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Effects of forest roads and forest degradation on invasive alien plant species in Sumatran lowland rainforest

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Abbreviations

%	Percent
°C	Degree Celsius
AIC	Akaike Information Criterion
ANOVA	Analysis of variance
CABI	Centre for Agriculture and Biosciences International
DAAD	Deutscher Akademischer Austauschdienst
e.g.	for example
ERC	Ecosystem Restoration Concession
FAO	Food and Agriculture Organization
ha	Hectare
HSD	Honest Significant Difference
IAPS	Invasive Alien Plant Species
ISSG	Invasive Species Specialist Group
ITTO	International Tropical Timber Organization
KEHI	Konservasi Ekosistem Hutan Indonesia
Km^2	Square Kilometer
m	Meter
MEA	Millennium Ecosystem Assessment
mm	millimeter
MoF	Ministry of Forestry of Indonesia
N	North
REKI	Restorasi Ekosistem Indonesia
S	South
SEAMEO BIOTROP	Southeast Asian Regional Centre for Tropical Biology
WWF	Word Wildlife Fund

Abstract

Invasive alien plant species (IAPS) are species which are introduced, established and spread in areas outside their natural range due to human assistance. These plants have to be introduced, colonized and then naturalized in the new environments. Structural alterations in the forest can be the main reason for the establishment of IAPS, growing concern are thus in the case of tropical rainforests as deforestation and forest degradation is highest in countries like Indonesia. Sumatra is the highest forest cover change region in Indonesia, so to understand the influence of the disturbances of forest, the main aim of this study was to find the number and distribution of IAPS in the region. The effect of forest roads on the number of individual IAPS varies with different forest types. The distance to road and the structure was examined to find the number of IAPS and possible influences on them. IAPS were assessed in a disturbed primary forest, old and young secondary forests as well as a burnt area. In these four different forest types, a total of 50 transects and 400 plots at the distance of 0, 2, 5, 10, 15, 20, 30 and 40 m distance to road were studied. Each plot measured 1 m^2. We investigated the effect of forest type, distance to road, crown cover and average vegetation height on the number of IAPS with a linear mixed effect model. In total 2,343 individuals were found with individuals in disturbed primary forest (143), old secondary forest (344), young secondary forest (512) and the burnt area (1,344) individuals respectively. *Melastoma malabathricum* (720 individuals) was the most abundant species, followed by *Clidemia hirta* (496 individuals). The distance to the road affects the number of species and number of individuals. The linear mixed effect model shows there is no significant importance of crown cover and average vegetation height. It can be concluded that disturbance of the forest area can promote the number of IAPS. Especially in the case of tropical rainforest it should be a major concern as the rate of disturbance is severely increasing which will ultimately destroy the forest and will also make the existing forest more vulnerable to IAPS.

Effekte von Waldwegen und Walddegradierung auf invasive Pflanzenarten in den Tieflandregenwäldern Sumatras

Invasive Pflanzenarten (IAPS) sind solche Arten, welche in Gebieten außerhalb ihres natürlichen Verbeitungsgebiets durch menschlichen Einfluss eingeführt, niedergelassen und verbreitet sind. Diese Pflanzen müssen hierzu in der neuen Umgebung eingeführt, angesiedelt und eingebürgert werden. Struktureller Wandel in Wäldern stellt den Hauptgrund für die Verbreitung und Etablierung von IAPS dar und daher besteht zunehmend Besorgnis vor allem in tropischen Regenwäldern, da hier Entwaldungsraten und Walddegradierung am höchsten sind, etwa in Ländern wie Indonesien. In Sumatra finden sich die höchsten Änderungsraten der Waldfläche in der Region, weshalb es das Hauptziel der vorliegenden Studie war, herauszufinden wie viele und welche invasive Arten sich in der Region finden. Der Effekt von Waldwegen auf die Anzahl individueller IAPS ist je nach Waldtyp unterschiedlich. Die Entfernung zum Weg, sowie die Waldstruktur wurden untersucht um die genaue Anzahl von IAPS und eventuelle Einflüsse auf diese zu entdecken. Diese Untersuchungen wurden in einem menschliche beeinflussten Primärwald, in altem und jungen Sekundärwäldern, sowie auf einer Waldbrandfläche ausgeführt. In diesen vier Untersuchungsgebieten wurden insgesamt 50 Transekte und 400 Plots mit einem Abstand von 0, 2, 5, 10, 15, 20, 30 and 40 metern vom Weg etabliert und analysiert. Jeder Probekreis maß hierbei 1 m^2. Die Effekte die Waldtyp, Entfernung zur Straße, Kronenüberschirmung, und mittlere Vegetationshöhe auf die Anzahl von IAPS haben, wurden mit einem linear mixed effect Modell analyisert. Insgesamt wurden 2.343 Individuen in allen Untersuchungsgebieten gefunden, davon 143 im Primärwald, 344 im alten Sekundärwald, 512 im jungen Sekundärwald und 1.344 in der Waldbrandfläche. *Melastoma malabathricum* war mit 720 Individuen die meistverbreiteste invasive Art, gefolgt von *Clidemia hirta* mit 496 Individuen. Der Abstand zum Weg hat einen Effekt auf die Anzahl individueller Arten und Individuen. Das linear mixed effect Modell zeigte keinen signifikanten Einfluss von Kronenüberschirmung und Vegetationshöhe auf das Auftreten von IAPS. Es kann geschlussfolgert werden, dass die Störung eines Waldgeietes die Anzahl von IAPS im Gebiet erhöht. Besonders im Falle von tropischen Regenwäldern sollten die Störrate und Intensität, die sich hier häufig erhöhen, Besorgnis erregen, denn diese können auf lange sicht den Wald zerstören und diesen angreifbar für IAPS machen.

1.Introduction

Invasive alien plant species (IAPS) represent a great threat to ecosystem degradation, biodiversity loss of and damage to ecosystem services worldwide (Pyšek *and Richardson*, 2010). IAPS are species which are introduced, established and spread in areas outside their natural range due to human assistance (Colautti and MacIsaac, 2004). In order to become invasive plants, they have to be introduced, colonized and then naturalized in new environments (Richardson et al., 2000). IAPS occur in many plant families and affect many ecosystems worldwide (Mooney and Drake, 1989).

The displacement of native species with IAPS can cause economic and environmental damage and can affect the health of human beings (FAO, 2007). To our present state of knowledge at least 13,168 vascular plant species have been naturalized in one of the 843 regions including 362 islands around the world (Van kleunen et al., 2015). Most of these changes occur through anthropogenically induced land-use change and habitat modification that fosters the spread of invasive plants (Richardson and Pyšek, 2006). Many IAPS have several characteristics in common, such as rapid growth, rapid reproduction, high dispersal abilities, high survival rates, phenotypic plasticity and the ability to survive under various environmental conditions (Macdougall and Turkington, 2005). These traits often are an advantage of IAPS compared to native species, as their new environment is less competitive, giving them a chance to outcompete and replace native plants (Macdougall & Turkington, 2005).

Invasive plants have invaded the forest with traits which help them to establish themselves in the disturbed forest condition, as such in Brunei, where planted *Acacia auriculiformis* and *A. cincinnata* from Australia invaded the disturbed heath vegetation with their ability to fix nitrogen (Peh, 2010). This resulted in the decrease of some of the native genera in that region for e.g. *Alphitonia, Commersonia, Dillenia, Gymnostoma, Macaranga*, *Melastoma* and *Ploiarium* being substituted by widespread invasive monospecific tree stands (Osunkoya et al., 2005). IAPS compete with the native species for the same resources and threaten their existence (Peh, 2010).

IAPS adapt to degraded forests with disturbed soils and climate (Harper et al., 2005) and are more easily found on the edge of the forest because of the higher level disturbance there compared to the interior of the forest (Harper et al., 2005). Usually, forests are also highly utilized by the local people over time, which also contributes to the degradation. However, many ecological studies are done for only brief periods of time, which makes it difficult to understand the relationship between species response and logging intensity as logging is rarely studied (with the time elapsed) during these short study periods (Ghazoul and Hill, 2001). Meanwhile, some general patterns of species numbers depend on the considered scale. For instance, logging can lead to an increase in species richness and diversity of a butterfly over a small spatial scale (Spitzer et al., 1993), but on large scale logged areas however, studies suggest a different pattern with fewer species in the logged area than in natural forest (Hamer and Hill, 2000).

Structural alterations caused by logging operations are instantly visible in a primary forest. The removal of only as few as 3.3% of all trees in an area can influence up to 50% of the crown cover (Johns, 1988). An opening of the crown can result in the change of biophysical conditions of the forest (Bawa et al., 1998). Many studies show a decline in the number of tree species after logging and an increase in the number of smaller stemmed species or pioneer species (Bawa et al., 1998). Despite the fact that forests are degrading and converting and logging activities are still increasing, the forest cover around the globe is however increasing (FAO, 2005). The degraded forests would not be similar to primary forest but still they are important to improve ecosystem services and increase biodiversity conservation (Chazdon, 2008).

