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Ecology and Conservation of Endangered Species in Sumatra: Smaller Cats and the Sumatran Rhinoceros (Dicerorhinus Sumatrensis) As Case Studies

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ECOLOGY AND CONSERVATION OF ENDANGERED SPECIES IN SUMATRA: SMALLER CATS AND THE SUMATRAN RHINOCEROS (*Dicerorhinus sumatrensis*) AS CASE STUDIES

A Thesis Presented

By

WULAN PUSPARINI

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ABSTRACT

ECOLOGY AND CONSERVATION OF ENDANGERED SPECIES IN SUMATRA:

SMALLER CATS AND THE SUMATRAN RHINOCEROS (*Dicerorhinus sumatrensis*)

AS CASE STUDIES

MAY 2013

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The island of Sumatra is rich with mammal biodiversity, and like many other developing country, the trajectory of their survival is mostly downward. Small- and medium-sized cats are a group of endangered species often neglected, overshadowed by the larger Sumatran tiger. Using results from a camera-trap study originally designed for tigers, spatial and temporal distribution of smaller cats in Gunung Leuser are described. Four of the five small cats were identified 68 camera stations yielding 3,452 trap nights. The Golden cat *Catopuma temmincki* was the most frequently photographed species (0.72 independent captures/100 trap nights), followed by the Sunda clouded leopard *Neofelis diardi* (0.41), the marbled cat *Pardofelis marmorata* (0.23) and the leopard cat *Prionailurus bengalensis* (0.20). Golden cats were mostly photographed in montane forests at elevations of 1,800-2,500m (34%), marbled cats in medium elevation hills 400-900m (38%) and montane forests (38%), clouded leopards in medium elevation hills (43%), and leopard cats in the lowlands <150m (100%). Golden cats seemed to be diurnal, clouded leopards and marbled cats were active at dawn/dusk, and leopard cats were strongly nocturnal. Trade in Medan of clouded leopards and golden cats (live and stuffed specimens) indicates some level of harvest, but data are insufficient to determine whether such harvest is a significant threat to their populations. Because I used data from a study focused on tigers, caution is warranted when estimating relative abundance since the camera set-up was biased against more arboreal cat species.

While we should celebrate the bicentennial of naming the Sumatran rhinoceros (SR), the only extant population on earth might be on the island of Sumatra. Since Strien's 1986 study in Mamas Valley, Leuser, very little more has been learned about how this species distributed and what factors are influencing its extirpation. This study is the first conducted in Sumatra at an Island-wide scale. Using hierarchical models, I estimate the occurrence rates (%) and indices of abundance of SR on three remaining population areas: Leuser Landscape (LL) in 2007 (2.77%, 26 (CI 12-61)), Way Kambas (WK) in 2008 (33.58%, 27 (CI 14-50)) and Bukit Barisan Selatan (BBS) in 2010 (36.4%, 31 (CI 19-66)). Primary dry land forest and rivers are factors affecting SR occurrence in LL, but the index of abundance also is affected by deforestation, roughness of terrain, and and a vegetation index. The index of abundance in WK is more affected by major roads, and brush and savannah cover types, and the occurrence there is additionally affected by deforestation. Secondary dry land forest, regular roads, and deforestation is affecting both the occurrence rate and index of abundance of SR in BBS. The identification of these environmental and disturbance factors is translated into spatially explicit map that can be used to update the IUCN distribution map. In LL, by comparison to the historical distribution based on Strien (1986), the small population in Bendahara Mountain might still persist outside the core population in Mamas Valley.

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CHAPTER 1

RECORDS OF SMALL AND MEDIUM CATS FROM GUNUNG LEUSER NATIONAL PARK, SUMATRA, INDONESIA

Abstract

Small and medium cat diversity and spatio-temporal distribution in Gunung Leuser National Park, Sumatra, Indonesia, was recorded between March and October 2010. A pair of infra-red cameras was set up in each of the 68 locations resulting in 54 independent events of small and medium cats in 3,452 trap nights. Four of the five small and medium cat species confirmed to inhabit Sumatra were photographed: Asiatic golden cat *Catopuma temmincki,* Sunda clouded leopard *Neofelis diardi*, marbled cat *Pardofelis marmorata* and leopard cat *Prionailurus bengalensis.* Golden cat was the most frequently photographed species (0.72 independent event per 100 trap nights), followed by clouded leopard (0.41), marbled cat (0.23) and leopard cat (0.20). Golden cats were predominantly photographed in montane forests 1,800/1,900-2,400/2,500m (34%), marbled cats in medium elevation hills 400/500-800/900m (38%) and montane forests (38%), clouded leopards in medium elevation hills (43%) and leopard cats were mostly found in the lowlands <150m (100%). Golden cats seemed to be diurnal, clouded leopards and marbled cats were active at dawn/dusk, and leopard cats were strongly nocturnal. Trade in Medan of clouded leopard and golden cat (live and stuffed specimens) indicates some level of harvest of these small and medium cats, but data are insufficient to determine whether such harvest is a significant threat.

Introduction

Sumatra is rich in mammal diversity: it is the only place in Asia where tiger *Panthera tigris*, Asian elephant *Elephas maximus*, Sumatran rhinoceros *Dicerorhinus sumatrensis*, Sumatran orang-utan *Pongo abelli* live sympatrically. Wild cat diversity is no exception. Six species of wild cats are known from Sumatra: the critically endangered Sumatran race of tiger *P. t. sumatrae*, Sunda clouded leopard *Neofelis diardi*, leopard cat *Prionailurus bengalensis*, Asiatic golden cat *Catopuma temminckii*, flat-headed cat *Prionailurus planiceps* and marbled cat *Pardofelis marmorata*. There are unconfirmed indications of the occurrence of two others: - leopard *Panthera pardus* and fishing cat *Prionailurus viverrinus* (van Strien 1996). Small and medium cats are defined here as all Sumatran cat species except *Panthera*. Little is known about the conservation status of these small and medium cats on the island (Bezuijen 2000, Holden 2001, Hutajulu et al. 2007, Dorsi et al. 2009, Duckworth et al. 2009, Sanderson 2009, and Wibisono & McCarthy 2010). Accurate assessment of their conservation status is difficult as only few field surveys specifically targeting the natural history of the island's small and medium cats have been undertaken (Povey et al. 2009) compared to big cats such as tigers.

The island of Sumatra is part of a distinctive biogeographical region known as Sundaland (Myers et al. 2000). Sundaland's once undisturbed natural forests are now restricted to isolated fragments that survived as a result of official protection. Three protected areas maintain assemblages of Sundaland's unique flora and fauna in Sumatra: Leuser Ulu Masen Ecosystem (including the Gunung [meaning Mount] Leuser National Park [NP] (34,000 km^2), Kerinci Seblat NP (15,000 km^2) and Bukit Barisan Selatan NP (3,600 km^2). These three national parks were designated by UNESCO in 1980 as a Clustered

Natural World Heritage Site, reflecting their collective global importance for biodiversity conservation (UNEP 2007). Gunung Leuser NP is part of the larger area known as the Leuser Landscape (27,000 km^2) mandated by the Presidential Decree No. 33/1998 for the conservation and restoration of Leuser biodiversity and ecosystem. Together with the Ulu Masen Landscape to the north-west, the area forms the largest natural forest area and biodiversity resource surviving in Sumatra, called Leuser-Ulu Masen Ecosystem (UNEP 2007), a Class I Tiger Conservation Landscape (TCL) with global priority (Wibisono et al. 2011). Gunung Leuser NP has a rugged forest interior bordered with human-dominated areas and covers various habitat types ranging from lowland forest at 5 m above sea level to the subalpine zone of Gunung Leuser at 3,445 m. This is the highest non-volcanic mountain in Sumatra, located in the NorthWestern corner of the park (van Strien 1985, Wind 1996, Whitten et al. 1997, UNEP 2007). Griffiths (1996) stated that the full species list of cats in Gunung Leuser was then unknown, but that tigers, clouded leopards, golden cats and leopard cats were already known to inhabit the area.

Three of the five small and medium cats in Sumatra are listed on *The IUCN Red List of Threatened Species* as Vulnerable, the exceptions being leopard cats which are listed as Least Concern and flat-headed cats *Prionailurus planiceps* listed as Endangered. The fishing cat *Prionailurus viverrinus* whose presence is unconfirmed is also listed as Endangered. All the above species except leopard cats are listed in Appendix I of CITES (2012). At the national level, all the species are on the list of protected species according to Government Regulation No. 7 year 1999 on Preserving Flora and Fauna Species. Although this study did not gather evidence of targeted hunting, indirect evidence of local hunting is apparent from wildlife trade monitoring in Sumatra. Povey et al. (2009)

suggested that some of these small and medium cats may be facing significant population declines due to habitat destruction and fragmentation, declining prey base and targeted hunting.

The conservation status of small and medium cats has not been investigated in North Sumatra. In recent decades, there has been an increase in studies using camera-traps in Sumatra, resulting in many records of small and medium cats. However, there has been little dissemination of these data, in part due to funding and government priorities (Dorsi et al. 2009). This paper presents the small and medium cat records from a six-month study using camera-traps in Gunung Leuser NP, targeting tigers. It comments on each species' natural history to the extent possible. Evidences of potential threats to small and medium cats in the park are also discussed.

Methods

This was a collaborative study of the Wildlife Conservation Society – Indonesia Program and Leuser International Foundation (LIF) in north-eastern Gunung Leuser NP (centred on 3°41′N- 97°36′E). Infra-red cameras were set up in pairs in 68 stations (all Panthera V2Rev2, except one location with Bushnell game camera). The mean distance between nearest-neighbour cameras was 2.09 km (SE 1.04) with a density of 5.4 stations/100 km², within a 1,249 km² minimum convex polygon defined by the outer camera trap locations (Figure 1.1). Each camera was activated to photograph animals for 24 hours/day until it was retrieved by the field teams. On average, cameras were activated for 51 days. The cameras were specifically set up for tigers on trails in areas with the highest detection probability, i.e. areas with abundant tiger signs. The opposing cameras were set on a tree with the sensor direction perpendicular to the animal trail, ~45 cm above the ground and

4–5 m from the trail (8–10 m separation of the paired cameras). Baits and lures were not used. To prevent condensation within the cameras, they were not set in areas with a high contrast in temperature and humidity between night and day, such as forest gaps with direct sunlight facing the cameras.

Each station was equipped with a pair of cameras, so the total number of trap-nights per station was taken as the number of days that the longest-working camera was functional. Each animal photographed was identified to species: five people separately identified the cats photographed using a mammal identification guide to Borneo (Payne et al. 2000) which has an incomplete list of Sumatran cats. They then discussed uncertain identifications. This process was supervised by the author, with all photographs checked for identification by J. W. Duckworth and T. Lynam. All cat photographs were of sufficient quality for species identification. However, individual identification proved challenging, especially for marbled cats. Golden cats could not be individually identified due to the lack of complex pelage markings. Independent events were defined following O'Brien et al. (2003) as: a. different species, or consecutive photographs of different individuals from same species, b. consecutive photographs of same species with time span between capture more than 30 minutes, and c. non-consecutive individual photographs from the same species.

The set up did not take into account the ecology of arboreal cat species (marbled cat and clouded leopard), potentially affecting the detection probability. There probably is an under representation of species that are partly arboreal, or which avoid trails to a significant extent. Hence, the relative abundance of each cat species in the survey area cannot be deduced from these photographs alone. Altitudinal zonation based on temperature and vegetation were classified according to Laumonier (1997): lowland (0-150 m), low elevation hills (150-400/500 m), medium elevation hills (400/500-800/900 m), submontane (800/900-1,300/1,400 m), lower montane (1,300/1,400–1,800/1,900 m), montane (1,800/1,900-2,400/2,500 m) and tropical uppermontane and subalpine (>2,500 m). Altitudinal zonation was used as a proxy for spatial co-occurrence or general information on habitat use, though the limited number of records was insufficient for making a specific conclusion. Habitat use was evaluated based on the number of independent events of each species per habitat with the assumption that arboreal species showed no difference in habitat type use. This assumes that the proportion of time semi-arboreal species spent on the ground and in trees remains the same across the different habitats. Elevations were obtained from Digital Elevation Map SRTM 90 m (Jarvis et al. 2008) from the camera-traps positions measured using the Spatial Analyst Tools in ArcGIS ver. 9.3. Of the 68 locations ranging from 57 to 2,937 m; 23.5% were in lowlands (<150m), 27.9% in low to medium elevation hills (150-900m), and 48.5% in submontane to uppermontane (900->2,500m). The date and time data are available for each picture. The activity period of each species was assessed using the percentage of independent events in each of three time-of-day divisions (Azlan & Sharma 2006): night-time (19:00–05:00), day-time (07:00–17:00) and dawn/dusk (05:00–07:00 and 17:00–19:00). The activity period of small and medium cats were further defined as: strongly nocturnal (>85% with events between 19:00 and 05:00), nocturnal (50–85% of events between 19:00 and 05:00), dawn/dusk (up to 50% between 05:00 and 07:00, and up to 50% between 17:00 and 19:00), diurnal (50–85% records between 07:00 and 17:00), and strongly diurnal (>85% events between 07:00 and 17:00). This study recorded animals at ground level; therefore the percentage of arboreal activity in a 24h period is unknown.

Little is known about the threats to small and medium cats in Leuser. As preliminary information, records of wildlife trade collected by WCS's Wildlife Crime Unit between 2007 and 2011 were examined to describe the nature of illegal trade on these species in Gunung Leuser NP. The number of photo-trapped villagers was also used as an indicator of illegal human activity inside the park. Human activities without legal permit, other than those associated with park management, protection and research, are illegal according to Government of Indonesia Law No. 5 year 1990 on Conservation of Biological Natural Resource and Its Ecosystem.

Results

Four of the five small and medium cat species confirmed to inhabit Sumatra were photographed (Figures 1.1 – 1.2). A total of 3,452 trap-nights over eight months resulted in 54 independent events from a total of 124 photographs of small and medium cats: clouded leopard *Neofelis diardi* (14 independent photos; at least 5 individuals), golden cat *Catopuma temminckii* (25; not determined), marbled cat *Pardofelis marmorata* (8; at least 4 individuals) and leopard cat *Prionailurus bengalensis* (7, at least 3 individuals) (Tables 1.1 and 1.2).

Of these small and medium cat records, 20% were in lowland (<150 m), 29% in low to medium elevation hills (150-800/900 m) and 50% in the submontane to uppermontane (800/900->2,500 m). Golden cats were mostly recorded in montane (34% of 25 independent events) and lower montane forests (31%), clouded leopards were mostly in the medium elevation hills (43% of 14 independent events), marbled cats in montane forests (38% of eight independent events) and medium elevation hills (38%), and leopard cat presence was restricted to the lowlands (100% of seven independent events) (Figure 1.3). Due to very few records, they may not reflect the actual altitudinal distribution of this species. Caution should be taken in inferring any biological patterns from this, particularly with the few records of marbled cat and leopard cat. Golden cat records suggested diurnal activity (56% of records by day), clouded leopard and marbled cat records all suggested a cathemeral pattern with peak activity by day (43% and 50% respectively), while leopard cats were mostly recorded by night (86%) (Figure 1.4). Human activities were found only at two stations, both in lowland habitat.

Discussion

Our study area in Gunung Leuser NP, covering ~10% of the park, supports Asiatic golden cat, Sunda clouded leopard, marbled cat and leopard cat. Neither flat-headed cat nor fishing cat was detected; the former is known to occur on Sumatra while there is no confirmation of fishing cats inhabiting the island. Small and medium cat use of encroached and disturbed areas was not assessed: the survey area has mostly intact canopy, and only two of 68 locations had signs of illegal human presence. This perhaps reflects the difficult access to the study area due to its rugged terrain and long distance from surrounding villages.

Holden (2001) recorded golden cats only in the lowland forests of Kerinci Seblat NP, central Sumatra despite extensive survey in montane forest where clouded leopards and marbled cats were recorded. By contrast, golden cats in this study were more commonly recorded in montane forest and Griffiths (1996) also suspected that golden cats have a predilection for higher altitudes in Gunung Leuser NP. These contradictory results may simply reflect the chance patterns shown by small numbers of records, rather than any real difference between survey areas. The present study found clouded leopards mostly in medium elevation hills and some up to 1,848 m. Griffiths (1996) recorded the presence of this cat from sea level to over 2,000 m, indicating a distribution over a wide range of elevations. The lack of records in higher montane forest in the present survey may have simply been due to chance. The marbled cat is rarely found, with little published information on its ecology (Grassman et al. 2005, Macdonald et al. 2010, Wibisono & McCarthy 2010). In this study it had a lower encounter rate than did the golden cat or the clouded leopard, but the few records indicated a wide distribution from medium elevation hills to tropical upper montane and subalpine forest. The leopard cat was photo-trapped only in lowlands. The reason may be its tolerance or even its association with anthropogenic disturbance such as human settlements (Azlan & Sharma 2006, Povey & Spaulding 2009), and such areas are absent from the survey area's hilly interior. The small number of leopard cats recorded might also reflect the low numbers of cameras in disturbed areas.

Neither van Strien (1996) nor the unpublished data of the Leuser Management Unit 2004 (Dorsi et al. 2009) reported flat-headed cats in the park. There is no substantiated record of flat-headed cats in northern Sumatra, despite recent records in Southeast Sumatra and Kerinci Seblat (Bezuijen 2000, Holden 2001), as well as central Sumatra (Wilting et al. 2010). The occurrence of another wetland small cat, the fishing cat, in Sumatra, is still uncertain (Duckworth et al. 2009, Sanderson 2009). Siantar Zoo, ~200 km from the park, has a captive fishing cat, of unknown origin. The label on the cage informs visitors that it comes from Java (Figure 1.5), but it is unclear if this refers to the origin of this individual or the occurrence of the species there. An inquiry at the zoo into the capture location did not return any result. Duckworth et al. (2009) also noted this cat, but similarly could not determine its origin. Flat-headed cat and fishing cat are both strongly associated with wetlands (Azlan & Sharma 2006, Melisch et al. 1996). Whether these species inhabit the area cannot be determined. The presence or absence of these species was not established by this study as all stations were placed on ridges and not in their preferred habitat, close to water, still or riverine (Melisch et al. 1996). . Similarly, there were no records of another riparian small carnivore, otter civet *Cynogale bennettii*, even though this is already known to inhabit the park (van Strien 1996). The south-western area of the park, close to the coastline adjacent to Singkil Barat Nature Reserve, comprises an area predicted to have a great potential for flat-headed cats (Wilting et al. 2010).

Griffiths & van Schaik (1993) suggested that human presence could alter the natural activity patterns of mammals. Our study area had a low level of human disturbance, so the data presumably reflect each species' natural activity period at ground level. The overlap of activity patterns among small and medium cats indicated a level of interspecific interaction of these sympatric carnivorous species. One potential factor influencing the temporal separation of sympatric species is their body size, with similar size animals tend to avoiding each other. Holden (2001) concluded that golden cats in Kerinci–Seblat NP are cathemeral, and although in Gunung Leuser NP, recorded activity was somewhat higher during day time (Figure 1.4) this could simply have been sampling bias. Predominant diurnal activity by day concurs with activity readings from two radio-collared golden cats in Thailand’s Phu Khieu National Park (Grassman et al. 2005) and camera-trap records from 14 sites across Thailand (Lynam et al. 2013). The radio-collar work is particularly informative because it does not have the camera-trap bias of only recording activity at ground level. Clouded leopards in this study tended to be cathemeral, with more daytime activity, unlike those in Borneo (Cheyne & MacDonald 2011) and Thailand (Lynam et al. 2013), which were nocturnal. Most camera trap records of marbled cats have been by night (Grassman et al 2005, Macdonald et al 2010, Lynam et al. 2013); however in this study the few records of marbled cats fitted a cathemeral activity pattern. With only seven independent records, firm conclusions about leopard cat activity patterns are unwise, but the nocturnal activity pattern suggested agrees with findings by Macdonald et al. (2010), Cheyne & MacDonald (2011), and Lynam et al. (2013). Variation in temporal activity patterns between areas is largely driven by competition between species. Therefore, investigating interspecific interaction between species can provide a more meaningful interpretation (Ridout & Linkie 2009, Sunarto 2011).

All cameras were set for ground-dwelling animals; therefore the degree of arboreal tendency of each small and medium cat affected the detection probability (Giman et al. 2007, Cheyne & Macdonald 2011). This is one of a number of reasons why differences in encounter rates may not reflect patterns of abundance between species. Similar to Holden (2001) in Kerinci Seblat NP and WCS's study in Bukit Barisan Selatan NP (WCS-IP unpubl. data), golden cat was the most frequently photographed species, followed by clouded leopard and marbled cat. Leopard cats were photographed least of all (Table 1.3). Tigers and golden cats are believed to be active mainly at ground level (Guggisberg 1975) and, if correct, tiger-focused camera-traps may be biased towards golden cats among the small and medium cats. Clouded leopards are to some extent arboreal (Grassman et al. 2005, Kitchener et al 2006, Macdonald et al. 2010). Compared to conspecifics in Borneo, clouded leopards in Sumatra are believed to be more arboreal, hence less likely to be camera-trapped (Macdonald et al. 2010, Holden 2001), but evidence for this is not compelling. The measured abundance at one site in Borneo is much higher (9 adults/100 sq km) (Wilting et al. 2006 *in* Macdonald et al. 2010) than at another site in Sumatra (1.29/100 sq km - Hutajulu et al. (2007), but as few sites have been studied caution is urged when assuming island-specific differences. Marbled cats are purportedly heavily arboreal, but again have been too poorly studied to be sure to what extent; they are camera-trapped more often than truly arboreal species like white-handed gibbons *Hylobates lar* and siamang *Symphalangus syndactylus* in Leuser, and appear to be relatively rare in Sumatra and Borneo (Macdonald et al. 2010).

WCS found evidence of medium cat poaching and trade near Gunung Leuser NP (Figure 1.6). In 2008, two stuffed specimens (one tiger and one clouded leopard) found in trade did not lead to legal prosecutions. In 2011, two live golden cats were found during a WCS-initiated ranger police raid after months of investigation. This case also included the trade of tiger bones and skins. The offenders were successfully prosecuted and imprisoned for 16 months as a result of legal support from the WCS – Wildlife Crime Unit. Both the trade cases were found in Medan, the capital of North Sumatra Province, an important centre for domestic and international wildlife trade (Shepherd et al. 2004). Although the field source of cats in trade is unknown, it is plausible that they came from Gunung Leuser NP. Several unconfirmed reports of small and medium cat trade were also received from villagers around Gunung Leuser NP.

Camera-trap records show low human activity in the study area (Figure 1.7). However, human pressure is considerably higher in other parts in the park, and leads to habitat destruction. Such areas include Langkat (Aceh's military operation refugee location), around the Kutacane – Blangkejeren road, and the palm oil concession in Tripa swamp forest (Paneco Foundation et al. 2008). Although the park harbours one of the last three populations of Sumatran rhinoceros left on the island (MoF 2007), too few effective anti-poaching patrols are employed, especially given Gunung Leuser NP's proximity to Medan (Shepherd et al. 2004). The city has an international airport and seaport, and serves as Sumatra’s primary port of entry and exit. Although we could not infer the impacts of trade on populations of small and medium wild cats in the park, any such trade is illegal under national law (Peraturan Pemerintah No. 7 tahun 1999 = Government Regulation No. 7 year 1999). On an international scale all the species except leopard cats are listed on Appendix I of CITES.

