008) found them only a few times in the lowlands (400–700 m asl), where most survey took place, and had no records from above about 1.500 m asl. They have been found on Gunung Gede–Pangangro up to about 1.600 m asl (V. Nijman pers. comm. 2008). Hoogerwerf's (1970) description of favoured habitats on Java suggests that chevrotains there might be an 'edge' species, certainly seeming to prefer areas with thick understorey vegetation, such as that along riverbanks. This would not be unusual within the genus
Tragulus kanchil (lesser mouse deer)	LC [ver 3.1]	Occurs in Borneo, Sumatra, the Thai–Malay Peninsula, many islands within the Greater Sunda region, and continental Southeast Asia north to at least 18°10′N. Generarly they are a native species from Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, Singapore, Thailand, Viet Nam.	This species is found in lowland/foothill primary and secondary forests as well as cultivated areas up to 600 m in elevation (Semiadi and Boeadi pers. comm.). The habitat of this species is a mosaic of riverine, seasonal swamp and dry undulating country, vegetated predominantly by legumes and dipterocarps. In Sabah, it also inhabits mangrove forest. In Peninsular Malaysia, it feeds on shoots, young leaves and fallen fruits in the tall forest of the lowlands. However, all *Tragulus* species are associated with forests, but there is strong evidence that *T. kanchil* does not require old-growth forest or even particularly mature secondary forest. Its heavy use of disturbed habitats was confirmed by Matsubayashi *et al*. (2003).

Tragulus napu (greater mouse deer)	LC ver 3.1	*Tragulus napu*, as constituted here (that is, excluding *T. versicolor* of Indochina and *T. nigricans* of the Philippines) occurs in the Sundaic subregion, extending some way up the Thai–Malay peninsula, in the following countries: Brunei, Indonesia (Kalimantan, Sumatra, and many small islands), Malaysia (West Malaysia, Sabah, Sarawak, and many small islands), Myanmar (far south only), Singapore (Pulau Ubin only), and Thailand (south only) (Meijaard & Groves; 2004a; Chua et al., 2009).	In the lowlands of Borneo both occur but *T. napu* apparently ranges to higher altitudes (up to at least 1.000 m asl) than does the latter (Payne et al., 1985). *T. napu* was found typically to range 19 ha in old logged forest and 7 ha in primary forest, this difference again suggesting an association with primary forest (Heydon, 1994). The abundance of *Tragulus* spp. (*T. napu* and *T. kanchil* combined, with no information on the proportions or even confirmation that both species were present) was higher (strongly statistically significantly so) in areas within 1 km inside the boundary of Bukit Barisan Selatan National Park, Sumatra than in the interior of the park, suggesting higher numbers in somewhat encroached habitat. Also at this site, *Tragulus* was more than nine times as abundant in areas of the park with low than with high human population density within 10 km of the park boundary, suggesting limited resilience to human presence, presumably the effects of hunting (O'Brien *et al*. 2003). The ability of *T. napu* to use plantations is probably low, because all (the admittedly relatively few) sources agree that it does not persist well in secondary or logged forest. Moreover, Belden Giman (pers. comm. 2008), in extensive observations at Sarawak Planted Forests, Bintulu, Sarawak, has never recorded *T. napu* in any of the blocks of monoculture plantations there, despite many records of *T. kanchil*.

Appendix 4: Example of data sheet (part of: Materials and Methods)

Appendix 4.a. Basic information to be included for each camera trap operating in the field

The following frame can be used as a basic data sheet and brought to the field for data collection

Study site : **General GPS location** :
Team who installed the CT : **Team who checks the CT** :

CT	**Location of the CT**			**Active period**			**Site specific variables**			**Results**		
ID	**Lat**	**Long**	**WP nb**	**Installation date**	**Removal date**	**Effort trap days**	**Set up**	**Var.1**	**Var.n**	**Species A**	**Species n**	**Comments**
DA01												
DA02												
DA03												
….												

<u>Legend</u>

CT ID : Camera trap identification (number)
WP nb : Waypoint number (from the GPS)
Active period : The gives the surveys effort (or number of days the trap has been active)
Site specific variables : This describes the micro-environmental conditions encountered at the CT site
Site up : Write down if the CT is located along a road (active or not); a trail, a salt lick; at a random location in the forest; etc
Var. : Environmental variables that need to be recorded for each CT site: habitat type (forest, shrub, mangrove, etc), logging activities, etc

Appendix 4.b. Records to be processed

The following table can be replicated in an Excel format or Dbase format or equivalent for processing information that is originating from the field

Species	CT ID	Date	Time	Individual ID	Nb. ind	Nb. male	Nb. females	Nb. young	Nb. fawn	Occasion	Primary sample	Observation
A												
B												
C												
….												

