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Structural and spatial characterization of swamp forests in northeastern Suriname based on field assessment techniques

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Summary

Research questions: How can the structure and composition of the forests in the study area be assessed in an efficient and effective way? What is the composition and structure of these forests? Do the existing classifications for swamp forests in Suriname suffice to classify these forests? What is the economic value of these forests?

Study area: In the Marowijne district in Suriname, covering the swamp forest and seasonal swamp forests along the *Oost-Westverbinding*.

Methods: In forty sample plots (5 of 20 x 50 m^2 and 35 of 20 x 50 m^2) spread over the different clusters encountered in an unsupervised classification, a floristic inventory of all trees whose diameter at breast height exceeding 10 cm was made. The tree height, diameter and location in the plot were recorded.
Diversity indices were calculated as well as measurements for the species richness and composition. To assess the forest structure, diameter and height distributions were made and the tree density, diameter at breast height, tree height, basal area and aboveground biomass were evaluated. Non-parametric tests were used to assess differences between the encountered forest types. Spatial point pattern analysis was also used to assess the forest struture.
A qualitative summary of value and usage of the encountered tree species was composed.

Results: A total of 1,770 trees, belonging to 131 different species were recorded. Five forest types can be distinguised: the low swamp forests, the high swamp forests, the high seasonal swamp forests on clay soils, the high seasonal swamp forests on sandy soils and the forests growing on former plantations and farmland. The low swamp forests are the least diverse and have the smallest dimensions but have a large number of trees per hectare. The *Pterocarpus officinalis* dominated low swamp forests showed the same structure as other *P. officinalis* forests in the Greater Caribbean region do. The high swamp forests are somewhat more diverse, both in species composition and in dimensions and structure, than the low swamp forests. The biodiversity and structural diversity continues to increase from the high seasonal swamp forests on sandy soils over the high seasonal swamp forests on clay soils to forests growing on former plantations and farmland. The tree density of the forests decreases with

increasing diversity, however the tree density in the ridge forests is lower than the other forest types.
Often the encountered species, thirty-eight are classified as marketable timber species by SBB and many more are used by the inhabitants of Suriname for medicinal and ritual reasons.

Conclusion: The proposed field protocol was suited for the rapid assessment of the structure and composition of the forests in the study area, but a slightly larger plot size might be advisable. The existing literature provides a good basis on the floristic composition of these kinds of forests but more research on the other features is desirable. The swamp forests in Northeastern Suriname also have a large economic value although not necessarily in the conventional way.

Samenvatting

Onderzoeksvragen: Hoe kan de structuur en de compositie van de bossen in het studiegebied op een efficiënte en doeltreffende manier vastgesteld worden? Wat is de samenstelling en de structuur van deze bossen? Voldoen de bestaande classificaties van moerasbossen in Suriname om deze bossen te classificeren? Wat is de economische waarde van deze bossen?

Onderzoeksgebied: De moerasbossen en seizoensgebonden moerasbossen langs de Oostwestverbinding in het Marowijne district in Suriname.

Methode: Er werd een inventaris gemaakt van alle bomen, met een diameter op borsthoogte groter dan 10 cm, voor de veertig opgemeten proefvlakken (5 van 20 x 50 m en 35 van 20 x 50 m), die verspreid lagen over de verschillende clusters aangetroffen in een ongesuperviseerde classificatie. De boomhoogte, de diameter en de locatie in het plot werden geregistreerd. Er werden diversiteitsindices en maten inzake soortenrijkdom en soortencompositie berekend. Om de structuur van het bos te beoordelen, werden diameter- en hoogtedistributies gemaakt, de bomendensiteit, diameter op borsthoogte, boomhoogte, het grondvlak en de bovengrondse biomassa werden geëvalueerd. Er werden niet parametrische tests gebruikt om de verschillen tussen de bostypes te beoordelen. D *Spatial point pattern analysis* werd ook gebruikt om de bosstructuur te beoordelen. Er werd een (kwalitative) lijst met de waarde en het gebruik van de verschillende boomsoorten uit de proefvlakken opgesteld.

Resultaten: Er werden in totaal 1.770 bomen van 131 verschillende boomsoorten geregistreerd. Er kunnen vijf bostypes onderscheiden worden: het laag moerasbos, het hoog moerasbos, het hoog seizoensgebonden moerasbos op kleigrond, het hoog seizoensgebonden moerasbos op zandgrond en het bos dat groeit op vroegere plantages en landbouwland. Het laag moerasbos is het minst divers, heeft de kleinste afmetingen en een groot aantal bomen per hectare. Het laag moerasbos waar de *Pterocarpus officinalis* dominant aanwezig is, vertoont dezelfde structuur als andere *P. officinalis* bossen in de Groot-Caribische regio. het hoog moerasbos toont een grotere diversiteit dan het laag moerasbos, zowel inzake soortencompositie als in afmeting en structuur. De biodiversiteit en structurele diversiteit stijgt van hoge seizoensgebonden moerasbossen op zandgronden, over seizoensgebonden moeras-

bossen op kleigrond tot het een maximum bereikt bij de bossen op vroegere plantages en landbouwland. Met de toename van de densiteit gaat een daling van diversiteit gepaard. het aantal bomen per hectare in de ritsbossen (hoge seizoensgebonden moerasbos op zandgrond) is echter lager dan in de andere bostypes. Van de voorkomende boomsoorten zijn er heel wat (38) door SBB als verhandelbare houtsoort opgelijst. Een nog grotere hoeveelheid wordt door de inwoners van Suriname gebruikt voor medicinale toepassingen en rituele handelingen.

Besluit: De voorgestelde inventarisatiemethode was geschikt voor de snelle evaluatie van de structuur en van de samenstelling van de bossen in het studiegebied, maar een iets grotere proefvlakgrootte is aangewezen. De bestaande literatuur voorziet in een goede basiskennis inzake boomsoortensamenstelling van dit soort bossen, maar een meer uitgebreid onderzoek inzake structurele kenmerken en diversiteit is wenselijk. De moerasbossen van Noordoost Suriname hebben ook een grote economische waarde, welke wellicht op een minder conventionele manier moet gegenereerd worden.

Contents

List of Abbreviations

ABE	Association for Forest Exploiters
ACT	Amazon Conservation Team
ACT	Amazon Cooperation Treaty Organisation
ADEKUS	Anton de Kom University
AGB	aboveground biomass
ANRICA	Austrian Natural Resources Management and International Cooperation Agency
ASFA	Association for Surinamese Manufacturers
ASHU	General Suriname Timber Association
asl	above sea level
ATM	Ministerie van Arbeid, Technologische Ontwikkeling en Milieu
bp	before present
CELOS	Center for Agricultural Research in Suriname
CI	Conservation International
dbh	diameter at breast height
FAO	Food and Agriculture Organization of the United Nations
FOB	Free on Board
FTE	full time equivalent
GDP	Gross Domestic Product
IPCC	Intergovernmental Panel on Climate Change

ITTO	The International Tropical Timber Organization
IUCN	International Union for Conservation of Nature and Natural Resources
IVI	Importance Value Index
KKF	Chamber of Commerce and Industry
LBB	Suriname Forest Service
Ltd.	Limited company
MAPs	Main Assessment Plots
mcf	mark correlation function
MUMAs	Multiple Use Management Areas
NATIN	Institute for Natural Resource and Engineering Studies
NB	Nature Conservation Division
NFI	National Forest Inventory
NGO	non-governmental organisations
NIMOS	Nationaal Instituut voor Milieu en Ontwikkeling in Suriname
NTFP	non-timber forest product
pcf	pair correlation function
PHS	Timer Sector Platform
PSP	Principle Sample Plots
RGB	Ministry of Physical Planning, Land Management and Forest Policy
SBB	Foundation for Forest Management and Production Control
SP	Sample plot
STINASU	Foundation for Nature Conservation
SUa	areal Sampling Units
UN-ESA	United Nations - Department of Economic and Social Affairs
VIDS	Association of Indigenous Village Chiefs
VSB	Surinamese Business Association
WWF	World Wildlife Fund

CHAPTER 1

Introduction

Suriname is one of the countries with the highest forest covers in the world (ITTO and FAO, 2011). Of the 14,775,000 ha of forests in the country 8.3% (1,225,000 ha) are fresh water inundated forests. The Ramsar Convention in 1971 recognized the importance of wetland ecosystems and emphasized the necessity of the conservation and the sustainable use of wetlands (Groombridge et al., 1992). Even though its importance has been recognized, knowledge on the structure and composition of swamp forests is often lacking. This knowledge is not only necessary for the conservation purposes and for the understanding of the processes that take place in these forests but also for the assessment of forest resources.
In Suriname this knowledge is largely restricted to the dryland forests in the Forestry Belt (Hendrison and de Graaf N.R., 2011) and the research that has happened in swamp forests was mostly limited to the western part of the country and/or is of considerable age (Lindeman, 1952; Lindeman and Moolenaar, 1959). Since it would be very expensive to commence logging in the more southern parts of the country because of the lack of infrastructure, the best option is to further study the less known swamp forests in the coastal region.
To be able to assess the composition and structure, a method to characterize these features in a fast and simple way is needed.

This situation raises the following four main research questions.
How can the structure and composition of these types of forests be assessed in an efficient and effective way?
To answer this question an inventory protocol will have to be developed and tested in practice. If necessary adjustments will have to be made so data can be collected in a short time frame.

What is the composition and structure of these forests?
The calculation of measurements for species richness, species diversity will be necessary as well as calculations of measurements that represent the structural complexity of the forests. These resulting indices will have to be compared between the different sample plots to assess the homogeneity of the forests in the study area.

Do the existing classifications for swamp forests in Suriname suffice to classify these forests? To answer this question an overview of the existing classifications will have to be made and the obtained data from the field inventory will have to be compared to the existing literature.

What is the economic value of these forests?
To answer the last question a qualitative overview of the uses of the tree species encountered during the field inventory will have to be listed and the potential economic and ecological value of these species will have to be assessed.

Chapter 2 will sketch an image of the forestry sector in Suriname and its swamp forests. This is followed by chapter 3: a detailed explanation of the field work and the field inventory protocol and the applied analyses on the obtained data. Chapter 4 lists the results, which are discussed and linked to the existing literature. In the last chapter, chapter 6, the conclusions of this thesis can be found.

CHAPTER 2

Literature Review

2.1 The Guiana Shield

2.1.1 Geography and geology

The Guiana Shield is a geological region of 2,288,000 km^2 in the northeast of South America formed by crystalline rocks of Proterozoic origin (4,567 million years before present (bp) to 635 million years bp) and is one of the three Precambrian rock formations in South America (next to the Central Brazilian and the Atlantic Shield). The Atlantic Ocean, the Orinocco Delta in Venezuela and the Amazon Delta can be regarded as its borders (de Granville, 1988; Hollowell and Reynolds, 2005; Lujan and Armbuster, 2011). The northernmost border is 10°N 62°W, the southernmost border is 4°S 63°W, the westernmost and easternmost points are respectively at 0°40'N 74°W and 2°N 50°W (Figure 2.1) (Hammond, 2005) . The Guiana Shield covers six countries: Colombia, Venezuela, Guyana, Suriname, French Guiana (technically a *département d'outre-mer* of France) and Northern Brazil. Guyana, Suriname and French Guyana are called the Guianas and are the countries of which 100% of their territory is part of the Guiana Shield. It is not only defined as a geological region but also as a geopolitical region and in this context it consists of Guyana, French Guyana, Suriname and some regions of Venezuela, namely Amazonas, Bolivar and Delta Amacuro (Mistry et al., 2014).

Geologically the Guiana Shield differs from other tropical forested lands because the formation processes were mainly sub-surface plutonic processes as opposed to the volcanic processes that formed the Caribbean, Central America and Southeast Asia. The crust exists of more Precambrian formations than the Australian and Indian tropical regions and it is less exposed than the African region. The cover is mostly Proterozoic and greenstone belts are common (Goodwin, 1996; Hammond, 2005).

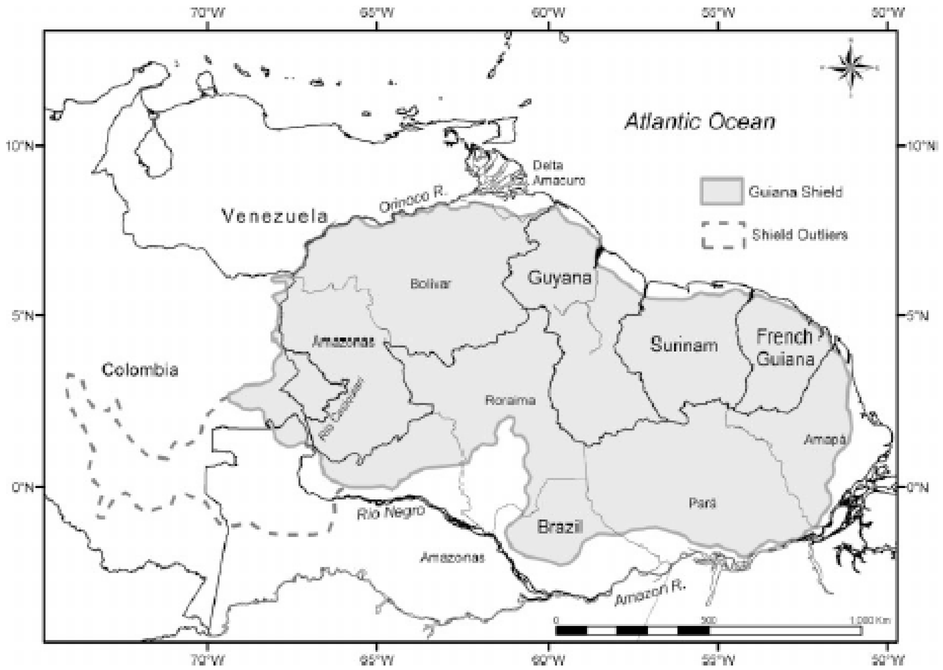

Figure 2.1: Map of northern South America with in grey the location of the (geological) Guiana Shield (Hollowell and Reynolds, 2005).

The Guiana Shield has a very dense hydrographic network with 47 medium to large rivers that belong to two basins: the Amazon Basin and the Guiana Basin. It is estimated that this tangle of rivers and streams holds 10 to 15% of the fresh water reserves in the world (Guiana Shield Facility, 2012). This very dense network is possibly the origin of the name Guayana or Guiana, which is thought to mean 'many waters' in Amerindian (Hammond, 2005; Lujan and Armbuster, 2011). The shield consists of two large regions in terms of landforms: the lowlands and the uplands (de Granville, 1988; Lujan and Armbuster, 2011). The lowlands are (1) recent coastal plains that have an elevation between -10 to 10 m above sea level (asl) and are covered by quaternary silt and clay layers; (2) the tertiary sandy plains that have an elevation between 10 - 50 m asl and cover about 30% of the Guiana Shield land area; and (3) the Precambrian rolling hills with an elevation between 50 - 300 m asl and account for more than 50% of the shield area. The uplands consist of the Guiana Uplands (300-1,500 m asl) and Guyana Highlands (1,500 - 3,000 m asl) (Hammond, 2005).

2.1.2 Climate

The whole region has an equatorial climate that is hot and wet, with a mean annual temperature between 25°C and 30°C and an annual precipitation between 1,500 and 4,000 mm with two dry and two wet seasons (Gond et al., 2011; de Granville, 1988). According to the

Köppen system the climate of the Guianas belong to group A: the tropical or megathermal climates. These are characterized by high temperatures above 18°C all year long. All three subclasses can be found here: tropical rainforest climate (Af), tropical monsoon climate (Am) and tropical savanna climate (Aw) (Figure 2.2) (climate data.org, 2016; Funk et al., 2007).

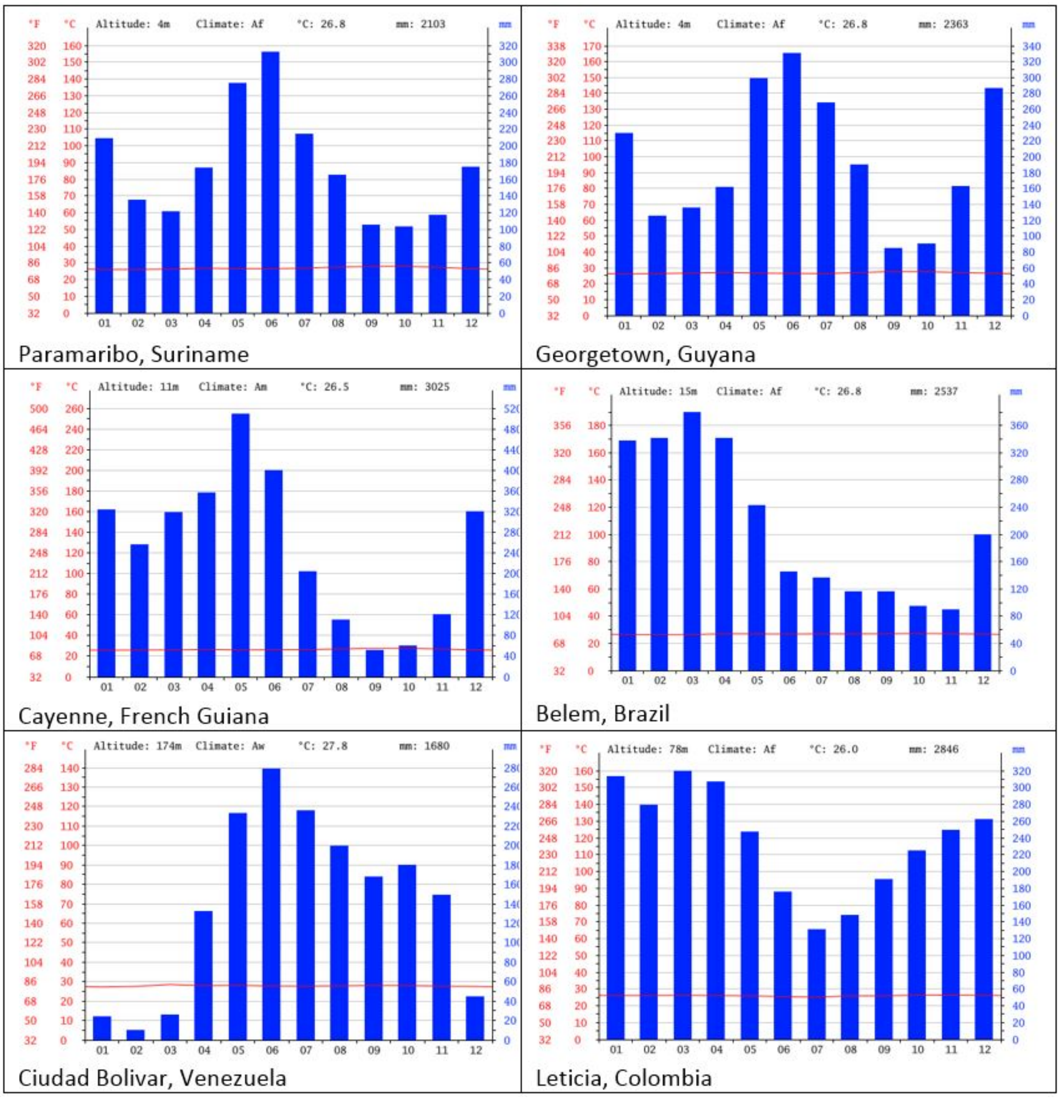

Figure 2.2: Climate diagrams for different big cities in the Guiana Shield (climate data.org, 2016).