After a tsunami hit Aceh province in December 2004, the conservation status of small and medium cats in the park may have deteriorated because of infrastructure reconstruction and oil palm plantation expansion (Povey et al. 2009). Rehabilitation of destroyed settlements relied mostly on local timber resources, resulting in forest degradation (UNEP 2007). The tsunami triggered reconciliation between the Aceh Liberation Movement and the Indonesian Government, thereby stimulating government approval of road-building plans, logging concessions, mineral exploitation and palm oil plantations in Aceh’s forested areas. Before the reconciliation, these were strongly discouraged by military activity (UNEP 2007).

Although all small and medium cats are poorly known, more studies are needed to assess the potential occurrence of flat-headed cat and fishing cat in and around the park. Both these endangered species might be severely threatened locally (if either occurs at all), since their preferred habitats, water bodies, occur mostly in lowlands at the fringe of the park.

Tables

Table 1.1 Small cats photographed during a camera trapping study in Gunung Leuser NP, March to October 2010.

Species	**Total Photographs**	**Independent Events**	**Individuals**	**Location Records**
Golden cat	63	25	unknown	11
Clouded leopard	38	14	at least 5	10
Marbled cat	15	8	at least 4	6
Leopard cat	8	7	at least 3	3
Total	**131**	**54**	**-**	**30**

Table 1.2 Location of 24 cameras where small cats were photographed, from a total of 68 cameras set in Gunung Leuser NP, March to October 2010 (datum WGS 1984).

Camera	**Latitude N**	**Longitude E**	**Altitude/m**	**Golden cat**	**Clouded leopard**	**Marbled cat**	**Leopard cat**
1	3.912369	98.055659	60	-	-	-	**P**
2	3.962810	98.106356	71	-	**P**	-	-
3	3.940628	98.079972	95	-	-	-	**P**
4	3.970138	98.050712	106	-	**P**	-	**P**
5	3.917859	98.079628	118	**P**	-	-	-
6	3.902692	98.010837	144	**P**	-	-	-
7	3.833651	98.061618	211	**P**	-	-	-
8	3.933143	97.975892	470	-	**P**	-	-
9	3.716204	97.975222	539	-	-	**P**	-
10	3.734564	98.011894	609	-	**P**	**P**	-
11	3.745958	97.985201	706	-	**P**	-	-
12	3.738795	97.970991	711	-	**P**	-	-
13	3.773631	97.995254	736	**P**	**P**	-	-

14	3.828526	97.978414	846	-	-	**P**	-
15	3.671114	97.976633	1071	-	**P**	-	-
16	3.640056	97.964505	1450	**P**	**P**	-	-
17	3.717562	97.922646	1710	**P**	-	-	-
18	3.770539	97.907427	1717	**P**	-	-	-
19	3.731239	97.937594	1798	**P**	-	-	-
20	3.707316	97.752697	1848	-	-	**P**	-
21	3.707273	97.723004	1848	**P**	**P**	-	-
22	3.717037	97.745031	1960	**P**	-	-	-
23	3.736547	97.751756	2486	**P**	-	**P**	-
24	3.730118	97.753205	2511	-	-	**P**	-

Table 1.3 Photo-trapped small cats at three sites in Sumatra.

Species	Independent events		Individuals	
	Bukit Barisan Selatan NP [WCS unpublished data]	**Gunung Leuser NP (this study)**	**Gunung Leuser NP (this study)**	**Kerinci Seblat NP (Holden 2001)**
Golden cat	97	25	unknown	10+
Clouded leopard	57	14	5+	4
Marbled cat	46	8	4+	4
Leopard cat	33	7	3+	3
Total	**233**	**54**		**21+**

Figures

Figure 1.1 the study area of Gunung Leuser NP, showing small cat record locations, March to October 2010.

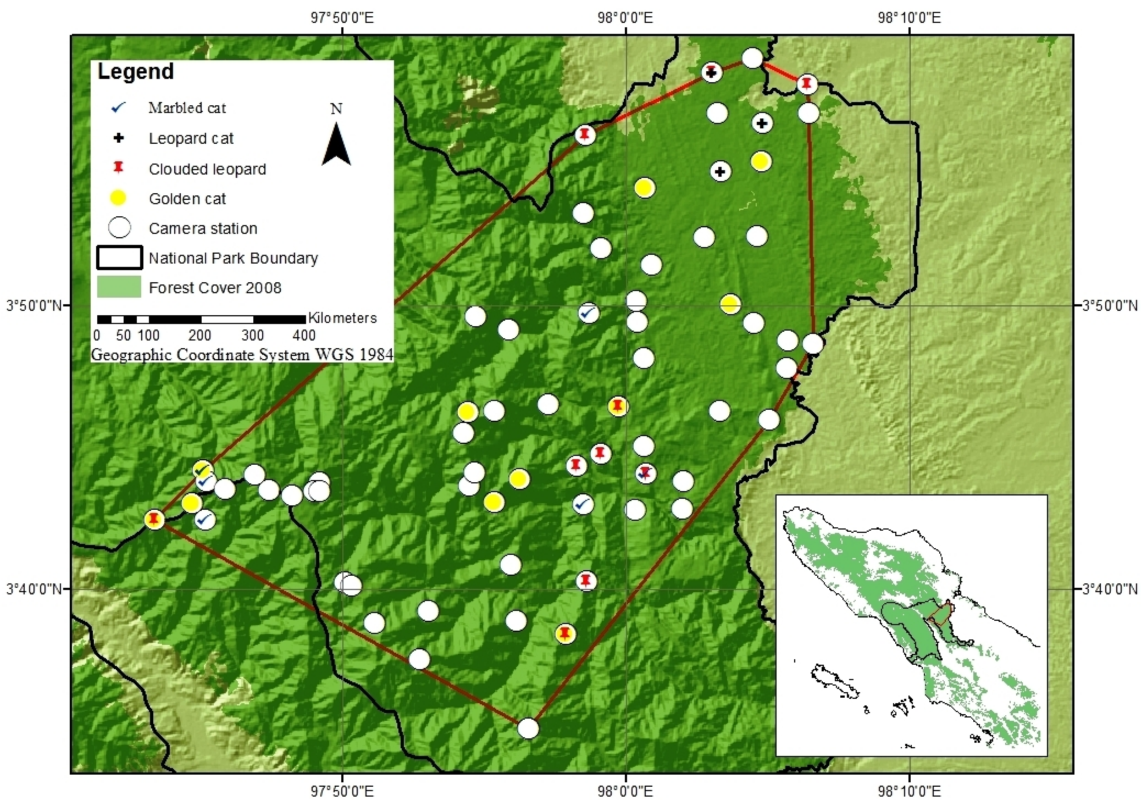
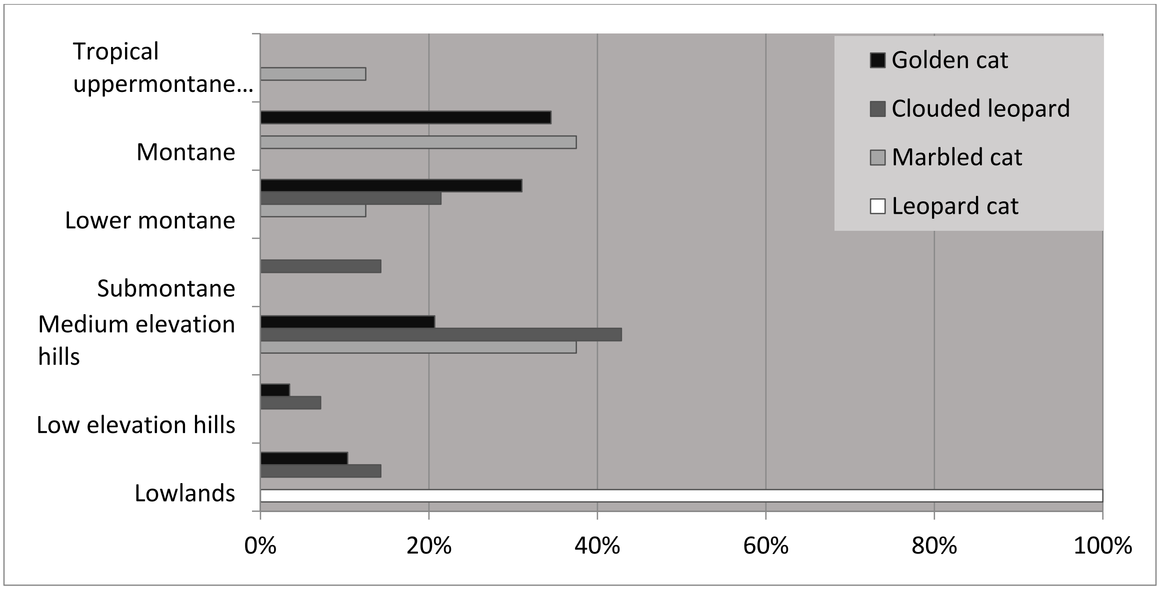


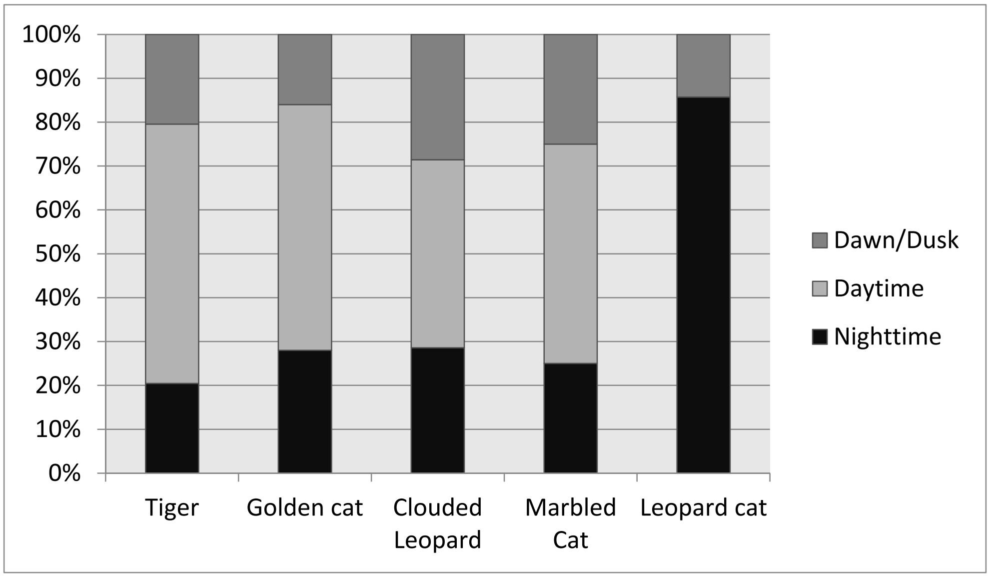
Figure 1.2 A. Golden cat Catopuma temminckii; 20 May 2010, 3.717562°N, 97.922646°E; B. Sunda clouded leopard Neofelis diardi, 8 April 2010, 3.745958°N, 97.985201°E; C. Marbled cat Pardofelis marmorata, 14 June 2010, 3.736547°N, 97.751756°E; D. Leopard cat Prionailurus bengalensis, 7 Oct 2010, 98.079972°N, 3.940628°E.

Figure 1.3 Habitat records of small cats in GLNP, March to October 2010.



*Percentage of total independent event records of a given species in a stated habitat compare to the total number of independent event records for that given species.

Figure 1.4 Apparent activity patterns of cats in GLNP, March to October 2010.



*Percentage defined as the number of independent event records of a given species in a stated habitat compare to the total number of independent event records for that given species.

Figure 1.5 Fishing cat at Siantar Zoo.

Figure 1.6 Small cat trade in Medan: A. Clouded leopard (with tiger) 2008, B. Golden cat 2011.

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CHAPTER 2

THE LAST OF THEIR KIND: SUMATRAN RHINOCEROS DISTRIBUTION AND ABUNDANCE IN WAY KAMBAS, BUKIT BARISAN SELATAN, AND GUNUNG LEUSER, SUMATRA FROM 2008-2010: A study of occupancy modeling of closed populations to estimate occurrence and indices of abundance

Abstract

As we celebrate the bicentennial of the Sumatran rhinoceros (SR) described in science, it appears that the only extant wild population of the species is on the island of Sumatra. Since Strien's 1986 study in Mamas Valley, Leuser, very little additional information has been gained regarding the species' distribution and the factors that may be responsible for its extirpation from large parts of its historical range. We conducted an island-wide survey of Sumatran rhinos and used hierarchical models to estimate occurrence rates (%) and indices of abundance for the species at three sites: Leuser Landscape (LL) in 2007 (2.77%, 26 (CI 12-61)), Way Kambas (WK) in 2008 (33.58%, 27 (CI 14-50)) and Bukit Barisan Selatan (BBS) in 2010 (36.40%, 31 (CI 19-66)). SR occurrence in LL was predicted by primary dry land forest, rivers, deforestation, roughness of terrain, and a vegetation index. The index of abundance in WK was most affected by major roads and the presence of brush and savannah cover, but occurrence was also influenced by the degree of deforestation. In BBS, occurrence and abundance of SR was influenced by secondary dry land forest, regular roads, and deforestation. Based on these environmental and disturbance variables, we developed a spatially explicit map that can be used to

updated the IUCN distribution map for SR. Comparing our results to those of Strien (1986) for LL, it appears that the small population in the Bendahara Mountain might still persist beyond the core population located in the Mamas Valley.

Introduction

The year 2014 marks two centuries since the Sumatran rhinoceros (*Dicerorhinus sumatrensis*, Fischer 1814) was described in Science by Johann Gotthelf Fischer von Waldheim, a German biologist. The Sumatran rhinoceros (SR) is the smallest and the most primitive of all five extant species of *Rhinocerotidae*. In terms of their evolutionary lineage, SR is far different from the two Asian rhino species, the Javan rhino (*Rhinoceros sondaicus*) and the Indian rhino (*Rhinoceros unicornis*). In fact, SR are more closely related to the two-horn rhinos of Africa, and the woolly rhino (*elasmotheres*) from the Pleistocene ice age. Despite its name, the SR also lived in Myanmar (*Dicerorhinus sumatrensis lasiotis*), Borneo (*Dicerorhinus sumatrensis harrisoni*), as well as Peninsular Malaysia and Thailand which had the ame subspecies as on Sumatra (*Dicerorhinus sumatrensis sumatrensi*s).

Once distributed from the Himalayas, Assam, and mainland Asia to island of Borneo and Sumatra, Indonesia (Foose and Strien 1997, van Strien et al. 2008), the past 200 years have seen SR extirpated from the majority of their historical range. The world population of SR is listed on the International Union for Conservation of Nature (IUCN) red list as Critically Endangered (Strien et al. 2008), and was estimated to have decreased from 600 animals in 1985 to less than 300 in 1995 (Foose and Strien 1997); the world population was believed to be around 200 individuals in 2007 (MoF RI 2007), while current estimates indicate there now may be as few as only 100 animals left on earth (IUCN SSC 2013).

The Sumatran rhinoceros is, not surprisingly, one of the least known mammals in term of natural habitat and ecological characteristics. Borner (1979) and van Strien (1986) provided an early description of this species in Sumatra, and since then the majority of work has shifted to understanding their physiology for captive breeding purposes. The SR indeed might be one of the most difficult species to study in the wild. Nico van Strien's study in Mammas Valley back in 1986 proved this; during thousands hours dedicated to their study in natural habitat, the frequency of actual observations was incredibly low. Essentially, since the van Strien study there have been no comprehensive field studies conducted in the wild. Pusparini and Wibisono (2013) initiated the first field survey of the species in 2008, and this work laid foundation for this study.

The island of Sumatra is the last stronghold of SR population; the SR population on the Malay Peninsula is presumed to be extinct (Clements et al. 2010), and only a few wild SR remain in Borneo (Zafir et al. 2011, Payne and Ahmad 2012). International conservation of the SR was marked with controversy related to a managed captive breeding program developed by the Sumatran Rhino Trust (SRT). Formed in 1988, SRT was a cooperative project overseen by Asian Rhino and Captive Breeding Specialist Group IUCN (Anonymous 1989, Doherty 1992, Hutchins 1995), and involved four American zoos (Bronx, Cincinnati, Los Angeles, and San Diego) and the governments of Indonesia and Malaysia under the American Association of Zoological Parks and Aquarium (AAZPA). In 1984, the IUCN declared the SR to be one of 12 most endangered species in the world, thus motivating SRT to rescue SR from regions where they could not be protected (Doherty 1992), their populations were too small and isolated to be viable (Anonymous 1989). The philosophy of SRT can be described as the "Noah's Ark Paradigm"; i.e., in response to species endangerment a captive breeding program should be developed to ward off extinction (Hutchins 1995, Hutchins and Conway 1995). However, after bringing 40 wild rhinoceroses into captivity and expending US$3 million, none successfully bred (Lessee 1995, Merz 1997, Nichols 2012).

Rabinowitz (1995) warned that money and effort spent on the capture and breeding of rhinoceroses alone would not solve the problem of declining wild populations. In his frank essay, he suggested that conservationists were 'helping a species go extinct' by placing too much emphasis on captive breeding at the expense of 'the more difficult job of protection and management in the field (Rabinowitz 1995, Nichols 2012). Further, Hutchins and Conway (1995) stated that the American Zoo Association (AZA) does not promote captive breeding as a panacea for endangered species. Whatever the conservation options selected, the primary goal must be to preserve wild animals and their nature habitat (Hutchins and Conway 1995). Today, conservationists and wildlife managers may have to consider conservation "triage" for this species that is now distributed in a relatively small metapopulation (Mcdonald-Madden et al. 2008).

Since 1998, wild SR have been protected from poaching by Rhino Protection Units in Bukit Barisan Selatan National Park (BBSNP) and Way Kambas National Park (WKNP), and recently formed in 2012 in Gunung Leuser National Park (GLNP). The current conservation strategy for the SR in Borneo is to capture all remaining individuals and put them in a captive breeding program directed by the Borneo Rhino Alliance (BORA) without any hope of re-introducing it back into the wild (Nichols 2012, Payne and Ahmad 2012, Ahmad *et al.* 2013). A female SR, named Iman, has recently been capture from the wild on March 21st 2014 in Danum Valley, Sabah, Borneo, to join Tam (male) and Puntung (female) in Borneo Rino Sancuary, Tabin Wild life Reserve (Sabah Wildlife Department 2014).

As predicted by Rabinowitz (1995), the SR on Borneo is now considered to be ecologically extinct (Payne and Ahmad 2012), and it does not appear that the captive breeding can restore this population. On the island of Sumatra, an attempt has been made to conserve the rhinoceros in the wild through Protection Units, and currently, Sumatra has the largest number of SR in the wild. Prior to this study, no systematic surveys had been conducted to estimate the population parameters for rhinoceroses in Sumatra, except for the van Strien (1986) study in Mammas Valley, Leuser. Pusparini and Wibisono (2013) initiated a survey of patch occupancy based on signs of occurrence for Sumatran rhinoceros in BBSNP. Implementation of the survey was found to be logistically feasible, required minimal equipment (compared to camera trapping), and could be completed in a relatively short time period (6 to 9 months). In addition, recently developed techniques for analysis of occupancy data are statistically robust and now commonly used in the field of wildlife ecology (Mackenzie et al. 2003, Mackenzie et al. 2005). The objective of this study is to estimate the occurrence rate and abundance of Sumatran rhinoceroses, and investigate which environmental and anthropogenic disturbance factors affect these parameters using the data from Island-wide occupancy survey. The effectiveness of conservation actions cannot be assessed unless population change over time can be quantified (Buckland et al. 2005), and the main goal of this study is to analyze field data to develop evaluation tools for conservation strategies toward protection of SR.

Methods

Study Area

Sumatra is one of more than 17,000 islands of the Indonesian archipelago, and is the largest volcanic island in the world (480,793 km^2) (BPS 2013). Geologically, Sumatra together with Java and the islands of Nusa Tenggara is part of ‘Sunda Archipelago Arc’ formed between 15 and 3 M years BP. Compared with the rest of Indonesian archipelago, Sumatra is geologically young, climatic changes and fluctuations of sea level during Quarternary glacial and inter-glacial periods shaped what is the present landscape (Laumonier 1997). According to Verstappen (1973) *in* Laumonier (1997), Sumatra Island can be divided into five physiographical units: 1. The coastal strip of the west coast; 2. Mountain zone: the Barisan range and the central graben; 3. The eastern piedmont; 4. The well drained eastern lowlands; and 5. The eastern swampy lowlands; in addition to islands in the west and east of Sumatra. Sumatra is almost equally divided between northern and southern parts by the equatorial line that pass in the center of the Island. Lying right on equator, Sumatra is abundant with rain that is evenly distributed throughout the year. Temperature in low altitude of Sumatra is always high, and overall fairly uniform. Mean monthly temperatures are between 25 to 27 ◦C. According to Laumonier (1997), Sumatra is divided into five bioclimates and rainfall regimes: 1. Subhumid (1,000<Precipitation<1,500 mm/year), 2. Humid (1,500<P<2,000 mm/year), 3. Very humid (2,000<P<2,500), 4. Superhumid (2,500<P<3,000 mm/year), and Hyperhumid (P>3,000 mm/year). Ninty percent of the surface of Sumatra consists of very humid, superhumid and hyperhumid bioclimates.

The study was carried out between 2007-2009 by eight organization (Wildlife Conservation Society, Fauna & Flora International, Zoological Society of London, Leuser International Foundation, World Wildlife Fund, Rhino Foundation of Indonesia, Sumatran Tiger Protection and Conservation Program and Durrell Institute of Conservation and Ecology). Over the two years, available forest habitat in Island of Sumatra was divided into sampling grid and surveyed for large mammals' occurrence (Figure 2.1). This study is analyzing the SR detection/non-detection data from the only three areas within Sumatra that still confirm the occurrence of the species: Leuser Landscape (2 May 2007 – 1 March 2009) and Way Kambas NP (6 January – 11 March 2008). The Bukit Barisan Selatan NP survey (19 October 2007 – 25 June 2008) is published (Pusparini and Wibisono 2013), and in this study we continue with analysis of the data from the second survey (28 September 2010-2 February 2011) conducted by Wildlife Conservation Society.

Leuser Landscape located in most northern part of Sumatra, while BBSNP and WKNP located in the other end, the southern part of the island. The Leuser Landscape of 26,000 km^2 (BPKEL 2013) outspread in two provinces of Aceh and North Sumatra provinces. The BBSNP is more than 3,500 km^2 in size (Ditjen PHKA Kemenhut RI 2012) with percentage of forest area in 2000 is 77% and rate of loss 0.57%/year, most of deforestation is due to coffee plantation and there are also history of logging concession in the park with logging trails of 60 km (Gaveau et al. 2009). The last and smallest area is WKNP, with size of 1,293 km^2 and 43% of the area is forested. Most of the area is secondary forest of concession areas with 234 km of logging trails inside the park and rate of forest loss of 1.01%/year (Gaveau et al. 2009). Both BBSNP and Leuser

Landscape lies in the Barisan geanticline, the Mountain zone physiographic unit along west coast formed by ancient Tertiary volcanic activity (Laumonier 1997). WKNP is located in southern part of the island, on eastern swamp lowlands physiographic unit. These three locations represent area where rhinos still roam probably not because of their particular ecological characteristic since historically they can found all over Sumatra, but for reasons we try to investigate in this study.