Deforestation has been triggered by the movement of humans from one place to another and with this movement agriculture, settlement and other activities started (Myers, 1993). Moreover, 50% of the world’s land area have been converted into grazed land or cultivated crops, and more than half of the world’s forests have been lost to other land-use systems (MEA, 2005). According to a study conducted on global forest cover change, Indonesia had the highest deforestation rate between the period of 2000-2012 with an average of 1021 km^2 per year, with a low of 10,000 km^2 loss between 2000-2003 and a little more than 20,000 km^2 between 2011-2012 (Hansen et al., 2013). The highest deforestation rate of Indonesia is concentrated in Central Sumatra, with a deforestation rate of 3.2 - 5.9% per year in their hot spots within a sampled area (Achard et al., 2002). The loss of forest area is not only caused by settlements or agriculture, it also arises from the construction of roads. Roads are viewed as often triggering the loss of forests, as it opens the area to logging and agriculture conversion (Laurance et al., 2009).

Roads are considered as contributing largely to the spread of alien species as they are the crucial path for the introduction of IAPS (Christen et al., 2006). Roadsides vary from naturally disturbed areas by representing linear structures and long-term openings in the forest (Mortensen et al., 2009). It also provides the main starting point for some alien species to grow and spread into natural ecosystems, because of the disturbance created (Jodoin et al., 2008). Roadsides are also considered as a pool for the alien plant propagule that is needed for the dispersal in anthropogenic disturbed natural habitats (Rooney, 2005). Thus, roads provide a corridor for IAPS to disperse.

Indonesia is composed of about 17,000 islands and extends across two biogeographic regions (Laumonier et al., 2010). The country has the second largest rainforest area in the world after Brazil (Hansen et al., 2009). Indonesian forests constitute 3% of the world’s total forest cover (FAO, 2010) and 39% of Southeast Asia’s forest cover (Achard et al., 2004). Its distinctive geological position combined with tropical climate causes high levels of species richness and endemism (Sodhi et al., 2010). Rainforests in Southeast Asia, especially in the lowlands, are threatened by deforestation, forest degradation and conversion of forest into other land-use types like monocultures of *Acacia* for pulp and paper production and rubber- or oil palm (Carnus et al., 2006). Deforestation has increased in Indonesia since mid-20th century, mainly on the island of Sumatra, where land-use change and deforestation amounts to a total loss of 1.21 million ha of lowland forest from 2000-2012. In 2012 the annual loss of forest area was 0.22 million ha (Margono et al., 2014).
The Indonesian island of Sumatra is home to more than 10,000 plant species, 201 mammal species, and 580 bird species (MoF, 2003), while at the same time land-use change and

increase in forest cover change is at high rates (Koh et al., 2004). The main reason behind this loss is large-scale conversion of forest for agricultural purposes, especially disturbed primary rainforest or secondary forest into monoculture tree plantations like rubber and most recently large oil palm (*Elaeis guineensis*) areas in most of the lowland provinces (Margono et al., 2012). The primary forest cover change in Sumatra from the period of 1990-2010 was 7.54 million ha out of which 7.25 was disturbed primary forest cover loss and 0.28 primary intact forest cover loss (Margono et al., 2012). In the case of the provinces of Jambi and South Sumatra, it was 1.51 and 0.94 million hectares of primary forest cover change respectively in the year 2010 (Margono et al., 2012). The area of disturbed primary forest cover change was 0.30 and 0.06 million ha for Jambi and South Sumatra provinces respectively (Margono et al., 2012).

The aim of this study was thus to understand the distribution of IAPS in Sumatran lowland forests in different magnitudes of disturbance. A particular focus was on the influence of roads as an entry point for alien plants. The study was part of the subproject B06 in the EFForTS project (Ecological and Socio-economic Functions of Tropical Lowland Rainforest Transformation Systems project (see http://www.uni-goettingen.de/EFForTS). EFForTS is an interdisciplinary German-Indonesian collaboration, studying the effects of land-use changes on socio-economical, environmental and ecological level. The main aim of the study was to find out which IAPS are found in Harapan Rainforest and the distribution of these IAPS along gradients of distance to the road and forest disturbance as well as in relation to crown cover and average vegetation height.

The hypothesis of the study was:

1) density and diversity of IAPS decreases with increasing distance from forest roads into the forest interior; and

2) crown cover and average vegetation height have a negative effect on the density and diversity of IAPS.

2.Methods

2.1 Study area

The study was carried out in Harapan Rainforest within the EFForTS study region in the lowlands of Jambi Province in Sumatra (Drescher et al., 2016). Sumatra is the largest island in Indonesia with an area of 475,000 km^2 and marks the westernmost part of Indonesia (WWF, 2006). The island stretches between 95˚ to 107˚ longitude East and from 5˚N to 5˚ S latitude (WWF, 2006). Jambi Province covers an area of 50,160 km^2 (WWF, 2006). The Harapan Rainforest region covers an area of 98,455 ha and is located in the two provinces Jambi and South Sumatra (see Figure1).

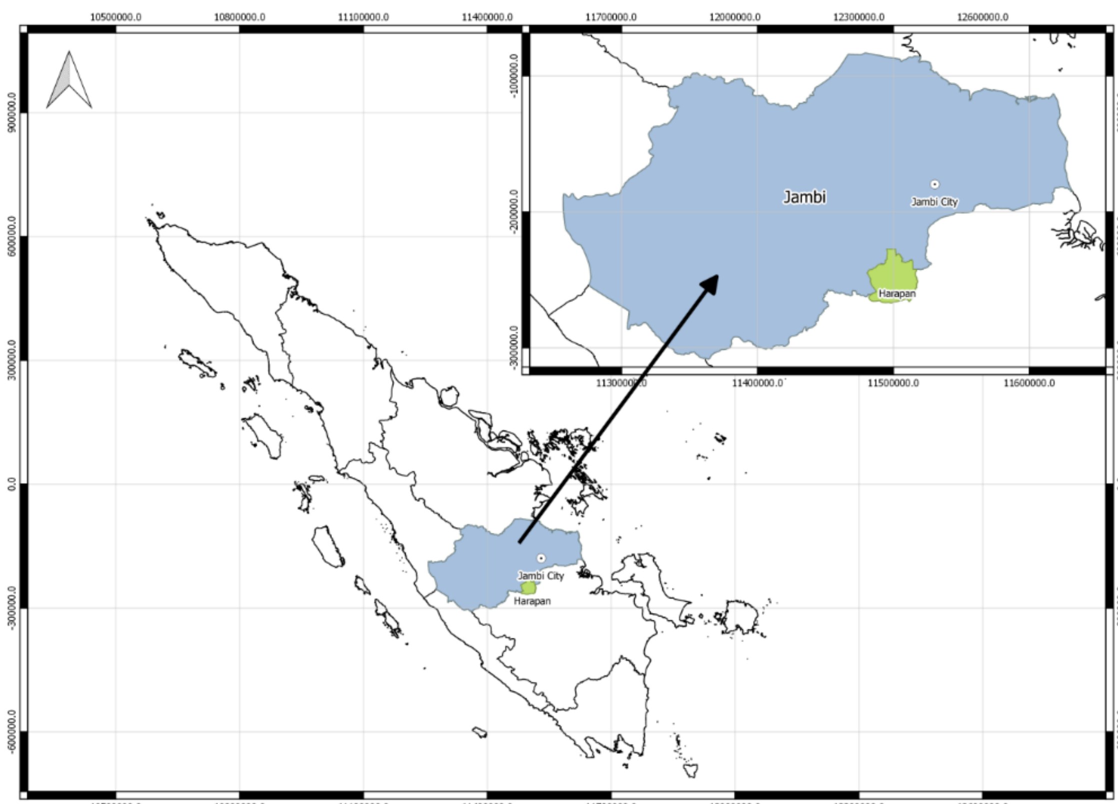

Figure 1: Map of Sumatra showing Jambi Province and Harapan Rainforest. Harapan Rainforest is located in two provinces: Jambi and South Sumatra. The map only shows the part in Jambi Province.

Harapan rainforest is the first ecosystem restoration concession (ERC) in Indonesia and is managed by a private company called PT. Restorasi Ekosistem Indonesia (PT. REKI) and a nongovernmental organization, Yayasan Konservasi Ekosistem Hutan Indonesia (Yayasan KEHI). In terms of a ERCs, the forest is leased for 65 or more years with management rights and a logging moratorium in order to restore the ecological functions of the area (Buergin, 2016). After the establishment of Harapan Rainforest as an ERC in 2008 as a model for nature conservation, Indonesia established 13 further ERCs covering a total of 519,505 ha and allocated 2.7 million ha of production forest to ERCs in order to restore ecosystem functions all over the country to the present (Silalahi & Utomo, 2014).

Harapan Rainforest is classified as disturbed primary forest (Margono et al., 2012) and Dipterocarpaceae are the dominant tree family (Harrison & Swinfield, 2015). The area was extensively logged over the past 20-30 years, leaving the forest in a patchy stage with young secondary, disturbed primary forest, old secondary forest types, open areas, riparian forest, plantations and other land uses (Harrison & Swinfield, 2015). Almost 20% of the concession area has been legally or illegally transformed into small oil palm and rubber plantations (Buergin, 2016). Disturbed areas are colonized by native early successional tree species (*Macaranga* spp.) but also include IAPS such as *Bellucia pentamera,* which is native to Tropical America, Central and South America, and is taking over large areas of Harapan Rainforest (Harrison & Swinfield, 2015). Harapan Rainforest is one of the last remaining larger areas of lowland rainforest and an important refuge for wildlife. Currently, 307 bird species have been observed in Harapan Rainforest and 64 species of mammals (Harrison & Swinfield, 2015). Additionally, 728 tree species belonging to 107 families (HutanHarapan, 2016) have been recorded and local plant species diversity is six times higher than in surrounding monocultural plantations (Drescher et al., 2016).