2.1.3 Biodiversity and its threats

Not only does the Guiana Shield has a unique position regarding its geology but also in relation to its nature and biodiversity. The largest unfragmented tropical forest block of frontier forest can be found here (Bryant et al., 1997; Haden, 1999) and it also has a very high biodiversity (more than 20,000 vascular plant species, 2,200 fish and 1,000 bird species (Higgins, 2007)), many endemic species (up to 40%) (Funk et al., 2007) , the very localized restrictions of individual species (Haden, 1999) and mostly undisturbed ecosystems. However, recently the rate of human disturbance in these previously undisturbed ecosytsems has increased (Funk et al., 2007). Mittermeier et al. (1998) classified the Amazon Basin (that contains the whole of the Guiana Shield) as one of only three major tropical wilderness areas on Earth (the others being: the Congo Basin and the island of New Guinea and the adjacent islands). These are areas with a high biodiversity (more than 75% of the original pristine vegetation) and a low threat (less than 5 people·km^{-2}) (Mittermeier et al., 1998).

There are several causes for the population density which allow this undisturbed nature. The estimates for the population density are 3.26 people·km^{-2}, 3.65 people·km^{-2} and 2.65 people·km^{-2} for respectively Suriname, Guyana and French Guiana (in comparison: Belgiums population density is 370.9 people·km^{-2}). Only some of the least hospitable regions on Earth such as Svalbard, Greenland, Mongolia and Western Sahara have lower population densities (The World Bank, 2015; UN-ESA, 2015). Most of the population is concentrated in big cities (in Suriname, 60% of the population lives in the capital city Paramaribo (Mohren and van Kanten, 2011)). Hence, large parts of the land are uninhabited. One of the reasons for the low population densities is the low agricultural potential. This low potential is caused by the low mineral content in the mother rock and the very high weathering rates that are typical for this kind of humid tropical climate. This leads to a soil that is very acidic and poor to very poor in nutrients (Haden, 1999; Hammond, 2005; Hollowell and Reynolds, 2005). A second cause is the limited access: the infrastructural development is mostly limited to the bigger cities where the largest part of the population lives and the other existing infrastructure is often neglected or was destroyed during civil wars, such as the *Binnenlandse Oorlog* (1986-1992) in Suriname (Buddingh', 2012; Hendrison and de Graaf N.R., 2011). Another possible cause is the low interest from logging companies (until recently). On these poor soils the commercial tree species have smaller statures and smaller diameters and they grow in low densities, resulting in high extraction costs and low profits (Haden, 1999).

Even though it is not as rampant as in the Amazonian rainforest, deforestation and loss of biodiversity are happening in the Guiana Shield. In French Guiana the deforestation rate is assumed to be zero whereas the deforestation rate for the Brazilian parts of the Guiana Shield are estimated on 720,000 ha·yr^{-1} and 202,446 ha·yr^{-1} in Venezuela (Table 2.1) (EcoSecurities Ltd., 2002).

The main threats that will be described in this paragraph have one issue in common: they all illustrate the conflict between economic development and the conservation of forests. A first threat is the transnational timber industry. Until recently there was little interest in these forests but as the Southeast Asian logging companies are depleting forests in their own region, they are starting to shift their attention to yet unexploited forests elsewhere (EcoSecurities

Table 2.1: Summary of the baseline emissions by conversion of forests to pasture for the six Guiana Shield countries (EcoSecurities Ltd., 2002).

Country	Total forest cover (Mha)	% of forest cover of GS region	Average carbon stock ($tC \cdot ha^{-1}$)	Deforest -ation rate ($ha \cdot yr^{-1}$)	Carbon loss per year (Mt C)	CO_2 emissions per year (Mt CO_2)
Guyana	18.1	10.9	171.0	542	0.1	0.3
Brazil	76.0	45.8	125.0	720,000	82.8	303.9
Suriname	14.1	8.5	126.5	n.s	n.s	n.s
French Guiana	7.9	4.8	126.0	n.s	n.s	n.s
Colombia	12.2	7.4	160.0	24,439	3.7	13.5
Venezuela	37.5	22.6	170.0	202,446	32.4	118.9
Total	165.8	100.0	146.4	947,427	118.9	436.5

Ltd., 2002; Funk et al., 2007; Haden, 1999) . The infrastructural development is a second threat. Although this can be regarded as a bonus for the people who live in remote parts, it also leads to deforestation and fragmentation (EcoSecurities Ltd., 2002; Haden, 1999). In Suriname three large road building projects are planned (e.g. between Atjonie and the Brazilian border) which will grant access to previously inaccessible forest. It is predicted 2,000 ha will have to be deforested for this (FAO, 2015). Further, there is the expansion of agriculture, which is population related. It is still mainly restricted to the coastal and the more easily accessible areas, but along with the infrastructural development this will expand. Furthermore, the number and surface area of plantations and commercial agriculture are also increasing (EcoSecurities Ltd., 2002; Funk et al., 2007). In Suriname there are plans to clear marsh forest for sugar cane plantations and to cut 30,000 ha of swamp forests to expand the paddy agriculture (FAO, 2015). In the Guiana Shield the growth rate of the population is also quite high (an average of more than 3.5% increase per year), which leads to an increase in shifting agriculture and in grazing (Cincotta et al., 2000), but this is not a problem for countries such as Suriname and French Guiana as there are still large parts unpopulated. Another threat is (illegal) gold mining as well as the mining of bauxite and diamonds. The consequences or at least the scale of influence will be different for small-scale and large-scale mining but next to deforestation there will also be trophic chain disruption, lowered water quality and siltation, overhunting and biotoxin release (EcoSecurities Ltd., 2002; Funk et al., 2007; Haden, 1999; Hammond et al., 2007). Lastly, (illegal) wildlife trade is a major threat, might lead to biodiversity loss and may lead to the decrease or extinction of some species (van Andel et al., 2003). Other possible but currently less significant threats for Suriname are the possible overharvesting of non-timber forest product (NTFP) and uncontrolled ecotourism

(Funk et al., 2007; Hammond et al., 2007; Olsder, 2004; van Andel et al., 2003). Most of these threats can be averted by a clear regulation (and enforcement) and a balanced consideration of the pros and cons of every activity.

2.2 The forest sector in Suriname

2.2.1 Forest statistics of Suriname

Suriname features, with more than 90% forest cover, one of the highest forest cover indices in the world. The country covers an area of 16,382,000 ha and it is the smallest country in South America (the French overseas territory of French Guiana excluded) (ITTO and FAO, 2011). Around 15,332,000 ha is forest and this can be categorized as high dryland forest (13.3 million ha), high savanna forest or dry evergreen forest (132,000 ha), low savanna forest (18,000 ha), high and low swamp forest (483,000 and 239,000 ha), mangrove forest (100,000 ha) and marsh and ridge forest (468,000 and 35,000 ha) (Blaser et al., 2011; FAO, 2010). The definitions of the forest types used in the classification above can be found in Table 2.2.
94.8% of the forests is primary forest and 0.05% is forest that is naturally regenerated but with clear indications of human activities. Only 13,000 ha is planted forest of which 54% exists of introduced species such as *Eucalyptus globulus* Labill. (Myrtaceae) (FAO, 2010; Forest Legality Alliance, 2016). In 2010 2,192,000 ha (slightly little less than 15%) of the forest area had a conservation status as defined in the Nature Conservation Act of 1952. There is no forest designated as protected forest (as defined in the Forest Management Act of 1992). However, there is 4,500,000 ha (31%) assigned as permanent forest[1] and as production forest (this also includes the 550,000 ha of Community forest) and 7,997,000 ha (54%) as preliminary maintained forest (forest that needs to be preserved until a final designation is decided (Staatsblad van de Republiek Suriname, 1992)) (FAO, 2010).
In 2015 it was estimated that 1,764,3000 ha was allocated for the conservation of biodiversity (forest within nature reserves) and that 1,890,300 ha was allocated as forest area within protected areas (this includes forests within nature reserves, forests within Multiple Use Mangagement Areas (MUMAs) and forest in Brownsberg National Park) (FAO, 2015). The Forest Management Act of 1992 states that all not privately owned land is property of the state. Only 50,000 ha is privately owned (FAO, 2010).

The total growing stock in 2015 (comprised of broadleaved species only) was estimated at 3,815.74 million m^3. This indicates that the used methods did not include some of the coniferous planted forests. The total biomass adds up to 4,203.96 million metric tonnes oven-dry weight with 86% above ground biomass, 12% below ground biomass and around

[1] Forest that needs to be maintained permanently for sustainable logging or collecting NTFP or the persistence of an ecological, protection or recreation function (Staatsblad van de Republiek Suriname, 1992).

Table 2.2: Definitions of the forest types of Suriname as used in FRA 2010 and adapted from Lindeman (FAO, 2010).

Forest type	Definition
High Dryland Forest (Rainforest)	Is a three or four storey forest with emergent trees up to 45 meters. The lower storey reaches 25 to 30 meters and consists of small trees and poles.
High Savannah Forest or Dry Evergreen Forest	Is a two storey forest with a closed canopy reaching 25-30 meters. Big trees are scarce. Palms are few and small. Dominant species are the same as in the rain forest. It is an edaphic forest that occurs on deep white sand.
Low Savannah Forest	This forest does not show any storeys. Height varies from 10-20 meters. This type of forest is very dense, closed and more homogeneous than the previous ones.
High Swamp Forest	These forests are marked by very wet conditions all year round. The shorter the inundation period the more it resembles the rainforest. Is at least 20 meters high with two storeys and is fairly closed.
Low Swamp Forest	This forest is marked by very wet conditions all year round. The shorter the inundation period the more it resembles the rainforest. Varies in physiognomy from open scrub to a low closed forest. Palms and epiphytes are rare. This forest does not have big trees and is poor in species. Low swamp forest which varies from open woodland to single storey 10-15 meter high forest van be found in permanently inundated terrain.
Mangrove Forest	One storey and closed forest. The undergrowth is restricted to ferns. Two types are distinguished: (1) along the coast: *Avicennia germanis* (L.) L. and (2) along major rivers: *Rizophora mangle* L. and patches of *Laguncularia*.
Marsh Forest	This forest is characterized by insufficient drainage, causing seasonal fluctuation in moisture conditions from very dry to very wet.
Ridge Forest	This forest is a two storey forest up to 30 meters and the species composition is comparable with the rainforest with mainly palms in the undergrowth. It growns on sandy ridges.

2% dead wood (FAO, 2015). The mean total carbon stock in the Surinamese forests totals 189.2 tons·ha^{-1} or 694 CO_2-equivalents (tons·ha^{-1}). Most of the carbon is stored in the high dryland forests (215.8 tons·ha^{-1}). In the marsh forests and the low xerophytic forests respectively around 196.8 tons·ha^{-1} and 80.9 tons·ha^{-1} are stored (Crabbe, 2012).

2.2.2 Forest governance in Suriname

History

The forestry sector in Suriname has featured a turbulent history. From 1904 till 1926 there was a first flourishing period with the establishment of the first Forest Service and the harvesting of *balata* rubber from *Manilkara bidentata* (A.DC.) A.Chev. (Sapotaceae). A second prosperous period for the sector started in 1947 with the re-establishment of the Suriname Forest Service (LBB). The way the forests were managed, became an example and role model for the entire Caribbean region. The military coup in 1980 ended this era and destroyed a large part of the infrastructure and equipment. Not only the public sector took a big hit but the private sector did as well, especially with Bruynzeel Wood Company moving towards bankruptcy. Since the establishment of the Foundation for Forest Management and Production Control (SBB), the sector is slowly recovering and shows a promising future. In spite of this, there is still a lot of work to modernize and to maintain a stable and fruitful industry (Hendrison and de Graaf N.R., 2011). However, the employment in the forest industry and the amount of expenditure barely increased since 2005, even though the revenue increased (FAO, 2010, 2015).

Public sector

The Ministry of Physical Planning, Land Management and Forest Policy (RGB) has the responsibility over forests. Other ministries that have some authority over the forests are the Ministry of Natural Resources and the Ministry of Regional Development (Government of Suriname, 2016). The laws that provide the framework for the RGB are based on the Forest Management Act of 1992 which stipulates the rational usage of the forest and treats both the economic factor such as licenses and concessions and the importance of the stabilizing functions of the forests, the Nature conservation Act of 1954 and the Game Act of 1954. The RGB provides direct control of the Foundation for Forest Management and Production (SBB) that enforces the Forest Management Act and has a key role in the management of production forests, the Nature Conservation Division (NB) that enforces the Nature Conservation Act and the Foundation for Nature Conservation (STINASU). There are plans to merge SBB and NB into Forest and Nature Management Authority (BOSNAS) but because of political difficulties and loss of funds that were allocated from the Dutch Development Funds this has not yet been realized (Hendrison and de Graaf N.R., 2011; SBB, 2014).

Future foresters can be trained at the Institute for Natural Resource and Engineering Studies (NATIN), which offers a vocational education in Forestry: Production Systems and in Forestry: Tourism (NATIN, 2016) and at the Anton de Kom University (ADEKUS), which offers a BSc in Agricultural Production Systems and a MSc in Sustainable Management of Natural Resources (ADEKUS, 2016). The Centre for Agricultural Research in Suriname (CELOS), which is an autonomous body in ADEKUS, is a research institute in the fields of agriculture, forestry and biodiversity and has developed the CELOS Management System (Mohren and van Kanten, 2011; Tropenbos, 2004). Other research bodies are those of SBB and NB, the educational institutions and some in the private and civil sector as well.

Private sector

The interest in the Surinamese forests from international logging is growing as the reserves in other timber producing countries are depleting (ITTO and FAO, 2011). The logging companies are represented by the umbrella organization Timber Sector Platform (PHS) that includes the General Suriname Timber Association (ASHU) , the loggers of the Association for Forest Exploiters (ABE) and other organizations such as the Surinamese Business Association (VSB), Association for Surinamese Manufacturers (ASFA) and the Chamber of Commerce and Industry (KKF) (PHS, 2016). The PHS' goals are to develop the forest and timber industry in a sustainable manner with regard to several factors such as the legislation, the technology and environmental concerns in order to increase the well-being of the population of Suriname (PHS, 2016). These stakeholders have meetings with SBB on a regular basis and this gives the private sector a chance to participate in policy making and give constructive feedback. In 2014 there were around 200 loggers and license holders, both companies, private persons and village communities (Mohren and van Kanten, 2011; SBB, 2015; Tropenbos, 2004). Ecotourism is a growing sector in Suriname and there are lots of private tour operators (Orange Travel, Waterproof tours,. . .) and resorts (Berg en dal, Pingpe,. . .), but there is not one single umbrella organization for tourism in Suriname (Tropenbos, 2004).

Civil sector

There are many non-governamental organisations (NGOs) active in the Guianas and in Suriname, so only some of the more important ones will be discussed in this paragraph, such as: World Wildlife Fund Guianas (WWF), Conservation International (CI), the Amazon Conservation Team (ACT) and Tropenbos.

WWF Guianas is an international conservation organization with the mission to conserve biological diversity, ensuring the sustainable use of renewable natural resources and promoting the reduction of pollution and wasteful consumption. It has grant agreements with the NB, SBB and STINASU and helps financing the National Forest Inventory (NFI) but also runs projects about payment for ecosystem services and marine turtle conservation (WWF Guianas, 2016).

CIs mission is ”to conserve ecosystems, biological diversity and the ecological processes that support life on Earth, with special emphasis on building local capacity”. CI is working on protected area managements projects (such as Coronie Freshwater Swamp Protected Area) and the promotion of nature tourism (Conservation International, 2016).

ACT Suriname commits itself to the protection of the Amazonian rainforest through participation and continuous cooperation with the indigenous people of South Suriname. Their projects extend over several branches like biodiversity, health, education and culture (ACT Suriname, 2016).

Tropenbos International Suriname has the objective to increase knowledge in the forest sector to support decision making at policy level and at all management levels and aims at the wise use of the forest, so the country can maintain a high forested and low deforestation status and improving the national living standards (Tropenbos Suriname, 2016).

Other important civil society organizations focus on the forest or forest dependent people such as the Bureau Forum. This is a rural development organization that supports initiatives of residents, specific groups and local organizations through economic strengthening, the provision of basic services and environmental and health services. Other forest people groups are the Association of Indigenous Village Chiefs (VIDS) and the Network of Organizations of Indigenous Women (Bureau Forum, 2016; Tropenbos, 2004).

Importance of the forest sector

Most of the forest-related activities in Suriname are confined to a region that is aptly named the Forestry Belt, a ribbon in the easily accessible region behind the coastal plains that cover about 4.5 million ha with a productive area of 2.5 million ha (Figure 2.3) (Hendrison and de Graaf N.R., 2011). The inaccessibility of the other parts of the country not only protect the forests further inland but also limit the economic importance of the logging industry in that part of the country.