Data Collection

The basic design of the survey followed the landscape-wide patch occupancy protocol (Karanth and Nichols 2010) and is described in detail in the Wibisono and Pusparini (2008) survey protocol for Sumatran rhinoceroses. A grid of 72.25 km^2 (8.5x8.5 km) was used as a sampling unit to reflect the largest home range of the SR, measuring 60 km^2 (van Strien 1986). In total, 337 survey grids in Leuser Landscape, 28 grids in WKNP and 56 in the BBSNP were surveyed. Four teams of four technicians each were employed to search along paths having the highest probability of finding SR signs. The team simultaneously recorded SR's footprints, dung, wallow, tree-twist, and body/foot scrub, and also any signs of threats/disturbance inside the park (Table 2.1). Signs were collected at every 100m segment. To provide an element of randomness, a smaller cell of 18 km^2 was randomly chosen in each grid for the survey team to traverse. Presence of rhinoceros signs was recorded along 4,479km of irregular transects in Leuser Landscape (13.29km/grid, min 2km, max 38km), 345km in WKNP (12.32km/grid, min 1km, max 44km), and 1,051km in BBSNP (18.77km/grid, min 4km, max. 41 km), makes the total transect effort of 5,875km over 421 survey grids.

Next, 1-, 2- and 3-km replicates (detection segments) were used to develop a detection matrix of '1' and '0', each representing detected and not detected. A detection means that a grid is occupied, while no detection could be one of three scenarios: 1) true absence, where no signs of rhinos is detected because the grid is not within a SR home range, 2) false absence, where sign exists within the grid but failed to be detected, and 3) pseudo-absence, where no sign exists, but none the less, the grid occurs within the SR's home range. Using ArcGIS 10.1, the survey track log was downloaded from GPS and overlaid with SR's signs location. I calculated the 3D length of each survey transect route and then splice it every 1km as detection-segment (spatial replicates). Further, not all sampling units had the same proportion of unsuitable area (e.g., sea or human settlement), resulting in different transect lengths among grids (Figures 2.5 to 2.7 show the data for 1-km detection segments). In the detection matrix, detection history of a grid with the longest transect represents a full trial. Therefore, missing values were assigned to the detection histories of grids with shorter transects, which contribute nothing as they are treated as 0 by the log-likelihood function (Royle and Dorazio 2008).

Assessment of Landscape and Disturbance as Covariates

<u>Quantifying the landscape and disturbance</u>

Distribution of rhinos may be influenced by covariates, which will affect their occupancy and a latent variable of index of abundance. Covariates are factors that contribute to the heterogeneity of rhinoceros dispersal and abundance across landscape. In this analysis, I am using 17 different covariates (Table 2.1) derived from various sources. Environmental and anthropogenic variables evaluated with respect to rhinoceros distribution include: landcover type, road, river, disturbance found in the survey transect both natural and anthropogenic, roughness as metric of altitude and slope, forest cover, deforestation, and vegetation index (NDVI). To address the issue of scale in landscape wide analysis, given the same extent, prior to getting into calculation some covariates were extracted using various cell size (grain) and search radius (scale) in kernel density estimator. Kernel density estimator (Silverman 1986; Worton 1989), which is used for home-range analysis is chosen for extracting the value of the covariates to represent pattern intensity across a range of spatial scale. For each of the covariates, cell size of 50m, 100m and 200m are chosen as the smallest grain in which SR might respond to the process. One of utility of kernel is that we can adjust the width of each kernel to capture various scales of pattern intensity. For conducting this, each cell size was extracted with 10 different search radius (scale) in 500m replication starting from 500m to 5,000km.

All measurements were conducted in ArcGIS 10.1, using the kernel density tools for the point and polyline data, and a weighted focal statistic for the polygon and raster data. The more detailed technical method on conducting this is provided in separate material (W. Pusparini. Unpublished. Generating response and predictor input data for ecological modeling: Sumatran rhinoceros occurrence and abundance). The focal statistic to calculate kernel density in polygon and raster data type is weighted neighborhood representing distance-weighted density estimate with weight kernel matrix created in R (Supplement 1). For line type data such as river and road, a kernel density tools is use directly from ArcGIS 10.1, and for the disturbance data, I weighted the kernel density of point disturbance using 1 for natural disturbance, 2 for anthropogenic disturbance, and give special weight of 5 for any poaching signs of any species. These weights reflect intensity of disturbance.

The multiscale analysis is conducted for almost all the covariates except the gradient data of DEM and NDVI. To extracting the gradient matrix of elevation and vegetation index, I am using the ArcGIS Geomorphometry and Gradient Metrics toolbox created by Jeffrey Evans of The Nature Conservancy (Evans *et al*. In Prep). Roughness is one of the surface matrices extracted from DEM, and it is a combination measures of two sub-components, the overall variability in surface height (non-spatial) and the local variability in slope (spatial) (McGarigal *et al.* 2009). Used of roughness as covariates represent the SR preference on elevation structure. Anecdotal information generally indicates that SR is a lowland dweller species and does not like very rugged areas. Curvature of the NDVI summarized the combination of amplitude and spatial characteristic of the NDVI local peaks where the index value is maximum. The use of vegetation index is important because rhinoceros is a mega-herbivore and depends on good vegetation cover as food resource.

<u>Selecting the appropriate set of covariates for each landscape.</u>

I test the a priori assumption and anecdotal information on several covariates with the rhinoceros signs to select the appropriate scale (i.e. large mammals responding to road disturbance within 5km distance). We run each the covariates in the single season occupancy model with PRESENCE var. 6.2 (Hines 2006), using only that certain covariate and their different values of scale, and select the best parsimonious model using information criterion model selection procedure in AIC. After checking the model fit and dispersion, we assume the best covariate scale is the one that the most parsimonious model is used in model selection procedure.

Data Analysis

I performed all data analyses using R package UNMARKED (Fiske and Chandler 2011) and PRESENCE var. 6.2 (Hines 2006).

<u>Single season, single species occupancy modeling.</u>

To estimate the occurrence, I use a class of hierarchical models of "site-occupancy models" (MacKenzie et al. 2002, 2003, 2004, 2005), in the statistical literature these models are also called zero-inflated binomial models (Kery & Schaub, 2011). The site-occupancy models are essentially a hierarchical logistic regression with Bernoulli random effects for modeling probability of observation (detection) and process (occupancy), coupled together using a logit-link function. This modeling approach was designed to estimate the proportion of an area occupied by a species. However, it can also be used to predict the geographical range and habitat characteristics of a species (MacKenzie et al. 2004). Estimation of detection probabilities and occurrences will be conducted by incorporating occupancy probabilities directly into the model likelihood (Mackenzie et al. 2002). The model is essentially a discrete random-effects model that are assumed to be drawn from Bernoulli or a Poisson distribution which correspond to the true, but imperfectly observed, state of occurrence (Kéry 2010). The model runs with three different length of detection-segment (1, 2, and 3km) and I choose the one which give the highest R square. The objective in using three different length segment is the assumption that with longer detection segment the autocorrelation in detecting SR signs in continue transect will be reduced. All of the modeling is done with set of selected covariates specific for each area (Table 2.2).

Single season, single species occupancy modeling with abundance induced heterogeneity in detection probability (Royle-Nichols 2003).

It is a very straightforward idea to assume that probability in detecting any species will be affected by how many of that species are in a given area. The second model that we use put that assumption explicitly in the model. The Royle and Nichols (2003) model is a form of *functional independence* relating the *p* (detection probability) to *N* (local population). The Royle and Nichols heterogeneity model estimates local abundance as a function of some heterogeneity in the detection probability across sites (Royle and Nichols 2003). While the MacKenzie 2002 model used earlier is a *functional independence* between *p* and *N* (Royle and Dorazio 2008). Again, we also run the model with three different detection segment (1, 2, and 3km) and selected covariates (Table 2.2). This model is a hierarchical in which the first stage of the model, the observation model, is a Bernoulli model for detection/non-detection data in which the *p* is related explicitly to the local population exposed to sampling (Royle and Dorazio 2008). The second stage of the model, the process model, describes variation in local abundance among sample (Royle and Dorazio). *N* is a latent variable and in UNMARKED the posterior distribution is estimated using empirical Bayes method. To get the value of *N*, we are using the sum of posterior mean of each site (survey grid). The local abundance estimated or *N* is not necessarily the abundance of SR in the area, Royle and Dorazio (2008) prefer to interpret it in terms of density –abundance per unit area, though in most cases sample unit are not of known area. It is interesting to apply this model in my study area, because of the explicit assumption of N induced heterogeneity, and also because it provide the information to compare among three population in relative term of which areas probably has the most SR.

Results

Covariates selection process

I assessed the landscape characteristic and disturbance from a SR point of view. To do this, I quantified the landscape and disturbance factors (covariates) in various cell sizes (50, 100 and 200m) and scales (search radius of kernel density 500 – 5,000m in 500m repetition). Confronting the covariates with the data in occupancy model, I found that for the same covariates, SR perceived it differently in scale (cell size and distance) between three locations (Table 2.2). This suggests that each population's behavior is site specific and the covariates that important in one site not necessarily important in another.

The landcover type that selected for WKNP is Brush at scale of 200m cell and 4km search radius, and savanna at 100m cell and 1km search radius. While SR in BBSNP is response more to secondary and primary dry land forest at cell size 200m and 100m, and search radius 4km and 4,5km respectively. Leuser landscape SR population is respond to landcover type of brush in 200m cell and 5km search radius, and primary dry land forest in 200m cell size and 4km search radius. All type of roads (major and regular) are responded by SR in all the study area with scale up to 10km, with exception of population in BBSNP, which responded the regular road at shorter scale of 1.5km. Some of the covariates did not converge, or converged but the null model is the best model. For covariates that did not converge, I removed them from subsequent modeling. While for the covariate which are not better than the null model, I used it from the second best model. The argument is because these covariates might still show an effect to SR occurrence when use in interaction with other covariates.

The correlation among selected covariates is tested using Pearson correlation. For Leuser Landscape, the selected covariates are not highly correlated (Figure 2.2). Exception might be for the Roughness, which is slightly negatively correlated with Regular Road (RegRoad, -0.56) and positively with Secondary Dry Land Forest (SecondDryFor, 0.51). WKNP has a very strong correlation of 1 between the RegRoad and the Majorroad (Mroad) (Figure 2.3), and Deforestation has a negative correlation with both RegRoad (-0.64) and MRoad (-0.63). Regular Road and Major Road also highly correlated, 0.94, in Leuser Landscape (Figure 2.4), with Roughness is negatively correlated (-0.62) with River. For all of these covariates that are correlated, I did not use them as covariates in the same model, but still use it in different model, in the same model-selections.

Leuser Landscape (LL)

Occupancy modeling and the Royle-Nichols occupancy with heterogeneity model in Leuser Landscape are presented in Tables 2.1 to 2.6. In term of detection segment scale, the occupancy model is better at the 3km detection with R square of 30% (table 2.3), while the occupancy with heterogeneity is better at shorter segment of 2km with R square of 34% (table 2.5). The occupancy with heterogeneity also converged with a more complex model, fitted with five covariates in comparison to only two covariates in the standard occupancy model. The spatially explicit map of occurrence (*psi*) and index of abundance is showed in figures 2.4 to 2.6. Figure 2.4 show estimates of occurrence rate for each of the sampling grid and this value is mapped spatially explicit in figure 2.6, allowing interpolation to areas within the landscape that are not covered by the field survey. Both the occurrence probability map and the index of rhino abundance showed that Mamas Valley is a high probability area. The occupancy with heterogeneity predicted Sumatran rhinoceros occurrence with the density of river, presence of primary dry land forest, deforestation (between 1990 to 2000), roughness of the area as a function of slope and elevation, and the vegetation index. In comparison, the standard occupancy model can only be fitted with covariates of kernel density of river and the primary dry land forest. The parameter estimate is showed in table 2.7. Occurrence estimation rate from basic occupancy modeling has both of the covariates statistically significant with p-value of 0.05, primary dry land forest (0.99) and river (0.99), and positively influenced the occurrence of rhinoceros (Figures 2.7 and 2.8). However the estimation of detection probability is not significant (0.37). The overall occurrence rate for the landscape from model averaging is 0.0277. The Royle-Nichols heterogeneity model fitted covariates that are all significant except for deforestation (0.06) and roughness (0.70), and the estimation of detection probability in this model is significant (0.11). Summing the posterior probability of $N(i)$ over the entire sampling grid, we found N to be 26 with 90% CI of 12-61.

Way Kambas National Park (WKNP)

Occupancy modeling and the Royle-Nichols occupancy with heterogeneity model in Leuser Landscape are presented in tables 2.8 to 2.13. Running the model with three different lengths of detection segment, the occupancy model performed better with 3km length, as in the case of Leuser Landscape. It seems that at this length, the spatial autocorrelation might be reduced, though further statistical test is needed to confirm this.

The R square of the occupancy model for Way Kambas NP in 3km segment length is 60% (table 2.10), much higher than the R square for the occupancy with heterogeneity best model in 1 km segment length, which is 52% (table 2.11). The spatially explicit map of occurrence (*psi*) and index abundance is showed in figures 2.9 and 2.10, and both concurred that the center of the park is the main area of distribution. The parameter estimate for the best model of both type occupancy modeling is presented in table 2.14. The occurrence and abundance index are affected by the presence of brush (1.00) and savanna (0.002) as preferred land type in Way Kambas. Deforestation in 1990-2000 (1.00) and major road as anthropogenic disturbance (0.00) also affect the occurrence probability. Major roads also affected the index of abundance (0.51). However, almost all estimates had a wide range of confidence interval and none of the covariates is significant, except for the covariate Brush in Royle-Nichols Occupancy model (0.99). The overall occurrence rate for WKNP from model averaging is 0.338, and *N* from the sum of posterior mean *N(i)* is 27 with 90% CI 14 – 50.

Bukit Barisan Selatan National Park (BBSNP)

This is the most intensively surveyed area among the three populations, and the data presented here is from the second survey in 2010, part of a time series data 2008-2010-2012. The survey period in 2012 only cover the ‘core-zone’ and not the whole park, so the 2010 data is the current whole area of the park data. Running both the basic occupancy and the occupancy with heterogeneity model, we found similar pattern. Basic occupancy model performed better at 2km (table 2.16), shorter detection-segment compare to 1km (table 2.18) in occupancy with heterogeneity model, given the same set of covariates. Although both of the best models from either basic occupancy or occupancy with heterogeneity fit the same number of covariates, the R square from the heterogeneity is larger (26%) compared to the basic occupancy (22%). The spatially explicit map of occurrence (figure 2.15) and index of abundance (figure 2.16), showed a different result. In term of occurrence, Sumatran rhinoceros occupy the park from southern part up to the middle part just north of Suoh area. While index of abundance showed very low or almost none in the southern part of the park, and the abundance seems to extend farther up north compare to the occurrence probability map. Both of the occurrence and index of abundance of Sumatran rhinoceros in 2010 were positively influenced by the presence of secondary dry land forest type (0.998 and 0.998), and the presence of regular road (0.99 and 0.97), and negatively influenced by deforestation that happened in 1990-2000 (0.07 and 0.19). However, among all the covariates, only secondary dry land forest is significant (table 2.21), for both the occupancy and occupancy with heterogeneity model. The overall occurrence rate for BBSNP from model averaging is 0.364, and N from the sum of posterior mean $N(i)$ is 31 with 90% CI 19 – 66.

Discussion

Assessing the distribution of a species is a basic concept in conservation that has practical implications. Although it seems very basic in ecology, for a very rare species such as SR what we know about their distribution is, surprisingly, mainly from anecdotal records or protection efforts; hence, it is difficult to gain information more exact than where they were at a given time. Using the hierarchical modeling approach, we assessed the distribution of SR by also taking into account the fact that the animals are not always detected, even if they were, the problem of detection is imperfect. Errors of commission (species predicted but not observed) in wildlife habitat relationship modeling, both real and apparent, affect the predictive accuracy of wildlife habitat relationship models (Stauffer et al. 2002). In this study, I used the detection/non-detection signs of SR to construct a spatially explicit occurrence, and also, index of abundance, SR distribution map throughout Sumatra. This technique can be used to predict the probability of occupancy/habitat use both for sites that were surveyed, and those that were not (Linkie et al. 2006, Karanth et al. 2009), as long as values for the same set of covariates are available from unsurveyed sites.

Leuser Landscape

The most comprehensive study of Sumatran rhinoceros in Leuser was conducted more than 20 years ago (van Strien 1986). His study, and Booker (1979) previously, set the groundwork for what we know about Sumatran rhinoceros ecology in their natural habitat. My analysis provides the most current systematic assessment of Sumatran rhinoceros occurrence and index of abundance. The map of occurrence showed that Sumatran rhinoceros is mostly concentrated in the Mamas Valley area (Figures 2.8 – 2.10), the location where Nico van Strien conducted his field study. Comparing our occurrence estimate map and the International Union for Conservation of Nature's distribution map (IUCN SSC 2013), and also van Strien's map (Figure 2.12), we found a result similar to a previous study using niche distribution modeling using MaxEnt (Figure 2.11 – Pusparini *et al.* 2013). In our 2013 study of niche modeling with MaxEnt, we found that the current distribution stretch farther than what is delineated by the International Union for Conservation of Nature (IUCN SSC 2013). A smaller population concentration around Bendahara Moutain might still persist, and the survey in 2009 (Pusparini *et al.* 2013) confirmed this.

The sum of posterior mean abundance of 26 is very low in comparison to the other two parks, which if we divide it by the total number of grids surveyed translated into a local abundance of 0.077/grid (grid = 72.25 km^2). The total occurrence rate is also the lowest among three areas, of only 2.77% occurrence. It is clear the Mammas Valley is still the 'core area' for the SR in LL, and this is associated with primary dry land forest and river. It is quite surprising that Roughness did not come up as one of the best predicting variable, since the assumption is that SR prefer Mammas Valley due to the low elevation and gentle slope, compared to the surrounding rugged terrain of Leuser. My map shows that this might not be the case, as some SR are also found around Bendahara Mountain range with high elevation.

Way Kambas National Park (WKNP)

Among all three parks where SR still reside, Way Kambas National Park (WKNP) is by far the smallest and most different. The 1,293 km^2 national park is dominated with swamp forest unlike the two other parks, and secondary low land forest as a result of intensive logging in the entire area in 1960-70s. Hence, the SR was already considered to be locally extinct (Borner, 1979) before being 'rediscovered' by Reilly et al., (1997). The park is a low-lying coastal land in south-east Sumatra, bordered by sea in the East and no buffer zone separating the rest of boundary of the park from surrounding settlements (Reilly et al., 1997). The park harbors the Sumatran Rhino Sanctuary (SRS) of a semi-captive breeding of Sumatran Rhinoceros.

As can be expected by the type of the forest left in the park, Sumatran rhinoceros occurrence in WKNP is mostly associated with brush landcover type. The relationship between brush and occurrence is positive, although it is only significant for the occupancy modeling with heterogeneity. Though smallest in area, the mean local abundance in WKNP is quite high at 26, translated into 0.93/grid, the highest local 'density' of all the three parks. And the occurrence rate is almost the same as in BBSNP, the SR occupying 33.58% of the areas and mainly concentrated in the center of the park (Figure 2.15, 2.16). The latest incidence of poaching happens in this park is in 2007, and since then the National Park office confirms that the park has zero poaching. Similar with Leuser Landscape, the SR distribution zone is within the center of the park, this might also indicate a degree of protection SR receives. From the occupancy and the highest local density of SR, WKNP might be the most important area to protect the SR wild population. Although, the small size is a double-edged sword. With small size, the protection of the park and management is relatively easier. However, the carrying capacity of SR to growth is also limited.

Bukit Barisan Selatan National Park (BBSNP)

The BBSNP is long thought to be the area with highest abundance of Sumatran rhinoceros in Sumatra. Their signs are frequently found, and by merely plotting it, previous analysis showed that the middle part of the park, namely Sukaraja area, is the area with high activity (Pusparini 2006). In fact, a young female rhinoceros, called Rosa, is spotted in that area in early 2006, and currently 'rescued' to a captive breeding facility in WKNP the Sumatran Rhinoceros Sanctuary (SRS). Starting in 2007, the crossing road between Sukaraja-Bengkunat is revitalized by the local government of Lampung province, and initiated a heavy use of it as a hub between eastern part of province and Bengkulu (a big coastal city in the west).

Although there is a strong belief that this area holds the largest population of Sumatran rhinoceroses, no systematic study on the population had ever conducted. The initiative in 2008 used patch-occupancy modeling of rhinoceros signs to estimate occurrence and map the distribution area (Pusparini and Wibisono 2013). From the study, it is clear that even the distribution and occupancy rate (0.32, SE 0.09) of the park is much lower than previously thought. The index of abundance based on Royle-Nichols, despite its usefulness as an actual estimate of abundance, suggest the abundance is as low as 21 (±7) individuals in 2008 (Pusparini and Wibisono 2013), much lower than the 60-70 individuals educated guess (Rubianto and Suparman 2008, Talukdar *et al.* 2010). This analysis for 2010 data showed that the estimated mean posterior distribution of abundance from the empirical Bayes method is 31 (90% CI 12-61), with overall occupancy of 36.4%. It is clear that BBSNP is having the most occupied areas relatively of its park size compare to WKNP and Leuser Landscape. However if we took the local 'density' per grid, it translated into 0.55/grid, almost half of the local 'density' in WKNP. Even though it is seems increase in occupancy rate and local mean of abundance compared to year 2008. Since 2008, the conservation effort in BBSNP has indeed increase significantly. More agencies have joined to conserve and study the SR population in this area. This effort might result in the increase numbers. However the interval of only 2 years is not enough to monitor the change in population based on its natural growth of reproduction cycle every 2-3 years. But in the least, we do not see drop in population that very likely not only happen from natural, but unnatural factors such as poaching, for the species is highly prized for its body part.

Conservation of Sumatran rhinoceroses

More and more pressure occurs nowadays to remove all individuals in the wild population of SR and put them into captivity (Ahmad *et al* 2013, Payne and Ahmad 2012). The belief is that whatever we do to try protecting them in the wild, and however accurate our population assessment is, it will not really help the survival of this species (Ahmad *et al* 2013). This depressing outlook might be true if we see the rate of human population growth and development in this sixth biggest island continue without increased protection of rhinoceros habitat. Sumatra is home to more than 50 million people, about 21% of the population of Indonesia (BPS 2013), and has a high rate of growth. Consequently, its natural habitats are under pressure from development. One of these developments is the government's economic corridors plan in which Sumatra will be the center for production of natural resources and the nation's energy reserve (Strategic Asia 2012). One direct impact of this plan has on the population of rhinoceroses is through the development of roads which pose a real danger to wildlife (Wibisono et al. 2012, ATBC 2011). Approximately 49,020 km of logging roads have been built in remaining forest areas (Gaveau et al. 200) and demand for open more areas for road is ever increasing. The old-growth forest in Sumatra has already shrunk by 40% over the past 20 years (1990-2010), while overall forests in Indonesia have declined by 36% (Margono et al. 2012).

However, this is always seems the case with conservation of any endangered species in developing tropic countries. How we manage endangered populations depends on the balance between ecology and economic dimensions. This might sounds like a cliché, but if every panacea for endangered species conservation is to bring them in captivity, we will lose the battle of protecting the habitat that is left. Protecting the habitat without the species inside it is needed because the SR inhabit parks is potential home of this endangered mega-herbivore. It becomes more ‘worthwhile’ to save the landscape if we know that there is a species that depends on it. And we can also learn from orangutan (*Pongo abelii*) conservation; after rehabilitation process to teach them how to be wild again, there are no habitat left to reintroduce them since most have been converted to palm oil plantations (Butler 2009, Butler 2009b).