<u>Legend</u>

Individual ID	: for identifiable species/individual only
Nb. ind	: Number of individuals recorded in the picture
Nb. male	: Number of males
Nb. females	: Number of females
Nb. young	: Number of sub-adult
Nb. fawn	: Number of cubs
Occasion	: for capture-recapture and maximum entropy modelling
Primary sample	: if sampling is repeated over a long time frame

Appendix 4.c. Building a capture-recapture matrix

The following table can be replicated in a spreadsheet (Excel, Dbase format or equivalent format) to generate a capture-recapture matrix

	Individual	Occasion 1	Occasion 2	Occasion 3	Occasion ….	Occasion n
	AKM01	1	1	1	0	….
	AKF01	1	0	0	0	….
Axis kuhlii	AKF02	0	0	1	1	….
	AKY01	1	0	1	0	….
	AKC01	0	0	1	0	….
	MMM01	1	1	0	0	….
	MMM02	0	0	1	1	….
Muntiacus muntjac	MMF01	0	1	1	1	….
	MMY01	0	0	0	1	….
	MMC01	1	1	1	1	….
	….	….	….	….	….	….
	….	….	….	….	….	….
Species n	….	….	….	….	….	….
	….	….	….	….	….	….
	….	….	….	….	….	….

Nb: This format is the basic format for single-season closed population models. The input format for multi season analysis will depend on the models and the programs used for data analysis.

Appendix 5: Pearson's correlations between the environmental variables (part of: Paper 3)

Appendix 5A. Pearson's correlations between the environmental variables used in the distribution modeling for Bawean deer in Bawean Island Nature Reserve and Wildlife Sanctuary.

Variables	NDVI	Elevation	Slope	Distance to river	Distance to primary forest edge	Distance to secondary forest edge	Distance to settlement	Distance to cultivated area	Distance to road	Ann.m.temperature	Min.temp. of the coldest month	Max.temp. of the warmest month	Ann.rain fall	Rainfall during the wettest month	Rainfall during the driest month
NDVI	1														
Elevation	-.044	1													
Slope	.365*	-.105	1												
Distance to river	.007	.276	.188	1											
Distance to primary forest edge	-.122	-.680**	-.024	-.056	1										
Distance to secondary forest edge	.350*	.446**	.369*	.113	-.604**	1									
Distance to settlement	-.128	.549**	-.293	.044	-.216	.091	1								
Distance to cultivated area	.079	-.438*	.022	-.388*	.634**	-.235	.322	1							
Distance to road	.252	.691**	-.045	-.011	-.462**	.595**	.307	-.541**	1						
Ann.mean temperature	-.204	-.647**	.162	.203	.581**	-.393*	-.437*	.328	-.078**	1					
Min.temp. of the coldest month	-.210	**-.759****	.158	.187	.387**	-.393*	-.447**	.330	-.184**	**.999****	1				
Max.temp. of the warmest month	-.192	.529**	.157	.173	.504**	-.401*	-.440*	.355*	-.092**	**.999****	.689**	1			
Ann.rainfall	.138	.605**	-.121	-.156	-.264**	.402*	.298	-.491**	.012**	-.662**	-.663**	-.570**	1		
Rainfall during the wettest month	.177	.464**	-.103	-.210	-.354**	.444**	.263	-.473**	.018**	-.559**	**-.958****	-.463**	**.991****	1	
Rainfall during the driest month	.095	**-.774****	-.168	-.078	-.451**	.351*	.419*	-.461**	.094**	-.567**	-.470**	**-.978****	**.975****	.246**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