The total roundwood production in Suriname in 2014 was 494,047 m^3, of which 98% belongs to the saw- and veneer log assortment. 246,931 m^3 of wood products are exported (of which 94% is exported to Asia, especially China and India). This accounts for a total revenue of 27,977,965 US$. More details are presented in Tables 2.3 and 2.4. The class A timber species with the highest roundwood production between 2012 and 2014 are *Angelique* (*Dicorynia guianensis* Amshoff (Leguminosae)), *Maçaranduba* (*Manilkara bidentata*), *Quaruba* (*Qualea rosea* Aubl. (Vochysiaceae)), *Amarante* (*Peltogyne paniculata* Benth. (Caesalpiniaceae)) and

Angelim da mata (*Hymenolobium flavum Kleinhoonte* (Leguminosae)) (SBB, 2015). There are between 89 and 120 marketable species in Suriname (SBB, 2000, 2015). 87 sawmills are in operation of which 24 are mobile and there are 91 furniture and carpentry manufacturers (SBB, 2010).

Table 2.3: Import of timber products per assortment in Suriname in 2014 (SBB, 2015).

	Round wood (m^3)	Hewn square pole (m^3)	Letter wood wood (m^3)	Ply wood (m^3)	Sawn wood (m^3)	Finish product (m^3)	Total volume (m^3)	Total value (US$)
Export	208,762	1,903	1,127	27	34,567	545	246,931	27,977,965

Table 2.4: Export of timber products per assortment in Suriname in 2014 (SBB, 2015).

	Fuelwood (kg)	Charcoal (kg)	Particle board (kg)	Fibre board (kg)	Plywood (kg)	Total (kg)	Total value (US$)
Import	22,489	4,331	824,749	1,500,876	1,897,626	4,250,071	2,637,913

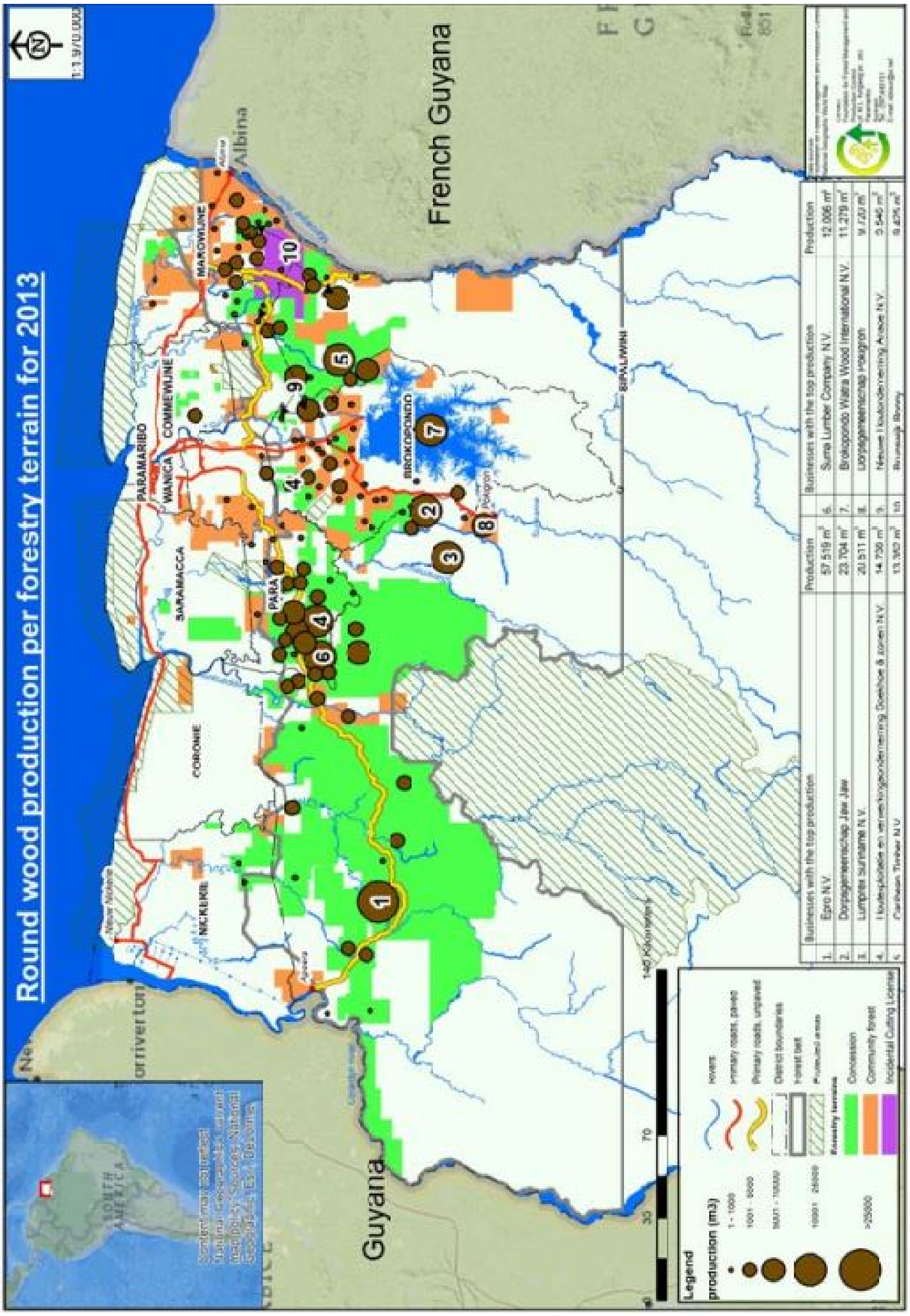

Figure 2.3: Roundwood production map of 2013. The green, orange and purple areas are respectively the concessions, the community forests and the areas with an incidental cutting license. These three types of forestry terrains make up the Forestry Belt, where the majority of forestry activities are executed (RGB and SBB, 2014).

In 2011 the contributions of the logging, timber transport, timber processing and export of timber products to the Gross Domestic Product (GDP) was 1.7% (Bureau voor Statistiek, 2015). This does not account for NTFP and fire wood, so the actual value will be higher (FAO, 2010). The only economically important NTFP is wildlife for export but there are a lot of other NTFPs which are extracted from the forest and these are mostly used in a subsistence way of living (van Andel et al., 2003). The forest sector directly employs 55,000 years full time equivalent (FTE) in 2010 for forest planning, logging and inventorying (FAO, 2010). In 2005 there were 5,000 people employed in the primary production of forests of which 4,750 in the industrial roundwood production and 250 in the non-wood forest production and in the conservation sector (FAO, 2015). It is expected that some of the forest workers will shift to the gold industry because of the increasing gold prices on the global market (the prices climbed until 2013 after which they made a steep drop, but are increasing again since 2016) (FAO, 2015; goldprice.org, 2016). To compensate the shortage of local forest workers and the possible future loss of employees, the logging companies have already been bringing in foreign workers (FAO, 2015).

There is a sizeable amount of forest people present in Suriname. These are people who live in or near the forests and developed life styles in tune with their surroundings, and use the forests in their day to day life. In Suriname, two groups are distinguished: (1) the indigenous people or Amerindians, who live in 51 different villages and can be divided in the Kaliña, the Lokono, the Wayana and the Trio, and who comprise about 4% (± 20,000 persons) of the total population of Suriname and (2) the Maroons, who exists out of six tribes: the Saramaka, the N'djuka, the Matawai, the Kwinti, the Aluku and the Paramaka. They total to around 117,500 persons according to a 2012 census, or 21% of the population (Forest Peoples Programme et al., 2015). Hence more than 25% of the Surinamese people are dependent of the forest in one way or another. The rights they claim on their ancestral lands are not recognized in Suriname and there are no legal provisions that recognize or protect them to own or control their traditional resources. The only mechanism that is used in Suriname, is a preferential treatment for wood cutting licences in their ancestral regions (Forest Peoples Programme et al., 2015; Haden, 1999). However in November 2015 the Kaliña and Lokono people won a case in court concerning three nature reserves in the Lower Marowijne region that both the conservation of the natural areas and their resources and the protection of the rights of the indigenous and tribal people are compatible. Hence an effective participation, access and use and the possibility of obtaining benefits from conservation should be granted to the Kaliña and Lokono peoples provided they are compatible with the protection and sustainable use of the nature reserves (American Court of Human Rights, 2015).

Forest inventory in Suriname

In the past several forest inventories have been conducted in Suriname. However, most of them were restricted to the more easily accessible forest belt in Northern Suriname. A series of inventories were done by Food and Agricultural Organisation (FAO) in 1974 whereby three large areas (Fallawatra, Kabalebo and Nassau) were surveyed and a total of 9,120 circular plots of 0.04 ha were assessed (growing stock, forest types) (FAO, 2010). There also have been a few greenhouse gas emission inventories, conducted from 1995 on, observing the Intergovernemental Panel on Climate Change (IPCC) guidelines, but they were often based on incomplete data (mostly due to the inaccessibility of the forests and the absence or discontinuity of collected data) (NIMOS, 2005). Other inventories that are worth mentioning are the Kabo experiments 78/5 and 82/2 that were started in 1979 and 1983. The 78/5 experiment was revisited in 2000 and 2010 (Ter Steege et al., 2000). In 2010 36 permanent plots of 50x100 m^2 were placed in the Forestry Belt to make an assessment on carbon (Crabbe, 2012). There was also an inventory on commercial NTFPs for the Guiana Shield (van Andel et al., 2003).

In 2013 a pilot project for the National Forest Inventory was set up by SBB. The sampling design is based on a 20x20 km^2 systematic grid that covers the entire country. Along the gridlines, in a north-south direction, aerial photographs are obtained. The aerial Sampling Units (SUa) have a size of 750x750 m^2, since this is the minimum width for most of the aerial photographs. The field sampling units consist of 8 plots (Principle Sample Plots (PSP)) of 100x20 m^2 that will form a cross. Each of these plots is further divided in 20 Main Assessment Plots (MAPs) of 10x10 m^2 and there are two subplots of 5x5 m^2 form the measurements of regeneration and lying dead wood (Figure 2.4). Trees with a diameter at breast height (dbh) $\geq$ 20 cm and standing dead trees with a dbh $\geq$ 10 cm are measured for the entire plot, while lianas and palm trees will be measured in four MAPs and pole trees will be measured in two plots. The project is still in its pilot phase and there are possibilities for adaptions in the plan, so that efficiency can be increased and costs can be lowered (SBB and ANRICA, 2014). The PSP that are already inventoried can be found in Figure 2.5.

Next to the National Forest Inventory, there are other forest monitoring projects such as the Forest Cover Map created in 2010, the 'Monitoring deforestation, logging and land use change in the Pan Amazonian Forest' with Amazon Cooperation Treaty Organisation (ACTO) and LogPro that tracks where trees are felled and to where they are transported and exported (FAO, 2010).

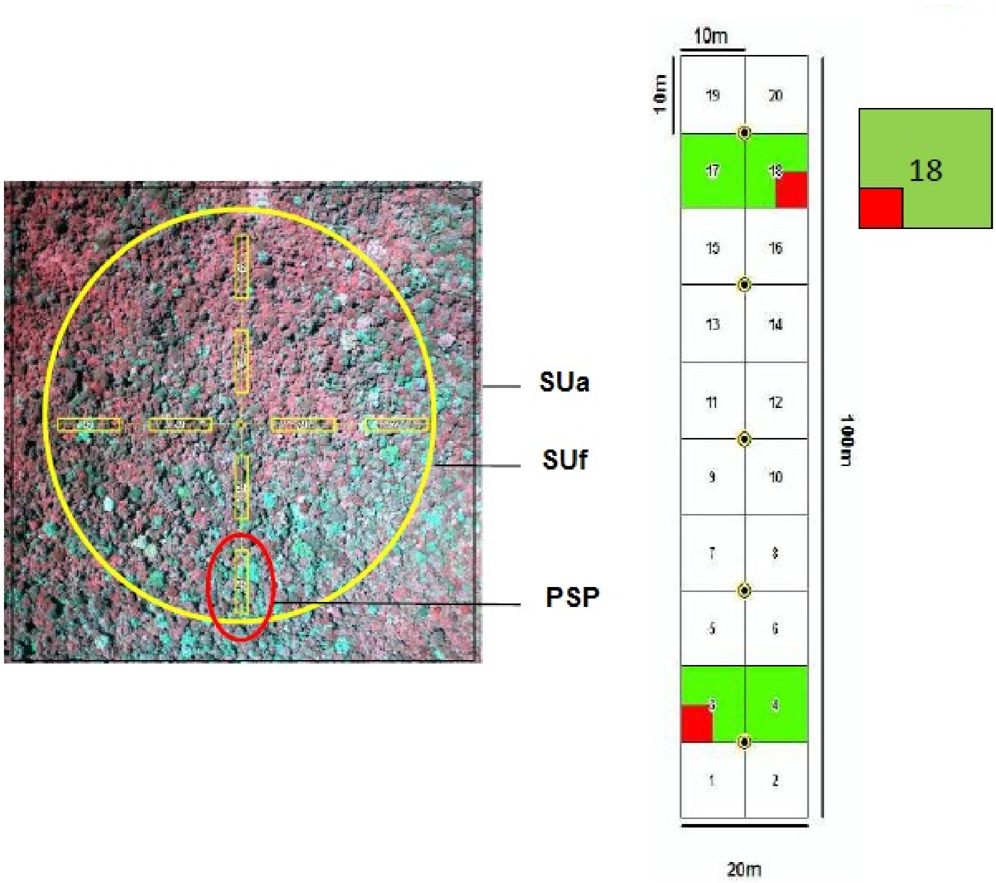

Figure 2.4: Left: Layout of the standard SUf (the SU established in the field). Right: Layout of a Principle Sample Plot (100 x 20 m^2) with 20 MAPs (10x10 m^2) (SBB and ANRICA, 2014).

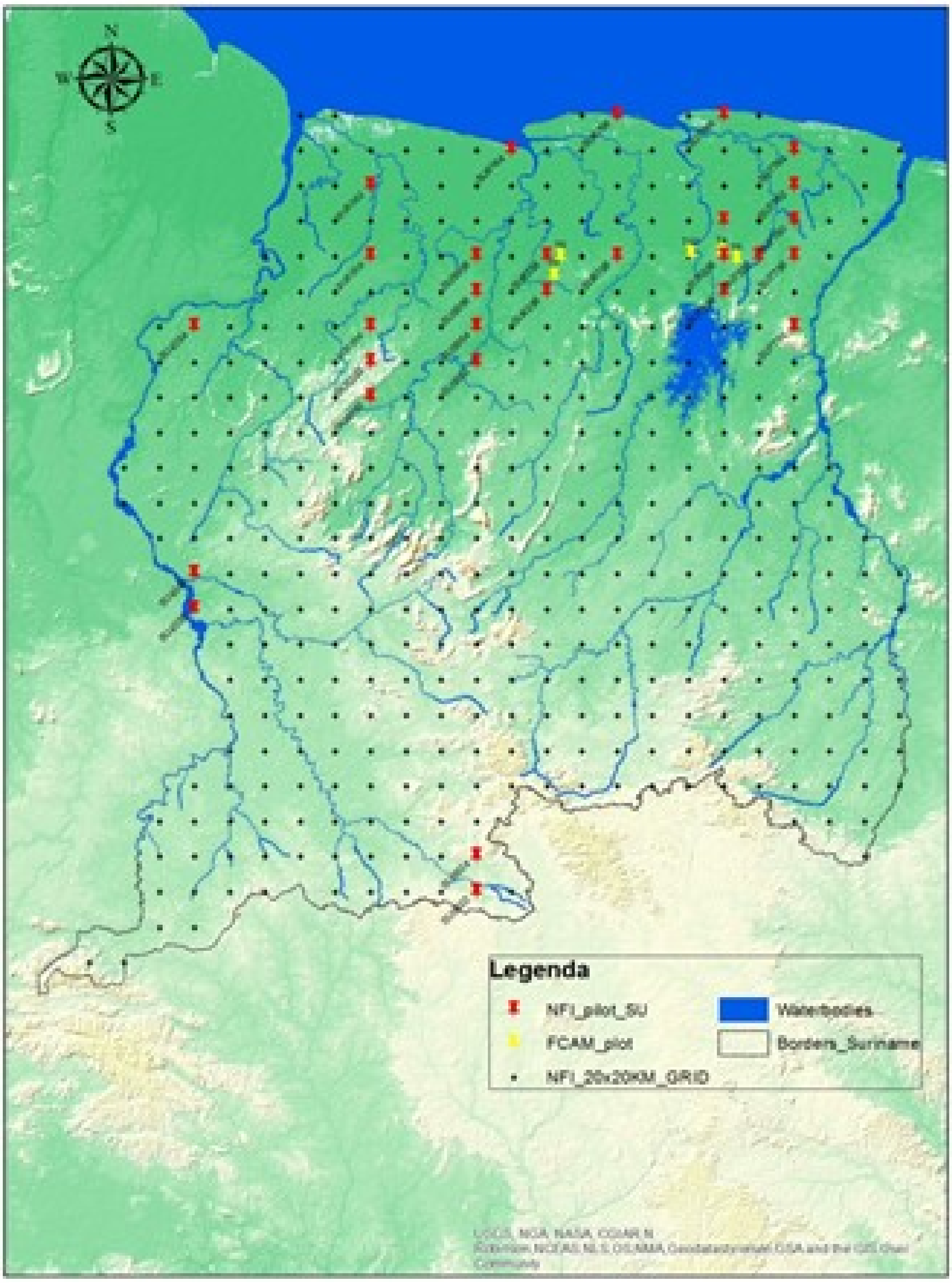

Figure 2.5: Sampling Units already visited in 2015 by SBB for the National Forest Inventory (SBB and ANRICA, 2014).