My results show the areas where the SR has a high probability to occur, and what factors affect them specifically in those areas. I argue that even this ‘simple’ analysis of distribution can shed light on poorly known population parameters of SR. Using my maps, we can better guide the currently going on protection effort for this species. Learning the success story from Nepal this year, in which zero poaching of Rhino is achieved (GTI 2014), we feel that protection in the wild, and conservation of SR in the wild, is possible.

Tables

Table 2.1 List of available covariates.

No	Covariate – Class	Type	Year	Source
	Landcover			
1	Landcover Type – Brush	Patch	2003	Indonesian Ministry of Forestry – BAPLAN
2	Landcover Type – Dry Land Agriculture	Patch	2004	Indonesian Ministry of Forestry – BAPLAN
3	Landcover Type – Dry Land Agriculture with Brush	Patch	2005	Indonesian Ministry of Forestry – BAPLAN
4	Landcover Type – Primary Dry Land Forest	Patch	2006	Indonesian Ministry of Forestry – BAPLAN
5	Landcover Type – Secondary Dry Land Forest	Patch	2007	Indonesian Ministry of Forestry – BAPLAN
6	Landcover Type – Savanna	Patch	2008	Indonesian Ministry of Forestry – BAPLAN
7	Landcover Type – Secondary Swamp Forest	Patch	2009	Indonesian Ministry of Forestry – BAPLAN
8	Landcover Type – Settlements	Patch	2010	Indonesian Ministry of Forestry – BAPLAN
9	Landcover Type – Swamp Brush	Patch	2011	Indonesian Ministry of Forestry – BAPLAN
10	Major Road	Line		
11	Regular Road	Line		
12	River		?	Indonesian Ministry of Forestry
13	*Disturbance – Type*			
	Natural – Forest Gap	Point	2007, 2008, 2010	Field Survey
	Natural – Landslide	Point	2007, 2008, 2010	Field Survey
	Natural – Flood	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Fire	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Logging	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Forest Clearance	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Non Timber Forest Product	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Human presence	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Poaching	Point	2007, 2008, 2010	Field Survey
	Anthropogenic – Coffee field	Point	2007, 2008, 2011	Field Survey
	Other	Point	2007, 2008,	Field Survey

			2010	
14	Roughness	DEM	2008	The CGIAR Consortium for Spatial Information
15	Forest Cover left 1990-2000	Patch	2000	Gaveau et al. 2007
16	Deforestation 1990-2000	Patch	2000	Gaveau et al. 2007
17	NDVI Curvature	NDVI	2007, 2008, 2010, & 2012	MODIS Atmosphere

Table 2.2. Selected Covariates.

No	Best Covariates	Cell size (m)	Search Radius (m)	Note on Convergence
		Leuser Landscape		
1	Brush	200	5000	Did Not Converged
2	Secondary Dry Land Forest	100	1000	Null model as the best model, Converged
3	Primary Dry Land Forest	200	4000	Converged
4	Major Road	100	5000	Did Not Converged
5	Regular Road	100	4000	Did Not Converged
6	River	100	5000	Converged
7	Disturbance	200	5000	Null model as the best model, Converged
8	Roughness	90	-	
9	NDVI Curvature	100	-	
10	Deforestation 1990-2000	100	1000	Converged
11	Forest 1990 – 2000	50	500	Did Not Converged
		Way Kambas NP		
1	Brush	200	4000	Converged
2	Dry Land Agriculture	100	500	Did Not Converged
3	Dry Land Agriculture with Brush	100	500	Did Not Converged
4	Savanna	100	1000	Converged
5	Secondary Swamp Forest	50	250	Null model as the best model, Converged
6	Settlement	50	500	Did Not Converged
7	Swamp brush	100	4500	Null model as the best model, Converged
8	Major Road	100	10000	Converged
9	Regular Road	100	10000	Converged
10	River	100	10000	Null model as the best model, Converged
11	Disturbance	50	1500	Converged
12	Roughness	90	-	-
13	NDVI Curvature	100	-	-
14	Deforestation 1990-2000	100	500	Converged

15	Forest 1990 – 2000	100	1500	Did Not Converged
		Bukit Barisan Selatan NP		
1	Brush	100	1000	Null model as the best model, Converged
2	Dry Land Agriculture	100	500	Null model as the best model, Converged
3	Dry Land Agriculture with Brush	100	500	Null model as the best model, Converged
4	Settlement	50	1000	Did Not Converged
5	Secondary Dry Land Forest	200	4000	Converged
6	Primary Dry Land Forest	100	4500	Converged
7	Major Road	100	10000	Converged
8	Regular Road	100	1500	Converged
9	River	100	500	Converged
10	Disturbance	200	4500	Null model as the best model, Converged
11	Roughness	90	-	-
12	NDVI Curvature	100	-	-
13	Deforestation 1990-2000	100	1500	Converged
14	Forest 1990 – 2000	50	1000	Null model as the best model, Converged

Table 2.3 Leuser Landscape 2007 – 1km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ PrimDryLandFor + River	4	337	174.79	0.00	0.22	0.21	0.22
~1 ~ PrimDryLandFor + River + Roughness	5	337	175.14	0.34	0.18	0.22	0.40
~1 ~ PrimDryLandFor + River + Deforestation + SecondDryFor	6	337	175.51	0.71	0.15	0.23	0.56
~1 ~ PrimDryLandFor + River + Deforestation	5	337	175.68	0.89	0.14	0.22	0.70
~Roughness ~ PrimDryLandFor + River	5	337	176.74	1.95	0.08	0.21	0.78
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	176.76	1.97	0.08	0.22	0.86
~1 ~ PrimDryLandFor + River + Disturbance	5	337	176.79	2.00	0.08	0.21	0.94
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	177.68	2.89	0.05	0.22	0.99
~1 ~ SecondDryFor + PrimDryLandFor	4	337	182.82	8.03	0.00	0.16	1.00
~1 ~ PrimDryLandFor	3	337	186.55	11.75	0.00	0.13	1.00
~1 ~ River	3	337	186.69	11.90	0.00	0.13	1.00
~1 ~ Deforestation	3	337	191.60	16.81	0.00	0.10	1.00
~1 ~ Roughness	3	337	199.91	25.12	0.00	0.04	1.00
~1 ~ 1	2	337	204.41	29.62	0.00	0.00	1.00
~1 ~ SecondDryFor	3	337	204.52	29.73	0.00	0.01	1.00
~1 ~ Disturbance	3	337	206.41	31.62	0.00	0.00	1.00

Table 2.4 Leuser Landscape 2007 – 2km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ PrimDryLandFor + River + SecondDryFor	5	337	123.53	0.00	0.33	0.29	0.33
~1 ~ PrimDryLandFor + River	4	337	124.81	1.28	0.17	0.26	0.50
~1 ~ PrimDryLandFor + River + Roughness	5	337	125.14	1.62	0.15	0.27	0.65
~1 ~ PrimDryLandFor + River + Deforestation	5	337	125.67	2.14	0.11	0.27	0.76
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	126.74	3.22	0.07	0.28	0.83
~Roughness ~ PrimDryLandFor + River	5	337	126.78	3.25	0.06	0.26	0.89
~1 ~ PrimDryLandFor + River + Disturbance	5	337	126.81	3.28	0.06	0.26	0.95
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	127.67	4.14	0.04	0.27	0.99
~1 ~ SecondDryFor + PrimDryLandFor	4	337	132.33	8.80	0.00	0.20	1.00
~1 ~ PrimDryLandFor	3	337	136.14	12.61	0.00	0.16	1.00
~1 ~ River	3	337	136.33	12.80	0.00	0.16	1.00
~1 ~ Deforestation	3	337	141.03	17.50	0.00	0.12	1.00
~1 ~ Roughness	3	337	149.52	25.99	0.00	0.05	1.00
~1 ~ 1	2	337	154.01	30.48	0.00	0.00	1.00
~1 ~ SecondDryFor	3	337	154.05	30.53	0.00	0.02	1.00
~1 ~ Disturbance	3	337	156.01	32.48	0.00	0.00	1.00

Table 2.5 Leuser Landscape 2007 – 3km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ PrimDryLandFor + River	4	337	101.12	0.00	0.24	0.30	0.24
~1 ~ PrimDryLandFor + River + Roughness	5	337	101.51	0.38	0.20	0.31	0.43
~1 ~ PrimDryLandFor + River + Deforestation	5	337	102.08	0.96	0.15	0.31	0.58
~Roughness ~ PrimDryLandFor + River	5	337	102.90	1.78	0.10	0.30	0.68
~1 ~ PrimDryLandFor + River + Disturbance	5	337	103.12	2.00	0.09	0.30	0.77
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	103.16	2.03	0.09	0.32	0.85
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	103.16	2.03	0.09	0.32	0.94
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	104.08	2.96	0.05	0.31	0.99
~1 ~ SecondDryFor + PrimDryLandFor	4	337	108.46	7.34	0.01	0.24	1.00
~1 ~ PrimDryLandFor	3	337	112.26	11.14	0.00	0.18	1.00
~1 ~ River	3	337	112.64	11.52	0.00	0.18	1.00
~1 ~ Deforestation	3	337	117.35	16.22	0.00	0.14	1.00
~1 ~ Roughness	3	337	125.67	24.55	0.00	0.06	1.00
~1 ~ Mroad	3	337	126.45	25.33	0.00	0.05	1.00
~1 ~ 1	2	337	130.16	29.04	0.00	0.00	1.00
~1 ~ SecondDryFor	3	337	130.20	29.07	0.00	0.02	1.00
~1 ~ NDVI	3	337	130.72	29.60	0.00	0.01	1.00
~1 ~ Disturbance	3	337	132.16	31.04	0.00	0.00	1.00

Table 2.6 Leuser Landscape 2007- 1km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + NDVI	7	337	168.08	0.00	0.22	0.28	0.22
~1 ~ PrimDryLandFor + River + Roughness	5	337	169.38	1.30	0.12	0.25	0.34
~1 ~ PrimDryLandFor + River + Deforestation + SecondDryFor	6	337	169.62	1.54	0.10	0.26	0.44
~1 ~ SecondDryFor + PrimDryLandFor + River + Disturbance + Deforestation + Roughness + NDVI	9	337	169.88	1.80	0.09	0.30	0.53
~1 ~ PrimDryLandFor + River + Deforestation	5	337	170.22	2.14	0.08	0.25	0.61
~Roughness ~ PrimDryLandFor + River	5	337	170.41	2.33	0.07	0.25	0.67
~1 ~ PrimDryLandFor + River	4	337	170.44	2.36	0.07	0.24	0.74
~1 ~ River + PrimDryLandFor + Deforestation + Roughness	6	337	170.50	2.42	0.07	0.26	0.81
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	170.50	2.42	0.07	0.26	0.87
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + SecondDryFor	7	337	171.16	3.08	0.05	0.27	0.92
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	172.22	4.14	0.03	0.25	0.95
~1 ~ PrimDryLandFor + River + Disturbance	5	337	172.44	4.36	0.03	0.24	0.97
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + Disturbance	7	337	172.50	4.42	0.02	0.26	1.00
~1 ~ SecondDryFor + PrimDryLandFor	4	337	179.24	11.16	0.00	0.18	1.00
~1 ~ River	3	337	182.94	14.86	0.00	0.15	1.00
~1 ~ PrimDryLandFor	3	337	183.73	15.65	0.00	0.14	1.00
~1 ~ Deforestation	3	337	189.79	21.70	0.00	0.10	1.00
~1 ~ Roughness	3	337	199.50	31.42	0.00	0.04	1.00
~1 ~ SecondDryFor	3	337	203.92	35.84	0.00	0.01	1.00
~1 ~ 1	2	337	204.00	35.92	0.00	0.00	1.00
~1 ~ NDVI	3	337	204.37	36.29	0.00	0.01	1.00
~1 ~ Disturbance	3	337	206.00	37.92	0.00	0.00	1.00

Table 2.7 Leuser Landscape 2007- 2km Detection – Royle Nichols Model.

Formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + NDVI	7	337	120.08	0.00	0.22	0.34	0.22
~1 ~ PrimDryLandFor + River + Roughness	5	337	121.24	1.16	0.12	0.30	0.34
~1 ~ PrimDryLandFor + River + Deforestation + SecondDryFor	6	337	121.33	1.26	0.12	0.32	0.45
~1 ~ SecondDryFor + PrimDryLandFor + River + Disturbance + Deforestation + Roughness + NDVI	9	337	121.68	1.60	0.10	0.36	0.55
~1 ~ PrimDryLandFor + River + Deforestation	5	337	121.98	1.90	0.08	0.30	0.64
~1 ~ PrimDryLandFor + River	4	337	122.05	1.97	0.08	0.28	0.72

~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	122.43	2.35	0.07	0.31	0.79
~1 ~ River + PrimDryLandFor + Deforestation + Roughness	6	337	122.43	2.35	0.07	0.31	0.85
~Roughness ~ PrimDryLandFor + River	5	337	122.62	2.54	0.06	0.29	0.91
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	123.98	3.90	0.03	0.30	0.94
~1 ~ PrimDryLandFor + River + Disturbance	5	337	124.05	3.97	0.03	0.28	0.97
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + Disturbance	7	337	124.43	4.35	0.02	0.31	1.00
~1 ~ SecondDryFor + PrimDryLandFor	4	337	130.70	10.62	0.00	0.22	1.00
~1 ~ River	3	337	133.33	13.25	0.00	0.18	1.00
~1 ~ PrimDryLandFor	3	337	135.00	14.92	0.00	0.17	1.00
~1 ~ Deforestation	3	337	140.28	20.20	0.00	0.13	1.00
~1 ~ Roughness	3	337	149.44	29.36	0.00	0.05	1.00
~1 ~ SecondDryFor	3	337	153.81	33.73	0.00	0.02	1.00
~1 ~ 1	2	337	153.86	33.78	0.00	0.00	1.00
~1 ~ NDVI	3	337	154.38	34.30	0.00	0.01	1.00
~1 ~ Disturbance	3	337	155.86	35.78	0.00	0.00	1.00

Table 2.8 Leuser Landscape 2007- 3km Detection – Royle Nichols Model.

Formula	**nPars**	**n**	**AIC**	**delta**	**AICwt**	**Rsq**	**cumltvWt**
~1 ~ PrimDryLandFor + River + Roughness	5	337	99.07	0.00	0.13	0.33	0.13
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + SecondDryFor + NDVI	8	337	99.08	0.01	0.13	0.38	0.26
~1 ~ River + PrimDryLandFor + Deforestation + Roughness + NDVI	7	337	99.18	0.12	0.12	0.37	0.38
~Roughness ~ PrimDryLandFor + River	5	337	99.52	0.45	0.10	0.33	0.49
~1 ~ PrimDryLandFor + River + Deforestation + SecondDryFor	6	337	99.62	0.56	0.10	0.35	0.59
~1 ~ PrimDryLandFor + River	4	337	100.04	0.97	0.08	0.31	0.67
~1 ~ PrimDryLandFor + River + Deforestation	5	337	100.28	1.22	0.07	0.32	0.74
~1 ~ PrimDryLandFor + River + Deforestation + Roughness	6	337	100.47	1.41	0.06	0.34	0.80
~1 ~ River + PrimDryLandFor + Deforestation + Roughness	6	337	100.47	1.41	0.06	0.34	0.87
~1 ~ SecondDryFor + PrimDryLandFor + River + Disturbance + Deforestation + Roughness + NDVI	9	337	101.01	1.95	0.05	0.38	0.92
~1 ~ PrimDryLandFor + River + Disturbance	5	337	102.04	2.97	0.03	0.31	0.95
~1 ~ PrimDryLandFor + River + Deforestation + Disturbance	6	337	102.28	3.22	0.03	0.32	0.97

~1 ~ River + PrimDryLandFor + Deforestation + Roughness + Disturbance	7	337	102.47	3.41	0.02	0.34	1.00
~1 ~ SecondDryFor + PrimDryLandFor	4	337	107.35	8.29	0.00	0.24	1.00
~1 ~ PrimDryLandFor	3	337	111.43	12.36	0.00	0.19	1.00
~1 ~ River	3	337	111.47	12.41	0.00	0.19	1.00
~1 ~ Deforestation	3	337	117.12	18.05	0.00	0.14	1.00
~1 ~ Roughness	3	337	125.68	26.62	0.00	0.06	1.00
~1 ~ SecondDryFor	3	337	130.08	31.02	0.00	0.02	1.00
~1 ~ 1	2	337	130.16	31.09	0.00	0.00	1.00
~1 ~ NDVI	3	337	130.72	31.65	0.00	0.01	1.00
~1 ~ Disturbance	3	337	132.14	33.07	0.00	0.00	1.00

Table 2.9 Parameter estimate for best model of Leuser Landscape 20007.

Leuser Landscape – Occupancy Model						
Occupancy:						
	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
(Intercept)	-8.62	1.74	-12.02	-5.21	0.00018	0.000
Primary Dry Land Forest	7.83	2.26	3.39	12.26	0.99	0.001
River	8.43	2.94	2.66	14.18	0.99	0.004
Detection:						
(Intercept)	-0.543	0.335	-1.24	0.15	0.37	0.126
Leuser Landscape - Royle-Nichols Occupancy Model						
Occupancy:						
	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
(Intercept)	-11.47	4.99	-21.26	-21.26	0.00	0.021
River	8.01	2.37	3.36	12.66	1.00	0.001
Primary Dry Land Forest	5.49	1.98	1.61	9.38	1.00	0.005
Deforestation	-2.75	1.92	-6.52	1.02	0.06	0.152
Roughness	0.86	0.85	-0.81	2.54	0.70	0.309
NDVI	0.02	0.01	0.00	0.05	0.51	0.045
Detection:						
(Intercept)	-2.05	0.75	-3.53	-0.57	0.11	0.006

Table 2.10 Way Kambas NP 2008 – 1km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ Mroad + Brush + Deforestation + NDVI	6	28	162.32	0.00	0.29	0.58	0.29

~1 ~ Mroad + Brush + Deforestation	5	28	162.70	0.38	0.24	0.54	0.52
~1 ~ Mroad + Brush + Deforestation + River	6	28	163.89	1.57	0.13	0.56	0.66
~1 ~ Mroad + Brush + Deforestation + River + NDVI	7	28	164.47	2.15	0.10	0.58	0.75
~River ~ Mroad + Brush + Deforestation	6	28	164.70	2.38	0.09	0.54	0.84
~1 ~ Mroad + Brush + Savanna	5	28	165.15	2.83	0.07	0.50	0.91
~1 ~ Mroad + Brush	4	28	165.45	3.13	0.06	0.46	0.97
~1 ~ Mroad	3	28	169.11	6.79	0.01	0.34	0.98
~1 ~ RegRoad	3	28	169.11	6.79	0.01	0.34	0.99
~1 ~ Brush	3	28	169.78	7.46	0.01	0.32	1.00
~1 ~ Deforestation	3	28	171.64	9.32	0.00	0.28	1.00
~River ~ Deforestation	4	28	173.60	11.28	0.00	0.28	1.00
~1 ~ Savanna	3	28	177.74	15.42	0.00	0.10	1.00
~1 ~ 1	2	28	178.64	16.32	0.00	0.00	1.00
~1 ~ SwBrush	3	28	179.53	17.21	0.00	0.04	1.00
~1 ~ NDVI	3	28	180.24	17.92	0.00	0.01	1.00
~1 ~ River	3	28	180.56	18.24	0.00	0.00	1.00
~1 ~ SecondSwampFor	3	28	180.64	18.32	0.00	0.00	1.00

Table 2.11 Way Kambas NP 2008 – 2km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ Mroad + Brush + Deforestation + NDVI	6	28	106.04	0.00	0.31	0.58	0.31
~1 ~ Mroad + Brush + Deforestation	5	28	106.49	0.45	0.25	0.54	0.56
~1 ~ Mroad + Brush + Deforestation + River	6	28	107.55	1.51	0.15	0.56	0.70
~River ~ Mroad + Brush + Deforestation	6	28	107.97	1.93	0.12	0.55	0.82
~1 ~ Mroad + Brush + Savanna	5	28	108.82	2.78	0.08	0.50	0.90

~1 ~ Mroad + Brush	4	28	109.20	3.16	0.06	0.46	0.96
~1 ~ Mroad	3	28	112.59	6.55	0.01	0.34	0.97
~1 ~ RegRoad	3	28	112.60	6.56	0.01	0.34	0.99
~1 ~ Brush	3	28	113.17	7.13	0.01	0.32	0.99
~1 ~ Deforestation	3	28	114.81	8.77	0.00	0.28	1.00
~River ~ Deforestation	4	28	116.51	10.47	0.00	0.29	1.00
~1 ~ Savanna	3	28	120.76	14.72	0.00	0.11	1.00
~1 ~ 1	2	28	121.85	15.81	0.00	0.00	1.00
~1 ~ SwBrush	3	28	122.69	16.65	0.00	0.04	1.00
~1 ~ NDVI	3	28	123.43	17.39	0.00	0.01	1.00
~1 ~ River	3	28	123.74	17.70	0.00	0.00	1.00
~1 ~ SecondSwampFor	3	28	123.84	17.80	0.00	0.00	1.00

Table 2.12 Way Kambas NP 2008 – 3km Detection – MacKenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ Mroad + Brush + Deforestation + Savanna	6	28	78.54	0.00	0.59	0.60	0.59
~1 ~ Mroad + Brush + Deforestation	5	28	80.63	2.09	0.21	0.53	0.79
~River ~ Mroad + Brush + Deforestation	6	28	82.09	3.55	0.10	0.54	0.89
~1 ~ Mroad + Brush	4	28	83.06	4.52	0.06	0.44	0.95
~1 ~ Mroad	3	28	86.00	7.46	0.01	0.32	0.97
~1 ~ RegRoad	3	28	86.00	7.46	0.01	0.32	0.98
~1 ~ Brush	3	28	86.64	8.10	0.01	0.31	0.99
~1 ~ Deforestation	3	28	87.94	9.40	0.01	0.27	1.00
~River ~ Deforestation	4	28	89.59	11.05	0.00	0.28	1.00
~1 ~ Savanna	3	28	92.66	14.12	0.00	0.13	1.00
~1 ~ 1	2	28	94.42	15.88	0.00	0.00	1.00
~1 ~ SwBrush	3	28	95.38	16.84	0.00	0.04	1.00
~1 ~ NDVI	3	28	95.89	17.35	0.00	0.02	1.00
~1 ~ River	3	28	96.26	17.72	0.00	0.01	1.00
~1 ~ SecondSwampFor	3	28	96.41	17.87	0.00	0.00	1.00

Table 2.13 Way Kambas NP 2008 – 1km Detection – Royle Nichols Model.

formula	**nPars**	**n**	**AIC**	**delta**	**AICwt**	**Rsq**	**cumltvWt**
~1 ~ Mroad + Brush + Savanna	5	28	157.88	0.00	0.23	0.52	0.23
~1 ~ Mroad + Brush + Deforestation	5	28	158.15	0.27	0.20	0.52	0.44
~1 ~ Mroad + Brush + Deforestation + River	6	28	158.17	0.29	0.20	0.55	0.64
~1 ~ Mroad + Brush + Deforestation + NDVI	6	28	159.18	1.30	0.12	0.53	0.76