The average annual temperature of the area is 26.7±0.2˚C with an average precipitation of 2235±881 mm per year and mean monthly rainfall >100 mm throughout the year (Drescher et al. 2016). The area has an undulating topography with minimum and maximum elevations between 30-120 meter above sea level (Harrison & Swinfield, 2015; WWF, 2006). The soils of the area contain fractions of sand, silt and clay (Acrisols) (Harrison & Swinfield,

2015) with yellow or red colors which are typical for the tropical rainforests of Southeast Asia (Allen et al., 2015; Harrison & Swinfield, 2015).

Due to anthropogenic disturbances, especially logging, Harapan Rainforest is composed of a patchy mosaic of different forest types like primary forest and secondary forest. Primary forest is mature forest with an area of around 5 ha, which maintains its natural composition and structure and has not been completely cleared or re-planted in recent history. It includes both intact and disturbed types of forest (Margono et al., 2012; ITTO, 2002). Disturbed primary forests are forests which have been fragmented or subject to forest utilization (Margono et al., 2012; ITTO, 2002). Secondary forests are re-growing forests after clearance or disturbance where the area was largely cleared of its original vegetation cover (ITTO, 2002). Depending on their age, secondary forests can be divided into old secondary forest (>30 years or more) and young secondary forest (<30 years). Except for these three different forest types based on structure and age, the study was also conducted on a burnt site, where fire occurred during September 2015 (seven months before our field survey). From the assessment of the forest area it was clear that the fire did not burn the forest evenly, but some parts got damaged more severely than others and some patches of old and young secondary forest was unaffected by the fire and remained intact.

2.2 Study design

For this study, 50 transects were established in four different forest types along a disturbance gradient: 10 transects in disturbed primary forest, 13 transects in young secondary forest, 12 transects in old secondary forest, and 15 transects in burnt areas (see Figure 2). Each forest type had at least 10 transects of 40 m length. Each transect was placed at a minimum distance of 150 m from each other and at an angle of 90˚ from the road into the forest. Each transect has eight plots measuring 1 m^2 each. These plots were placed on the right-hand side of the transect with distances of 0, 2, 5, 10, 15, 20, 30 and 40 m distance to the road respectively (see Figure 3).

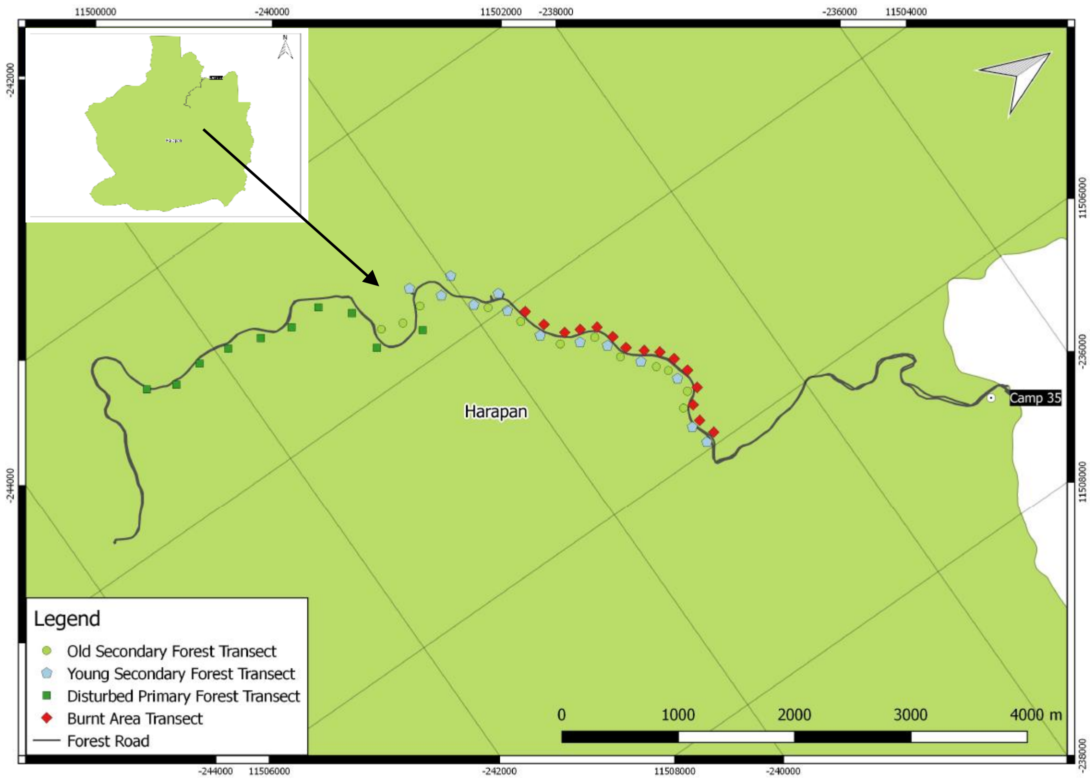

Figure 2: The whole area of Harapan Rainforest and study area in Harapan Rainforest showing the position of 50 transects in four different forest along a forest road. Different colours and symbols in the map represent different forest types.

The number of transects varied to maintain a minimum distance of 150 m between transects. The burnt area plots were established along the same road, but on the opposite side as only one roadside was affected by the fire (see Figure2). Thus, one side of the road was studied for three different types of forest (disturbed primary forest, old secondary forest and young secondary forest) and the other side for the burnt area only, where the fire created a patchy forest area. However, some plots are also on the burnt side of the road as the fire did not destroy the whole forest.

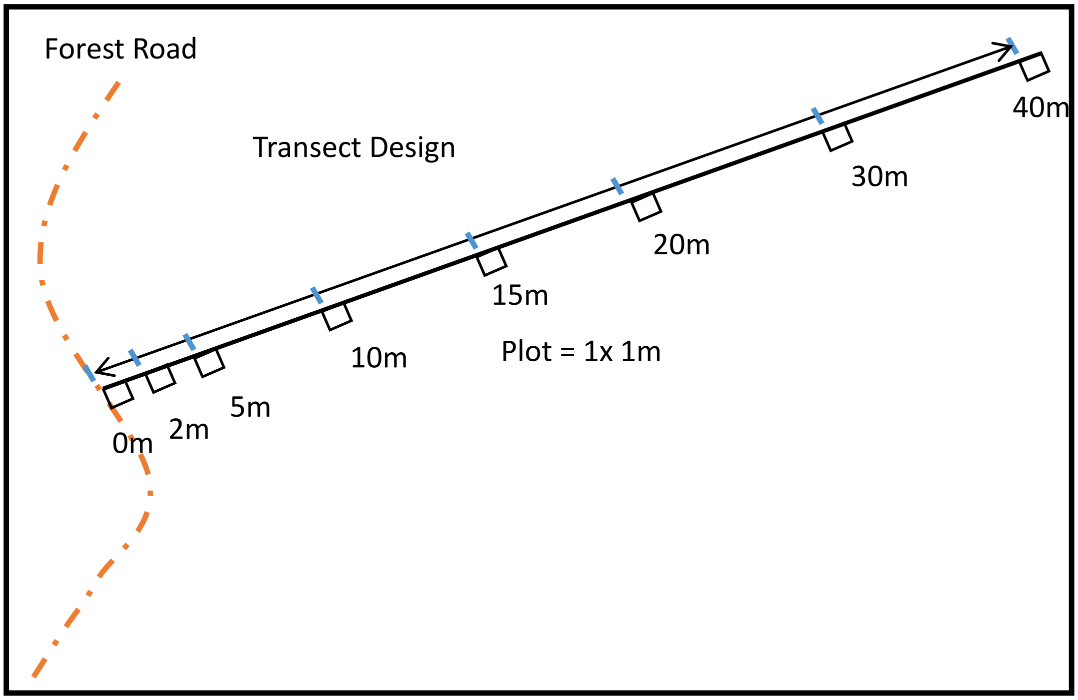

Figure 3: Transect design with embedded plot design at different distances from the road. All the plots measure 1m2 and are located on the right hand side of the transect.

2.3 Data collection and preparation

The data collection in Harapan Rainforest was carried out from 27th April to 30th May 2016. In each transect, all IAPS were identified and counted. Voucher specimens of all IAPS were collected for later identification and for deposition at the Herbarium. Species identification took place in Bogor from 6th June to 20th of June 2016. It was carried out in Southeast Asian Regional Centre for Tropical Biology (SEAMEO BIOTROP) in Bogor. The average vegetation height and crown cover of each plot was measured. Crown cover was measured using a densiometer in the four different corners of the plot. These measurements were averaged and then multiplied by 1.04 to convert the value into percentage. The variables which were measured during the field work are explained in detail in Table 1.