2.3 The swamp forests of Suriname

There are many different forest types in Suriname but they can roughly be divided in three groups that more or less coincide with the physiographic regions: (1) the hydrophytic forests in the coastal area (3 and 4 on Figure 2.6), (2) the xerophytic savanna forests in the savanna belt (3 on Figure 2.6) and (3) the mostly mesophytic moist forest types (in region 1 on Figure 2.6) (Blaser et al., 2011). The hydrophytic group is composed of (high and low) swamp forest, ridge and marsh forest and mangroves. The focus in this thesis will be on the first three types, those belonging to the edaphic fresh water ecosytems. The total area occupied by these types is estimated to be around 1,225,000 ha or around 8% of the forest area (FAO, 2010). They all have the following features in common: the soils are hydromorphic, they are at least temporally inundated with fresh water or have very high water tables (FAO, 2010; Groombridge et al., 1992). All these forests can be found in the low lying coastal plain, shattered between other forest types (WWF, 2012). This coastal plain can be divided into two zones (2.6): (1) the old coastal plain with elevations between 4 and 12 m and marine Pleistocene swamp clays and sand ridges and (2) the young coastal plain with elevations between 0 and 4 m and Holocene swamp clays (Mittermeier et al., 1990).

All these edaphic factors lead to forests that are unique forests in respect of its specific flora and fauna. Because even the slightest variation in inundation time, inundation depth, microtopography or soil composition will be limiting or enabling the species (Koponen et al., 2004), there is a need to propose a more thorough classification. The many different classifications for wet or hydrophytic forest types proposed for this region (the Guianas or South America and the Caribbean) illustrate how difficult it is to define different types. Most of the classifications are based on the duration of the inundation in combination with the floristic composition (de Granville, 1988).

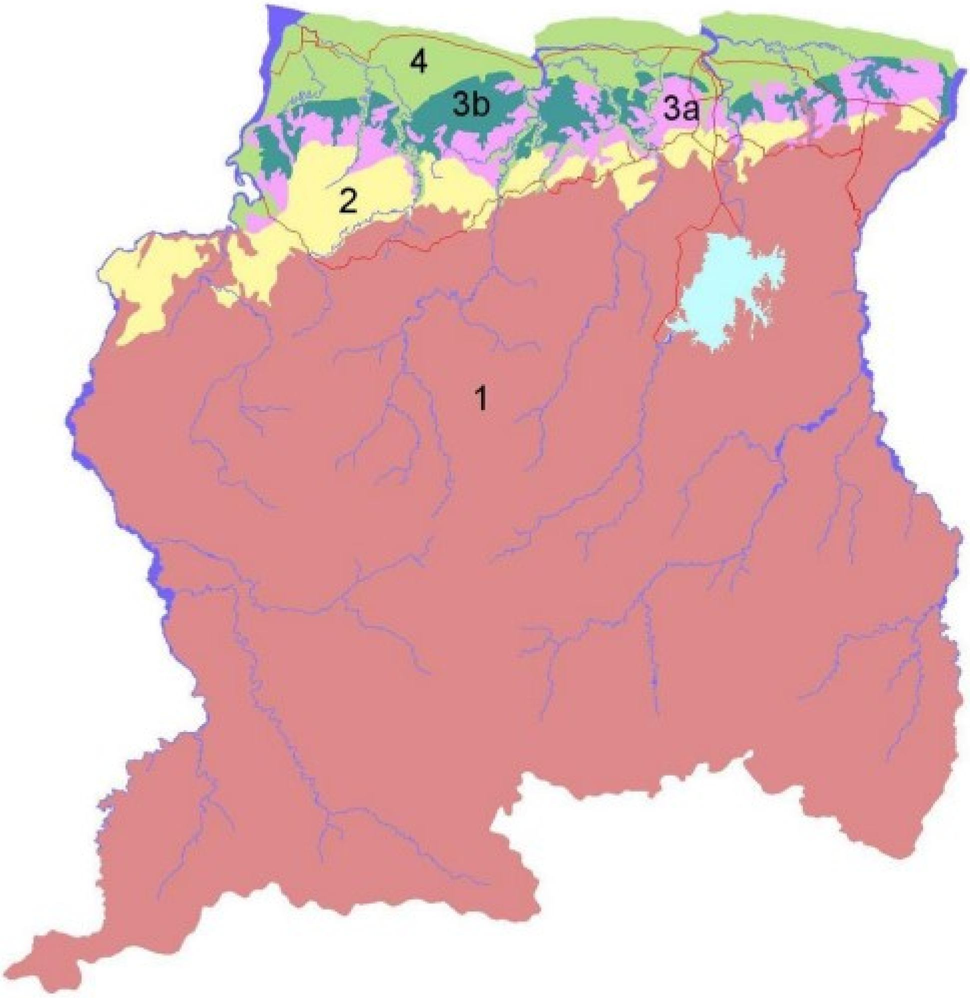

Figure 2.6: Map of Suriname with the physiographic regions. 1) Precambrian Guiana Shield area, popularly also known as the Interior, the Interior Uplands, or the Hill and Mountain Land; 2) Cover landscape; also known as Zanderij or Savanna Belt (Late Tertiary); 3) The Old Coastal Plain: a. Old ridges and sea clay flats (Pleistocene) b. Swamps (Early Holocene); 4) Young Coastal Plain (Late Holocene) (ATM, 2013).

The Ramsar Convention defined wetlands as "areas of marsh, fen, peatland or water whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Groombridge et al., 1992). In (Groombridge et al., 1992) the definition for swamp was "forested freshwater wetlands on waterlogged or inundated soils where little or no peat accumulation occurs" and for marsh it was "herbaceous mires with vegetation commonly dominated by grasses, sedges or reeds. They may be either permanent or seasonal.

Salt marshes have been excluded" (Groombridge et al., 1992). These definitions immediately illustrate a big difference in nomenclature with the definitions used in Table 2.2.

Beard (1944) made one of the first vegetation classifications important for the Guianas (and tropical America) and he did this by classifying the forests in five different formation series, based on habitats and successional relations. The "swamp" series (Figure 2.7 is the habitat type where the soil never absolutely dries out: the soil is (nearly) year-round inundated or waterlogged. It was further divided in a "brackish water" formation (with mangrove woodland) and into a fresh water formation. This one was divided in (1) swamp forest: a single story forest between 20 and 30 meters high, often with pure stands and root specializations, (2) palm swamp: a transition from forest to herbaceous, dominated by palms and (3) herbaceous swamp. Another series of interest is the marsh or seasonal swamp series (Figure 2.8) where habitat types with seasonally waterlogged or inundated soils that occasionally dry out can be found. In this series the next four formations can be found: (1) marsh forest: a forest of about 25 m height and with two stories and a large number of palms, (2) marsh woodland: a low woodland with trees with small dimensions, (3) palm and (4) savanna (Beard, 1944, 1955).

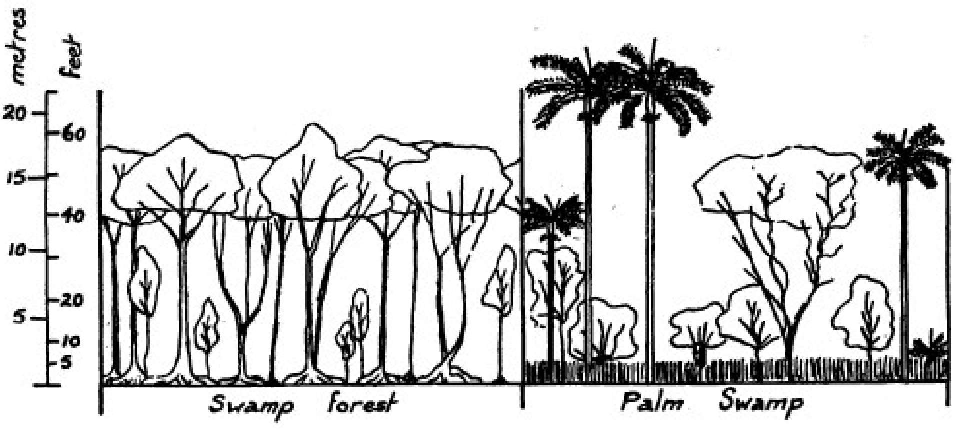

Figure 2.7: Profile diagrams of swamp formations. Swamp forest from measurements, Oropoucge, Trinidad; palm swamp from a photograph, the Nariva Swamp, Trinidad (Beard, 1944).

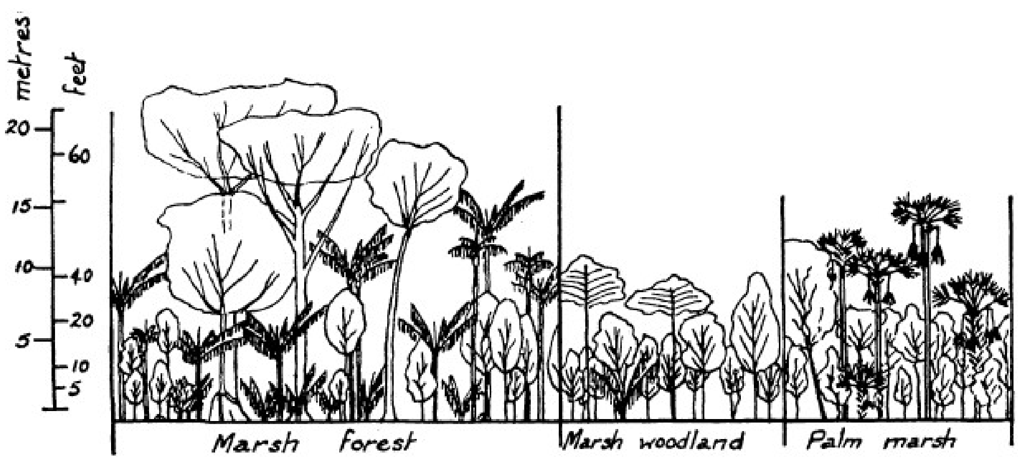

Figure 2.8: Profile diagrams of marsh formations. Marsh forest measured at the Long Stretch, Trinidad; marsh woodland after Charter; palm marsh from a photograph at the Aripo savanna, Trinidad (Beard, 1944).

In the 1950s Lindeman (1952) and Lindeman and Moolenaar (1959) researched the vegetations of northern Suriname and proposed their own classification. For their "wet vegetation types" they used the term marsh (rather than seasonal swamp) in imitation of Beard. The types they proposed were: (1) mangrove forest, (2) open swamps, (3) swamp wood, (4) swamp forest and (5) marsh forest. Swamp woods vary from scrub to a low, one-storey forest with a maximum height of 15 m, and are mainly found in the young coastal plains and consist out of species like *Pterocarpus officinalis* Jacq. (Leguminosae), *Tabebuia insignis* (Miq.) Sandwith (Bignoniaceae), *Triplaris weigeltiana* (Reichenbach) Kuntze (Polygonaceae) and *Annona glabra* L. (Annonaceae). Swamp forests are two-storey forests with heights between 18 and 30 m and include such species as *Euterpe oleracea* Mart. (Arecaceae), *Virola surinamensis* (Rolander) Warb. (Myristaceae), *Symphonia globulifera* L.fil. (Clusiaceae), *Tabebuia insignis*, *Pterocarpus officinalis* and *Triplaris weigeltiana*. The marsh forests are characterized by having two storeys and an irregular canopy between 15 and 30 m high. Common tree species are *Euterpe oleracea*, *Attalea maripa* (Aubl.) Mart. (Arecaceae), *Carapa* spp. (Meliaceae), *Eschweilera* spp. (Lecythidaceae), *Copaifera guyanensis* Desf. (Leguminosae) and *Hura crepitans* L. (Euphorbiaceae).

Other important classifications have been proposed by Fanshawe (1952) for Guyana, by Vann (1959) for the Guianan coastal plain and by Prance (1979) for the Guianas.
As can be seen in Table 2.5 the subdivisions based on plant communities vary wildly and this might give the impression that the communities are incomparable and incompatible but this is not the case (Bacon, 1990).

Table 2.5: The inundated forest types in the Guianas according to different authors, after de Granville (1988).

Beard (1944); Fanshawe (1952)	Lindeman (1952)	Prance (1979)
A. Marsh forest	A. Marsh forest	A. Periodically flooded forests
1.Palm marsh forest	1. *Triplaris weigeltiana-Bonafousia tetrastachya* type	1. Mangrove forests
2. Marsh forest	2. *Symphonia globulifera* type	2. Tidal swamp forest (tidal varzea)
3. Marsh woodland	3. *Hura crepitans* forest	3. Seasonal swamp forest (seasonal varzea)
4. Palm marsh	4.*Mauritia-Chrysobalanus* association	4. Flood plain forest
B. Swamp forest	B. Swamp forest	B. Permanent swamp forest
1. *Mora* forest	1. Mixed swamp wood	
2. Swamp forest	2. *Machaerium lunatum* scrub	
3. Swamp woodland		
4. Mangrove forest		
		C. Gallery forests

Even though these freshwater swamps and marshes generally have a lower floristic diversity than *terra firme* ecosystems (Koponen et al., 2004), it still harbours a great variety of plants, birds, fish, insects and mammals. Some of the more vulnerable species that live in these habitats are the jaguar (*Panthera onca*), baboonwood (*Virola surinamensis*), the agami heron (*Agami agami*), the Guiana spider monkey (*Ateles paniscus*) and the Guianan streaked antwren (*Myrmotherula surinamensis*) (Fearnside et al., 1996; IUCN, 2016).

Up to 80% of the Surinamese population lives in or near the coastal region, that includes the biggest share of the logging operations (in the Forestry Belt), agriculture and infrastructure as well. The human induced pressures are the largest in this region (Fearnside et al., 1996). When the Dutch colonized Suriname, they started to impolder the more fertile swamp clay lands to use for agriculture and to build dykes for impoldering and improved drainage of the area. These practices have continued into present day and are a threat to the swamp forests (67). In the western part of the country lots of paddy rice fields have already replaced the swamp forests and another 30,000 ha of swamp forest is planned (FAO, 2015) to be cut down in favour of paddy agriculture as well as 1,500 ha of marsh forest in favour of sugar cane (FAO, 2015).

CHAPTER 3

Material and methods

3.1 Study site

General

The study was conducted in the northeastern part of Suriname, more specific in the Marowijne district, between Perica and Moengo (between 5° 45' 51" N, 54° 36' 3" W and 5° 29' 10" N, 54° 28' 32" W) and has an area of about 44,000 ha (Figure 3.1). The Cottica river and its tributaries can be found in the area. The *Oost-Westverbinding* and a road between Perica and Agiti-Ondro also cut through the landscape.

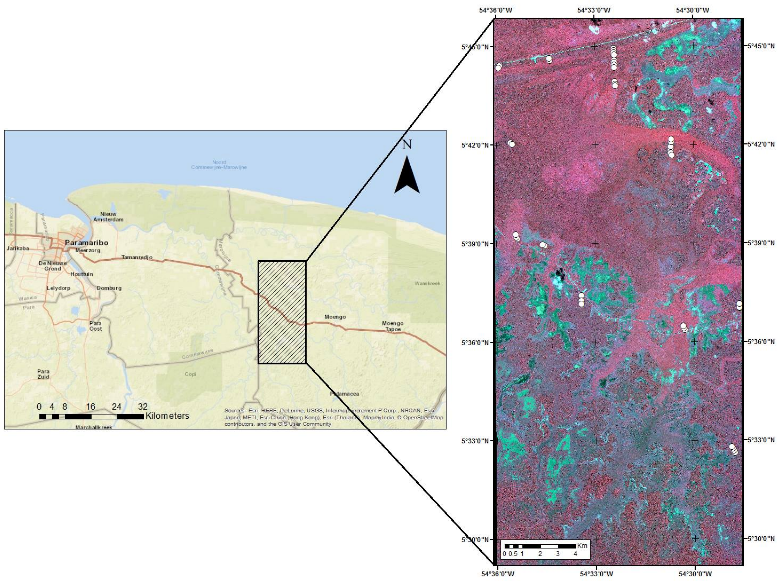

Figure 3.1: Left: positioning of the study area on the eastern coastal plain of Suriname. Right: false colour composite (G-R-IR) of the study area.

Although no villages can be found in this area, some small settlements exist along the *Oost-westverbinding*. The closest city is Moengo (established because of the bauxite industry (Buddingh', 2012)), less than 10 km from the eastern border of the study area. Other villages in the close proximity are Perica, Akalikondre, Damptapoe and Ricanau Moffo. The inhabitants of these villages use the forests that were researched for this study for hunting, gathering of food and medicinal purposes and agriculture (Figure 3.2). There is the communal forest for Kraboe-Olo and there are several communal wood-cutting permits, which are obtained by the chief of the village but are meant to permit access to the whole village, for the villages of Rikanau Moffo, Abadoekondre, Morakondre, Manjabon, Lantiwei and Agiti-Ondro. One concession and one incidental cutting license terrain are partly located inside the study area as well as a reserve belonging to LBB (RGB, 2015).

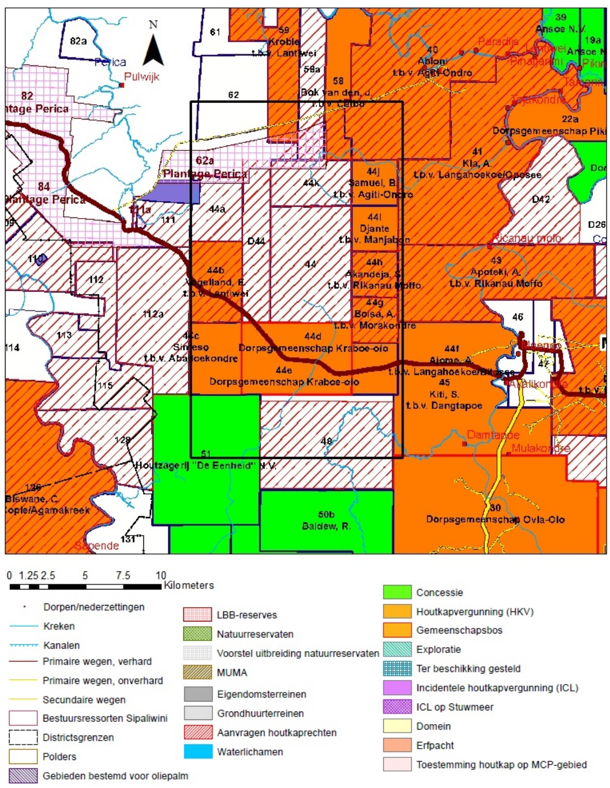

Figure 3.2: The 2015 logging rights map for the study area. Green areas are concessions, orange areas are communal wood-cutting permits or community forests, diagonally red shaded areas are requests for wood-cutting privileges whereas square red shaded areas coincide with LBB reserves and the purple areas are incidental cutting licenses (RGB, 2015).