~1 ~ Mroad + Brush	4	28	159.92	2.03	0.08	0.45	0.85
~1 ~ Mroad + Brush + Deforestation + River + NDVI	7	28	160.20	2.32	0.07	0.55	0.92
~1 ~ Brush	3	28	161.32	3.43	0.04	0.37	0.96
~1 ~ Mroad	3	28	163.96	6.08	0.01	0.31	0.97
~1 ~ RegRoad	3	28	163.98	6.09	0.01	0.31	0.98
~1 ~ Deforestation	3	28	164.07	6.19	0.01	0.31	1.00
~River ~ Deforestation	4	28	166.03	8.14	0.00	0.31	1.00
~1 ~ Savanna	3	28	170.19	12.31	0.00	0.14	1.00
~1 ~ 1	2	28	172.39	14.51	0.00	0.00	1.00
~1 ~ SwBrush	3	28	173.33	15.45	0.00	0.04	1.00
~1 ~ SecondSwampFor	3	28	174.14	16.26	0.00	0.01	1.00
~1 ~ River	3	28	174.33	16.45	0.00	0.00	1.00
~1 ~ NDVI	3	28	174.39	16.51	0.00	0.00	1.00

Table 2.14 Way Kambas NP 2008 – 2km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ Mroad + Brush + Deforestation + River	6	28	106.64	0.00	0.23	0.52	0.23
~1 ~ Mroad + Brush + Savanna	5	28	106.85	0.21	0.21	0.48	0.44
~1 ~ Mroad + Brush + Deforestation	5	28	107.41	0.76	0.16	0.47	0.60
~1 ~ Mroad + Brush + Deforestation + NDVI	6	28	107.91	1.27	0.12	0.50	0.72
~1 ~ Mroad + Brush + Deforestation + River + NDVI	7	28	108.66	2.02	0.08	0.52	0.81
~1 ~ Mroad + Brush	4	28	109.13	2.48	0.07	0.39	0.87
~1 ~ Brush	3	28	110.45	3.81	0.03	0.31	0.91
~1 ~ Deforestation	3	28	110.70	4.06	0.03	0.30	0.94
~1 ~ Mroad	3	28	111.45	4.81	0.02	0.28	0.96
~1 ~ RegRoad	3	28	111.46	4.82	0.02	0.28	0.98
~River ~ Deforestation	4	28	112.01	5.37	0.02	0.32	1.00
~1 ~ Savanna	3	28	116.32	9.68	0.00	0.15	1.00
~1 ~ 1	2	28	118.66	12.01	0.00	0.00	1.00
~1 ~ SwBrush	3	28	119.13	12.48	0.00	0.05	1.00
~1 ~ River	3	28	120.38	13.74	0.00	0.01	1.00
~1 ~ SecondSwampFor	3	28	120.39	13.75	0.00	0.01	1.00
~1 ~ NDVI	3	28	120.62	13.98	0.00	0.00	1.00

Table 2.15 Way Kambas NP 2008 – 3km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ Mroad + Brush + Savanna	5	28	82.32	0.00	0.32	0.46	0.32

~1 ~ Mroad + Brush + Deforestation	5	28	83.55	1.23	0.17	0.44	0.49
~1 ~ Mroad + Brush + Deforestation + NDVI	6	28	84.07	1.75	0.13	0.47	0.62
~1 ~ Mroad + Brush + Deforestation + River + NDVI	7	28	84.53	2.21	0.10	0.50	0.72
~1 ~ Mroad + Brush	4	28	84.96	2.64	0.08	0.36	0.81
~1 ~ Deforestation	3	28	85.91	3.59	0.05	0.28	0.86
~1 ~ Brush	3	28	85.94	3.62	0.05	0.28	0.91
~1 ~ Mroad	3	28	86.58	4.26	0.04	0.26	0.95
~1 ~ RegRoad	3	28	86.60	4.28	0.04	0.26	0.99
~1 ~ Savanna	3	28	90.01	7.70	0.01	0.16	0.99
~1 ~ 1	2	28	92.70	10.38	0.00	0.00	1.00
~1 ~ SwBrush	3	28	93.42	11.11	0.00	0.05	1.00
~1 ~ River	3	28	94.39	12.07	0.00	0.01	1.00
~1 ~ SecondSwampFor	3	28	94.41	12.10	0.00	0.01	1.00
~1 ~ NDVI	3	28	94.63	12.31	0.00	0.00	1.00

Table 2.16 Parameter estimate for best model of Way Kambas NP 2008.

Way Kambas - Occupancy Model

	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
Occupancy:						
(Intercept)	-25.1	3708.4	-7293.48	7243.32	0.000	0.995
Major Road	-64.7	140.2	-339.54	210.22	0.000	0.645
Brush	18.9	33.7	-47.13	84.85	1.000	0.575
Deforestation	35.3	3926	-7659.54	7730.17	1.000	0.993
Savanna	-23.9	36.7	-95.76	48	0.000	0.515
Detection:						
(Intercept)	-0.75	0.294	-1.33	-0.17	0.321	0.010

Way Kambas - Royle-Nichols Occupancy Model

	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
Occupancy:						
(Intercept)	0.04	0.88	-1.69	1.77	0.510	0.96
Major Road	-7.59	5.32	-18.04	2.85	0.001	0.15
Brush	5.6	2.56	0.57	10.64	0.996	0.028
Savanna	-6.27	4.47	-15.03	2.49	0.002	0.16
Detection:						
(Intercept)	-2.52	0.587	-3.66	-1.36	0.075	0.000

Table 2.17 Bukit Barisan Selatan NP 2010 – 1km Detection – Mackenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	364.24	0.00	0.26	0.21	0.26
~1 ~ SecondDryFor + RegRoad + Deforestation + Forest	6	55	364.86	0.63	0.19	0.23	0.46

~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	6	55	365.67	1.44	0.13	0.22	0.59
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	366.28	2.05	0.10	0.18	0.68
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	367.56	3.32	0.05	0.22	0.73
~1 ~ PrimDryLandFor	3	55	367.73	3.49	0.05	0.10	0.78
~1 ~ RegRoad	3	55	367.88	3.64	0.04	0.10	0.82
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad	6	55	368.11	3.87	0.04	0.19	0.86
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Roughness	9	55	368.69	4.45	0.03	0.26	0.89
~1 ~ Mroad	3	55	368.88	4.65	0.03	0.08	0.91
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	9	55	369.28	5.05	0.02	0.25	0.93
~1 ~ SecondDryFor	3	55	369.91	5.68	0.02	0.06	0.95
~1 ~ Deforestation	3	55	371.17	6.93	0.01	0.04	0.96
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	10	55	371.25	7.02	0.01	0.26	0.97
~1 ~ 1	2	55	371.44	7.20	0.01	0.00	0.97
~1 ~ DryLandAg	3	55	372.36	8.12	0.00	0.02	0.98
~1 ~ Roughness	3	55	372.74	8.51	0.00	0.01	0.98
~1 ~ River	3	55	373.12	8.88	0.00	0.01	0.99
~1 ~ NDVI	3	55	373.16	8.92	0.00	0.01	0.99
~1 ~ Forest	3	55	373.29	9.05	0.00	0.00	0.99
~1 ~ DryLandAgwithBrush	3	55	373.31	9.07	0.00	0.00	0.99
~1 ~ Brush	3	55	373.31	9.08	0.00	0.00	1.00
~1 ~ Disturbance	3	55	373.44	9.20	0.00	0.00	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Deforestation + Forest + Roughness + NDVI	13	55	376.83	12.59	0.00	0.26	1.00

Table 2.18 Bukit Barisan Selatan NP 2010 – 2km Detection – Mackenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	257.53	0.00	0.36	0.22	0.36
~Roughness ~ SecondDryFor + RegRoad + Deforestation	6	55	259.25	1.72	0.15	0.22	0.52
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	259.51	1.99	0.13	0.19	0.65
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	260.96	3.44	0.07	0.22	0.72
~1 ~ PrimDryLandFor	3	55	261.04	3.51	0.06	0.10	0.78
~1 ~ RegRoad	3	55	261.23	3.70	0.06	0.10	0.84
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad	6	55	261.39	3.87	0.05	0.19	0.89
~1 ~ Mroad	3	55	262.41	4.88	0.03	0.08	0.92

~1 ~ SecondDryFor	3	55	263.24	5.72	0.02	0.06	0.94
~1 ~ Deforestation	3	55	264.46	6.94	0.01	0.04	0.95
~1 ~ 1	2	55	264.77	7.25	0.01	0.00	0.96
~1 ~ DryLandAg	3	55	265.79	8.26	0.01	0.02	0.97
~1 ~ Roughness	3	55	266.08	8.55	0.01	0.01	0.98
~1 ~ River	3	55	266.45	8.93	0.00	0.01	0.98
~1 ~ NDVI	3	55	266.49	8.96	0.00	0.01	0.98
~1 ~ Forest	3	55	266.63	9.10	0.00	0.00	0.99
~1 ~ Brush	3	55	266.64	9.11	0.00	0.00	0.99
~1 ~ DryLandAgwithBrush	3	55	266.65	9.12	0.00	0.00	0.99
~1 ~ Disturbance	3	55	266.77	9.25	0.00	0.00	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + Mroad + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	15	55	268.43	10.90	0.00	0.34	1.00

Table 2.19 Bukit Barisan Selatan NP 2010 – 3km Detection – Mackenzie 2002 Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	212.15	0.00	0.32	0.21	0.32
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	6	55	213.61	1.47	0.15	0.22	0.47
~Roughness ~ SecondDryFor + RegRoad + Deforestation	6	55	214.13	1.98	0.12	0.22	0.59
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	214.17	2.02	0.12	0.18	0.71
~1 ~ PrimDryLandFor	3	55	215.44	3.29	0.06	0.10	0.77
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	215.50	3.35	0.06	0.22	0.83
~1 ~ RegRoad	3	55	215.81	3.66	0.05	0.09	0.88
~1 ~ Mroad	3	55	216.79	4.64	0.03	0.08	0.91
~1 ~ SecondDryFor	3	55	217.63	5.48	0.02	0.06	0.94
~1 ~ Deforestation	3	55	218.89	6.74	0.01	0.04	0.95
~1 ~ 1	2	55	219.15	7.00	0.01	0.00	0.96
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	10	55	219.18	7.03	0.01	0.26	0.97
~1 ~ DryLandAg	3	55	220.09	7.94	0.01	0.02	0.97
~1 ~ Roughness	3	55	220.42	8.27	0.01	0.01	0.98
~1 ~ River	3	55	220.83	8.68	0.00	0.01	0.98
~1 ~ NDVI	3	55	220.90	8.75	0.00	0.00	0.98
~1 ~ Brush	3	55	221.00	8.85	0.00	0.00	0.99
~1 ~ Forest	3	55	221.01	8.86	0.00	0.00	0.99
~1 ~ DryLandAgwithBrush	3	55	221.01	8.86	0.00	0.00	1.00
~1 ~ Disturbance	3	55	221.15	9.00	0.00	0.00	1.00

Table 2.20 Bukit Barisan Selatan NP 2010 – 1km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	350.29	0.00	0.20	0.26	0.20
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	6	55	351.56	1.27	0.11	0.27	0.31
~1 ~ SecondDryFor + RegRoad + Deforestation + Forest	6	55	351.73	1.44	0.10	0.26	0.41
~Roughness ~ SecondDryFor + RegRoad + Deforestation	6	55	352.19	1.91	0.08	0.26	0.49
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest	7	55	352.25	1.97	0.08	0.28	0.57
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	352.27	1.99	0.08	0.23	0.64
~1 ~ SecondDryFor	3	55	352.78	2.49	0.06	0.16	0.70
~1 ~ SecondDryFor + PrimDryLandFor	4	55	352.93	2.64	0.05	0.19	0.76
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	353.00	2.71	0.05	0.27	0.81
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest	8	55	353.67	3.38	0.04	0.29	0.85
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad	6	55	353.80	3.52	0.04	0.24	0.88
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River	8	55	353.93	3.64	0.03	0.29	0.92
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River	9	55	355.24	4.96	0.02	0.30	0.93
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Roughness	9	55	355.49	5.20	0.02	0.29	0.95
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	9	55	355.88	5.60	0.01	0.29	0.96
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Disturbance	9	55	355.93	5.64	0.01	0.29	0.97
~1 ~ PrimDryLandFor	3	55	356.42	6.14	0.01	0.11	0.98
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	10	55	357.30	7.01	0.01	0.30	0.99
~1 ~ 1	2	55	360.58	10.29	0.00	0.00	0.99
~1 ~ RegRoad	3	55	360.69	10.40	0.00	0.03	0.99
~1 ~ Deforestation	3	55	360.86	10.57	0.00	0.03	0.99
~1 ~ DryLandAg	3	55	360.91	10.62	0.00	0.03	0.99
~1 ~ Mroad	3	55	360.92	10.64	0.00	0.03	0.99
~1 ~ Forest	3	55	361.23	10.95	0.00	0.02	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Deforestation + Forest + Roughness + NDVI	13	55	361.37	11.08	0.00	0.32	1.00

~1 ~ DryLandAgwithBrush	3	55	361.39	11.11	0.00	0.02	1.00
~1 ~ River	3	55	362.22	11.93	0.00	0.01	1.00
~1 ~ Roughness	3	55	362.34	12.05	0.00	0.00	1.00
~1 ~ NDVI	3	55	362.47	12.18	0.00	0.00	1.00
~1 ~ Brush	3	55	362.52	12.24	0.00	0.00	1.00
~1 ~ Disturbance	3	55	362.58	12.29	0.00	0.00	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	14	55	363.42	13.13	0.00	0.32	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + Mroad + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	15	55	364.27	13.99	0.00	0.33	1.00

Table 2.21 Bukit Barisan Selatan NP 2010 – 2km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	249.25	0.00	0.21	0.25	0.21
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	6	55	250.29	1.05	0.12	0.27	0.33
~1 ~ SecondDryFor + RegRoad + Deforestation + Forest	6	55	250.74	1.49	0.10	0.26	0.43
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest	7	55	250.89	1.64	0.09	0.28	0.52
~Roughness ~ SecondDryFor + RegRoad + Deforestation	6	55	251.08	1.83	0.08	0.26	0.60
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	251.24	2.00	0.08	0.22	0.68
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	251.65	2.40	0.06	0.27	0.74
~1 ~ SecondDryFor + PrimDryLandFor	4	55	251.93	2.68	0.05	0.19	0.79
~1 ~ SecondDryFor	3	55	252.19	2.94	0.05	0.15	0.84
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River	8	55	252.46	3.21	0.04	0.29	0.88
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad	6	55	252.75	3.50	0.04	0.23	0.92
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Roughness	9	55	254.06	4.82	0.02	0.30	0.94
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Disturbance	9	55	254.46	5.22	0.02	0.29	0.95
~1 ~ PrimDryLandFor	3	55	254.62	5.37	0.01	0.11	0.97
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	9	55	255.05	5.80	0.01	0.28	0.98

~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	10	55	255.56	6.31	0.01	0.30	0.99
~1 ~ RegRoad	3	55	258.78	9.53	0.00	0.04	0.99
~1 ~ Mroad	3	55	259.03	9.78	0.00	0.04	0.99
~1 ~ Deforestation	3	55	259.09	9.84	0.00	0.04	0.99
~1 ~ 1	2	55	259.10	9.85	0.00	0.00	0.99
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Deforestation + Forest + Roughness + NDVI	13	55	259.53	10.28	0.00	0.33	0.99
~1 ~ DryLandAg	3	55	259.56	10.31	0.00	0.03	0.99
~1 ~ DryLandAgwithBrush	3	55	260.00	10.76	0.00	0.02	1.00
~1 ~ Forest	3	55	260.09	10.85	0.00	0.02	1.00
~1 ~ Roughness	3	55	260.74	11.49	0.00	0.01	1.00
~1 ~ River	3	55	260.75	11.51	0.00	0.01	1.00
~1 ~ NDVI	3	55	260.98	11.73	0.00	0.00	1.00
~1 ~ Brush	3	55	261.10	11.85	0.00	0.00	1.00
~1 ~ Disturbance	3	55	261.10	11.85	0.00	0.00	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	14	55	261.53	12.28	0.00	0.33	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + Mroad + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	15	55	262.03	12.78	0.00	0.35	1.00

Table 2.22 Bukit Barisan Selatan NP 2010 – 3km Detection – Royle Nichols Model.

formula	nPars	n	AIC	delta	AICwt	Rsq	cumltvWt
~1 ~ SecondDryFor + RegRoad + Deforestation	5	55	208.82	0.00	0.18	0.23	0.18
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	6	55	209.66	0.84	0.12	0.24	0.29
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest	7	55	210.33	1.51	0.08	0.26	0.38
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad	5	55	210.34	1.53	0.08	0.20	0.46
~1 ~ SecondDryFor + RegRoad + Deforestation + Forest	6	55	210.43	1.61	0.08	0.23	0.54
~Roughness ~ SecondDryFor + RegRoad + Deforestation	6	55	210.44	1.62	0.08	0.23	0.62
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation	7	55	210.91	2.10	0.06	0.25	0.68
~1 ~ SecondDryFor + PrimDryLandFor	4	55	210.96	2.14	0.06	0.16	0.74
~1 ~ SecondDryFor	3	55	211.43	2.62	0.05	0.12	0.79

~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad	6	55	211.75	2.94	0.04	0.21	0.83
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River	8	55	211.83	3.01	0.04	0.27	0.87
~1 ~ PrimDryLandFor	3	55	212.31	3.50	0.03	0.11	0.90
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Roughness	9	55	213.62	4.80	0.02	0.27	0.92
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Disturbance	9	55	213.83	5.01	0.01	0.27	0.93
~1 ~ SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	9	55	213.92	5.10	0.01	0.27	0.95
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + Roughness	10	55	214.42	5.60	0.01	0.29	0.96
~1 ~ DryLandAg + SecondDryFor + PrimDryLandFor + RegRoad + Deforestation + Forest + River + NDVI	10	55	214.86	6.05	0.01	0.28	0.97
~1 ~ RegRoad	3	55	216.04	7.23	0.00	0.05	0.97
~1 ~ Mroad	3	55	216.20	7.38	0.00	0.04	0.98
~1 ~ Deforestation	3	55	216.52	7.70	0.00	0.04	0.98
~1 ~ 1	2	55	216.57	7.75	0.00	0.00	0.98
~1 ~ DryLandAg	3	55	217.05	8.23	0.00	0.03	0.99
~1 ~ DryLandAgwithBrush	3	55	217.66	8.84	0.00	0.02	0.99
~1 ~ Forest	3	55	217.87	9.05	0.00	0.01	0.99
~1 ~ Roughness	3	55	218.04	9.23	0.00	0.01	0.99
~1 ~ River	3	55	218.29	9.47	0.00	0.01	0.99
~1 ~ NDVI	3	55	218.45	9.63	0.00	0.00	1.00
~1 ~ Brush	3	55	218.54	9.72	0.00	0.00	1.00
~1 ~ Disturbance	3	55	218.57	9.75	0.00	0.00	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Deforestation + Forest + Roughness + NDVI	13	55	219.18	10.36	0.00	0.30	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	14	55	220.99	12.17	0.00	0.31	1.00
~1 ~ Brush + DryLandAg + DryLandAgwithBrush + SecondDryFor + PrimDryLandFor + Mroad + RegRoad + River + Disturbance + Deforestation + Forest + Roughness + NDVI	15	55	223.08	14.26	0.00	0.30	1.00

Table 2.23 Parameter estimate for best model of Bukit Barisan Selatan NP 2010.

Occupancy:						
	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
(Intercept)	-1.42	0.972	-3.32	0.49	0.195	0.145
Secondary Dry Land Forest	6.73	3.021	0.8	12.65	0.998	0.026
Regular Road	16.02	9.299	-2.21	34.24	0.999	0.085
Deforestation	-2.52	1.684	-5.82	0.78	0.074	0.134
Detection:						
(Intercept)	-1.42	0.198	-1.81	-1.03	0.195	0.000

Bukit Barisan Selatan - Royle-Nichols Occupancy Model

Occupancy:						
	Estimate	SE	Lower CI	Upper CI	Transformed	P-value
(Intercept)	-1.711	0.686	-30.6	-0.36	0.153	0.012
Secondary Dry Land Forest	6.44	1.758	2.99	9.88	0.998	0.000
Regular Road	3.66	1.962	-0.18	7.51	0.975	0.060
Deforestation	-1.44	0.843	-3.09	0.21	0.191	0.080
Detection:						
(Intercept)	-2.34	0.259	-1.81	-2.85	-1.83	0.000

Figures

Figure 2.1 the study area of Leuser Landscape (encompassing Gunung Leuser NP), Way Kambas National Park, and Bukit Barisan Selatan National Park.

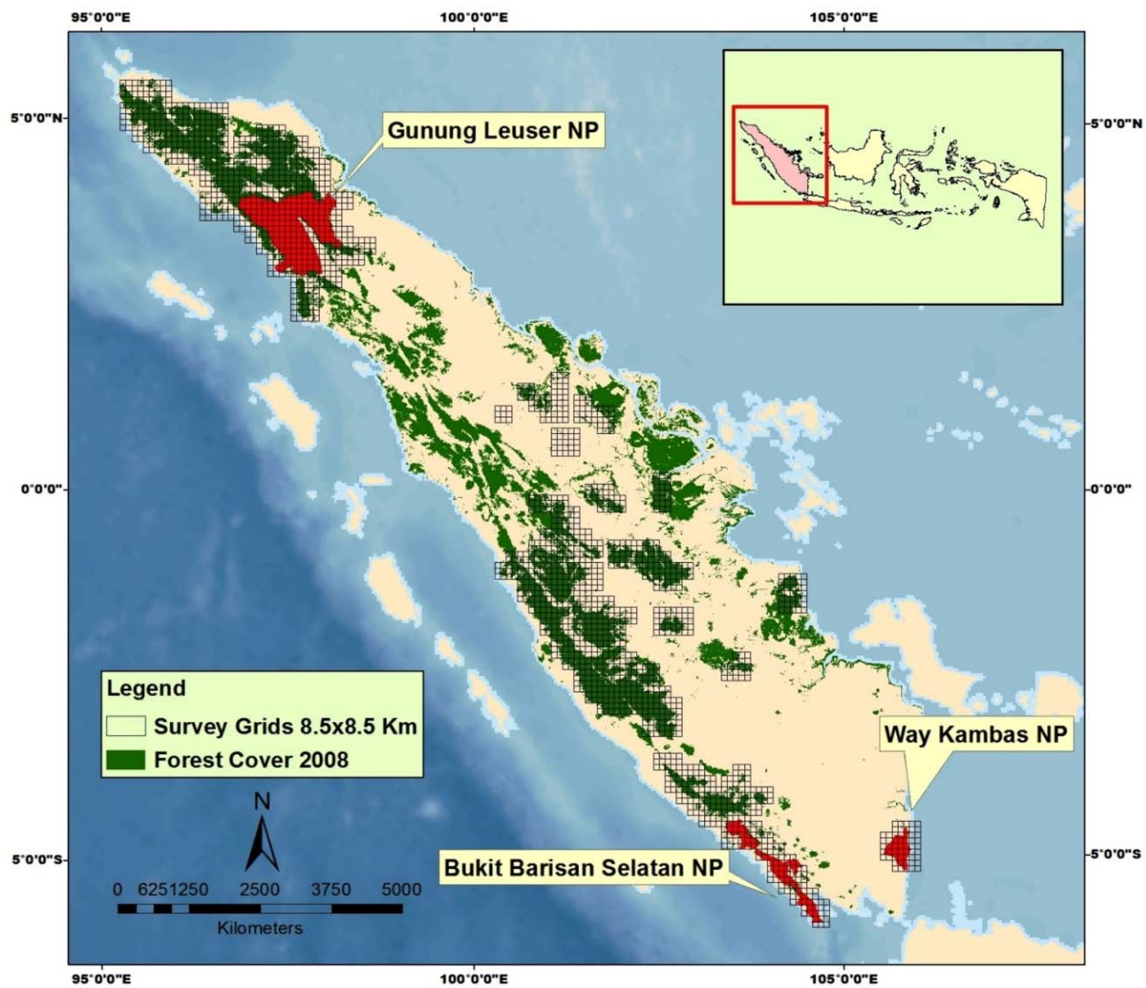


Figure 2.2 Pearson's Correlation Matrix for Selected Covariates Leuser Landscape.