Table 1: Physical variables used in statistical analysis, full field form see Appendix 5

Variable(Unit)	Description
Transect - No [m]	The first basic unit to randomize the whole study based on distance from the road side to the forest measured in meter
Plot - No [m]	Embedded in the design of the transect measured at every distinct distance from the road
Frequency	Number of Individuals
Average vegetation height [m]	Average height of the plant which was the main shade provider to the plot
CC_PP [%]	Average crown cover of the plot measured with the densitometer at four corners of the plot

All IAPS from the 50 transects were identified to the species level. The taxonomy in this study is based on The Plant List (see The Plant List, 2013) and the classification of the Angiosperm phylogeny group III. The status of plants as IAPS was determined based on databases present for the identification of IAPS (Global Invasive Species Database (ISSG, 2015), Centre for Agriculture and Biosciences International (CABI, 2015)). For the purpose of this study, the species were considered IAPS if the source or origin of the species is outside of Sumatra.

2.4 Statistical analysis

All statistical analyses were executed using the free software R version 3.3.1 (R Core Team, 2016) in combination with RStudio 0.99.903 (RStudio, 2016). Most graphs, figures, and calculations for this thesis were created in R using the packages *vegan* (Oksanen et al., 2007) and *lme*4 (Bates et al., 2014).

Any maps seen in this thesis were created using the open source software QGIS in version 2.14 with recorded GPS coordinates from the field, for which a Garmin eTrex GPS device was used. Additional free shape files from Global Administrative Areas (www.gadm.org) and open source data from Open Street Maps (openstreetmap.org) was used to compile the final maps seen in this thesis. Datasets for the number of individuals are log transformed so that the skewness of the count dataset is reduced. To find the average number of IAPS, the dataset was randomized and ten transects from each forest type were selected.

Species accumulation curves were used to estimate the total IAPS richness per forest type. A species accumulation curve was calculated and created for each forest type. Randomized species accumulation curves with 100 permutations were calculated for each forest type using the R function '*specaccum'* within the package *vegan* (Oksanen et al., 2016). These curves plot the number of new species found over the increasing number of the sampled area depending on the species identity (Gotelli & Colwell, 2009). As long as new species are found in each plot, the species accumulation curve keeps rising (Ugland & Ellingsen, 2003; Colwell & Coddington,1994). When no new species are found in spite of an increasing area, the curve will reach an asymptote, which shows that the species inventory was sufficient to detect the full extent of species richness corresponding to the area (Ugland & Ellingsen, 2003).

To model the effect of number of individuals, forest type, distance to road, average vegetation height, crown cover and transect number on number of individuals based on the random effect of transect, we used a linear mixed effect model, which is a statistical model that assumes normally distributed errors and also includes fixed and random effects (Eisenhart, 1947; Johnson and Omland, 2004). Fixed effects are the constant to be estimated from the dataset and random effects govern the variance–covariance structure of the response variable. These effects can be a single level of grouping, multiple nested levels, multiple crossed levels or a combination of all (Winter, 2013; Demetrio et al., 2011).

The first step of the model was to specify variables within the model and the relationship between the independent variables and response variable. All the variables measured (see Table 1) were tested against the hypothesis which assumes every variable has effect on number of individual IAPS based on randomization of the transects. Here, the response variable is the number of individuals. Independent variables are crown cover, average vegetation height, distance to road and forest type.

Generating the hypothesis and explaining them into models can be a repetitive process. In this study the hypothesis was set as the number of individuals affected by the crown cover, average vegetation height, distance to road, and forest types. To select the best model with these criteria, it was necessary to compare multiple models simultaneously. Model selection was based on Akaike information criterion (AIC), a measure to estimate the relative quality of a model. Linear mixed effect models were implemented in the R packages '*lme4*'. The function was *lmer* for the linear mixed effect model (Bates et al., 2014). To find the best model for the applied model package, MuMIn was used (Barton et al., 2013).

3.Results

3.1 Invasive plant species in Harapan Rainforest

On the investigated 50 transects in Harapan Rainforest, an overall of 200 species were found. In total, there were 400 plots out of which 115 were without the presence of alien plants. The remaining 285 plots contained 587 individuals of IAPS. At the end, the total number of observed plant species identified as Invasive Alien Plant Species in Harapan Rainforest were 31 species belonging to eleven families. The total number of individuals was 2,343.

Most of the IAPS in Harapan Rainforest are from Tropical, Central, or South American regions (19 species). Three species belong to the Australian region whereas eight species are from the Indo-China region. One species is from Malaysia or East Java and the origin of one species (*Syzygium jambos*) is unknown. These species origins show that 61% of the species come from the Americas followed by 25% and 10%, which were from Indo-China and Australia (see Table 2).

Table 2: Species, family, origin and individual number of IAPS in different forest type found in Harapan Rainforest

Species	Family	Origin	Disturbed primary forest	Old secondary forest	Young secondary forest	Burnt area	Reference
Acacia mangium	Fabaceae	Australia	0	0	0	4	Kew, 2016
Ageratum conyzoide	Asteraceae	Trop. America, Central and S. America	0	0	5	0	CABI, 2016 Van kleunen et al., 2015
Ampelocissus brevipedunculata	Vitaceae	China	4	1	0	0	Chen et al., 2016
Axonopus compressus	Poaceae	Trop. America	6	8	25	68	SEAMEO BIOTROP, 2016 Van kleunen et al., 2015, CABI, 2016
Bellucia pentamera	Melastomataceae	Trop. America, Central and S. America	25	51	45	65	SEAMEO BIOTROP, 2003 Slik, 2009
*Centhoteca lappacea**	Poaceae	Africa, Asia Tropical, Australia, Pacific, Asia	0	4	5	0	Kew, 2016
Chromolaena odorata	Asteraceae	Central and South America	0	1	3	41	Van kleunen et al., 2015, SEAMEO BIOTROP, 2016
Clibadium surinamense	Asteraceae	Trop. America	2	34	20	182	SEAMEO BIOTROP, 2016
Clidemia hirta	Melastomataceae	South America	31	59	179	227	SEAMEO BIOTROP, 2016 Van kleunen et al., 2015 Weber, 2003
Crassocephalum crepidioides	Asteraceae	Trop. America	0	0	0	3	SEAMEO BIOTROP, 2016 Van kleunen et al., 2015
Croton hirtus	Euphorbiaceae	Trop. America	3	14	1	2	Van kleunen et al., 2015
Cyrtococcum patens	Poaceae	India and tropical Asia	0	0	2	0	Kew, 2016
Homolanthus giganteus	Euphorbiaceae	Malaysia and East Java	0	0	4	2	Esser, 1997
Imperata cylindrica	Poaceae	Tropical Asia	3	15	2	111	Van kleunen et al., 2015
*Lindernia diffusa**	Linderniaceae	Trop. America, Trop. Africa	0	0	2	0	GBIF, 2015
Melastoma malabathricum	Melastomataceae	Asia	64	137	124	395	Van kleunen et al., 2015 CABI, 2016
Mikania micrantha	Asteraceae	Trop. America	0	1	1	25	SEAMEO BIOTROP, 2003, Van kleunen et al., 2015 CABI, 2016
*Morinda villosa**	Rubiaceae	North India to China	0	1	1	0	WCSP, 2016
Ottochloa nodosa	Poaceae	South-East Asia and also in India, Burma and Sri Lanka	0	15	54	21	FAO,2016
Paspalum conjugatum	Poaceae	Trop. America	0	0	0	5	Van kleunen et al., 2015
Paspalum dilatatum	Poaceae	Trop. America	2	3	2	0	WCSP, 2016 SEAMEO BIOTROP, 2003
Pennisetum polystachyon	Poaceae	Tropical Africa	2	0	0	0	SEAMEO BIOTROP, 2003

*Rolandra fructiosa**	Asteraceae	South America	0	0	24	169	Tropicos, 2016
*Scleria ciliaris**	Poaceae	Australia	0	0	0	1	ATRF, 2016
Scoparia dulcis	Scrophulariaceae	Trop. America	0	0	0	2	Van kleunen et al., 2015
Solanum jamaicense	Solanaceae	America	0	0	0	8	Van kleunen et al., 2015
Spermacoce exilis	Rubiaceae	S. Mexico to Trop. America	0	0	9	8	Van kleunen et al., 2015
Spermacoce laevis	Rubiaceae	Mexico, Caribbean to S. Trop. America	0	0	0	4	Van kleunen et al., 2015
Synedrella nodiflora	Asteraceae	C and South America	0	0	1	0	CABI, 2016
*Syzygium jambos**	Myrtaceae	unknown	0	0	0	1	CABI, 2016
*Uncaria cordata**	Rubiaceae	Indochina to New Guinea and Australia (Northern Queensland)	1	0	3	0	Asian plant, 2016

** Not confirmed IAPS species in Sumatra*

The family Poaceae has the highest number of species (9 species), followed by Asteraceae (7 species), Rubiaceae (4 species) and Melastomataceae (3 species) (see Table 2). Fabaceae, Linderniaceae, Myrtaceae, Scrophulariaceae, Solanaceae and Vitaceae are the families which have only one species representing each of them. The three families Melastomataceae, Asteraceae and Poaceae together accounted for about 2,268 individuals, which is 97 % of all individuals occurring in the study area. Out of 31 species, 61% of the species also come from these three families. The remaining species account for only 75 individuals which is a mere 3 % of the total number of individuals (see Tables 2 and 3).