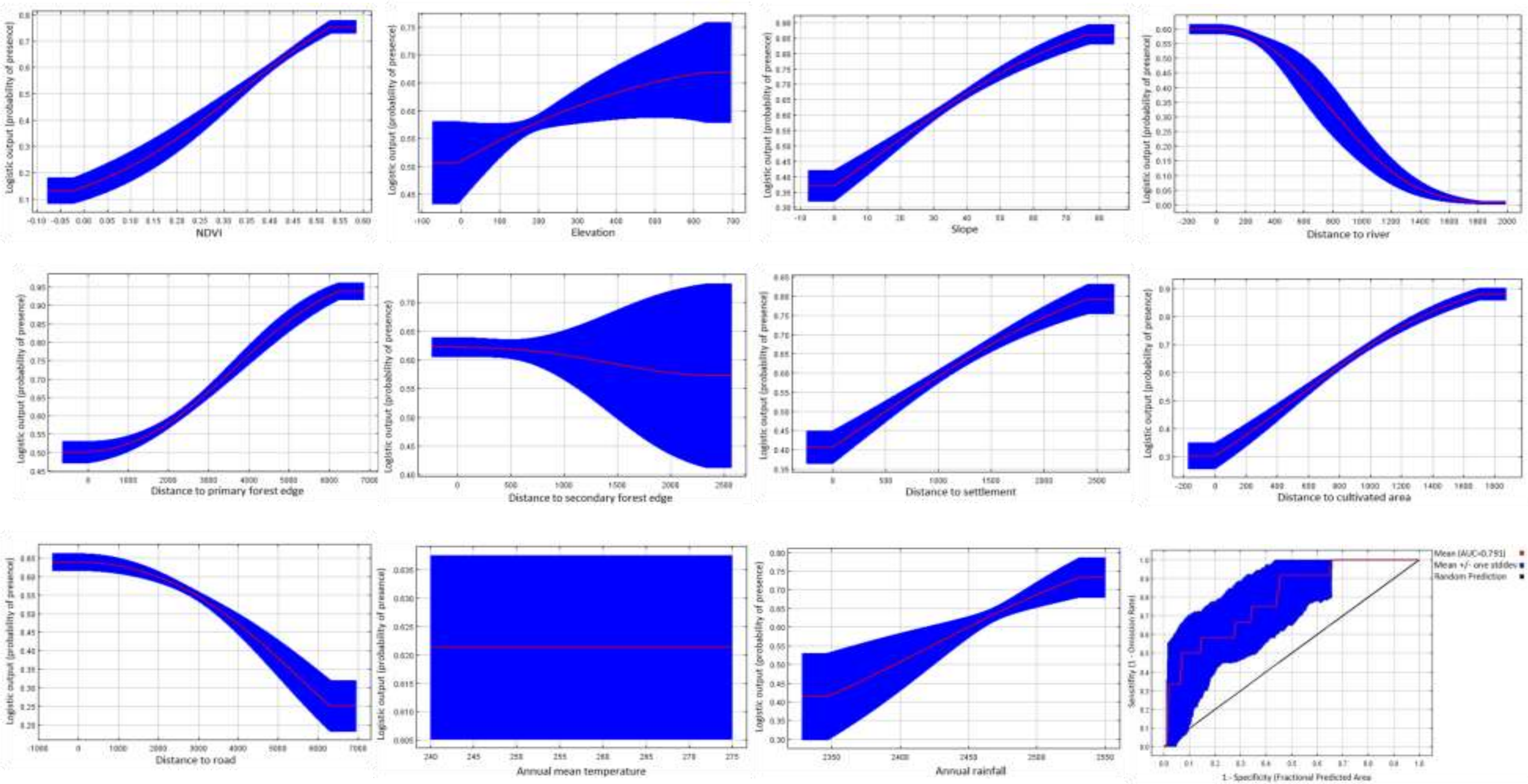
Appendix 5B. Pearson's correlations between the environmental variables used in the distribution modeling for red muntjac in Ujung Kulon National Park.

Variables	NDVI	Elevation	Slope	Distance to river	Distance to primary forest edge	Distance to secondary forest edge	Distance to settlement	Distance to cultivated area	Distance to road	Ann.m.temperature	Min.temp. of the coldest month	Max.temp .of the warmest month	Ann.rainfall	Rainfalld uring the wettest month	Rainfall during the driest month
NDVI	1														
Elevation	-.009	1													
Slope	-.036	.185**	1												
Distance to river	-.064	.213**	-.098	1											
Distance to primary forest edge	.093	-.529**	-.206**	.014	1										
Distance to secondary forest edge	-.038	.513**	-.056	.354**	-.321**	1									
Distance to settlement	.042	.538**	.147*	.038	-.559**	.231**	1								
Distance to cultivated area	.040	.507**	.128*	.045	-.527**	.228**	.394**	1							
Distance to road	.041	.509**	.129*	.045	-.527**	.228**	.495**	.089**	1						
Ann.mean temperature	-.003	-.541**	-.142*	-.187**	.587**	-.534**	-.572**	-.534**	-.536**	1					
Min.temp. of the coldest month	.029	**-.920****	-.150*	-.165**	.609**	-.508**	-.515**	-.473**	-.474**	**.974****	1				
Max.temp. of the warmest month	.009	.023**	-.146*	-.173**	.624**	-.534**	-.628**	-.590**	-.592**	**.978****	.673**	1			
Ann.rainfall	-.070	.042**	.148*	.137*	-.541**	.475**	.261**	.208**	.210**	-.690**	-.439**	-.477**	1		
Rainfall during the wettest month	-.196**	-.253**	.026	-.122*	.052	-.158*	-.647**	-.675**	-.676**	.246**	**-.826***	.282**	**.777****	1	
Rainfall during the driest month	.114	**-.932****	.052	.227**	-.333**	.500**	.519**	.496**	.499**	-.546**	-.593**	**-.751****	**.839****	-.601**	1