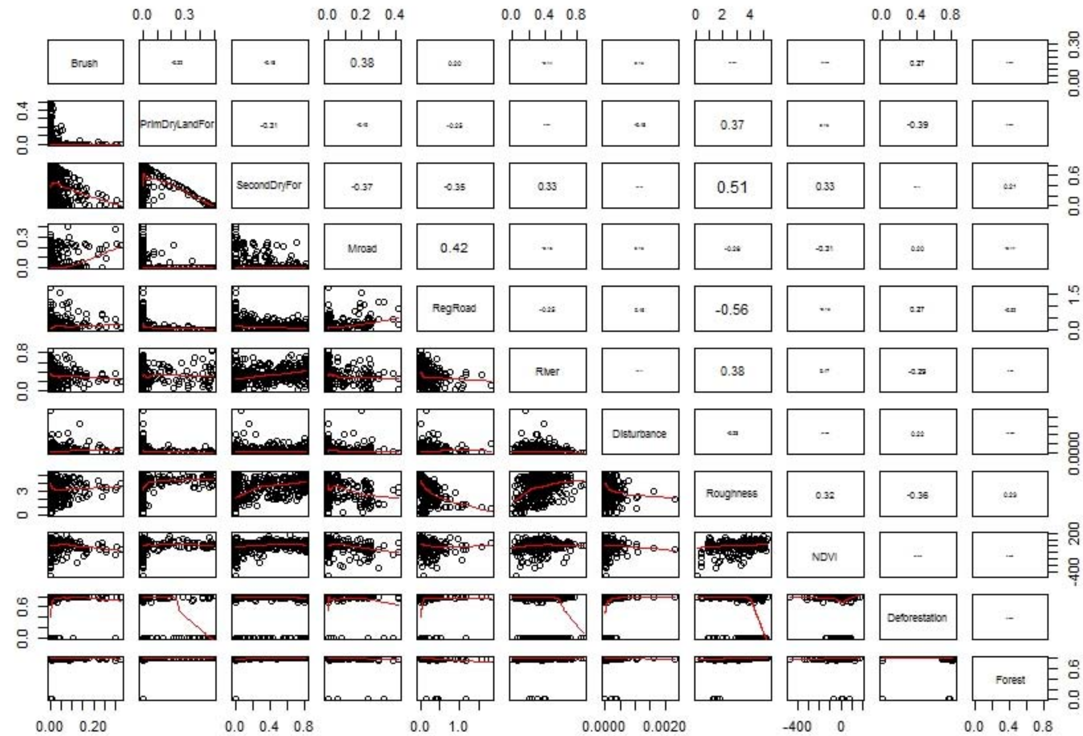


Figure 2.3 Pearson's Correlation matrix for Selected Covariates Way Kambas National Park.

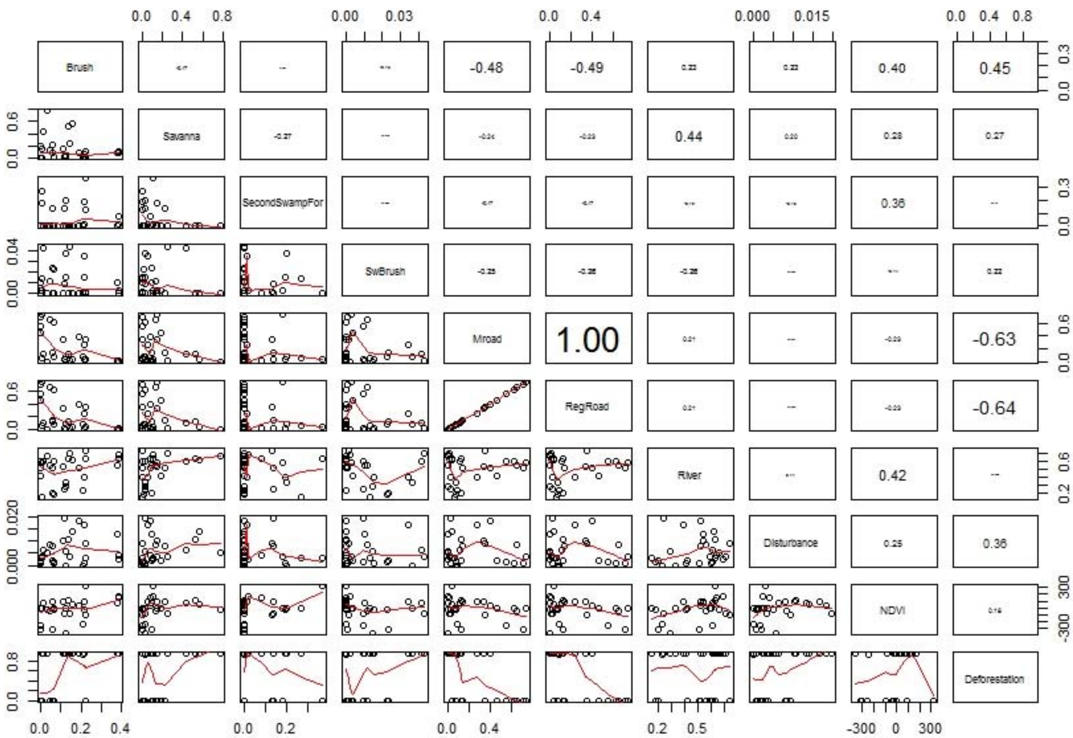


Figure 2.4 Pearson’s Correlation Matrix for Selected Covariates Bukit Barisan Selatan National Park.

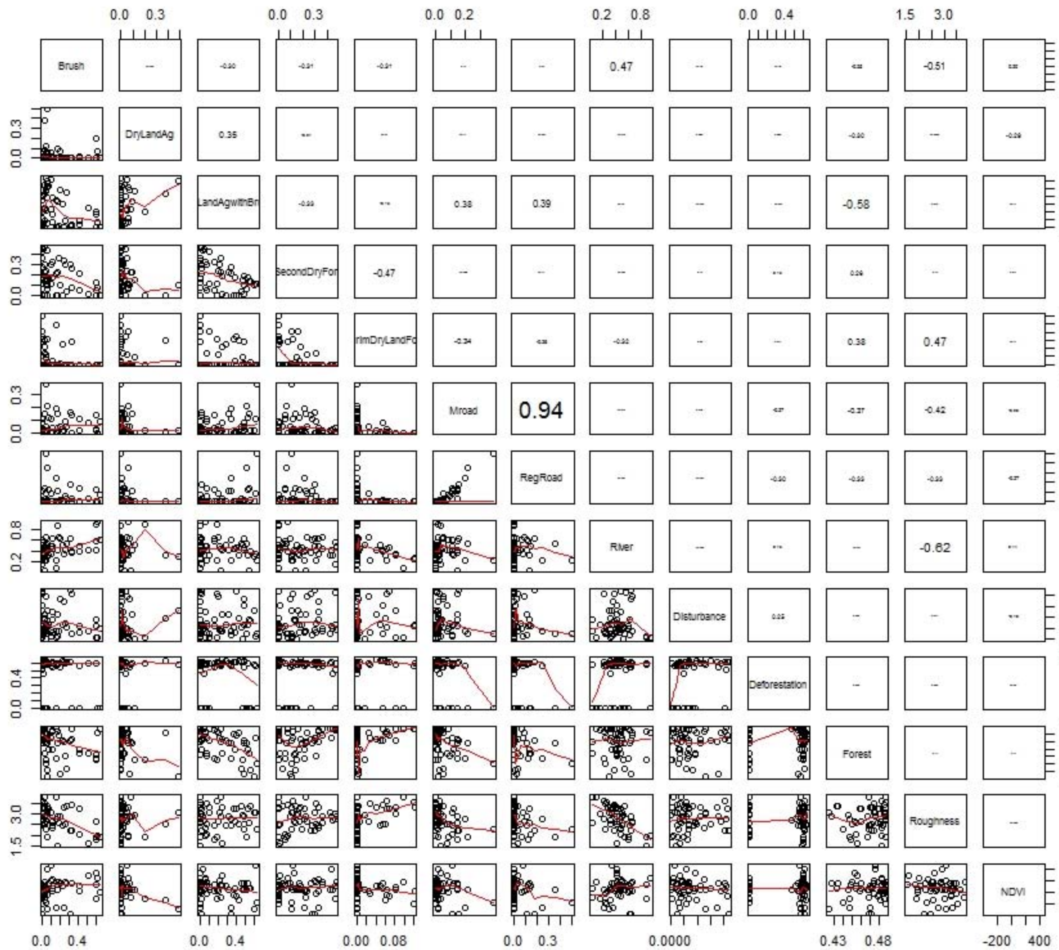


Figure 2.5 Detection/non-detection matrix of 1km detection-segment for Leuser Landscape 2007.

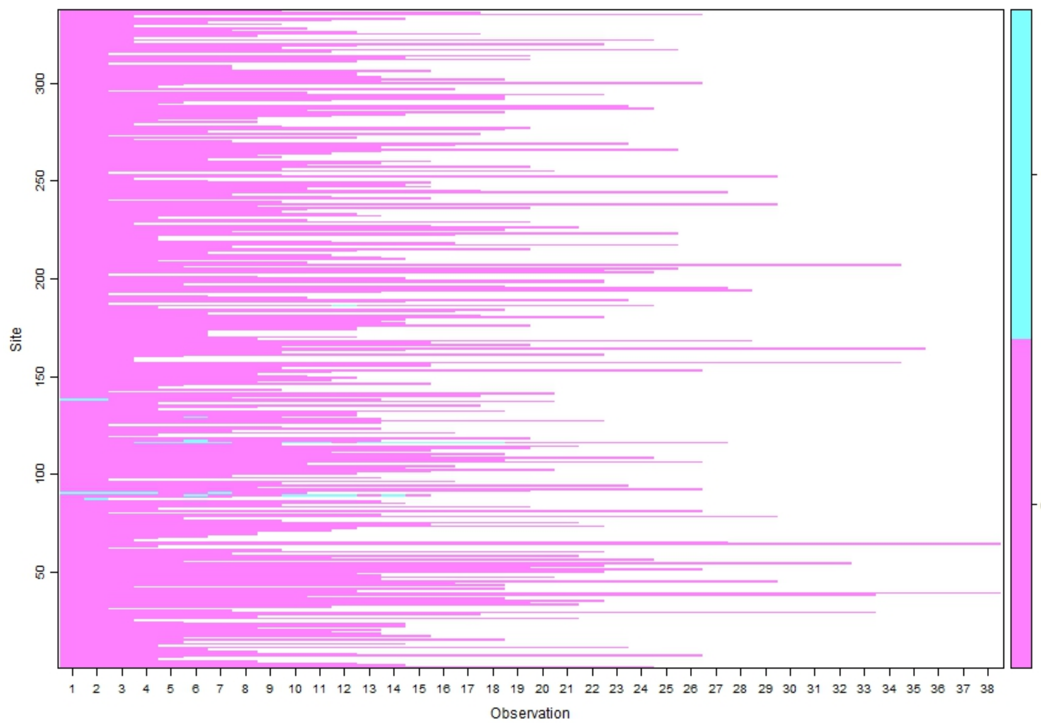


Figure 2.6 Detection/non-detection matrix of 1km detection-segment for Way Kambas National Park 2008.

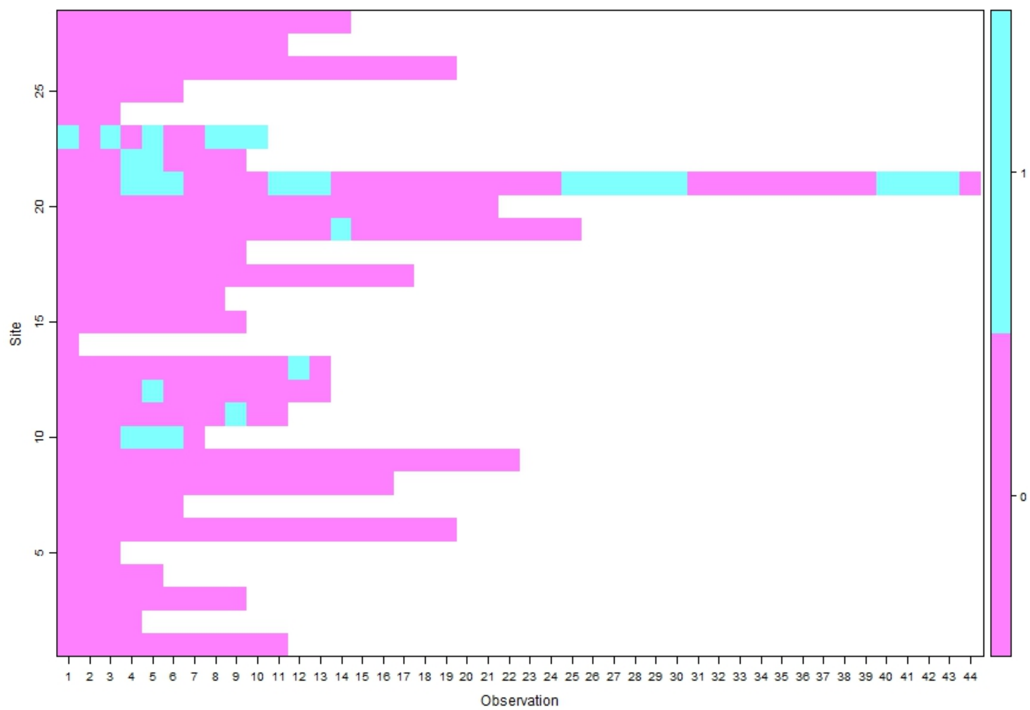


Figure 2.7 Detection/non-detection matrix of 1km detection-segment for Bukit Barisan Selatan National Park 2010.

Figure 2.8 Occupancy estimate for each sampling grid based on MacKenzie 2002 single season occupancy modeling for Leuser Landscape 2007 with 3km detection segments.

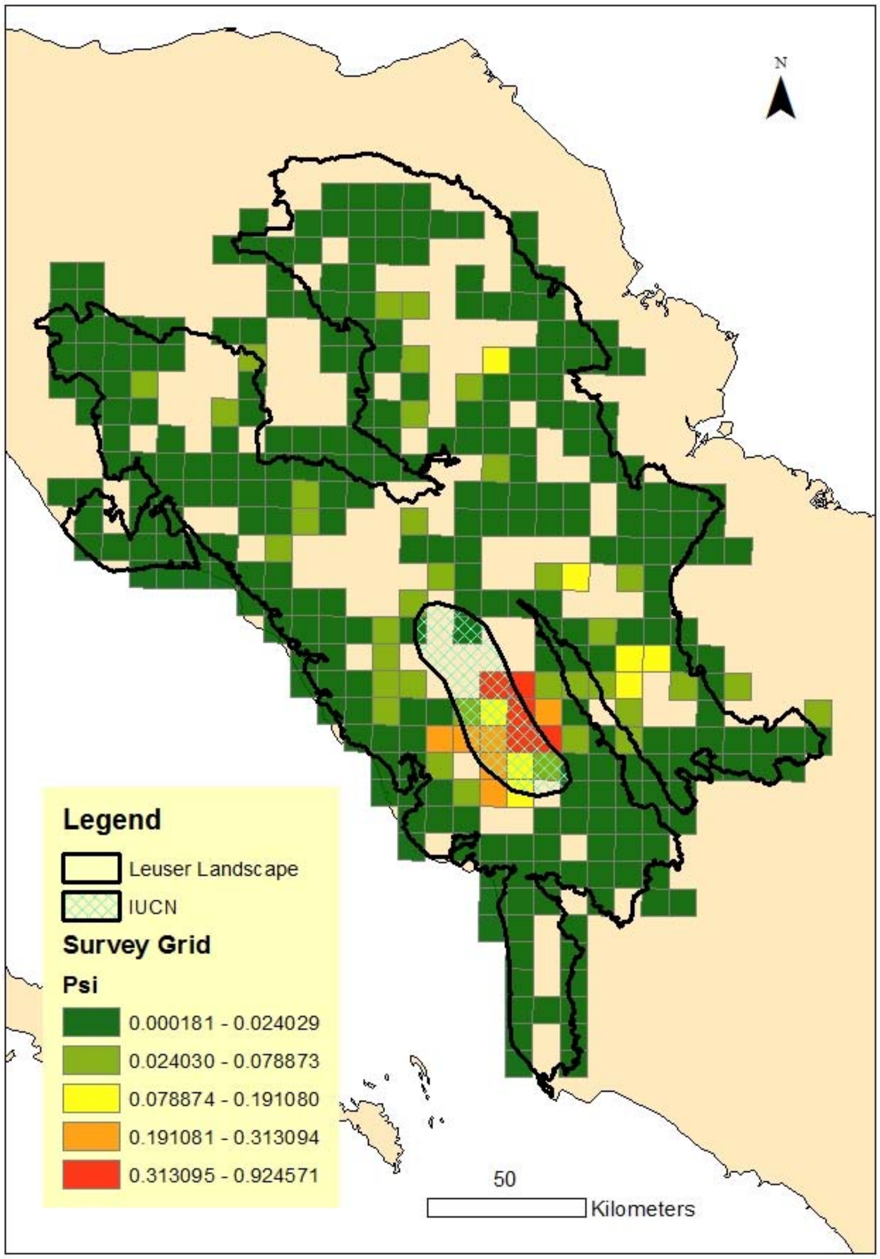


Figure 2. 9 Index of abundance estimate for each sampling grid based on Royle-Nichols 2003 occupancy modeling with heterogeneity for Leuser Landscape 2007 with 2km detection segments.

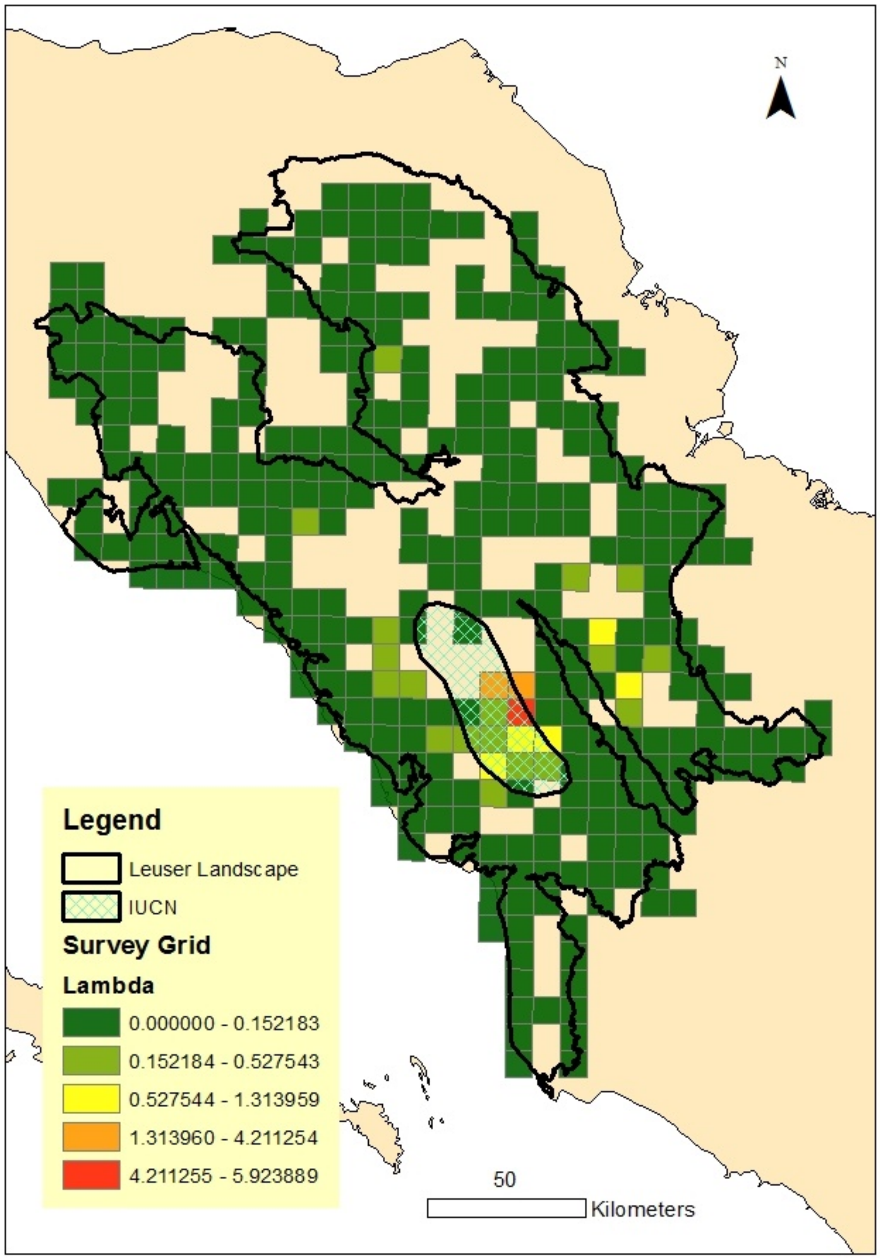


Figure 2.10 Occupancy estimate for the Leuser Landscape 2007 based on the best model of MacKenzie 2002 single-season occupancy with 3km detection-segments.

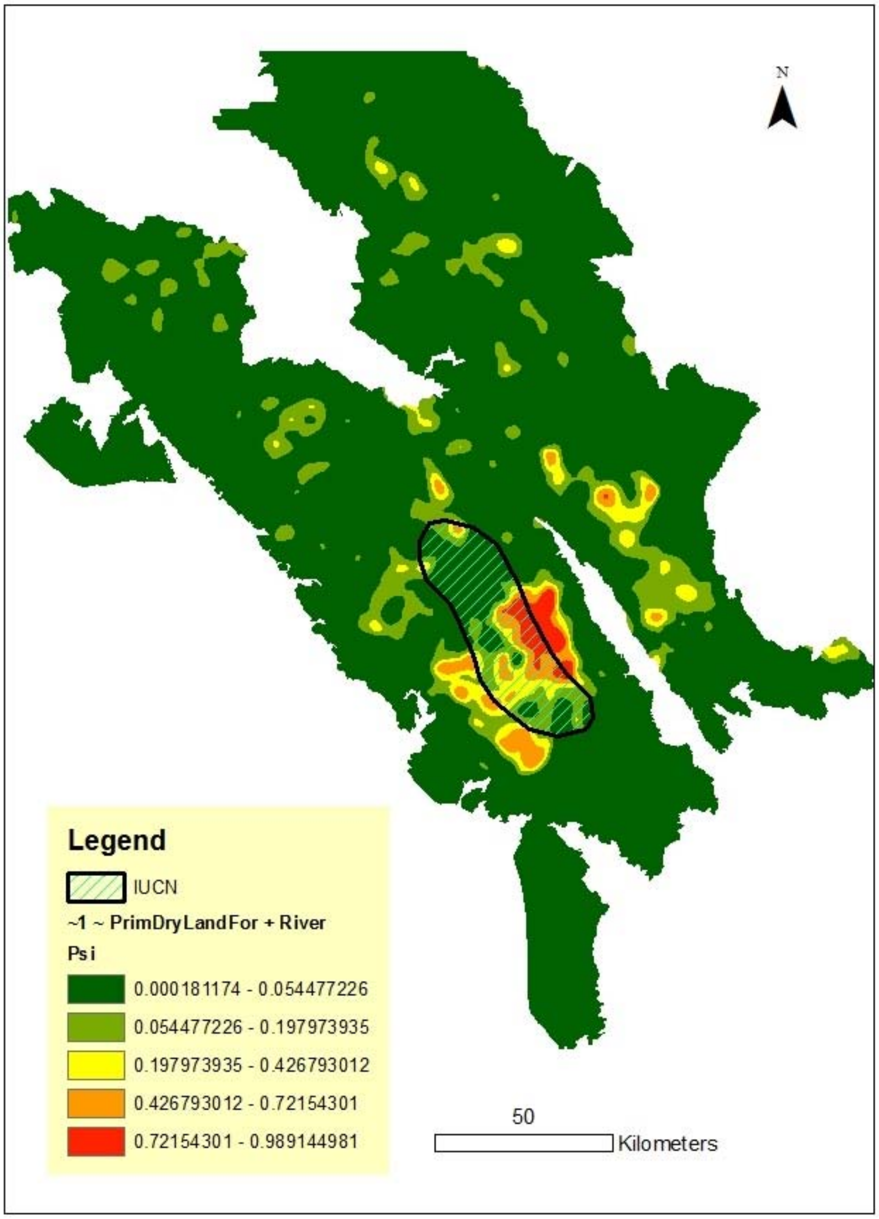


Figure 2.11 Rhino niche modelling (MaxEnt) (Pusparini et al. 2013).