The Melastomataceae had the highest number of individuals (1402 individuals) from three species present named *Melastoma malabathricum* (720 individuals), *Clidemia hirta* (496 individuals) and *Bellucia pentamera* (186 individuals). Out of these 1402 individuals, 120 individuals were found in disturbed primary forest, 247 in old secondary forest, 348 individuals in young secondary forest and 687 in the burnt area respectively. The Asteraceae family (7 species) has the second highest number of IAPS with 512 individuals which were found in four different forest types, namely disturbed primary forest (2 individuals), old secondary forest (36 individuals), young secondary forest (54 individuals) and burnt area (420 individuals). Poaceae has the highest number of species (9 species), but only 354 individuals, which is less compared to Melastomataceae and Asteraceae family.

Table 3: Families, total number of species, and number of individuals in four different forest type

Family	Number of Species	Total number of individuals	Disturbed Primary Forest	Old Secondary Forest	Young Secondary Forest	Burnt Area
Asteraceae	7	512	2	36	54	420
Euphorbiaceae	2	26	3	14	5	4
Fabaceae	1	4	0	0	0	4
Linderniaceae	1	2	0	0	2	0
Melastomataceae	3	1402	120	247	348	687
Myrtaceae	1	1	0	0	0	1
Poaceae	9	354	13	45	90	206
Rubiaceae	4	27	1	1	13	12
Scrophulariaceae	1	2	0	0	0	2
Solanaceae	1	8	0	0	0	8
Vitaceae	1	5	4	1	0	0
Total	**31**	**2343**	**143**	**344**	**512**	**1344**

There are 11 species in disturbed primary forest, 14 in old secondary forest, 21 in young secondary forest and 22 in the burnt area (see Figure 4). Species such as *Axonopus compressus, Bellucia pentamera, Clibadium surinamense, Clidemia hirta, Croton hirtus, Imperata cylindrica* and *Melastoma malabathricum* are the species which are found in all forest type. Likewise, species such as *Acacia mangium*, *Crassocephalum crepidioides, Paspalum conjugatum, Scleria ciliaris, Scoparia dulcis, Solanum jamaicense* and *Syzygium jambos* are only found in the burnt area whereas *Ageratum conyzoide, Cyrtococcum patens, Lindernia diffusa* and *Synedrella nodiflora* are only occurring in young secondary forest. *Rolandra fructiosa, Homolanthus giganteus* and *Spermacoce exilis* are the species which are found in young secondary forest and the burnt area but not in other forest type. *Pennisetum polystachyon* is the species which is only found in disturbed primary forest whereas *Ampelocissus brevipedunculata* is the only species found in both disturbed primary forest and old secondary forest. *Morinda villosa* and *Centhoteca lappacea* are the species which are common between old secondary forest and young secondary forest only. Meanwhile there is not a single species which only occurred in old Secondary forest. *Paspalum dilatatum* is the only species which is found in young secondary forest, old secondary forest and disturbed primary forest but not in burnt area (see Table 2).

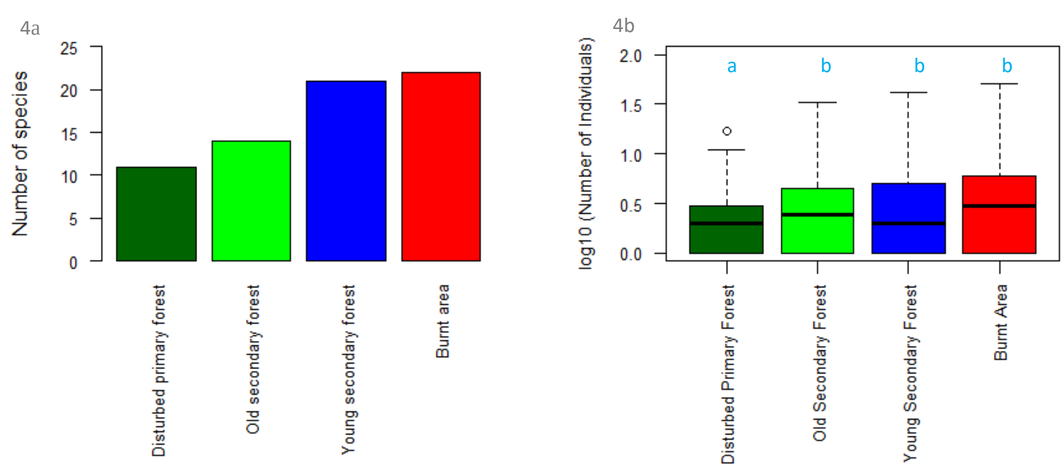

Figure 4: Total number of species in each forest type (a) and logarithmic transformed number of individuals in different forest type (b). One-way ANOVA and Tukey's HSD multiple comparisons (Different letters indicate significance different), with p value

There was a significant difference between the forest types (p-value = 0.00795, F = 3.983, df = 3), especially between disturbed primary forest and burnt areas (p-value = 0.01, Tukey's HSD test). There was no significant difference between old secondary forest and young secondary forest (p-value=1), and young secondary forest and the burnt area (p-value =0.16) or even burnt area to old secondary forest (p-value=0.28) (see Figure 4).

The species accumulation curves show the cumulative number of sampled species with increasing sample area and thus number of plots. If the curve reaches an asymptote it can be expected, that increasing the sample area further will not result in finding more species, meaning the sample size was sufficiently large enough to discover all species that occur in the investigated area. Species area curves were drawn for four forest types in Harapan Rainforest and can be seen in Figure 5. It was observed that in none of the forest types an asymptote was not reached through the inventory, indicating that there are more species present and a larger sample area is needed to uncover all present species.

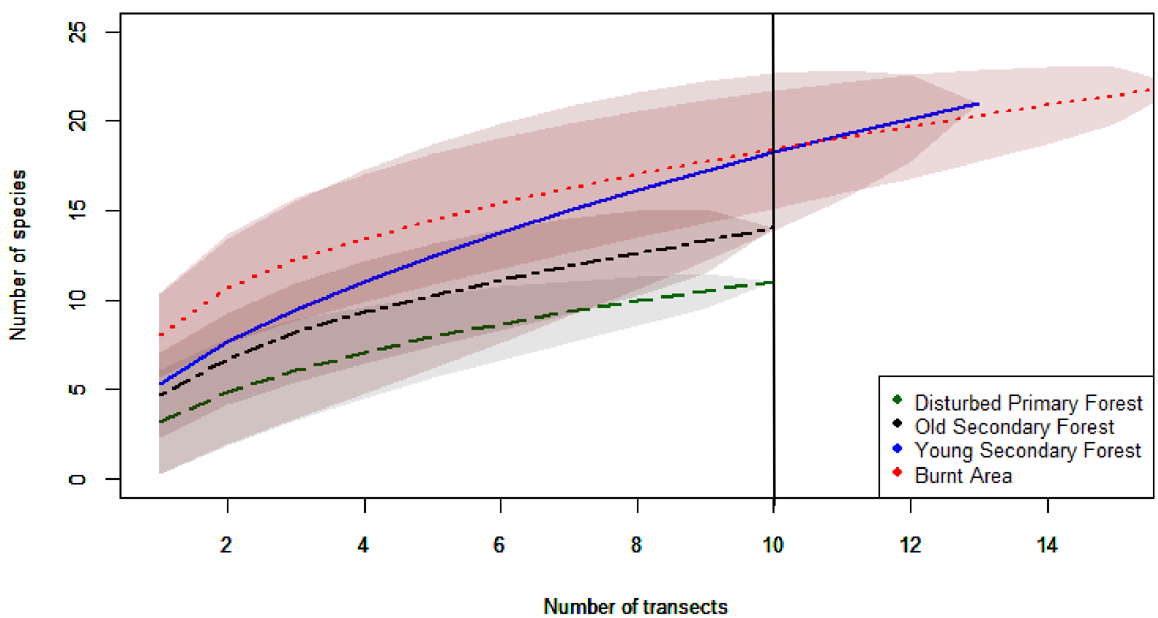

Figure 5: Species accumulation curves of invasive alien plant species in four forest types: disturbed primary forest (green), old secondary forest (black), young secondary forest (blue), and burnt area (red).

3.2 Effects of distance to road and forest type on number of species

In Harapan Rainforest, the average number of IAPS is 8.22 individuals per plot. The highest number of species was *Melastoma malabathricum* with 720 individuals. This means that in average 2.52 individuals of *Melastoma malabathricum* were found in each single plot. The second highest number of individuals was observed in *Clidemia hirta* with 496 individuals and an average of 1.74 individuals per plot.

Logarithmic transformation of the number of individuals showed that all medians of the $\log_{10}$ number of individual species are at the same level at distance 5, 10, 15, 20, 30 and 40 m (see Figure 6). The p-value of the one way ANOVA was 0.000616 *** (F = 3.71, df = 7). There was no significant difference between 0, 2, 5 and 10 m of distance to the road (p-value=0.36, Tukey's HSD test) and no significant difference between 15, 20, 30 and 40 m distance to the road (p-value=0.98, Tukey's HSD test). There is a significant difference between the plot at 0 m to the plots at 15, 20, 30 and 40 m plot, as the p-value is 0.02. For further information about the distance to road see Appendix 4 and on number of individuals in different forest types see Table 2.