Climate

The climate of the region is tropical, hot (average temperature of 26.6°C) and humid (a mean annual precipitation of 2,348 mm) which corresponds to Af following the Köppen classification. There is no dry season in the strict sense of the word but there are two less wet seasons: (1) a short one in February and March and (2) a longer one from August till November. The annual variation of the temperature is 2.1°C with September as the hottest month and February as the coldest month (Figure 3.3) (climate data.org, 2016).

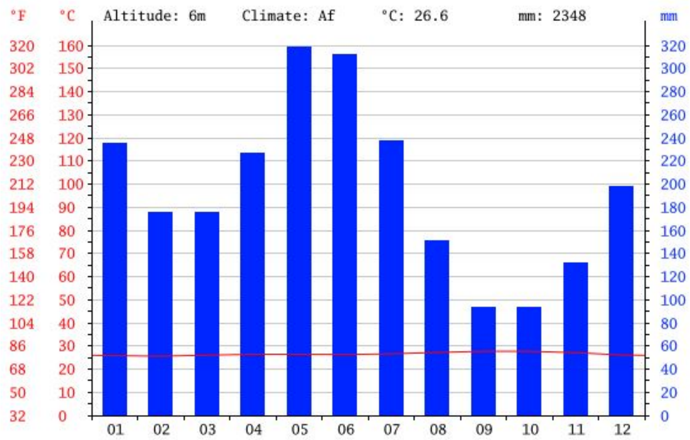

Figure 3.3: Climate diagram from Moengo, the closest city to the study area (climate data.org, 2016)

Soil types

The study area can be found on the coastal plain with an altitude between 0 and 4 m asl and has ridge soils with fine sand and sandy loam or with sandy loam and very fine sand over clay and both ripe and unripe swamp clay soils with or without a peat layer. The swamp soils (purple in Figure 3.4) are submerged yearlong or at least for the greater part of the year. There is a very poor drainage and because of this there is an accumulation of organic material. This mineralizes slowly and forms peat (in Suriname known as *pegasse*). The fine sandy ridge soils (orange in Figure 3.4) are mostly dry year round and are well drained on the higher parts (which rise up to 4 m above the surrounding swamps) and imperfectly drained in the lower parts. In these lower parts the iron compounds leach out and there is slow podzolization while in the higher parts there is a relative enrichment of ferri-oxides. The swamp soils that can be found in between the ridges (green in Figure 3.4) resemble the previously mentioned swamp soils a lot and are also very poorly drained and are rich in organic material. However the upper soils may be somewhat more sandy. The plateau soils that can be found more landward are relatively poorly drained but are dry most of the year (Van der Eyk, 1957).

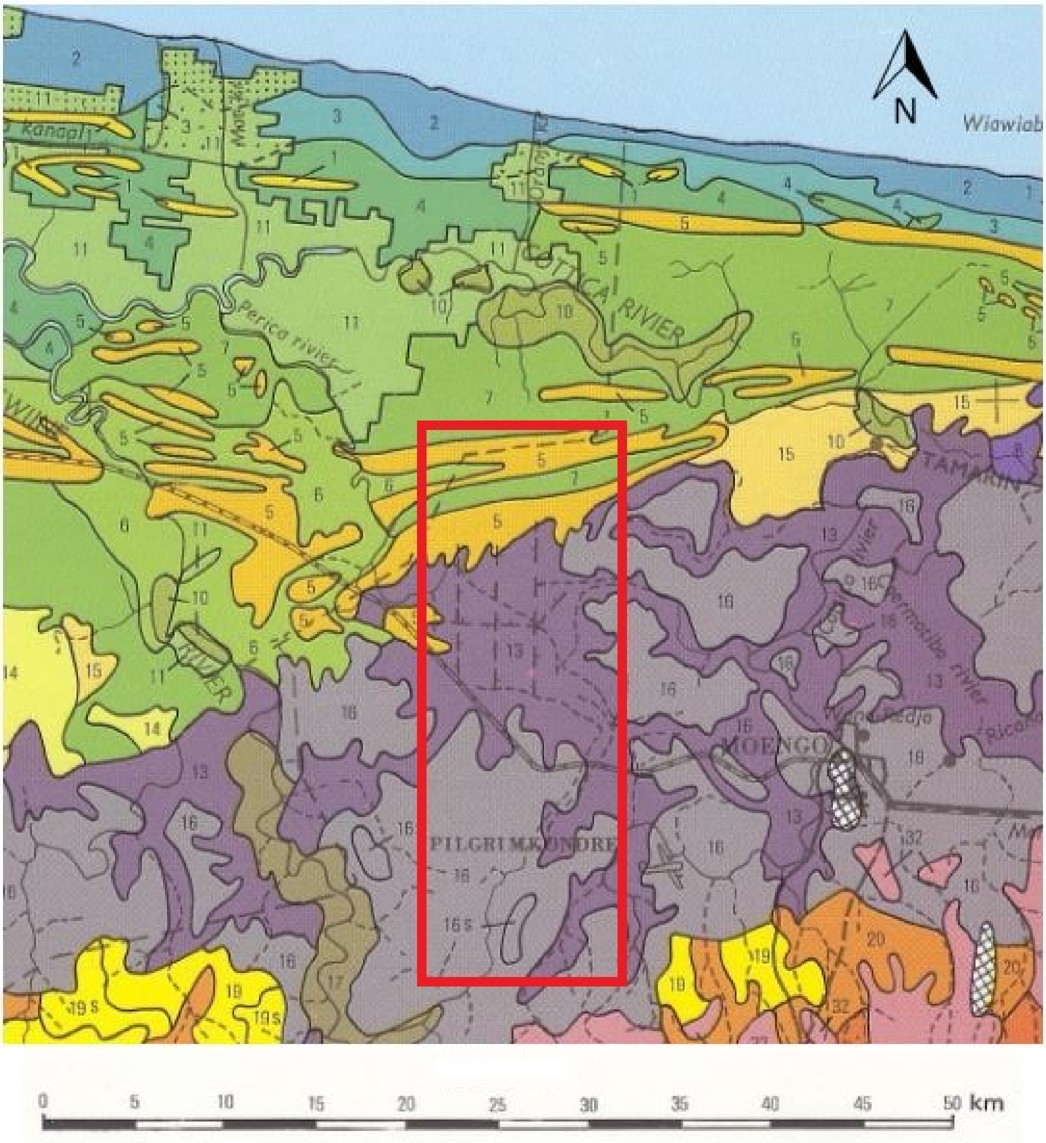

Figure 3.4: Detail of the Reconaissance Soil Map of Northeastern Suriname. The study area can be found inside the red rectangle. Legend of soil types inside study area: 5 (orange): Ridge soils with (loamy very) fine sand, and sometimes sandy loam. 6 (green): Nearly ripe swamp clay soils, mostly desalinized to more than 2 m depth, sometimes with loamy topsoil (and often has a (thin) peat layer). 13 (dark purple): Unripe & practically unripe mostly pyritic swamp clay soils, often with a thick peat cover. 16 (light purple): Plateau soils with silt loam and silty clay loam over stiff (silty) clay (Van der Eyk, 1957).

3.2 Field inventory

3.2.1 Selection of sampling plots

Preparatory work

For the preparatory work IKONOS images of the study area which were obtained on October, 16th 2009 were used. These images comprised 4 multi-spectral bands (blue, green, red and infra-red) with a spatial resolution of 1 m and 1 panchromatic image with a spatial resolution of 0.4 m. The images were orthorectified with as coordinate system UTM zone 21N (ellipsoid WGS84). The original size of the images was 3,502x11,313 pixels but the bottom part of the image was eliminated since this area is located outside the area that is the focus of this study. An image with a size of 3,502x7,676 pixels remained. An unsupervised classification using a histogram peak selection technique was made in IDRISI Selva. In this technique, the midpoint between two peaks of the histograms are used as line of demarcation between clusters. This lead to an image with 11 clusters. Preliminary visual interpretation of the image already led to a few conclusions. Three major forest clusters and one linked to cloud cover could already been discerned (Figure A.1).

Sampling issues

One of the issues encountered while setting up the experiment is the lack of a ready-made or universal method to characterize these types of forests in a simple, fast and efficient way. Most of the plots for sampling forests and for complete inventories are often 1 ha. This size is infeasible, and not relevant for the purpose of this study.
A second issue was a lack of knowledge, for both the forest type and the region. The lack of knowledge about swamp forests in the Guyanas and the previous issues are actually a main driver to conduct the research in this study. At the same time they represent both the reasons for this masterthesis, but the lack of knowledge about the region and its accessibility were a problem for the experimental set-up.

3.2.2 Inventory protocol

General information

The composition of the field team differed slightly every week but basically it consisted of:

- An experienced expedition leader who helped organizing the day trips
- A tree expert who identified the tree species
- Students who took measurements and determined the locations of the sample plots

- A local guide who had knowledge of the region and helped assessing accessibility
- A cook

Timing

There were 29 field days between August, 24th and October, 9th 2015 and these were divided over 6 weeks from Monday till Friday.

Plot layout

The plots were laid out in transects along straight lines. Originally the accessibility of the forest and the time needed to perform the measurements were underestimated and it was initially thought possible to cover one transect with more than 6 sample plots per week.
After a preliminary expedition day and consulting with locals, it became clear that the water level was too high in many places and that there was a need to return to a base camp every night. So it was decided to make transects of a minimum of 2 plots (which are 100 m apart from each other) and if field conditions (the travel time, the presence and condition of forest,. . .) permitted it, these transects would be extended. The locations of the transects were set via the preliminary classification of the satellite images and the estimated accessibility (roads, rivers, creeks,. . .). Care was taken to spread the transects out as widely as possible, and to divide them over the different clusters. It soon became clear that some of the clusters on the classified satellite image represented open or herbaceous swamps that were nearly impossible to traverse as well as being less relevant to this study. Therefore the transects were chosen in accessible locations, in clusters that appeared to be relevant and on places that people with local field knowledge indicated as swamp forests.
The dimensions of the plots were originally set at 50x10 m^2 (Koponen et al., 2004). Following the advice of Sarah Crabbe (officer at SBB), this was changed to 50x20 m^2, since this would give a better representation of the diversity and it is also the width adopted by the SBB for their NFI (SBB and ANRICA, 2014). After the first week, the length was shortened to 25 m due to time issues. It took too long to finish up one plot compared to the total available time and the tree species composition of the first five plots (that were measured for the dimensions 50x20 m^2) indicated that the reduction would not have a big influence on the species composition recorded in the plot since most of them were dominated by only a few species. Edge trees whose centre (the measured distance from the transect line summed with the radius of the tree) could be found inside the 10 m distance from the transect line were retained while edge trees whose centre lay outside the 10 m distance from the transect line were discarded.

Figure 3.5: Left: the poles used to set out a transect and used for location measurements. Right: stem slash method for tree species identification.

Tree species field identification

Tree species were identified by qualified tree experts (who are affiliated with CELOS or SBB) by using a combination of stem slashing and the observation of the leaves, bark and, if present, flowers and fruits. This was done to species level if possible and otherwise till genus level. The vernacular names were used.

Measurements

The dbh (at 1.3 m) was measured for every tree with a fabric metric diameter tape from Forest Suppliers inc. with a millimetre subdivision. Trees with a diameter smaller than 10 cm were not recorded. If it was impossible to measure the dbh (due to buttress roots, inaccessibility, presence of termites (Isoptera), . . .) a Criterion RD 1000 (Laser Technology, Inc.) was used. The accuracy of these diameter measurements is ± 6 mm and ± 0.1° for the inclination.

For every tree with a dbh ≥ 10 cm, and if visibility allowed it, the height till the first branch and the total height were measured. For this the TruPulse 360°R (Laser Technology, inc.) was used. The target quality has an influence on the accuracy of the measurements. This quality depends on the colour of the target, the angle and the lighting conditions. When a high quality target is achieved this will result in a measurement that has one decimal place and an accuracy of ± 30 cm. A low quality target will result in a whole number and an accuracy of ± 1 m. There was always sought after a high quality target. For the measurements of inclination there is a ± 0.25° accuracy.

Garmin GPSMap 62st was used to navigate and measure the coordinates of the plots. This was done at the beginning, the centre and the end of the sampling line. To determine the locations of the trees TruPulse 360°R (Laser Technology, inc.) was used to measure distances. The distance from the tree to the transect line was measured and the distance from the perpendicular projection of the tree on the transect to the start point of the plot. This resulted in the relative coordinates for every tree in the plot. All trees in a cluster of *Euterpe oleracea* were assigned the same coordinates.

3.3 Data preparation

3.3.1 Tree species identification

Because the tree experts used vernacular names, the names had to be translated to the scientific names. This was done by using a list provided by the tree experts. This list can also be found in Crabbe (2012). To double check that the correct species was assigned to each vernacular name, they were verified by using the wood species list from SBB and the index of vernacular plant names of Suriname by van't Klooster et al. (2003). Before assigning the scientific name to a vernacular name, the scientific names were also verified by using the Catalogue of Life, so the latest accepted names are used (Roskov et al., 2016). A complete list of the tree species and their vernacular names can be found in Appendix B.

3.3.2 Forest type

To assign the plots to a forest type to optimize the data processing the Reconnaissance map for the Lowland Ecosystems in Coastal Suriname by Teunissen (1978) was used. This map was compiled by stereoscopic interpretation of 2,200 aerial photographs (obtained between 1971 and 1973) and three years of fieldwork in which 36 key areas were visited. In these key areas 500 field and soil surveys were done. The vegetation surveys were grouped into habitat types based on the physiognomy, the kinship between species composition, the landscape and the soil type present (Teunissen, 2016). The forest type for every plot was determined by locating the plots on the map and by comparing the tree species composition of the measured plots with the tree species frequency tables that were used to compile the map by Teunissen (Teunissen, 1980).

3.3.3 Tree coordinates and missing heights

In every plot, the relative coordinates were determined for every tree. Since the measured distance was to the visible front of the tree, the radius was added to the measured distance so coordinates would correspond to the centre of the tree.
The heights of the trees that were not visible in the field were calculated by using the allometric diameter height model proposed by Chave et al. (2014). In this the environmental stress factor is used together with the diameter of the tree. The environmental stress factor is computed from an allometric relation which takes the temperature seasonality, long-term climatic water deficit and precipitation seasonality into account. The stress factor was obtained from raster files supplementary to Chave et al. (2014).

3.3.4 Wood density and above ground biomass

Since no wood densities were measured, the DRYAD wood density database (Zanne et al., 2009) was used. The wood density values were determined by using the mean value in DRYAD for the species of which the density was measured in the same region (tropical South America) if there was a match on species level. If only the genus level matched an analogous procedure was followed by calculating the mean wood density value of the wood densities of specimen of that genus that were recorded in the same region as our study. According to Chave et al. (2009) the genus-level average gives a good approximation, except for hypervariable genera.
When the wood densities were obtained, the aboveground biomass (AGB) was calculated using the allometric model proposed by Chave et al. (2014), who found that the form factor (AGB$\cdot$ $((\rho D^2 H)^{-1}$, with ρ the wood density, D the dbh and H the tree height)) varies only weakly across vegetation types and that this model is a good estimator when more local models are lacking (Chave et al., 2014).

3.4 Data processing and statistical analysis

3.4.1 General approach

To evaluate the obtained data and to characterize the study area, the following approach was used: the forest structure is divided into three aspects: (1) species diversity, (2) spatial distribution and (3) variations in tree dimensions (Albert and von Gadow, 1998; Gadow, 1999; Pommerening, 2002). Though this approach was not developed for tropical forests, it is sufficiently generic for application.

The different forest types were tested for significant differences by applying the non-parametric Kruskal-Wallis test followed by the post-hoc Mann-Whitney-Wilcoxon two-sample test. Non-parametric tests are used as it is not known if the all obtained data follows the normal distribution curve (Nayak et al., 2011).

For all analyses R, an open source programming software was used. For the analysis of the species composition and diversity the packages vegan (Oksanen et al., 2016), sciplot (Morales et al., 2012), mvabund (Wang et al., 2016) and corrplot (Wei and Simko, 2016) were used while the package spatstat (Baddeley and Turner, 2005) was used for the spatial distribution analysis and the analysis of the variations in tree dimensions.

3.4.2 Species composition and diversity

The following calculations were done on both plot level and forest type level. For every plot the number of species were determined as well as the abundancies, dominance and frequencies of the tree species present. Furthermore, the Importance Value Index (IVI) for every species was calculated according to the formulas in Table 3.1. This not only takes the frequency of a tree species into account but also its relative dominance and relative density and thus portraying a more representative image of the importance of a species in a forest (van Andel, 2003; de Pádua Teixeira et al., 2011).

Table 3.1: The formulas used to calculate the Importance Value Index.

Name	Symbol	Formula
Relative dominance	*Rdom*	$\frac{totalbasalareaoforaspecies}{totalbasalareaforallspecies} * 100\%$
Relative density	*Rdens*	$\frac{numberofindividualsofaspecies}{totalnumberofindividuals} * 100\%$
Relative frequency	*Rfreq*	$\frac{frequencyofaspecies}{sumoffrequenciesofallspecies} * 100\%$
Importance Value Index	*IVI*	$Rdom + Rden + Rfreq$

To ensure the species richness on plot level is comparable (as different plot sizes are used and different numbers of measured trees are recorded), a rarefied number of species was calculated. This generates the expected number of species when drawn at random from a larger population. They were rarefied to the lowest observed number of trees (14, plot x, type y) (Chao et al., 2014; Gotelli and Colwell, 2001). Simpsons index was used as a diversity index since it has a low sensitivity to sample size. Rather than providing a measure of species richness (which has already been calculated by rarefaction), this index is weighted towards the abundances of the most common species, which is suited for this experiment since it aims to quantify the main characteristics (Magurran, 1988). Furthermore, the evenness was determined by using Pielous evenness, based on the Shannon index. Even though the total number of species has to be known, this is a popular measure (Peet, 1974). Since the Shannon index is often used and it is also used to calculate the eveness, it was calculated as well, to facilitate the comparability to results reported in literature (Infante Mata et al., 2011; Migeot and Imbert, 2011; Popma et al., 1988).