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

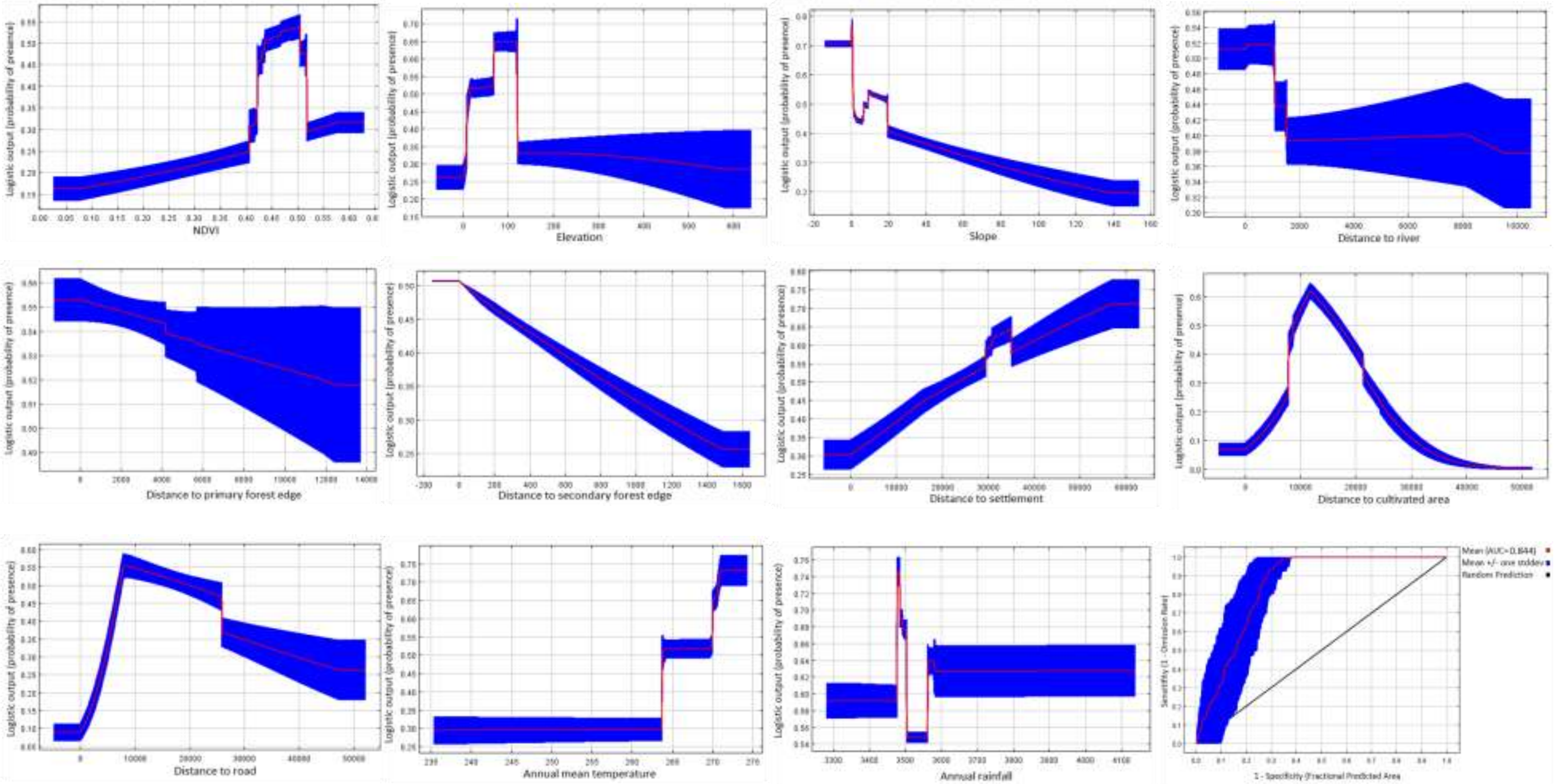
Appendix 6: Pearson's correlations between the environmental variables (part of: Paper 3)