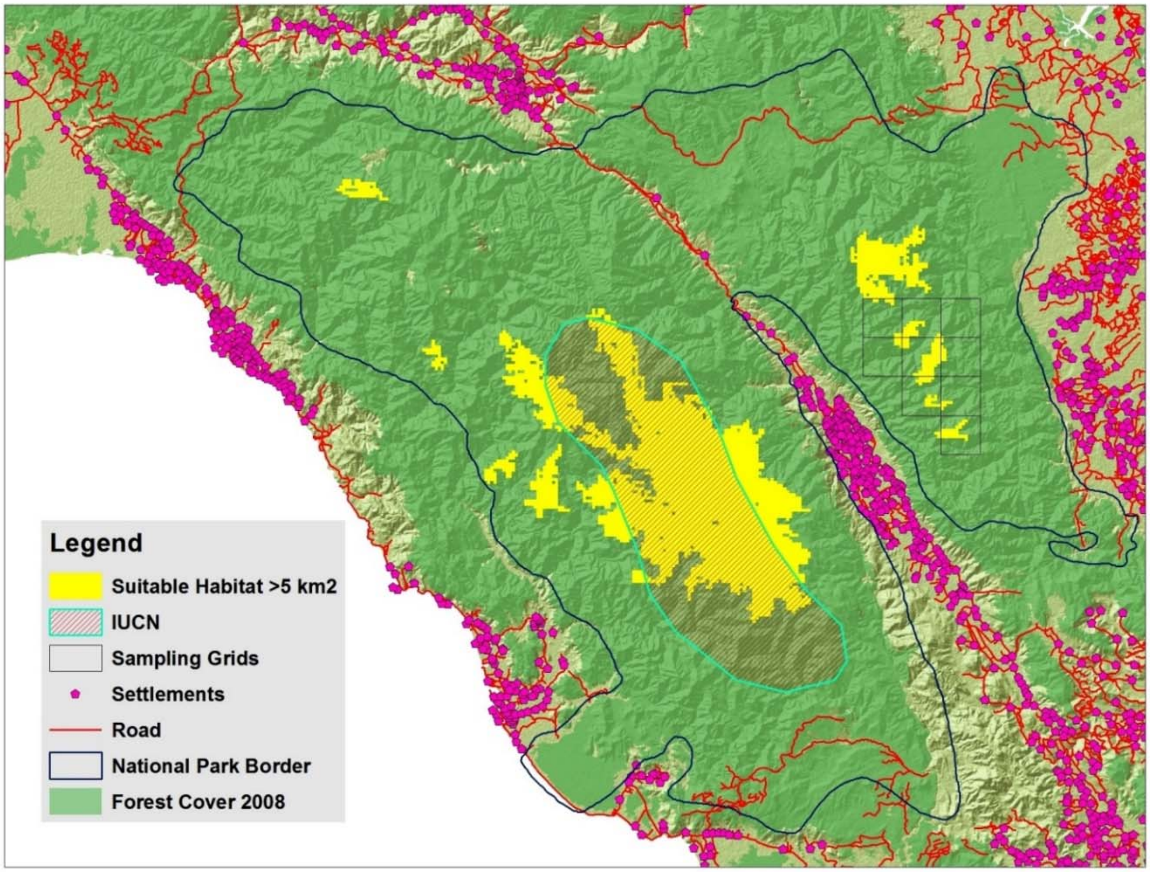


Figure 2.12 Historical Sumatran rhinoceros distribution (Strien 1986).

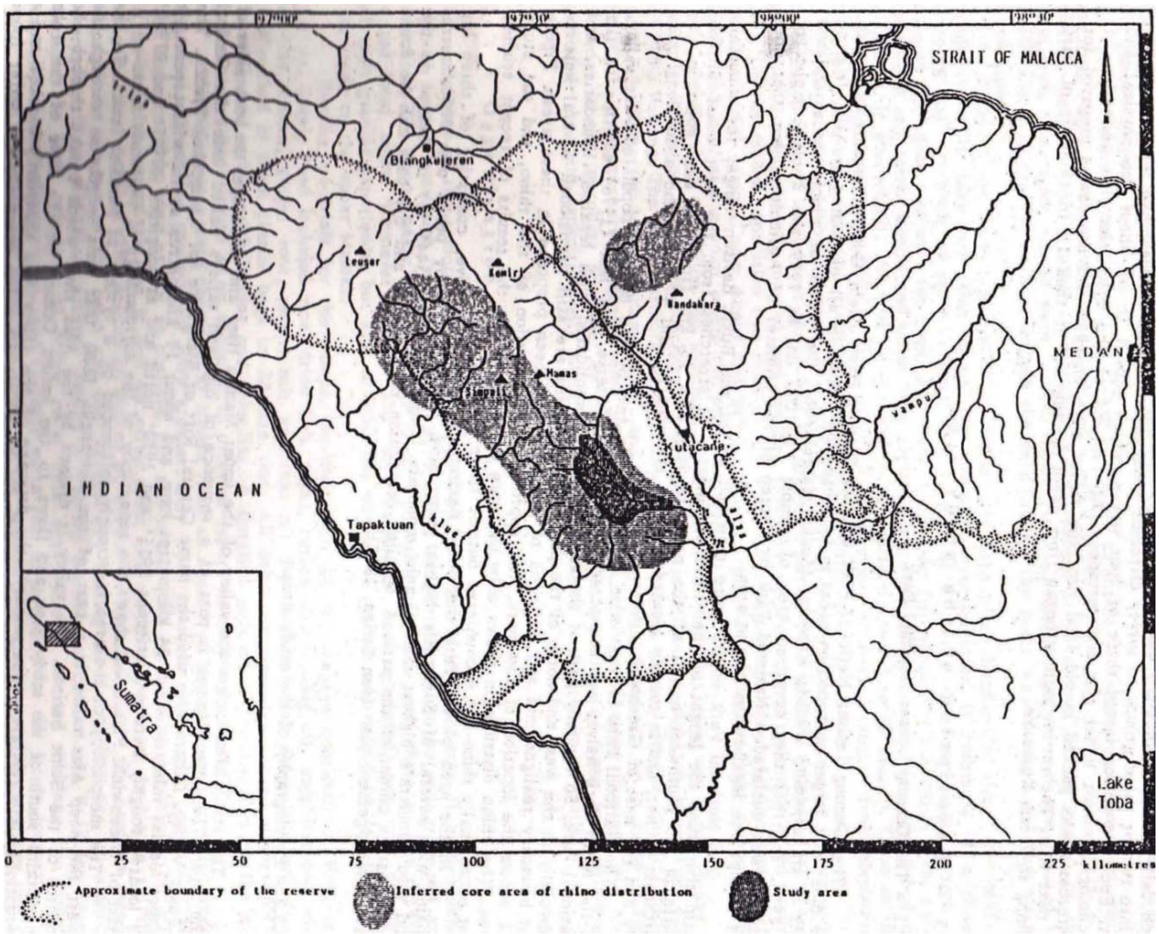


Figure 2.13 Occurrence Probability and Primary Dry Land Forest, Leuser Landscape 2007.

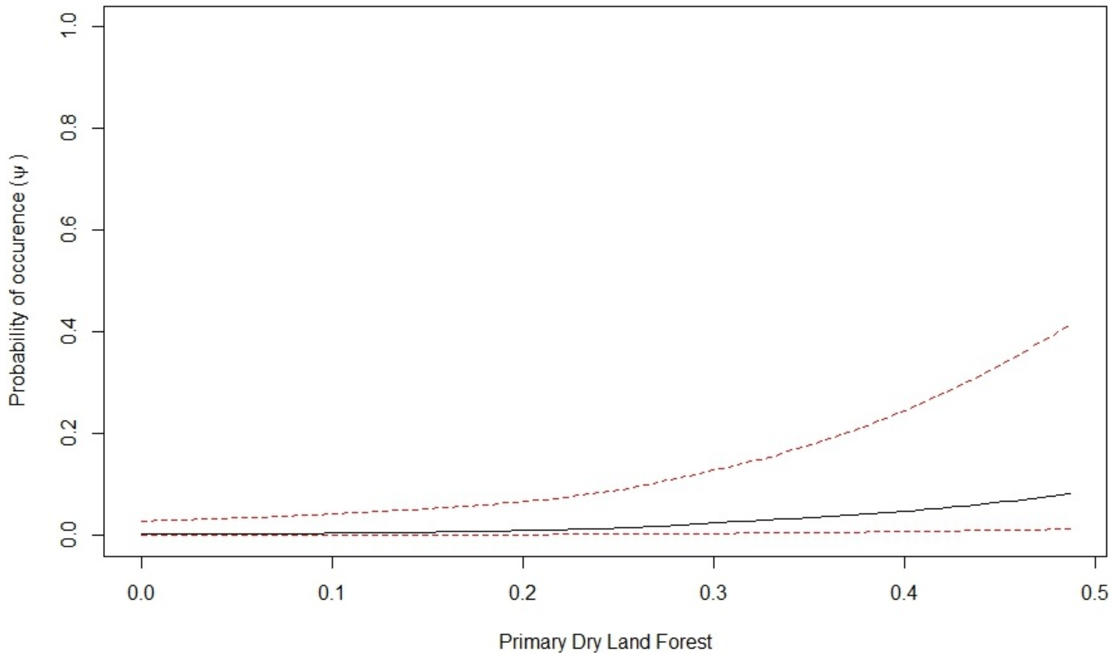


Figure 2.14 Occurrence Probability and River, Leuser Landscape 2007.

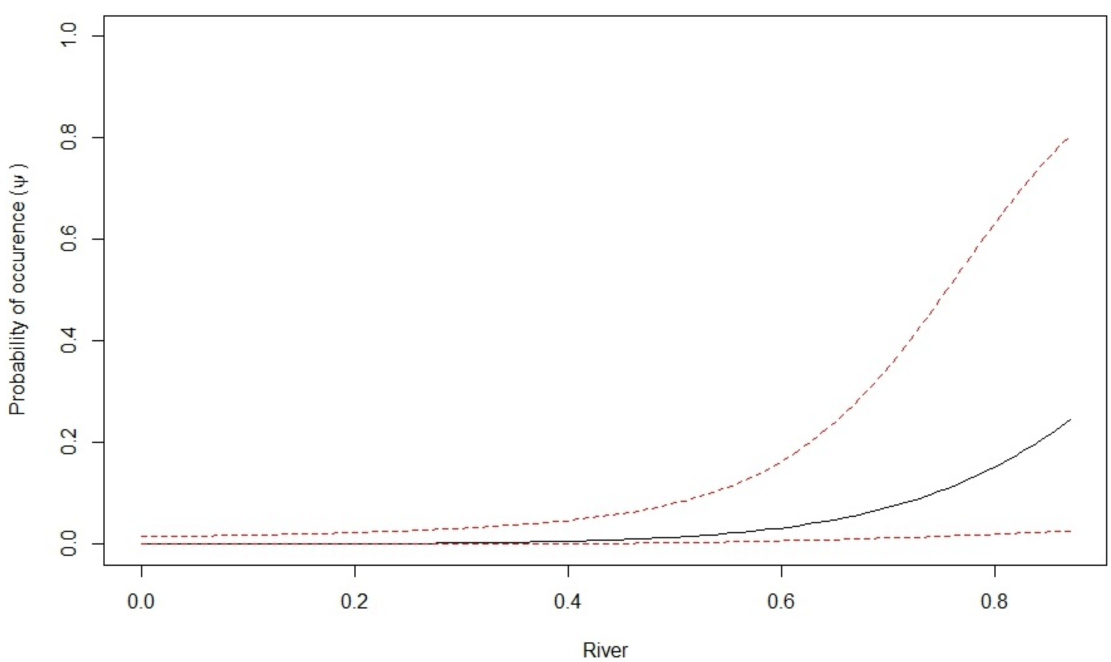


Figure 2.15 Occupancy estimate for each sampling grid based on MacKenzie 2002 single season occupancy modeling for Way Kambas NP 2008 with 3km detection segments.

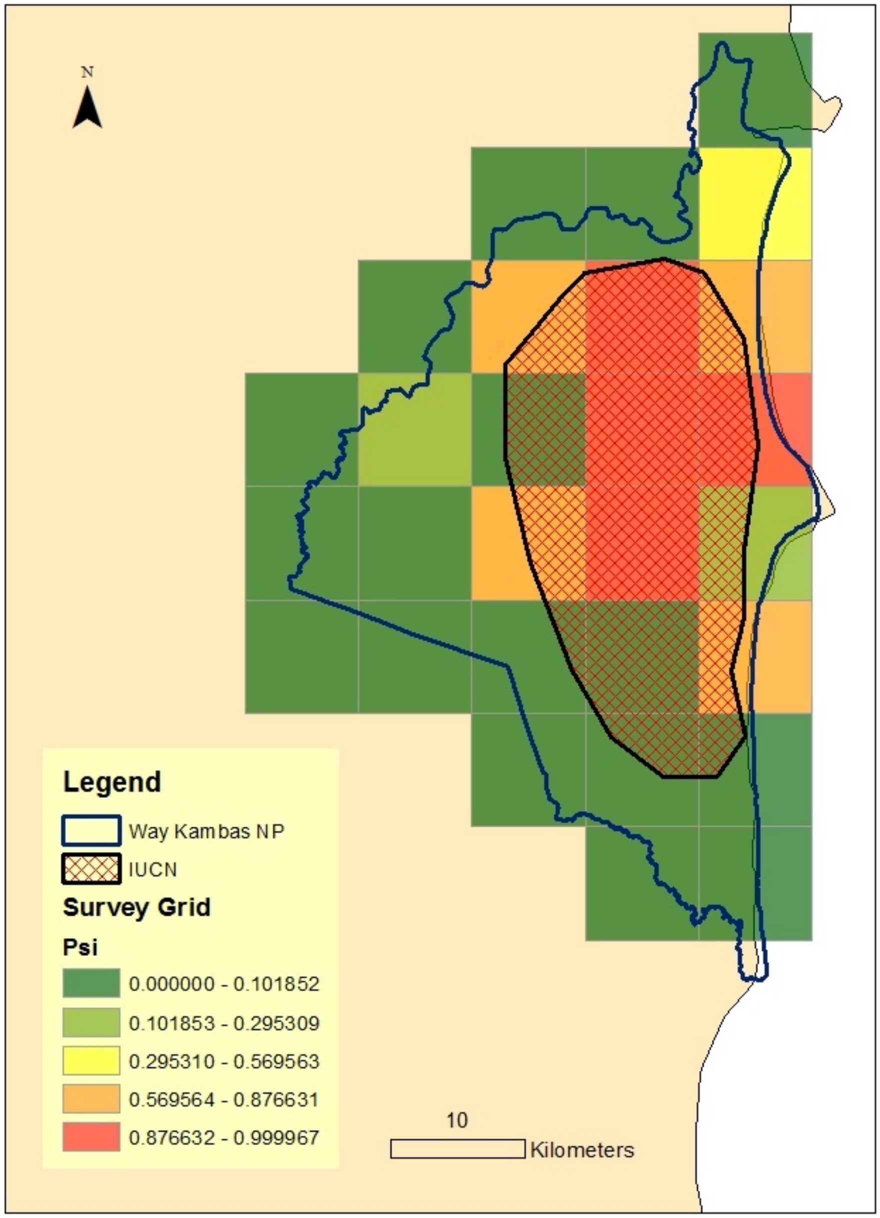


Figure 2.16 Index of abundance estimate for each sampling grid based on Royle-Nichols 2003 occupancy modeling with heterogeneity for Way Kambas NP 2008 with 1km detection segments.

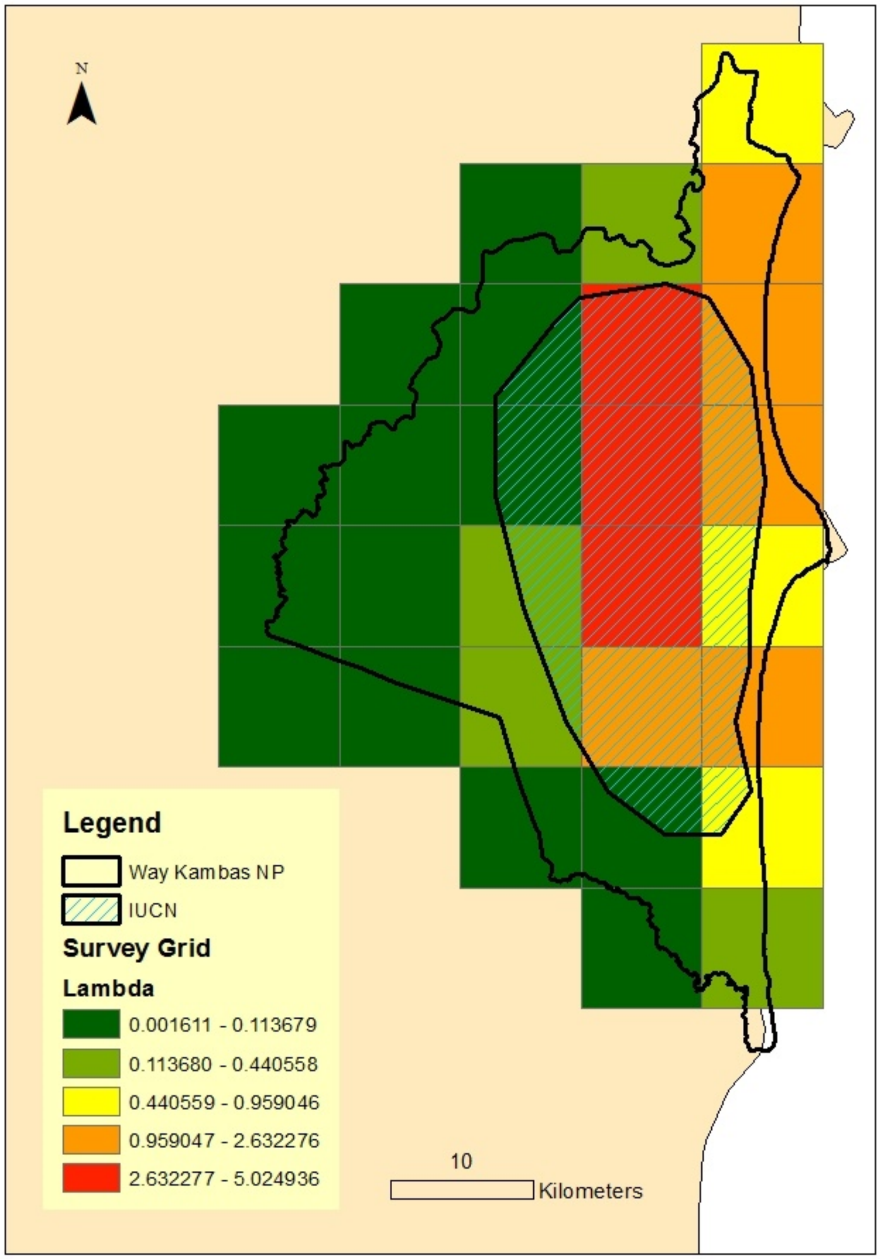


Figure 2.17 Occurrence Probability and Brush Landcover type, Way Kambas NP 2008.

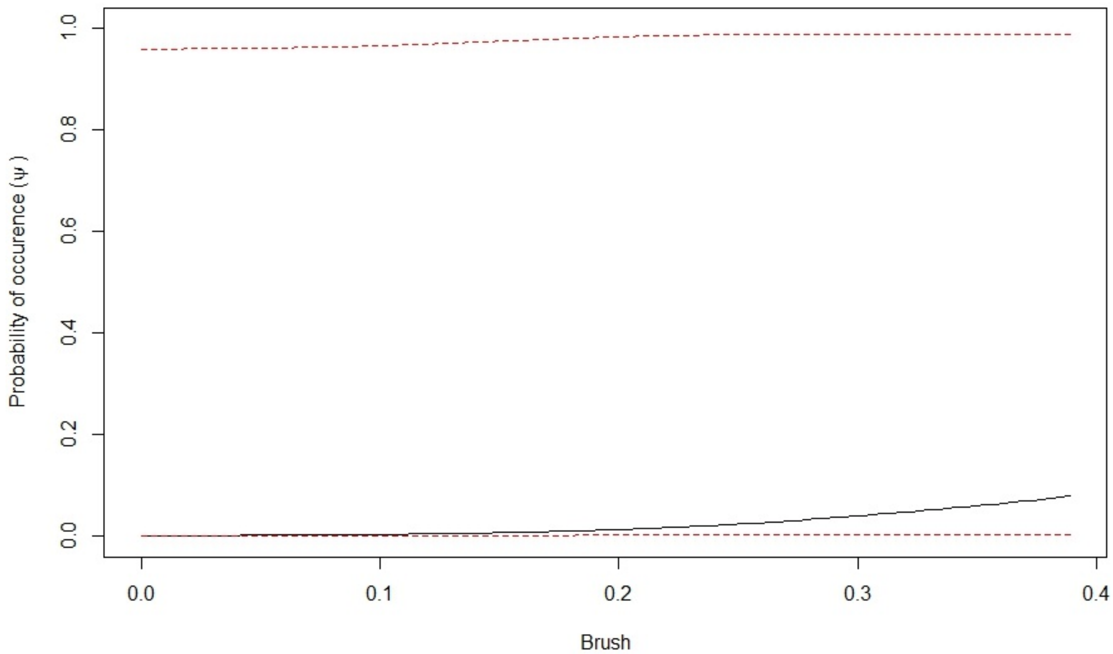


Figure 2.18 Occurrence Probability and Savanna Landcover type, Way Kambas NP 2008.