Table 3.2: The diversity indices calculated. p_i is the proportion of individual belonging to the ith species of the dataset, x_i is number of times species i is represented in the total X from one sample, y_i is number of times species i is represented in the total Y from another sample, D_x and D_y are the Simpson's index values for the x and y samples respectively, S is the total number of unique species.

Name	Symbol	Formula
Simpson's Index	*D*	$\sum_{i=1}^{S} p_i^2$
Shannon Index	*H'*	$-\sum_{i=1}^{S} p_i * ln(p_i)$
Pielou's Evenness	*J'*	$\frac{H'}{H'_(max)}$
Morisita Index	*Cd*	$1-\frac{2\sum_{i=1}^{S} x_i * y_i}{(D_x + D_y) * XY}$

To assess the β-diversity (or species turnover: the rate of change in species composition between different communities) the quantitative Morisita index was calculated. This index is a statistical measure for dispersion as it compares the overlap of specimen amongst the sample plots. As opposed to most indices, this index is independent of sample size and species diversity (Morisita, 1959; Wolda, 1981).

3.4.3 Spatial distribution

To assess the spatial distribution of the forests, different methods were applied. The tree density per hectare was calculated as well as the Clark-Evans aggregation index, which is a measure of clustering and ordering of a point pattern defined as the ratio of the observed mean nearest neighbour distance to the expected mean nearest neighbour distance for a Poisson

process under the same intensity. The edge correction of Donnelly was used to adjust for edge effects (Clark and Evans, 1954; Doguwa and Upton, 1988; Donnelly, 1978).
Since the relative coordinates of all the trees in every sample plot are known, it is possible to calculate distance-dependent measures that take all possible inter-tree relationships into account (Gadow et al., 2012).
To test for complete spatial randomness Besag's L-function was calculated. This is a linearised version of Ripley's K-function that allows for a more simple interpretation (Goreaud et al., 1997).
Both Ripley's K-function and Besag's L-function are cumulative functions and thus confound effects on large scale with small scale effects. Because of this, the pair correlation function was calculated as well, which does not have this cumulative property and thus complements Besag's L-function (Fibich et al., 2016; Hao et al., 2007).

3.4.4 Tree dimension variation

To characterize the variations in tree dimensions, the mean diameter and its standard deviation were calculated and the same was done for the tree heights. The basal area (calculated as $g= \pi \cdot r^2$) per hectare and the AGB per hectare were calculated as well.
The histograms for the diameter distribution (with diameter classes per 5 cm) and the tree heights along the transect were visualized as well. The number of storeys were visually discerned from these heights along the transects and taking the findings in the field into consideration.

To analyse the interaction between trees and their attributes (the dbh and tree height for the dimensions) on a spatial scale marked point processes were applied.
Mark correlation functions analyse the correlations within a tree attribute in the sense of mutual stimulation or inhibition of trees. A positive correlation will indicate that the point pairs at a distance r tend to have an average mark larger than the mean mark (and points to mutual stimulation) while a negative correlation indicates that point pairs at an inter-tree distance r have an average mark smaller than the mean mark and thus inhibit each other. When the distance between point pairs elongate, it is expected that the marks will become independent.
The mark variograms measure the spatial mark similarity in dependence of the distance between point pairs. Small values will indicate a positive autocorrelation which means that the marks of a point pair at a distance r tend to be similar. Large values will indicate negative autocorrelation, meaning that the marks of a point pair at a distance r tend to be different (so some are large and some are small).
Together these two measurements give a good indication of the structure of the forest depending on the distance between trees (Gavrikov and Stoyan, 1995; Illian et al., 2008; Penttinen

et al., 1992; Pommerening and Särkkä, 2013; Stoyan and Stoyan, 1996; Stoyan and Penttinen, 2000; Szmyt and Stoyan, 2014; Wälder and Stoyan, 1996; Wälder and Wälder, 2008).

CHAPTER 4

Results

4.1 Species composition and diversity

To assess the species composition and diversity, several measurements for the species richness, species diversity, species composition and the β-diversity are calculated. The averages of the measurements are used to represent the different forest types and the forest types are tested for significant differences by applying non-parametric statistical tests.

A total of 1,770 trees, belonging to 131 different species, 103 genera and 48 families, were measured. They were spread over 40 plots, whose location can be found in Figure A.1.
Following Teunissen (1978), the plots belong to five different habitat types: (1) Predominantly mixed mesophytic dryland and marsh forest on young ridges, (2) Mixed mesophytic dryland and marsh forest on old flats, (3) Hydrophytic swamp forest dominated by *Pterocarpus officinalis* (both in old and young swamps), (4) Hydrophytic swamp forest with *Virola surinamensis, Symphonia globulifera* and *Euterpe oleracea* (on old swamps) and (5) Ecosystems of urban areas, farmland, livestock meadows, mining areas and abandoned forest plantations and farmlands. Some adaptions to the classifications (found by using the map and the plot coordinates) were made by the author when the composition differed greatly from the one recorded for that forest type (Teunissen, 1980) but showed similarities with the composition of a neighbouring forest type.

Table 4.1: Summary characteristics for every forest type of the field inventory of this study: the number of sample plots (SP), the total area measured, the total number of trees, the total number of species, genera and families recorded, the mean basal area per hectare, and the canopy height (estimated as the 90th percentile of the tree heights).

	Type 1	Type 2	Type 3	Type 4	Type 5
No of SPs	8	10	10	8	4
Area (m^2)	0.4	0.5	0.4625	0.4	0.3
No of trees measured	186	335	589	469	191
No of tree species	60	76	11	30	64
No of tree genera	50	61	10	27	54
No of tree families	28	30	9	15	29
Basal area (m^2 ha^{-1})	25.37	28.59	33.59	29.67	28.55
Canopy height (m)	21.1	23.2	17.1	18.6	23.6

The five species with the highest IVIs for every forest type and their ranking in the other forest types can be found in Table 4.2. The most common families are the following: Leguminosae (Papilionoidae (508 trees), Mimosoideae (42), Caesalpinioideae (28)), Arecaceae (481), Bignoniaceae (205), Lecythidaceae (88), Chrysobalanaceae (62), Clusiaceae (60) and Myristicaceae (46).

For every forest type the mean of the diversity indices of Shannon (H'), Simpson (D) and Pielous evenness (J') can be found in Table 4.3 as well as the mean rarefied species number (this is the number of different species that can be expected when 14 individuals are encountered) for every forest type. To accompany the mean values of the Shannon index, Simpson index, Pielou's evenness and the rarefied species number, the standard deviations are calculated to represent the spread of these indices within one forest type. These can also be found in Table 4.3. Figure A.2 illustrates the rarefied species number for all plots. For most plots, the sample size was not large enough to reach asymptotic curve values. Still it clearly demonstrates that the curves for forest type 1, 2 and 5 do not differ that much, while the curves for forest types 3 and 4 are clearly lower.

Table 4.2: The five most important species for every forest type according to their IVI and their importance in the other forest types.

Tree species	Type 1	Type 2	Type 3	Type 4	Type 5
Alexa wachenheimii	1 (40.54)	-	-	8 (6.82)	-
Aspidosperma excelsum	5 (11.52)	43 (1.54)	-	15 (2.66)	14 (4.68)
Attalea maripa	9 (8.70)	3 (16.76)	-	9 (4.72)	5 (13.38)
Copaifera guyanensis	23 (3.84)	4 (11.67)	-	-	31 (2.85)
Eschweilera congestiflora	36 (2.27)	2 (28.28)	-	12 (4.02)	1 (42.06)
Euterpe oleracea	2 (29.96)	1 (53.57)	5 (18.82)	1 (76.22)	2 (28.50)
Gordonia fruticosa	4 (11.97)	-	-	23 (1.98)	-
Licania densiflora	52 (1.66)	13 (5.78)	-	-	3 (16.03)
Licania macrophylla	-	19 (4.06)	-	7 (7.86)	4 (14.15)
Minquartia guianensis	48 (1.84)	5 (9.26)	-	-	-
Pterocarpus officinalis	-	36 (1.67)	1 (169.84)	3 (29.71)	-
Simarouba amara	3 (15.56)	-	-	30 (1.90)	-
Symphonia globulifera	56 (1.59)	12 (5.78)	3 (21.81)	4 (29.10)	-
Tabebuia insignis	20 (4.40)	17 (4.32)	2 (47.55)	2 (60.84)	-
Virola surinamensis	-	48 (1.43)	4 (21.00)	5 (17.83)	-

Table 4.3: The mean diversity indices and their standard deviation for every forest type (Rar SR is the rarefied species number, D is the Simpson index, H' is the Shannon index and J' is Pielou's evenness). Different letters indicate significant differences between the forest types ($p<0.05$).

	Type 1	Type 2	Type 3	Type 4	Type 5
Rar SR	6.77 ± 1.34^{a}	6.99 ± 1.14^{a}	3.92 ± 0.89^{b}	4.47 ± 0.77^{b}	8.78 ± 0.42^{c}
S'	0.70 ± 0.13^{ab}	0.78 ± 0.08^{ac}	0.61 ± 0.13^{b}	0.65 ± 0.07^{b}	0.86 ± 0.02^{c}
H'	1.89 ± 0.37^{a}	2.03 ± 0.31^{a}	1.23 ± 0.32^{b}	1.42 ± 0.23^{b}	2.57 ± 0.11^{c}
J'	0.54 ± 0.17^{ac}	0.59 ± 0.18^{a}	0.35 ± 0.13^{b}	0.43 ± 0.15^{bcd}	0.61 ± 0.02^{ad}

The statistical tests indicate that the species composition and diversity of forest types 3 and 4 and forest types 1 and 2 are quite similar. Within a forest type some variation could be detected for the diversity indices. This variation can mostly be found between different transects. However, inside a transect the indices were quite homogeneous. Variation thus not only exists between forest types but also inside a forest type. Within a forest type the characteristics are fairly homogeneous, however there are some outliers. Mostly this variation can be related to a different transect and thus a different location (see Tables A.1, A.2, A.3,

A.4, A.5). The diversity indices all give the same ranking for the different forest types. Forest types 2 and 5 are the most diverse, while forest type 3 is the least diverse.
The beta diversity calculated according to the Morisita index can be found in Figure A.3. The floristic dissimilarities are generally smaller within a forest type and larger between forest types. However, in forest types 1 and 2 quite a lot of dissimilarities between the plots can be found. Forest type 3 and 4 appear to be similar to each other and there are similarities between the plot that makes up forest types 2, 4 and 5.

4.2 Spatial distribution

The number of trees per hectare and the Clark-Evans index are calculated as these can already give a first impression of the structure of the forest. Next, Besag's L-function and the pair correlation function are calculated to assess if the trees present in a plot are randomly distributed and if they are not, what spatial pattern they might have.
An amount of 1,770 trees (with a dbh $\geq$ 10 cm) was recorded over the 40 sample plots. The overall tree density (the number of trees per hectare) of the region was 858.2 trees$\cdot$ha^{-1}. This however differs greatly between the different plots and forest types. A summary table for density and Clark Evans aggregation index of the forest types can be found in Table 4.4 and a more extended table for the different plots in Tables A.1, A.2, A.3, A.4, A.5. According to the Clark-Evans Index with Donnelly edge correction, all plots, except 16 and 25 (both belonging to forest type 2), are clustered. Plots 16 and 25 have a tendency towards regularity.

Table 4.4: The mean values for the density and the Clark-Evans index for every forest type.

	Type 1	Type 2	Type 3	Type 4	Type 5
Mean tree density (trees/ha)	465	670	1251	905.125	632.5
Mean Clark Evans Index	0.851625	0.843	0.7459	0.7555	0.8375

The figures relating to the following spatial point pattern analyses (Beslag's L-function and the pair correlation function) can be found in Figures A.14, A.15, A.16, A.17, A.18. Beslag's L-function indicates there are several plots of which the spatial pattern is not statistically different from the theoretical random distribution, namely: plot 2, 17 and 18 (which belong to forest type 5), plots 6, 15, 16, 25 (which belong to forest type 2), plots 12, 13, 14, 33, 34, 35, 36 (which belong to forest type 1), plots 27 and 28 (which belong to forest type 3) and plots 39 and 40 (which belong to forest type 4). There are a few plots whose spatial composition could be regarded as completely clustered (plot 3 and 41) and several plots who show clustering at short distances but show a random pattern further on (plot 1, 5, 7, 8, 9, 10, 11, 26, 29, 31, 37 and 38). A final pattern that arose are plots that are random in the immediate vicinity of a tree but then a clustering pattern starts. This pattern could only be found in forest type 3 (plot 19, 20, 21, 22, 23, 24, 30).

The pair correlation function of most plots follow approximately the same pattern: first it has a high positive value (this indicates clustering) which decreases fast and then there are fluctuations around or near the theoretical Poisson distribution. There are however 3 plots that diverge greatly from this pattern: plots 13, 14 and 35 (all belonging to forest type 1). These start with a value smaller than 1, which points to inhibition in the neighbourhood of a point. Plots 4, 20, 21, 22, 23, 24 and 30 appear to have clustering for over longer distances than their immediate neighbourhood.

4.3 Tree dimension variation

To assess the dimensions of the trees and its variations, average values for the diameter at breast height and for the tree height are calculated. The basal area and aboveground biomass are calculated per hectare, to allow comparison between plots and between forest types. The diameter distribution is assessed and the heights along the transect are plotted to give an impression of the distribution in dimensions in a plot. To analyse the interaction between the position of trees and the dbh and tree height, mark correlation functions and variograms are calculated.
An overview of the mean dbh, the basal area per hectare, the mean height and the above ground biomass per ha for every forest type can be found in Table 4.5. The mean diameter and height of forest types 3 and 4 are smaller, as well as the variation in these dimensions. However, the basal area per hectare for forest type 3 is larger than the other types. Only 1.6% of the trees (29 specimen) have a diameter larger than 25 cm and only 29.5% have a diameter larger or equal to 20 cm. The species with the largest recorded diameters are *Alexa wachenheimi* Benoist (Leguminosae), *Pterocarpus officinalis*, *Simarouba amara* Aubl. (Simaroubaceae) and the species belonging to the genus *Eschweilera*. Of the 50 trees with the largest diameter, 13 can be found in forest type 1, 17 in forest type 2 and 14 in forest type 5, while only 3 can be found in forest type 3 and another 3 in forest type 4. The tallest tree was 40.1 m (*Dicorynia guianensis*). The distribution of the 50 highest trees follows the same pattern as the diameter: 12 in forest type 1, 18 in forest type 2, 13 in forest type 5 and only 3 and 4 in respectively forest type 3 and 4. The largest species are also similar to those with the largest diameters.

Table 4.5: The mean diameter and height and their standard deviation for every forest type. Different letters indicate significant differences between the forest types ($p < 0.05$) and the basal area (BA) (m^2 $ha^{-}1$) and aboveground biomass (AGB) (Mg $ha^{-}1$).

	Type 1	Type 2	Type 3	Type 4	Type 5
dbh (cm)	22.5 ± 13.8^{a}	19.9 ± 12.1^{b}	17.2 ± 6.2^{b}	16.3 ± 7.5^{c}	20.9 ± 11.7^{ab}
height (m)	16.3 ± 5.3^{c}	15.3 ± 5.9^{a}	13.3 ± 3.6^{b}	13.1 ± 4.4^{b}	15.2 ± 6.4^{a}
BA ($m^2 \cdot ha^{-}1$)	25.37	28.60	33.59	29.67	28.55
AGB ($Mg \cdot ha^{-}1$)	199.93	250.64	158.15	160.57	261.44

The diameter distributions as well as the heights along every transect for every plot can be found in Figures A.4 to A.13. Most diameter distributions follow or approximate the inverted J-shape. This shape is typical for uneven-aged stands (Ducey, 2006). Some plots have trees with a large diameter and some absent diameter classes in between these larger trees and the majority of the trees. This phenomenon of these larger trees is more common in forest type 1, 2 and 5 than in forest types 3 and 4. In forest type 1 the range of the maximum diameters is between 40-60 cm. The shapes of plots 13, 14 and 33 deviate from the expected form. The range in forest type 2 extends to 40-50 cm and often remaining trees in higher diameter classes can be found. In forest type 3 the range only extends up to 40 cm and a huge number of small trees can be found, while the range in forest type 4 is a little bit bigger, up to 40 cm. There is however one exception: plot 37, which is dominated by *Euterpe oleracea.* In forest type 5 the largest range could be found, often up to 60 cm. The heights along the transect show that the lowest and least complex canopy (as it has only 1 storey) can be found in forest type 3, where the canopy height is 17.1 m and the maximum heights vary between 20-25 m for most plots and only 1 or 2 storeys can be found (not taking a possible herbaceous layer into account). It was followed by forest type 4 where 2 storeys and a canopy height of 18.6 m can be found and the maximum heights vary around 25-30 m. Forest type 1 was more complex, with often 2 or 3 storeys and a canopy heights of 21.1 m. The highest and most complex canopies can be found in forest types 2 and 5, where 3 storeys and a canopy heights of respectively 23.2 m and 23.6 m can be found and maximum tree heights over 30 m are common.