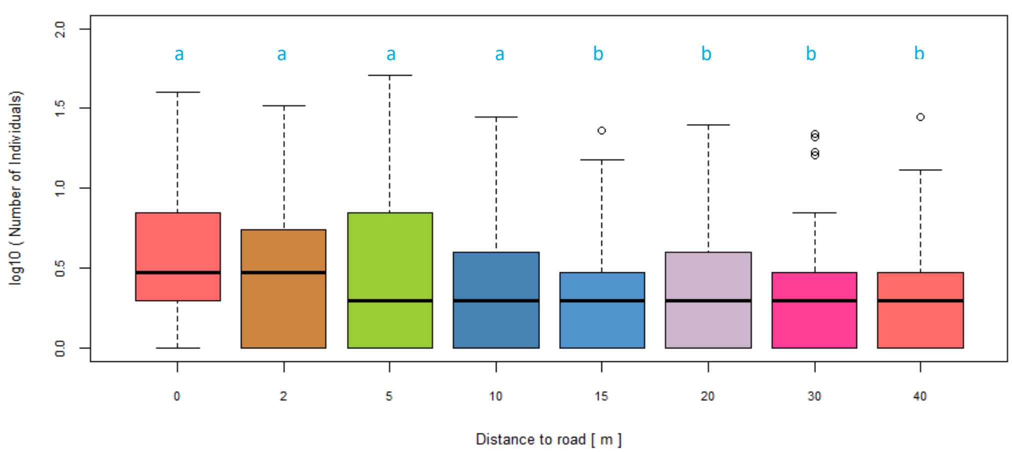

Figure 6: Distance to road and its effect on the number of individuals (note log10-scale). One-way ANOVA and Tukey's HSD multiple comparisons (different letters indicate significance difference), with p<0.000616 ***

One-way ANOVA and Tukey's HSD multiple comparison showed significant effects of forest type (p-value = 0.007) and distance to the road (p-value < 0.001). The interaction between the forest type and distance to road was not significant. The following assumptions can be drawn from the interaction of forest type with distance to road: The burnt area had more outliers than any other forest type. At a distance of 10 m, in burnt area the variability in the number of individuals is highest, compared to other forest types at the same distance plots (see Figure7).

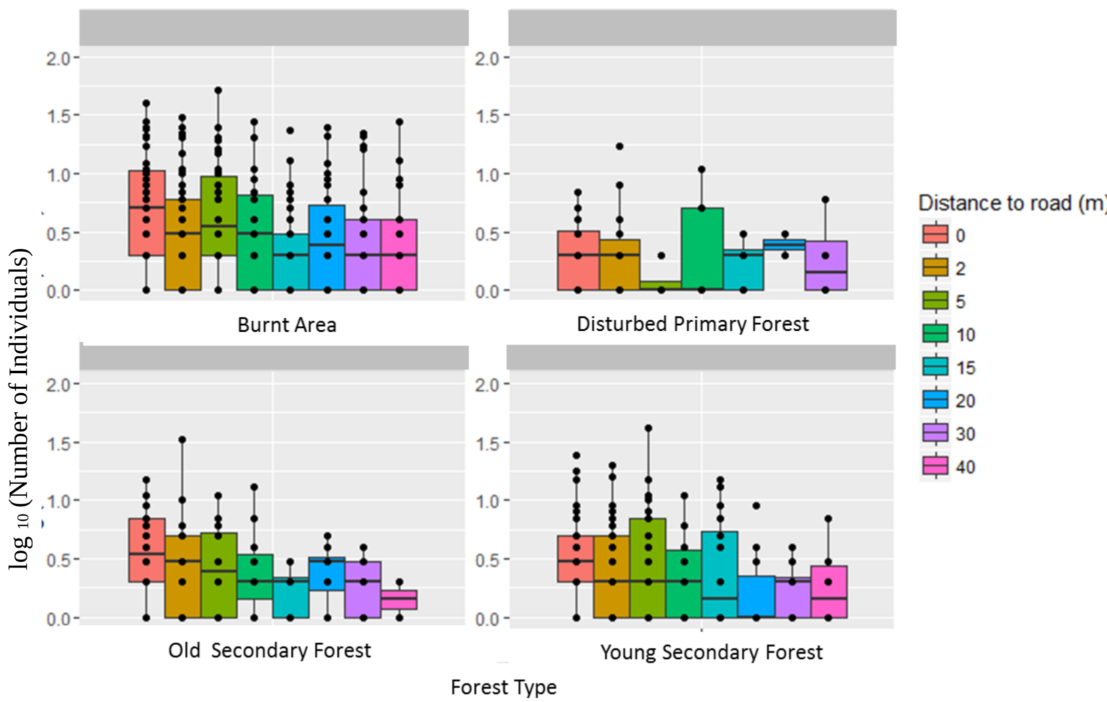

Figure 7: Log10 (Number of individuals of invasive plants) per forest type and distance to road. One-way ANOVA and Tukey's HSD multiple comparisons with p value 0.0061*** for comparisons between the forest type and for the comparison between the distance

In disturbed primary forest there were no IAPS at the distance of 40m. At the same time the disturbed primary forest had less outliers and the variability in all the distances to road is minimal. The variability at a distance of 5 and 20 m to the road is minimal, though the medians are different. At a distance of 0 and 2 m the median is equal but the variablity of the plots is different.

In the old secondary forest, there is more variability at distances of 0, 2 and 5 m compared to other plots. At the distance of 40 m, the variability is less than at other distances to the road plots. In the same manner, young secondary forest has the same median for 2, 5 and 10 m distance to road but the spread of the data looks different. The spread of the data is higher at 2 and 5 m distance to the road than to other distance to road plots. For more detail about the number of individuals in each forest type see Table 2 and for distance to road see Appendix 3.

Seven species occurred in all the forest types. Four species occurred in all the plots at different distances to the road (see Appendix 3). The number of individuals of all the species decline with distance from the road except for *Bellucia pentamera* with increasing individual numbers with increasing distance (see Appendix 2 and 3). 13 species were only recorded in plots of the first 5 m of the transects (see Appendix 3). Out of 31 species only nine were found at a distance of 40 meters from the road and 13 at the distance of 30 meters from the road. The mean number of individual IAPS for all forest types together was 59.6 (0m), 57.6 (2m), 37.7 (5m), 20.9 (10m), 16.4 (15m), 16.6 (20m), 14.3 (30m) and 11.2 (40m) individuals respectively. The mean number of individual IAPS in disturbed primary forest is 14.3, in old secondary forest 34.4, in young secondary forest 51.2 and in the burnt area 134.4 individuals respectively.

3.3 Forest structures influencing number of IAPS

All the variables studied, such as average vegetation height, crown cover, number of individuals IAPS, forest type, distance to road, and transects number does not show a noteworthy pattern of influence in the number of individual IAPS (see Table 4). To understand the relationship between all these variables, the best model analogous was set, the model with lowest AIC value was found which excludes the crown cover and the average vegetation height.

Distance to road had the largest effect on the number of individual IAPS (p-value= 0.001, Table 6). Disturbed primary forest and old secondary forest had significantly less species compared to the burnt area (p-values= 0.010 and 0.037 respectively) which is significant. Young secondary forest is not significantly different to the burnt area (p-value= 0.101) From the standardized estimation, it can be argued that apart from average vegetation height, all other values had a negative effect on the number of individuals.

To find the best model with the lowest AIC, model with the AIC value of 4205.1 was selected, which was lowest among all the models tested. In this model the fixed effect was distance to road and forest type only. As from the first model we already discovered that crown cover and average vegetation height of the species did not play an important role in the number of individuals occurring in the area.

Table 4: Linear mixed effect model predicting the effects of crown cover, average vegetation height, distance to road and different forest type, randomized based on transect number.

Response variable	Effect	Estimate (±SE)	Standardized estimate (±SE)	P value*	AIC
Number of individuals IAPS	Intercept	7.433 (0.783)	0.1326 (0.070)	8.88e-16***	4208.1
	Crown cover	-0.019(0.017)	-0.0573 (0.051)	0.264	
	Average vegetation height	0.054 (0.054)	0.0462 (0.046)	0.321	
	Distance to Road	-0.010(0.031)	-0.148 (0.045)	0.001	
	Disturbed primary forest	-3.675(1.417)	-0.422(0.162)	0.010	
	Old secondary forest	-2.452(1.160)	-0.281(0.133)	0.037	
	Young secondary forest	-1.818(1.095)	-0.208 (0.125)	0.101	
Fitted statistic of the best model from linear mixed effect model					
Number of individuals IAPS	Intercept	7.398 (0.700)	0.15870 (0.068)	<2e-16***	4205.1
	Distance to road	-0.101(0.028)	-0.145(0.041)	0.000448***	
	Disturbed primary forest	-3.951(1.372)	-0.450(0.161)	0.005**	
	Old secondary forest	-2.818(1.101)	-0.322(0.13)	0.013*	
	Young secondary forest	-2.390(0.968)	-0.2729(0.11)	0.165	

Note: Estimates and standard errors (in parentheses). The fixed effects must first be exponentiated in order to yield interpretable odds ratios 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 , 0.1 , 1

4.Discussion

The introduction of IAPS threaten various ecosystem types in Indonesia, especially areas which were disturbed in the near past. In a study conducted in Indonesia, 339 alien plant species were reported to be invasive (Tjitrosoedirdjo, 2005). In our study, we concluded with 31 IAPS in Harapan Rainforest alone. In this study, the maximum number of IAPS belong to the families of Melastomataceae, Asteraceae and Poaceae which was not the case when it was studied in oil palm plantation in West Sumatra (see Germer, 2003).