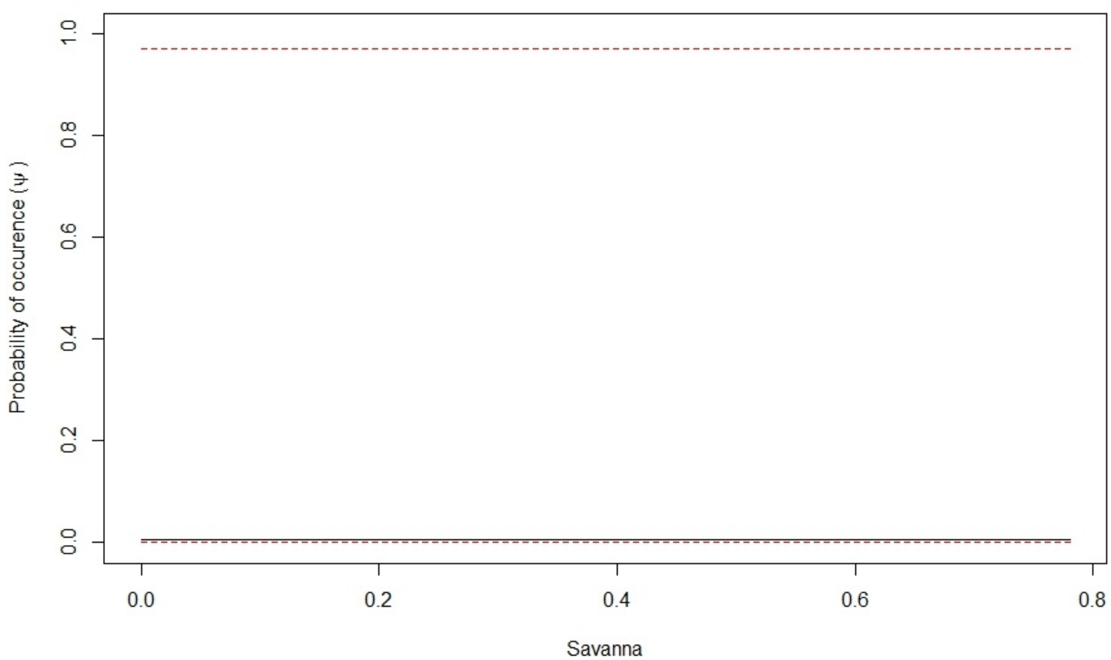


Figure 2.19 Occurrence *P*robability and Major Road, Way Kambas NP 2008.

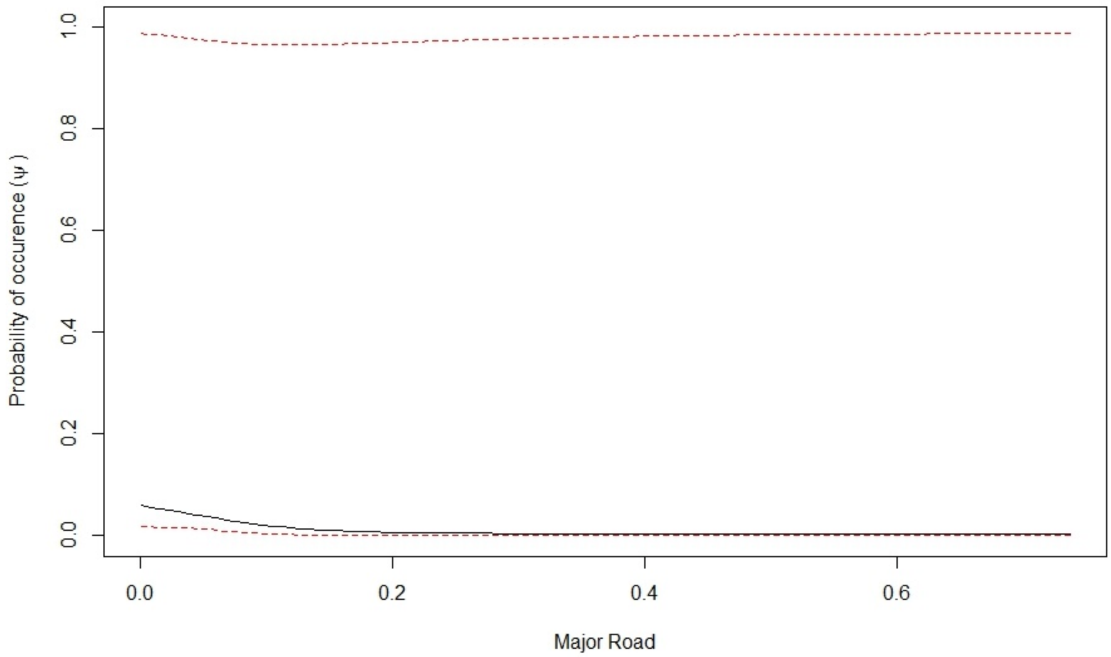


Figure 2.20 Occurrence Probability and Deforestation, Way Kambas NP 2008.

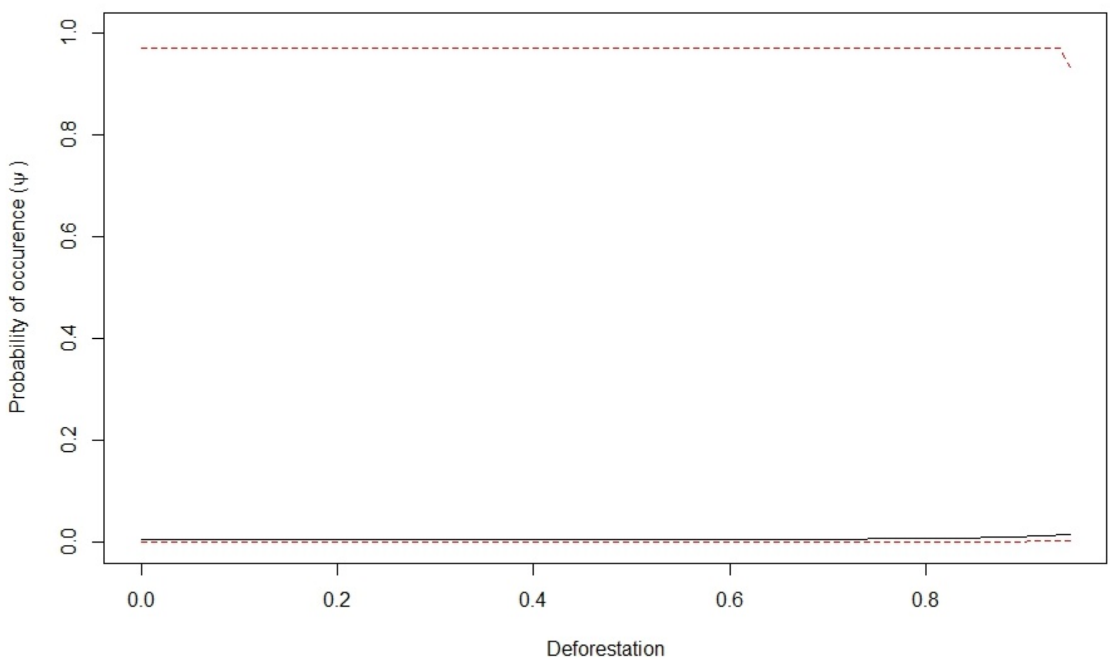


Figure 2.21 Index of Abundance and Brush Landcover Type, Way Kambas NP 2008.

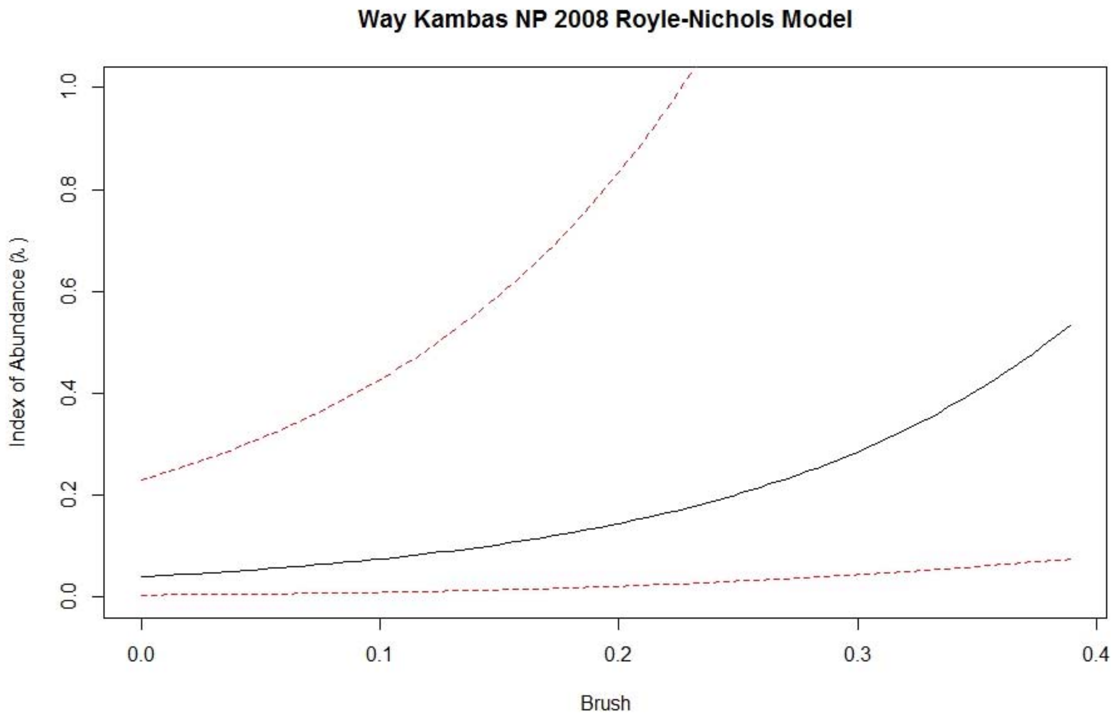


Figure 2.22 Occupancy estimate for each sampling grid based on MacKenzie 2002 single season occupancy modeling for Bukit Barisan Selatan NP 2010 with 2km detection segments.

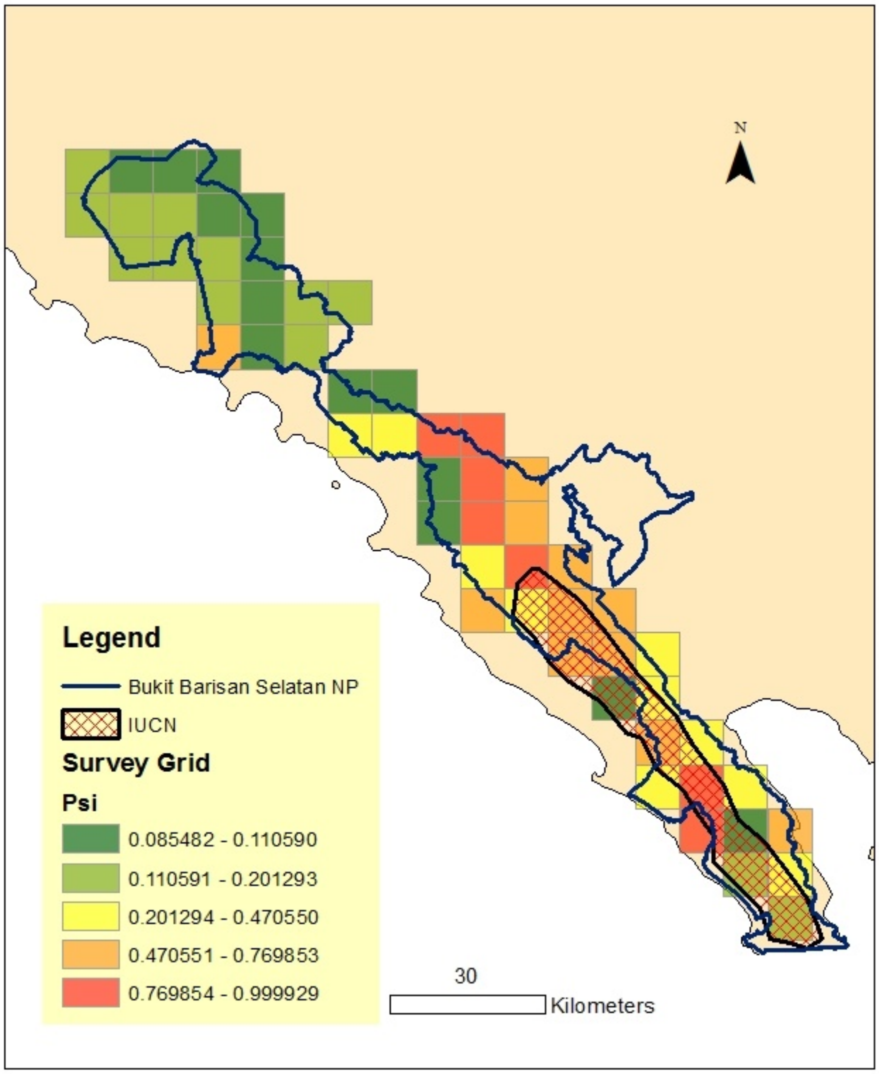


Figure 2.23 Index of abundance estimate for each sampling grid based on Royle-Nichols 2003 occupancy modeling with heterogeneity for Bukit Barisan Selatan NP 2010 with 1km detection segments.

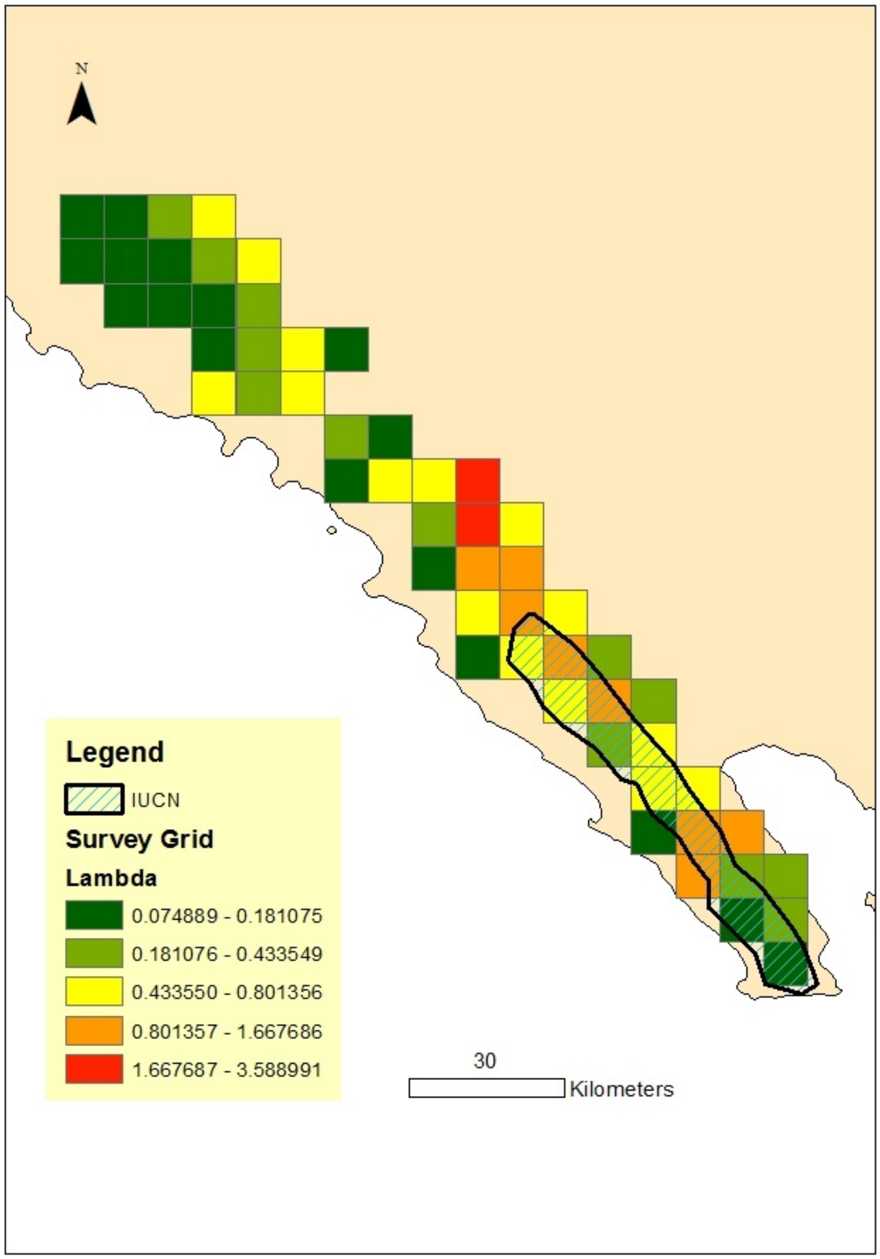


Figure 2.24 Occurrence probability and Secondary Dry Land Forest Bukit Barisan Selatan NP 2010.

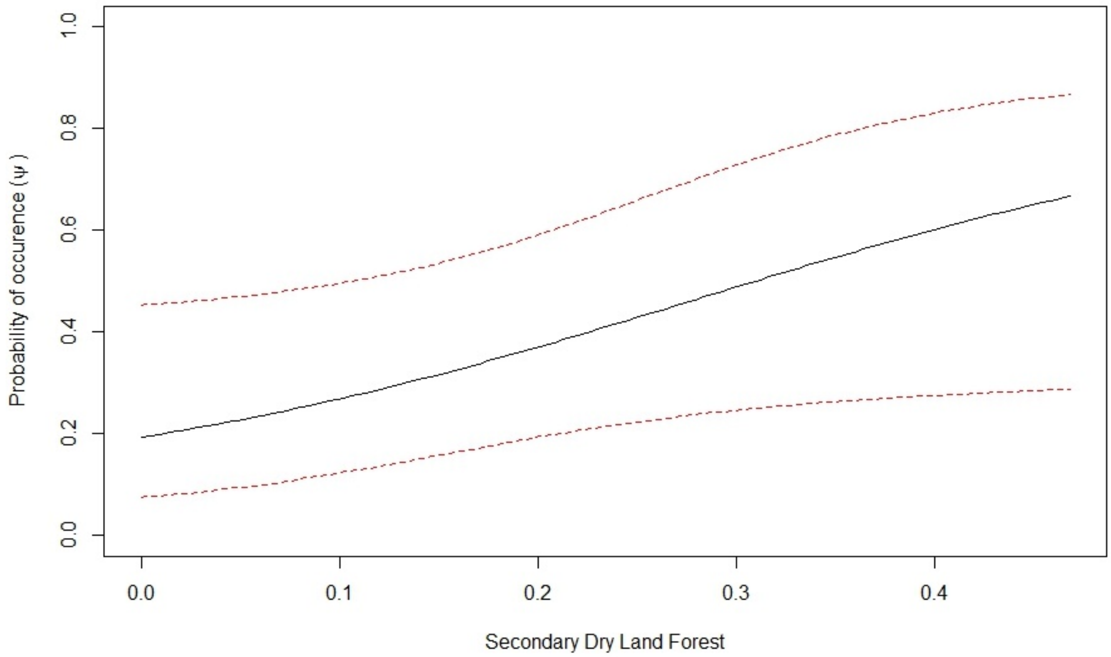


Figure 2.25 Occurrence probability and Deforestation Bukit Barisan Selatan NP 2010.

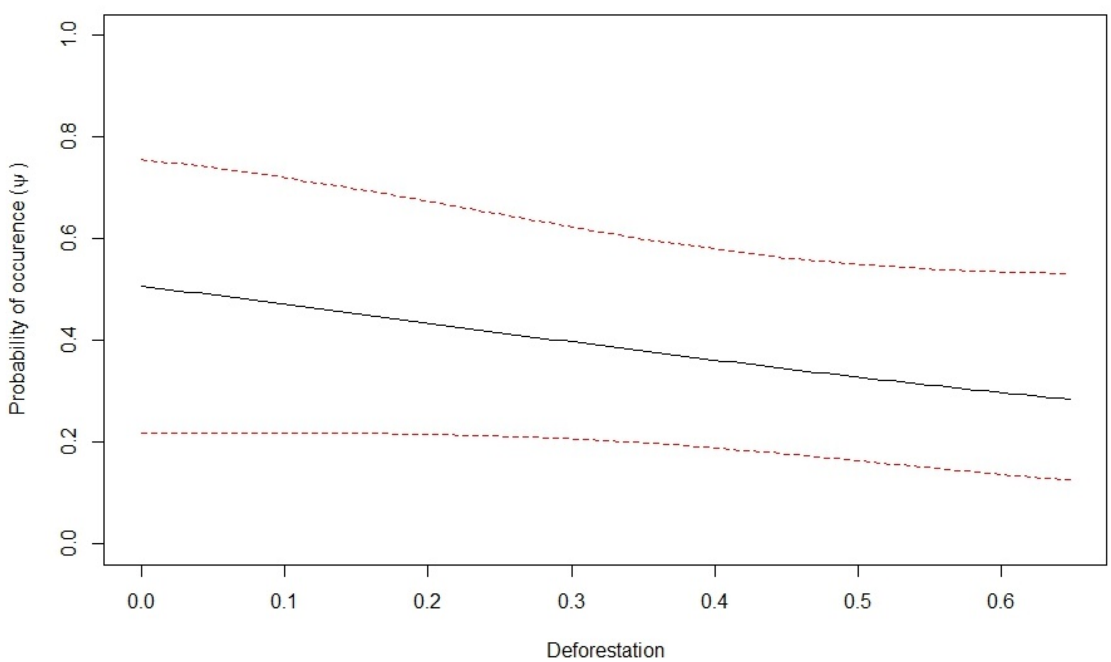
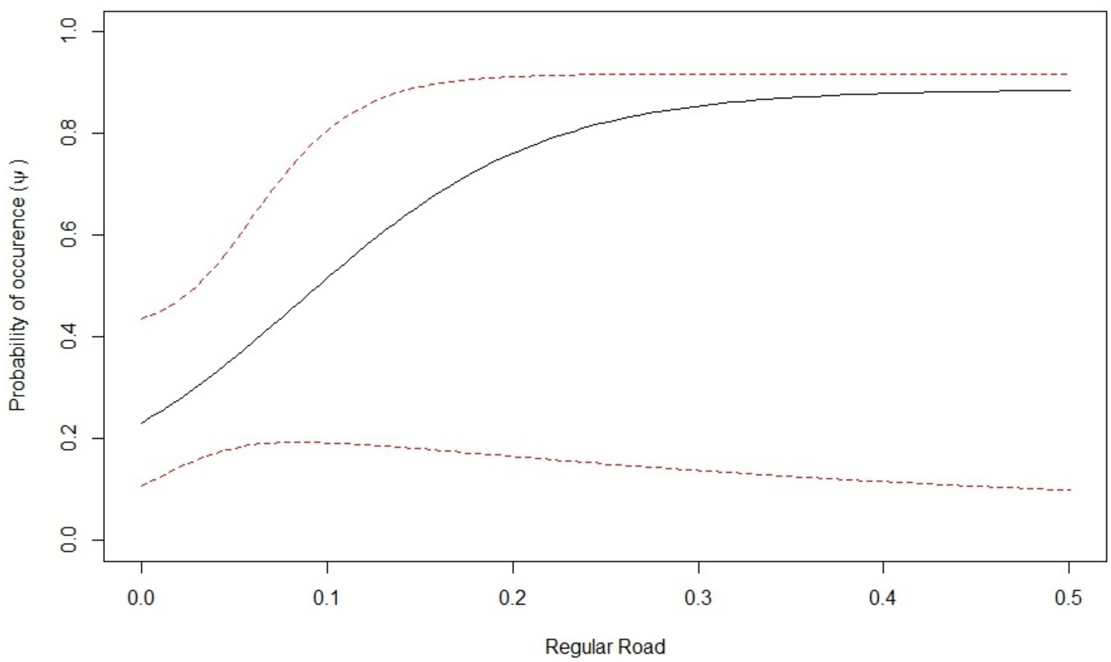


Figure 2.26 Occurrence probability and Regular Road Bukit Barisan Selatan NP 2010.



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