The mark correlation functions and variograms discussed next can be found in Figures A.14, A.15, A.16, A.17, A.18. The variograms of forest type 1 indicate that the heights are similar to each other in 3 out of the 8 plots, while in the other 5 plots the heights are dissimilar on short distances. The mark correlation functions showed that in 5 plots the diameter was smaller than the mean diameter over short distances and higher than mean in the other 3. The

mcfs of the heights do not show a specific pattern in forest type 1. In 2 plots no correlation between the mark values can be found, in 3 plots the heights are smaller over a short distance and in another 3, they are higher than the mean over short distances.
In forest type 2 both the height and diameter are similar over short distance followed by a region where these marks are dissimilar. Except for plot 2, all plots also show that they are smaller than the mean diameter on a distance under 2 m while the heights only shows this pattern for 4 plots. In the other plots no correlation could be found or the heights where larger than the mean on short distances.
The variograms and mark correlation functions of forest type 3 indicated that the diameters and heights in the plots (except in plots 19, 27 and 30) do not show any correlation in function of the distance r and thus the similarity of mark values are independent of the distance. Furthermore, for short distances the diameters more or less have the same size and the heights tend to show no similarities over the distance.
For forest type 4 the marks (height and diameter) are the similar for short distances except for plot 32, where the marks show dissimilarities over short distances. No correlation regarding stimulation or inhibition could be found for the height and diameter in most plots except in plots 31, 38 and 40, where on a short distance the heights and diameters are smaller than the mean, followed by a small zone where the heights and diameters are larger than the mean diameter and height of the plot.
In forest type 5, half of the plots show similarities between marks on short distances, while the other two show dissimilarities between marks (plots 2 and 17). In the two plots that showed dissimilarities on short distances the diameters where higher than the mean diameter and the heights showed no correlations, while in the plots where the marks are similar over short distances, both diameters and heights are smaller than the mean over short distances.

4.4 Usability of the encountered tree species

Of the 131 species identified, 38 species are classified marketable by SBB and 2 species are forbidden to be auctioned off, namely *Copaifera guyanensis* and *Manilkara bidentata*. However, only 348 of the 1770 trees belong to this class and not all these trees have attained dimensions which make them suitable for harvest with commercial purposes in mind. Next to the marketable species, another 23 species are locally used for timber and wood products. Because of the vast cultural variety of the population of Suriname and the large number of forest people, there is a widely spread use of plants for ritual and medicinal purposes. 28 of the encountered species have known uses of this genre.
The uses of the species that can be used for timber, medicinal or ritual purposes can be found next. If the species are marketable, numbers on their value and needed dimensions will be mentioned as well. The following list is a summary from Comvalius (2010); Gérard et al. (1996); Lorenzi (2002); SBB (2000, 2015) and van Andel and Ruysschaert (2014).

***Abarema jupunba* (Willd.) Britton & Killip (Leguminosae)**: Its wood can be used for interior trim, furniture and carpentry and veneer. However, it is mostly used for crates and tool handles. It has a poor natural durability against termites and marine borers and the hardwood has a poor treatability. The desired dimensions are a bole length of 10-15 m and a diameter of 0.35-0.95 m. Of the 3 encountered specimen only 1 has reached these dimensions. Yearly, an average of 130 m^3 of this class B timber species is harvested. The tree can also be used for ornamental landscaping.

***Agonandra silvatica* Ducke (Opiliaceae)**: This species is mentioned on the SBB list of marketable species. In 2014 1,902 m^3 of industrial roundwood was produced of which 467 m^3 was exported for a free on board (FOB) value of 59,163 US$. It is used for flooring, furniture, carving and carpentry and has a moderate to good natural durability against fungi and termites. A bole of 15-20 m and a diameter between 0.50-0.80 m are required. 2 of the 6 specimen fulfil these conditions.

***Alchorneopsis floribunda* (Benth.) Mll.Arg. (Euphorbiaceae)**: is a class B timber species of which 1,172 m^3 industrial roundwood was produced in 2014. For a total FOB value of 38,853 US$ a total of 342 m^3 of roundwood and 3 m^3 of sawn wood (FOB value of 710 US$) was exported in that year. It is used for carpentry, furniture and veneer, as well as plywood, boards and paper pulp. Only 1 of the 6 trees measured fulfils the dimensions of a dbh of 0.35-0.75 m and a bole of 10-20 m.

***Alexa wachenheimii* (Leguminosae)**: The wood of this tree is locally used for general carpentry and furniture components. In the period 2012-2014 between 250 and 300 m^3 a year was harvested of this class B timber species. It is very resistant to fungi and quite resistant to termites. The desirable dimensions are a diameter of 0.50-0.90 m and a bole of 18-20 m. Of the 22 specimen there are 5 who achieve these requirements. In rural zones it could also be used as a shade tree.

***Ambelania acida* Aubl. (Apocynaceae)**: The wood of this tree is only used for firewood and charcoal. Its fruits are edible, but not commonly consumed in Suriname.

***Andira spp.* (Leguminosae)**: This genus is listed on the list of class A timber species and is also known as Angelim or Rode Kabbes. A yearly average around 6,000 m^3 of roundwood is produced. In 2014 3,129 m^3 of roundwood (FOB value of 374,910US$) was exported and 54 m^3 of sawn wood (FOB value of 16,333 US$). For this tree family a diameter between 0.60 and 1.20 m and a bole of 12-20 m is searched for. It has a wide variety of high grade applications because of its decorative and durable characteristics such as carpentry, cabinets, flooring and marine construction. The 2 encountered specimen do not fulfil these requirements. The fruits are eaten by a variety of animals and as a pioneer it might be used for reforestation purposes.

***Aniba taubertiana* Mez (Lauraceae)**: This species can be found on SBBs class A timber species list. Since the wood species has a good natural durability and good processing characteristics it is used for furniture, turnery, inlays and boat construction. None of the two specimen accomplish the required dimensions of a diameter of 0.55-0.75 m and a bole of 15-20 m.

***Aspidosperma excelsum* Benth. (Apocynaceae)**: It has similar wood characteristics, required dimensions and applications as *Alchorneopsis floribunda* and is also listed as a class B timber species. However, it is less exported on the international market. The yearly production of this species is very low and fluctuates heavily. Only 171 m^3 of roundwood was exported in 2014 (FOB value of 18,765 US$). One of the 8 trees measured is harvestable.

***Attalea maripa* (Arecaceae)**: The pulp and palm heart of this palm are consumed all over Suriname. The seeds are used to produce oil for cooking or for cosmetic purposes. It is often used for ritualistic/medicinal purposes concerning pregnancy. The flyleaf is sometimes used as a basket but also to coax the ghosts that control the rapids. Other ritualistic traditions include an ancestral one that uses the ash of the palm and the use of the leaves to guard off malevolent spirits and persons. The entire trunk can be used for construction, but this only happens locally.

***Bellucia grossularioides* (L.) Triana (Melastomataceae)**: The fruits of this plant are edible and grow in great numbers but it is difficult to find specimens that are not already rotten. The Marron population uses the leaves for genital steam baths, while Indians in French Guiana use the leaves against boils. The orange fluids that can be found in the bark are used as a pigment by the original Surinamese population. Other less applied uses are for firewood, charcoal and an ornamental value.

***Carapa guianensis* Aubl. (Meliaceae)**: In the period 2012-2014 an average of 1,500 m^3 a year of roundwood was produced of this class A species. In 2014, a total of 101 m^3 of this species (better known as Andiroba, Crabwood or Krappa) for a FOB value of 30,225 US$ were exported, mostly as sawnwood. The wood has a poor natural durability but is hard and has good processing characteristics. Because of this it is used for carpentry, furniture, joinery and decorative veneer. None of the 3 specimen achieve the dimensions of a dbh of 0.50-1.00 m and a bole of 10-15 m. The seeds of this tree are used to extract a reeking oil that is mostly used for cosmetic reasons such as acne, rash, a dry skin and to prevent hair loss. It is also used to repel insects and parasites and locally to treat measles and chicken pox.

***Carapa procera* DC. (Meliacea)**: This tree species has similar characteristics and applications as *Carapa guianensis* but is of a smaller size and as a wood species the distinction is rarely made. Not a single one of the 7 trees has a diameter larger than 20 cm, and only one a total height over 20 m so they are probably not harvestable. The seeds are used together with the seeds of *Carapa guianensis* to create *Krapa* oil.

***Catostemma fragrans* Benth. (Malvaceae)**: It has a poor natural durability but the hardwood has a good treatability and it is mostly used for small appliances such as light carpentry, boxes and crates and pulpwood. A diameter between 0.60-1.20 m and a bole between 20-25 m is desirable, but because of its appliances smaller dimensions for harvest are possible. Of the two trees one has a diameter of 42.3 cm and a bole of 13.9 m, so this one might be harvestable. It is classified as a class B timber species but the volume of roundwood is negligible (only $4m^3$ of the period 2012-2014).

***Cedrela odorata* L. (Meliaceae)**: This light wood, internationally known as Cedro or Cèdre, with a moderate durability and good processing characteristics is known to be used for cigar boxes, musical instruments, the traditional drums of the Marrons and for decoration. Of this class A timber species an average of 570 m a year was produced in the period 2012-2014. Of this 73 m^3 was exported in 2014 for a total FOB value of 13,647 US$. A diameter between 0.5 and 1.50 m and a bole of 15-20 m is desirable and the three encountered trees do not achieve these dimensions. The shavings of this wood species are used for sweat baths or to combat headaches, diabetes and malaria.

***Ceiba pentandra* (L.) Gaertn. (Malvaceae)**: As one of the lightest wood species on Earth it is used for packaging, model building and plywood and its poor durability is not a hindrance. The floss of the seeds is known as kapok and is used as a stuffing for pillows and mattresses. Quite large dimensions are needed: a dbh of 0.85-2.50 m and a bole of 20-30 m, which are requirements the one specimen encountered does not fulfill. In the period 2012-2014 only 41 m^3 was harvested of this class A timber species. The tree is often seen as a holy tree and it is said that a multitudinous number of spirits live there. It is also possible to extract an oil from the seeds that can be used for soap and illumination.

***Copaifera guyanensis* (Leguminosae)**: This species (also known as Tauari or Hoepelhout) is valued for its gum and balsam and used for construction and carpentry. However, the auctioning of this species is forbidden in Suriname except with a special license. In 2012 18 m^3 was harvested and in 2014 46 m^3. 11 specimens were encountered. The oily resin, that can be collected from the trunk, is used as a medicinal oil. It is used for cuts, insect bites, acne and other ailments. Dried bark is also used to make a tea or a decoction that would help against diabetes and malaria or to improve the hunting skills.

***Cupania scrobiculata* L. C. Richard (Sapindaceae)**: Although not frequently used in Suriname, the wood of this tree can be used for general construction but it is hard to work with. The seeds of this tree also attracts wild birds.

Dicorynia guianensis **Amshoff (Leguminosae)**: This class A timber species is one of the most important wood species in Suriname. In 2014 it knew an enormous increase in roundwood production: namely from 62,017 m^3 in 2014 to 117,318 m^3. It was exported as roundwood (68,899 m^3), hewn square poles (1,802 m^3), sawn wood (5.648 m^3) and as finish product (37 m^3) for a total FOB value of 7,919,897 US$. On the international wood market, it is known as Angelique and more locally as Basralokus. The wood has a very good natural durability for fungi, termites and marine borers and is used for a wide variety of applications such as naval constructions, flooring, panelling and furniture. The straight boles of 20-25 m and a diameter of 0.60-0.90 m needed for harvestability were not achieved by either of the 4 trees.

Diplotropis purpurea **(Rich.)Amshoff (Leguminosae)**: Almost 4,000 m^3 roundwood of this class A timber species (known as Sucupina) was harvested every year in the period 2012-2014. In 2014 a total of 1,786 m^3 was exported, mostly as roundwood, for a total FOB value of 257,093 US$. This difficult-to-work wood species is used for flooring, stairs and heavy construction. It has a very good durability against fungi and termites. The only encountered tree does not fulfil a diameter larger than 0.40 m and a height above 18 m.

Drypetes variabilis **Uittien (Putranjivaceae)**: Mostly used for sleepers, flooring and heavy carpentry because of its good resistance against fungi and termites, the preferred dimensions for this species are a diameter between 0.60 and 0.75 m and a bole longer than 15 m. The one tree measured had a diameter of only 32.9 cm and a bole of 10.1 m (a height of 20.6 m).

Duroia aquatica **(Aubl.) Bremek. (Rubiaceae)**: The bark is used for protection against child illnesses and black magic. The fruits of the tree are edible.

Eperua falcata **Aubl. (Leguminosae)**: Better known as Wallaba, this class A timber species was exported in 2014 as roundwood, hewn square poles, sawn wood as well as finished product respectively for a FOB value of 91,377 US$ (761 m^3), 436 US$ (2 m^3), 551,913 US$ (1,484 m^3) and 65,856 US$ (41 m^3). The yearly roundwood production decreased in the period 2012-2014 from 34,874 m^3 to 9,738 m^3. Its wood has a tendency to split and is difficult to work with but it has a good natural durability and is often used for heavy construction, posts and industrial flooring. One out of four encountered trees has a required dimension with a dbh larger than 30 cm and a bole longer than 15 m.

Eriotheca globosa **(Aubl.) A. Robyns (Malvaceae)**: This light weight, easy to work, non-durable species is used for boxes, pulpwood and light carpentry. None of the two specimens meet the dimensions of a dbh between 0.7 and 1.10 m and a bole between 10 and 15 m that are required for harvest. The fibrous bark can be used for rope making.

***Eschweilera spp.* (Lecythidaceae)**: Of this class A timber species known as Kakaralli or Mata-mata an average of 1,500 m^3 roundwood is produced every year. In 2014 331 m^3 was exported as roundwood and 27 m^3 as hewn square poles, which totals in a FOB value of 45,830 US$. Most species within this genus have the same wood characteristics and applications. All have a very good durability, especially against fungi and marine borers. Also most are difficult to work and heavy. Because of this its wood is used for marine construction, shipbuilding, sleepers, poles and construction. A diameter larger than 0.40 m and a bole larger than 12 m is desirable. 13 of the 79 specimen fulfil these conditions and thus are harvestable.

***Euterpe oleracea* (Arecaceae)**: The berries of this palm are known in Suriname as *podosiri* but are globally better known as acai berries. In Suriname there is not a much global trade of this product but in Brazil the berries and palm heart of *Euterpe oleracea* contribute a fair share to the economy. In Marowijne the juice and a gruel are almost considered a staple food. The leaves, berries and roots also have lots of ritualistic purposes. The leaves are used to fend off evil powers and to protect toddlers. The different parts of the palm are also used for infertility problems, to improve the quality of the pregnancy and prevent miscarriages and to help with urinal problems. The stem as a whole can be used for crude construction.

***Genipa americana* L. (Rubiaceae)**: Although not often used in Suriname, the wood of this tree can be used for construction and carpentry. The fruits are edible and in Brazil often processed to jams, juices and liquors. It might also be useful for plantings in swampy areas as it produces feed for the fauna.

***Goupia glabra* Aubl. (Celastraceae)**: This easy to work, durable class A timber species, of which dimensions of a bole larger than 12 m and a diameter larger than 0.80 m are required, is used for flooring, bridges, sleepers and plywood. None of the two specimen have the right dimensions for harvest. It is one of the most harvested species in Suriname, averaging over 20,000$m^3 \cdot yr^{-1}$ in the period 2012-2014. In 2014 5,761 m^3 of roundwood (FOB value of 688,303 US$) and 272 m^3 of sawn wood (FOB value of 87,589 US$) of this timber species also known as Cupiuba, Kabukalli or Kopi, was exported

***Gustavia augusta* L. (Lecythidaceae)**: The wood can be used for general construction when not exposed to sun and rain. The tree has a high ornamental value with white, fragrant flowers.

***Handroanthus serratifolia* (Vahl) S.O.Grose (Bignoniaceae)**: Better known as *Tabebuia serratifolia*, Ipé or Groenhart, there was a yearly production around 6,000 m^3 a year in the period 2012-2014. About half of this was designated for export in 2014: 3,401 m^3 of roundwood and sawn wood for a total FOB value of 621,212 US$. This heavy wood species has a very good durability but a difficult workability. It is used for flooring, sleepers, hydraulic and naval construction, stairs and furniture. The only species encountered does have the required height of 25 m but not the required diameter of 0.50 m (it only has a 0.25 m dbh). Thanks to the lush yellow flowering the tree can be used as a lane tree. The bark and flowers are said to improve the male potency and to combat weakness and pains.

***Humiriastrum obovatum* (Benth.) Cuatrec. (Humiriaceae)**: Contrary to most species found on the Guiana Shield, this one dries easily and fast but it has poor natural durability. It is used for heavy construction and industrial flooring. A diameter over 0.35 m and a bole larger than 15 m are desired and this is not fulfilled by the only specimen encountered.

***Hymenaea courbaril* L. (Leguminosae)**: Every year an average of 3,300 m^3 of roundwood of this class A timber species also known as Courbaril or Jatoba, is produced. Of this 2,024 m^3 of roundwood and 92 m^3 is exported for a FOB value of 273,969 US$. It has a very good durability and an orange and purple colouring. A diameter of 0.50-1.50 m and a height of 18-24 m are required for its wide variety of uses such as marine construction, expensive furniture and decorative veneer and flooring. The one tree encountered almost reached a harvestable diameter (0.45 m). The bark of the tree contains lots of tannins and is used to make a tea that combats a wide variety of ailments such as anaemia, diarrhoea, menstrual pains, . . . The resin has an amber like appearance and used to be exported to produce varnish. The dried pulp of the pods can be eaten as a snack.

***Inga alba* (Sw.) Willd. (Leguminosae)**: This easy to work, non-durable class A timber species is mostly used for carpentry, plywood and crates. One out of three specimen reached the required diameter between 0.35 and 0.70 m and a height of 15 m. The bark of this tree is a very popular medicine against gonorrhoea, against abscesses and to stop wounds from bleeding. It is also thought to expel evil spirits. The production and export of roundwood in 2014 was very low, respectively 40 m^3 and 8 m^3.

***Inga heterophylla* Willd. (Leguminosae)**: The twigs of this tree are used for a genital steam bath and to improve the quality of pregnancies. It is also used to exorcise evil forest spirits.

***Iryanthera sagotiana* (Benth.) Warb. (Myristicaceae)**: Of the 12 encountered specimen none reached the required 0.30 m diameter and 15 m bole for harvestability of this non-durable, easy to work wood species. It is mostly used locally for toys, boxes, matches and cheap furniture.