The early introduction of these IAPS was mostly recorded to be caused by economic activities, which were either intentional or accidental (Meyerson and Mooney, 2007). One of the classic examples of deliberately introduced species was the introduction of *Mikania micrantha*. It was introduced as non-legume ground cover in rubber plantations. *Clidemia hirta* on the other hand is a typical example of accidental introduction (DeWalt et al., 2004).

Correspondingly, in our study, the occurrence of *Acacia mangium* of the Fabaceae family, is an example of the deliberate introduction of some IAPS, which spread from nearby plantations around Harapan Rainforest and especially colonized burned areas. It coincides with Rejmanek's observation in California, in which the species that were invasive were the ones which were planted (Rejmanek, 2000; Flory and Keith, 2005).

Additionally, *Bellucia pentamer*a was introduced in the early 20th century in the Bogor Botanic Gardens (Heyne, 1950 in Kok et al., 2015) which has escaped the garden and is a common IAPS in Harapan Rainforest. While most IAPS occur most frequently close to the road, the individual numbers of *Bellucia pentamera* did not decrease with increasing distance to the road and occurred more often in disturbed primary forest than in burnt areas. This result was surprising, as it seems to be colonizing the interior of the forest which can be harmful and it is also one of the dominant crown cover providers in the area (Harrison & Swinfield, 2015).

In this study, 61% of all the IAPS are native to South, Central, or tropical America and 10% are native in other parts of Asia. In this case it was similar to a study done by Guo in China (1999) where 68% of IAPS are native to America and 3% trace back to Asia. Moreover, most of the IAPS came from tropical America (Tjitrosoedirdjo, 2005). However, a recent study reported that the main sources of naturalized alien plant species were Temperate Asia and Europe (Van kleunen et al., 2015).

In the same manner, apart from the origin of the species, the other important finding were the species which were penetrating inside the forest. Out of 31 species described as IAPS in the forest area, only 13 were able to breach to the distance of 30 m and nine to the distance of 40 m. In a similar study done but in different climatic zones in Chequamegon-Nicolet national forest in the United States, four species of IAPS were found with up to 45 m distance from the road side into the forest and one species even with 150 m distance (Watkins et al., 2003).

In the species accumulation curve in the four forest types, an asymptote was not reached through the inventory, indicating that there are more IAPS present and a larger sample area is needed to assess all in either forest type. According to Cain and De Olivieria Castro (1959) though, a minimum representative area is reached when the number of species increases by less than 10% when the sampling area expands by 10% as well. Looking at the numbers underlying the graphs, this requirement was reached in disturbed primary forest and old secondary forest, thus it can be expected that an asymptote will be reached by increasing the sample size by one to two plots, but it was not the case with young secondary forest and burnt area (see Figure 5). The colored confidence interval spread in all graphs shows that standard deviation values were higher in the burnt area, making the inventory in the disturbed primary forest more precise and accurate.

The individual numbers of IAPS increased along a disturbance gradient from disturbed primary forest towards burnt areas. Burnt areas showed ten times more individuals of IAPS than the disturbed primary forest. This result agrees with a study from Southern Indiana

(USA) where there were 70% less invasive shrubs in mature forest stands than in young and mid successional forest (Flory & Keith, 2005). In general, non-native species are more frequent in grasslands compared to forests (Hansen and Clevenger, 2005) as in our study with more species in the burnt area compared to disturbed primary forest. From all this, we can conclude that if the number of individual IAPS are so varied in different forest types, it can be the general effect of land-use change (see Vilà & Ibáñez, 2011).

In this study it was observed that there were more individuals at the distance of 0, 2, 5 and 10 m than at the distance of 15, 20, 30 and 40 m distance to the road and there were five times more IAPS individuals at 0 m than at 40 m distance to the road. This result also agrees with the result of a previous study, which concludes that the number of IAPS were found to be more at the distance of 0 m than at 10, 20, or 30 m from the road (Flory and Keith, 2005). In this study, non-native species are found particularly between 0-10 m distance while in other studies the number of IAPS decreased after 25 m distance to the road (Hansen and Clevenger, 2005).

Roads are considered as the gateway for many introduced species to outcompete native species (Forman et al., 2003; Mortensen et al., 2009). In the case of Indonesia, if the density of roads keeps increasing, then the number of individual IAPS along the roads will increase as well. The proportion of road area to the forest can have an ecological impact on forest (Riitteers and Wickham, 2003).

Number of individual species, crown cover or average vegetation height of the tree in the study area had no significant influence on the occurrence of IAPS, though with increase in crown cover there seems to be a trend of decline, but the increase was not significant. The result with no significant impact of crown cover and average vegetation height can be related to the measurement devices used especially in case of crown cover. Measuring crown cover with an instrument better than a densiometer would have given some different results, however it was not the main aim of the study to understand the crown cover and individual number of IAPS rather than to understand the forest types and pattern of IAPS along the roadside. The concern with no significant result related to average vegetation height can be the main focus of a study in future, as there are not many studies on the height of the vegetation affecting the growth of the IAPS yet. Therefore, this area of study can be a new field to flourish.

5.Conclusion

The study of the forests in Harapan Rainforest is being done in detail in plots established by the EFForTs project, which express the unique characteristics and diversity of lowland rainforest. A particular emphasis is on the disturbed primary forest which leaves room for studies on the diversity of old secondary forests in the same area.

The study-design proved to be statistically accurate and easy to implement in the field. However, during field work it was already obvious that other variables other than distance to road and forest type were left out in the sample due to the static and small plot design which does not consider factors outside the plot. Other transect designs with plots trying to capture the surrounding of 5 m would possibly have increased the influence of variables like crown cover and average vegetation height. Future studies in the area related to the IAPS should focus more on the plots and peripheral surrounding of the plots in order to make the inventory more precise and to draw an even more detailed picture of the IAPS along the roadside and the influence of road on the occurrence of these species regarding crown cover and average vegetation height. As this was a first assessment of the area for the IAPS along the road, the study succeeds in its aim to find out the species occurring in the area as IAPS and the number of individuals of the species with forest type and distance to road. Hypothesis 1 of the study was accepted as diversity and density of individual IAPS decrease with distance to road and interior of the forest.

Furthermore, Hypothesis 2: crown cover and average vegetation height have a negative effect on the density and diversity of IAPS, was rejected. Though the reason behind this can be different. Ultimately studies such as the one at hand are still important to raise awareness of the vast diversity and occurrence of different IAPS in the area. Therefore, I recommend that future studies should give more attention to the invasion of alien plant species in the local plant communities and investigate not only the impact upon species loss, but also the change in overall community composition due to forest conversion and the influence of roads which increases the chances of occurrence of IAPS along the disturbance gradient. The influence of these disturbances should rather be minimized when thinking about the future of any forest in the tropics with disturbances created by humans such as roads.