Appendix 6A. Response curves and AUC for Bawean deer probability in dry seasons at Bawean Island Nature Reserve and Wildlife Sanctuary (BINR-WS)

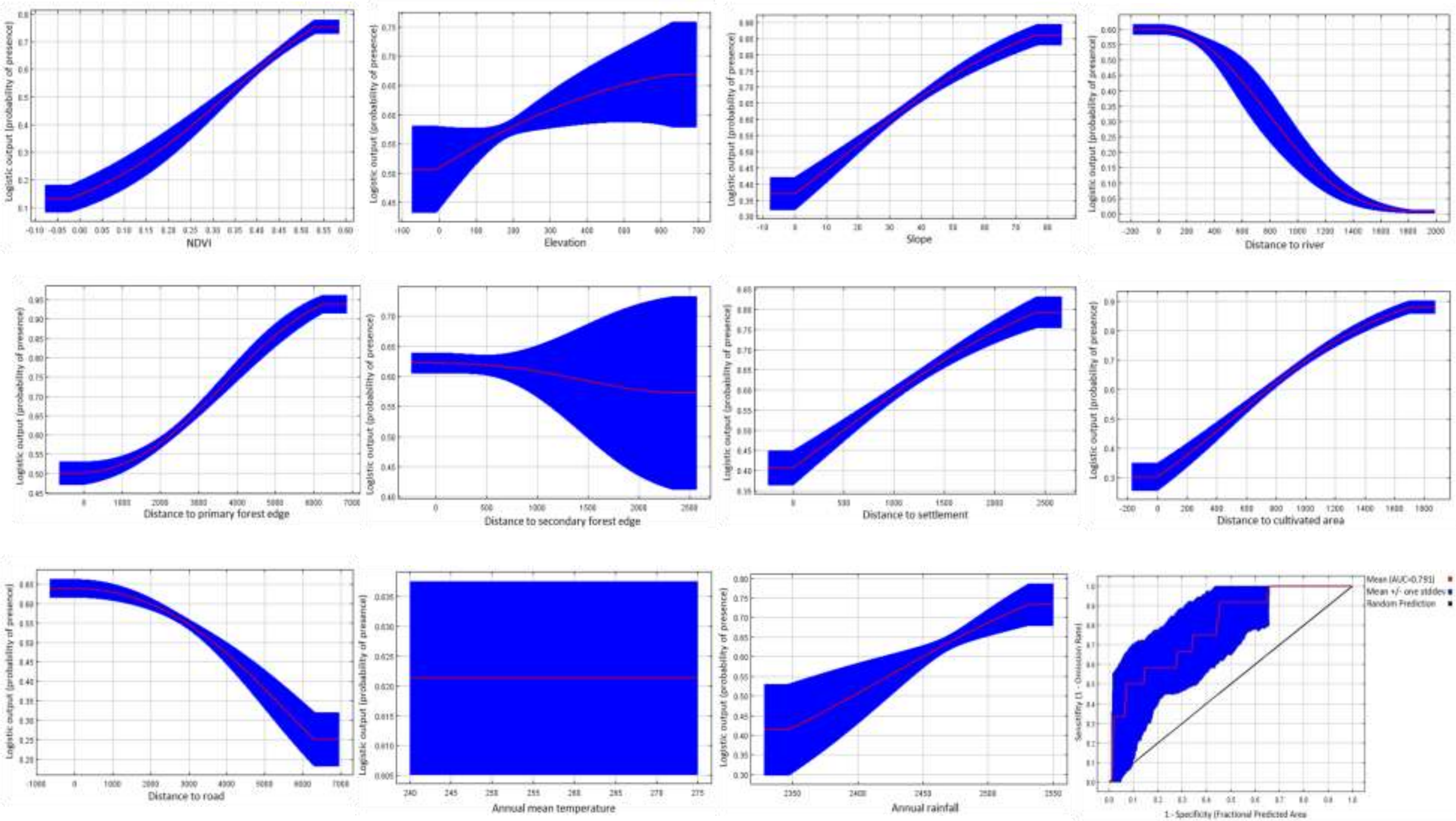


Appendix 6B. Response curves and AUC for red muntjac probability in A) wet and B) dry seasons at Ujung Kulon National Park (UKNP)

A



B



Logistic output (probability of presence)
NDVI
Elevation
Slope
Distance to river
Distance to primary forest edge
Distance to secondary forest edge
Distance to settlement
Distance to cultivated area
Distance to road
Annual mean temperature
Annual rainfall
Mean (AUC=0.791)
Mean +/- one stddev
Random Prediction
Sensitivity (1 - Omission Rate)
1 - Specificity (Fractional Predicted Area