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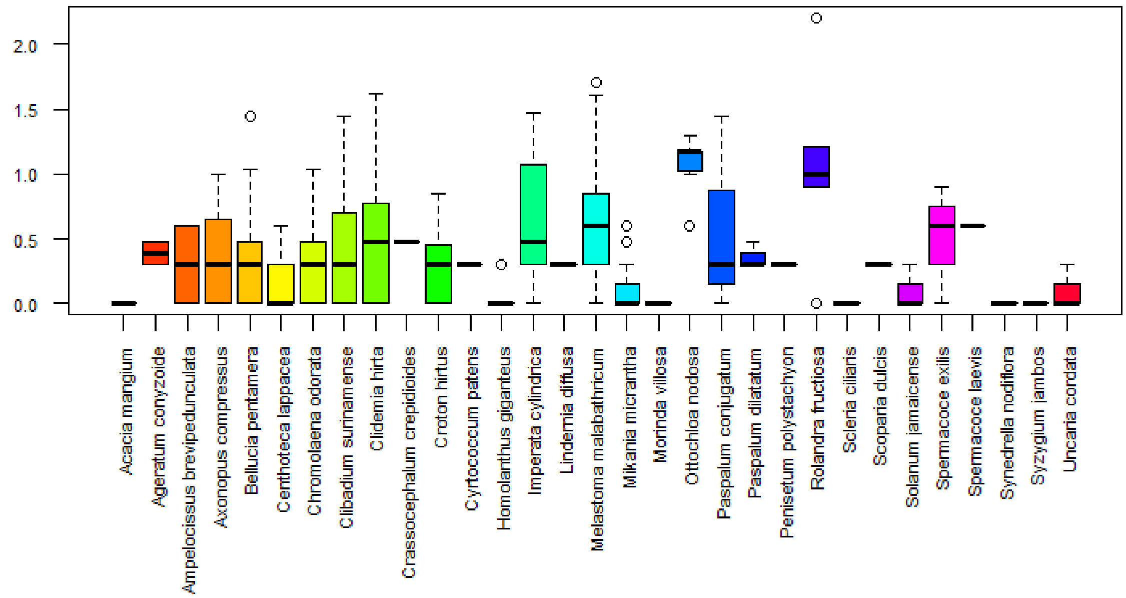
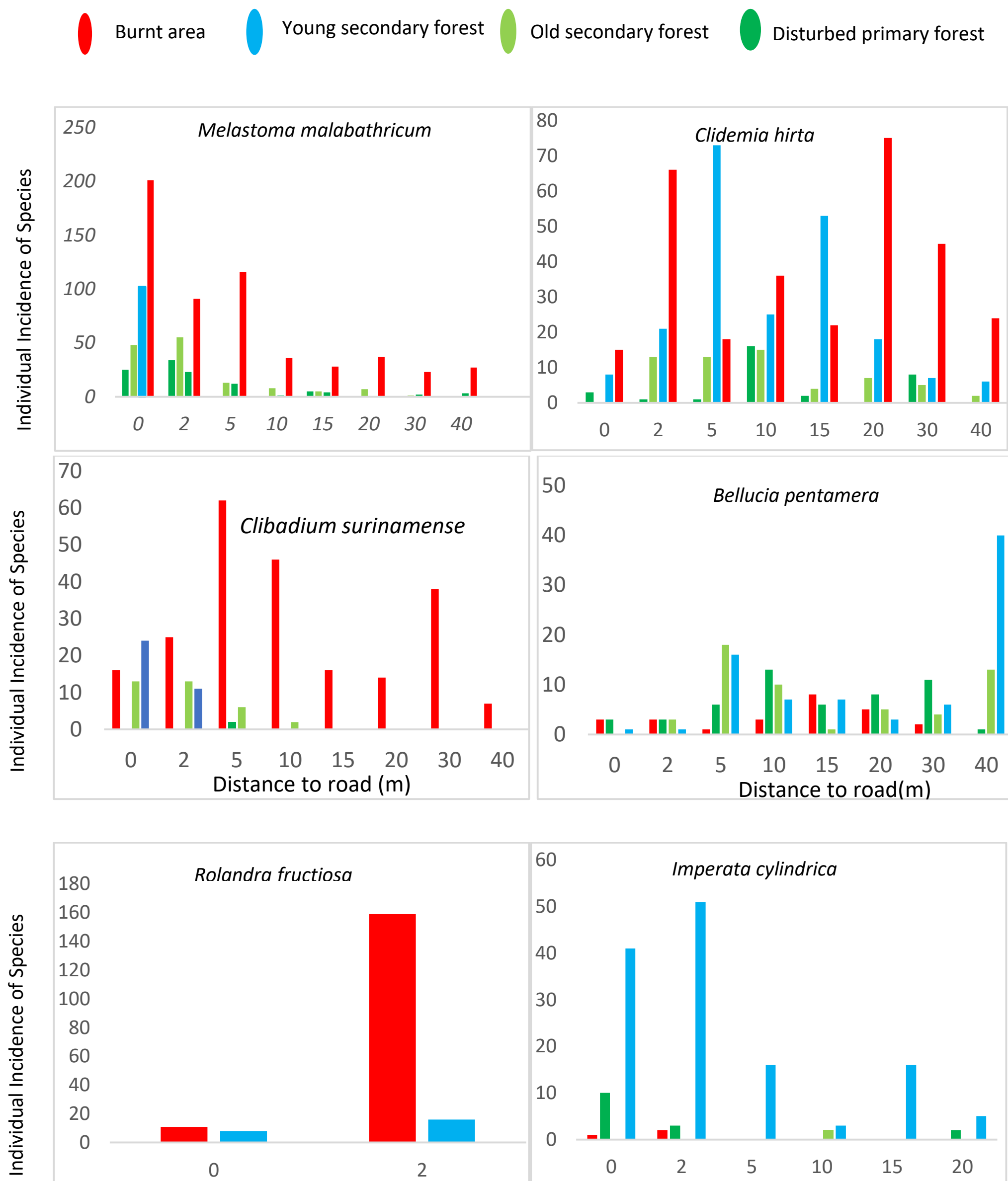
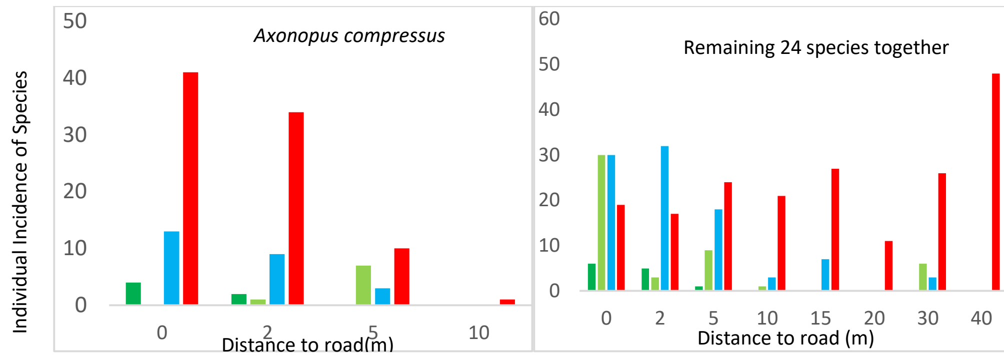
Appendix

Appendix 1: log 10 number of individuals per species along all forest types



Appendix 2: Number of individuals of species with more than 100 individuals and remaining species combined together across all forest types and with increasing distance to the road.




Individual Incidence of Species
Axonopus compressus
50
40
30
20
10
0
0
2
5
10
Distance to road(m)
Remaining 24 species together
60
50
40
30
20
10
0
0
2
5
10
15
20
30
40
Distance to road (m)

Appendix 3: Number of Individuals per species with increasing distance to the road [m]

Distance from road (m)/ Species	0	2	5	10	15	20	30	40	Total
Acacia mangium	0	0	0	1	1	0	2	0	4
Ageratum conyzoide	3	2	0	0	0	0	0	0	5
Ampelocissus brevipedunculata		4					1		5
Axonopus compressus	50	36	20		1				107
Bellucia pentamera	7	10	36	25	15	19	22	52	186
Centhoteca lappacea	3	1			1		4		9
Chromolaena odorata	4	2	3	13	13	5	5		45
Clibadium surinamense	45	20	70	45	13	11	30	4	238
Clidemia hirta	21	59	86	84	68	89	59	30	496
Crassocephalum crepidioides			3						3
Croton hirtus	19	1							20
Cyrtococcum patens			2						2
Homolanthus giganteus		1			1		2	2	6
Imperata cylindrica	52	56	16	2	3		2		131
Lindernia diffusa	2								2
Melastoma malabathricum	318	166	106	31	39	38	7	15	720
Mikania micrantha		2	4	5	1	3	7	5	27
Morinda villosa				1			1		2
Ottochloa nodosa	41	20	25		4				90
Paspalum conjugatum	2	1	2						5
Paspalum dilatatum	4	3							7
Pennisetum polystachyon	2								2
Rolandra fructiosa	18	175							193
Scleria ciliaris						1			1
Scoparia dulcis								2	2
Solanum jamaicense		1	2		3		1	1	8
Spermacoce exilis	5	12							17
Spermacoce laevis		4							4
Synedrella nodiflora			1						1
Syzygium jambos								1	1
Uncaria cordata			1	2	1				4

Appendix 4: Different forest type and number of individuals, mean, and standard deviation of species along the distance to road [m]

	Disturbed primary forest			Old secondary forest		
Distance to road	Total	Mean	Standard deviation	Total	Mean	Standard deviation
0	42	2.62	1.82	104	4.77	3.62
2	47	3.35	4.34	91	4.55	7.1
5	5	1.25	0.5	45	3.75	3.13
10	19	3.8	4.38	39	3.54	3.58
15	15	1.87	0.83	15	1.87	0.83
20	5	2.5	0.7	22	2.75	1.38
30	10	2.5	2.38	25	1.92	1.03
40	0	0	0	3	1.5	0.707
	Young secondary forest			Burnt area		
Distance to road	Total	Mean	Standard deviation	Total	Mean	Standard deviation
0	169	4.97	5.54	281	9.36	9.48
2	95	4.13	5.01	343	11.06	28.49
5	107	6.29	10.09	220	7.85	10.82
10	32	2.9	3.04	119	5.66	7.11
15	58	4.46	4.96	76	3.45	4.68
20	20	2.85	2.96	119	4.95	6.25
30	10	1.66	0.81	98	4.9	6.69
40	21	2.33	1.93	88	3.82	5.68

Appendix 5: Field form

Invasive Alien Plant Study Form

Distance to road:		X coordinate:
Date:		Y coordinate:
Aspect:	Latitude:	Crown cover:

S.No	Transect_No	Plot_No	Forest Type	Species	No	Vegetation height	Picture No	Remarks

Statement of Originality

I hereby assure that this thesis was exclusively made by myself and that I have used no other sources and aids then the ones enlisted.

Göttingen,

Anu Singh