***Laetia procera* (Poepp. & Endl.) Eichl. (Salicaceae)**: This easy to work class B species with good workability is mostly used for carpentry and indoor flooring and plywood. Both specimen reached the harvestable dimensions of a diameter of 0.45-0.75 m and a bole of 10-25 m. In the period 2012-2014 an average of 250 m^3 of roundwood was produced.

***Licania heteromorpha* Benth (Chrysobalanaceae)**: None of the 6 specimen reached a diameter of 0.70 m and a bole of 15 m required for harvest. The wood has a moderate durability (but a very good resistance against marine borers) but is difficult to process. It is used for above ground and marine construction and shingles.

***Licania majuscula* Sagot (Chrysobalanaceae)**: It has about the same wood characteristics as *Licania heteromorpha* but it has smaller dimensions. Because of this is it is less suitable for the same applications and thus less used. One of three specimen reached the required diameter of 0.40 m and a tree height over 20 m.

***Manilkara bidentata* (Sapotaceae)**: Its wood is difficult to work but has a very good durability (except against marine borers). Its harvest is forbidden in Suriname except with a special permission. It is used for heavy construction, violin bows, carpentry, furniture and its resin. In 2014 26,556 m^3 was produced as roundwood. Known as Maçaranduba or Bolletri on the wood market, it was good for an FOB value of 2,044,168 US$ as a total of 14,615 m^3 (as roundwood or sawn wood) was exported.

***Maprounea amazonica* Esser (Euphorbiaceae)**: The leaves of this tree are used in a mouth wash that tempers toothaches and heals infections in the mouth. By the Marrons a bath of the leaves is used to strengthen their babies and steam baths are used for a variety of vaginal ailments. The roots possess medicinal qualities.

***Martiodendron parviflorum* (Amshoff) R.C.Koeppen (Leguminosae)**: Also known as Grocai-rose or Bosmahonie, this class A timber species averages a yearly roundwod production around 8,000 m^3. In 2014 a total of 16,353 m^3 (with an FOB value of 451,465 US$) was exported, mostly as sawn wood.

***Mauritia flexuosa* L.f. (Arecaceae)**: The palm fruits are eaten by the Marrons and the Indians and contain a lot of vitamin A. The roots are used to prevent miscarriages, often in combination with roots of other palms. Fibres for hammocks and baskets can be produced from young palm leaves while the sugary fluids from the stem can be used to brew an alcoholic drink. The larvae of *Rynchophorus palmarum* can be found on this plant and can be eaten raw or baked.

***Micropholis guyanensis* (A.DC.) Pierre (Sapotaceae)**: In 2014 only 340 m^3 of roundwood of this timber species was produced and only 19 m^3 was exported. In 2013 the production of roundwood of this class A timber species, internationally known as Morabali or Apixuna was still 1,896 m^3. This wood species is used for furniture, flooring and decorative veneer. It works moderately well and has a moderate durability. The one encountered tree reached the looked for dimensions of a diameter larger than 0.45 and a bole larger than 12 m.

Minquartia guianensis **Aubl. (Olacaceae)**: This very heavy class B timber species with great durability is used in the Amazonian region for outdoor applications such as stakes and at the water front. In the period 2012-2014 46 m^3 of roundwood was produced. In 2014 14 m^3 of this was exported for a FOB value of 1,502 US$.

Ocotea glomerata **(Nees) Benth. & Hook. fil. (Lauraceae)**: In 2014 1,803 m^3 of roundwood of this class A timber species, known as Canelo or Louro was produced. Of this only 32 m^3 was exported as roundwood and 5 m^3 was exported as sawn wood. For this tree species a diameter larger than 0.5 m and a bole between 15-18 m is required. It has a good workability but a poor durability and because of this, it is used for light carpentry, boxes, plywood and decorative fittings. The one specimen encountered does not reach the harvest requirements.

Oenocarpus bacaba **Mart. (Areceae)**: The juice of the fruit is recommended for people with anemia but excessive use could cause high blood pressure. The pulp can also be used to press an oil similar to olive oil. The roots are used together with those of *Mauritia flexuosa*, *Attalea maripa* and *Euterpe olearcea* to create a medicine to prevent a miscarriage.

Ormosia coccinea **(Aubl.) Jacks. (Leguminosae)**: The one specimen encountered reached the searched for dimensions of a diameter larger than 0.40 m and a bole longer than 18 m. It is used for furniture, carpentry and veneer because of its good workability and its good processing characteristics. In the period 2012-2014 an average of 550 $m^3 \cdot yr^{-1}$ of roundwood of this class B timber species was produced.

Palicourea longiflora **DC. (Rubiaceae)**: The ashes of this plant are mixed with tobacco to add a more pepperlike taste and is said to 'make you feel good'. In the past it was used as a toothpaste or instead of salt.

Parinari excelsa **Sabine (Chrysobalanaceae)**: It has a good natural durability and a good treatability but is difficult to work. It is used for marine and heavy construction and flooring. Two out of nine specimen fulfilled the required dimensions of a diameter over 45 cm and a bole longer than 10 m.

Parkia pendula **(Willd.) Walp. (Leguminosae)**: This light wood is mostly used for light carpentry, crates and plywood. It is easy to work and has a poor durability. The required diameter over 40 cm has not been reached by the encountered specimen. Because of its globose flowers it has an ornamental value and can thus be used for landscaping. Of this class A timber species an average of 400 m^3 of roundwood a year was produced between 2012-2014. In 2014 only 19 m^3 of Faveira bolota (the more commonly used name on the wood market) was exported.

***Parkia ulei* (Harms) Kuhlm. (Leguminosae)**: Its wood characteristics are the same as *Parkia pendula*. The encountered specimen does not reach the required dimensions.

***Peltogyne venosa* (M.Vahl) Benth. (Leguminosae)**: The wood of this species turns deep purple when exposed to light. It has a very good durability but is difficult to process. It is often used for furniture, stairs and flooring but more commonly for carving, turnery, billiard cues and marquetry. Of the three encountered specimen one reached harvestable dimensions with a diameter of 0.45 m and a bole height over 18 m.

***Platonia insignis* Mart. (Clusiaceae)**: Its wood has a good durability but is quite difficult to work. It is used for flooring, marine construction, stairs and veneer. A diameter over 0.45 m and a bole longer than 16 m are required for harvest. Neither of the two specimen reached these dimensions.

***Pouteria cuspidata* (A.DC.) Baehni (Sapotaceae)**: This tree is mostly used for heavy construction and industrial flooring. It is difficult to work and has a moderate natural durability. The one encountered tree has not yet reached the required diameter between 0.25 and 0.60 m or the tree height over 25 m.

***Pouteria guianensis* Aubl. (Sapotaceae)**: This wood species with a very good natural durability but with poor processing characteristics is used for heavy construction, posts, and house framing. For this a diameter larger than 0.30 m and a bole longer than 15 m is required. None of the three encountered trees reached these dimensions.

***Protium polybotryum* (Swart) Daly (Burserceae)**: The wood of this tree species has a poor natural durability and is rather difficult to work with but peels well for veneering. It is used for framing, light carpentry, veneer and furniture. A bole between 15-20 m and a diameter between 0.35-0.75 m is required for processing. One of the 7 encountered specimen reached these dimensions.

***Protium spp.* (Burseraceae)**: This tree has a resin that smells of incense. In the past is was used for torches but it also has medicinal and magical applications. It is said to help against respiration problems and mental problems. It is also used during ancestral rituals.

***Pterocarpus officinalis* (Leguminosae)**: This light, easy to work species with poor durability can be used for plywood and particle boards but also for general carpentry. A diameter between 0.40 and 1 m and a bole longer than 15 m is required. Of the 481 specimen encountered, there was only 1 who reached these dimensions and another 6 almost reached these dimensions.

***Qualea coerulea* Aubl. (Vochysiaceae)**: Although less used than *Qualea albiflora* and *Qualea rosea* it has about the same properties. A bole between 20-25 m and a diameter between 0.60 and 1.00 m are searched for, so this wood can be used for flooring, furniture, plywood and veneer. It has a poor to moderate natural durability but the treatability is rather well. The processing characteristics vary from moderate to good. Not one of the 5 specimen reached these proportions

***Schefflera decaphylla* (Seem.) Harms (Araliaceae)**: This wood species is used for plywood, particle board, boxes, matches and carpentry. It is easy to process but has poor natural durability. A dbh between 0.35-1 m is required and a bole between 15-20 m. Neither of the two encountered trees reached these dimensions.

***Schefflera morototoni* (Aubl.) Maguire, Steyerm. & Frodin (Araliaceae)**: This species has very similar characteristics and uses to *Schefflera decaphylla*. The encountered specimen did not reach the required dimensions for harvest. The leaf was used by the Trio Indians against malaria and by the Marrons against colds. The bark was also used for protection against machetes and bullets. The Indians from Suriname and Guyana used to use this tree for making drums and horns. Although a class A timber species (known as Morototo) only an average of 36 $m^3 \cdot yr^{-1}$ was harvested between 2012-2014.

***Sclerolobium melinonii* Harms (Leguminosae)**: Of this class A timber species, also known as Tachyrana, Kadtiri or more locally, Dyadidya, an average of 87 m^3 of roundwood a year was produced in the period 2012-2014. A diameter between 0.35 and 0.85 m and a bole between 15-20 m are required to use its wood for panelling, furniture, packing and carpentry. It is easy to work and has a poor natural durability. None of the three encountered specimen reached the harvestable dimensions.

***Simarouba amara* (Simaroubaceae)**: This light wood species has a poor durability but is easy to work and to treat. It is used for boxes and crates (because it has and insectifuge quality), toys, packaging and musical instruments. The quite large dimensions of a diameter over 0.70 cm and a bole over 15 m are looked for and was reached by 1 of the 5 encountered trees. An average of 5,500 $m^3 \cdot yr^{-1}$ of roundwood of this class A timber species was produced in the period 2012-2014. In 2014 only 31 m^3 of roundwood (FOB value of 10,902 US$) and 14 m^3 of finished product (FOB value of 12,002 US$) was exported. Internationally this timber species is also known as Marupa or Simaruba.

***Sterculia pruriens* (Aublet) Schumann (Malvaceae)**: Around 1,200 m^3 of roundwood of this class A timber species, internationally known as Kobe, is produced yearly. Four out of 7 encountered specimens already reached the harvest dimensions of a diameter larger than 0.30 m and a bole longer than 18 m. The easy to work wood with poor natural durability can be used for boxes, paper pulp, plywood and particle board and light carpentry.

***Swartzia benthamiana* Miq. (Leguminosae)**: This durable class A timber species is mostly used for violin bows and other musical instruments, parquet flooring and fine furniture. For this a diameter of 0.35-0.60 m and a bole between 15-20 m is needed. The one encountered species did not reach these dimensions. The wood of the genus Swartzia is also known as Banya, Boco or Wanara. The production of roundwood increased in the period 2012-2014 from 1,073 to 8,127 m^3. In 2014 3,486 m^3 was exported as roundwood, sawn wood and hewn square poles for a total FOB value of 421,634 US$.

***Symphonia globulifera* (Clusiaceae)**: This class B timber species is also known as Mani, Manil, Mataki or Chewstick. An average of 320 m^3 of roundwood a year was produced in the period 2012-2014, of this only 71 m^3 was exported in 2014. This yellowish wood that has good processing characteristics and a moderate durability is used for sleepers, furniture, flooring, plywood and carpentry. For this a diameter between 0.35-1.00 m and a bole of 15-20 m is required. 6 of the 57 encountered specimen reached these dimensions. However, it is more well-known for its thick yellow latex which is used to fill leaks in canoes and to remove spines from the skin. The fruits are also used in a mixture to heal infertile women.

***Tabebuia insignis* (Myristicaceae)**: This easy to work wood species with a moderate natural durability is mostly used for carpentry, flooring, pulp and crates. A diameter between 0.30-0.65 m and a bole between 15-18 m is looked for. 8 out of 204 encountered trees reached these dimensions. Thanks to its small size and flowers it is very suitable for usage in urban settings.

***Terminalia lucida* Hoffmgg. ex Mart. (Combretaceae)**: It is used for flooring, furniture, sleepers, plywood and turnery. It has a good resistance against fungi. A bole between 15 and 22 m and a diameter over 0.50 m are required. None of the three specimen fulfilled these conditions.

***Trichilia quadrijuga* (C. DC.) Pennington (Meliaceae)**: This wood species with moderate durability and moderate processing characteristics is used for flooring, furniture and panelling. For this diameters larger than 0.50 and 0.85 m and a bole between 10 and 15 m are required. Not a single one of the 9 encountered specimen reached these proportions.

***Triplaris weigeltiana* (Polygonaceae)**: It has a poor durability but is easy to process. Because of this it is used for boxes, fiber and particle board and utility furniture. A bole longer than 10 m and a diameter between 0.30-0.45 m are needed for this. One of three encountered specimen reached these dimensions.

***Virola surinamensis* (Myristicaceae)**: This wood species known as Virola or Babun is classified as a class A timber species and has a variable density, good processing characteristics and a poor natural durability is used for plywood, particle board and crates. In 2014 3,289

m^3 of roundwood was produced. 21 m^3 was exported as roundwood and 27 m^3 as plywood for a total FOB value of 9,178 US$. For this a diameter between 0.60 and 0.90 m and a bole over 16 m is preferred. Not one of the 26 encountered trees reached these dimensions. The bark of this tree contains tryptamines and is a component of the psychedelic *ayahuasca*-drug that can be found in Brazil and Peru. However, this use is not widespread in the Guianas. Other uses of the plant are against rash and toothache and to learn toddlers to walk faster.

***Vismia cayennensis* (Jacq.) Persoon (Clusiaceae)**: Both the latex present in the tree and the leaves are used for a balm used on ulcers, abscesses, acne, cuts, fungi and infections. It is also used in different types of steam baths for genital hygiene and a variety of things concerning pregnancy.

***Vochysia guianensis* Aubl. (Vochysiaceae)**: A diameter between 0.30-0.50 m and a bole over 15 m are needed to use this wood species for furniture and utility plywood. It is easy to work but has a poor natural durability. Its sapwood is whitish while its heartwood is pink brown to golden brown. 1 of the 2 specimen encountered reached the required dimensions. Together with *Vochysia guianensis* this species is known as Quaruba or Iteballi and is listed as a class A timber species. In the period 2012-2014 a volume of roundwood of 3,663 m^3, 2,482 m^3 and 1,951 m^3 was produced. In 2014 only 43 m^3 of roundwood for a FOB value of 5,189 US$ was exported.

***Vochysia tomentosa* (G. Mey.) DC. (Vochysiaceae)**: This class A timber species is also known as Quaruba or Iteballi (together with Vochysia guianensis). In the period of 2012-2014 an average of 8,000 $m^3 \cdot yr^{-1}$ was produced. In 2014 180 m^3 was exported as roundwood and sawn wood for a FOB value of 25,260 US$. It has a lower density and a different colour from *Vochysia guianensis* but the end uses are mostly the same. The one encountered specimen has reached the harvestable dimensions.

CHAPTER 5

Discussion

5.1 Notes on the ecosystem map of Teunissen (1978)

The map that was used to classify the plots into different forest types dates from 1978 (Teunissen, 1978), only 14 years after forest fires afflicted the region gravely in 1964 (Bubberman, 1973). Because of this the forested landscape that was made up of swamp and marsh forest was reduced to a barren area. The afflicted areas were quickly overgrown by swamps with grasses, herbaceous plants and shrubs, that alternated by surviving pockets of trees (Bubberman, 1973). The area was surveyed in these conditions and because of this large patches of grass swamps and forests of early succession in the swamp forest succession series feature on the map. However, in the nearly 4 decades that have passed since that time, a great part of the grass swamps (although some still remain) have developed into swamp woods, while some of the remaining swamp woods (or low swamp forests) have already developed into high swamp forest (Teunissen, 1993). This was confirmed by comparing the tree species and their frequencies used to compile the different (plausible) ecosystem types in 1978 (Teunissen, 1980) with the current tree species composition and their frequencies and abundancies.
Another inaccuracy is linked to the available technology at the time of mapping. Since the map was composed in the pre-digital period and because of the lack of GPS equipment (Teunissen, 2016) inaccuracies could be found in the exact location of the *Oost-Westverbinding* and the ridges present of the area.
Because of these reasons, the forest types that were selected from the map for every plot were sometimes replaced by more suitable forest types as explained in section 3.3.2.

5.2 Forest types

5.2.1 Swamp forest

Low swamp forest

This type of forest, often called swamp wood, grows on mostly heavy clay soils that are inundated year round and only dry up in long periods of drought (Beard, 1944; de Granville, 1986; Lindeman and Mori, 1989; Teunissen, 1993). Because of the almost continuous inundation and thus lack of oxygen, the species occurring are specialized to survive (Lindeman and Mori, 1989; Beard, 1944). They have buttresses and pneumatophores (Oldeman, 1971), have smaller dimensions and a poorer species richness than drier forests (Lindeman and Mori, 1989; van Andel, 2003; Hoff, 1994). They feature only one storey and a very low canopy (not much higher than 15 m) (Beard, 1944; Lindeman and Mori, 1989). These characteristics are in line with the findings in this study. The canopys mean height was only 13.3 m, but included many trees that were where taller than 15 m.
Another characteristic is that one species is often dominant (Lindeman and Mori, 1989). Because of this, there are numerous subtypes of this forest discerned in Suriname and the Amazonian region over the years. Lindeman and Moolenaar (1959) distinguished the following: a mixed swamp wood that can be found immediately behind the mangrove, *Erythrina fusca* swamp wood (often associated with precolumbian settlements) and*Machaerium lunatum* swamp wood. Later other types were added that were not listed by Lindeman and Moolenaar (1959): *Chrysobalanus-Annona* forest that can be found in mid Suriname, fire-resistant *Mauritius flexuoasa* palm forest, *Triplaris weigeltiana* forests, *Pterocarpus officinalis* forests and *Dalbergia* scrub (Planatlas, 1988; Teunissen, 1993).

Of this variety of forest types only two were identified in this study. There was one plot (plot 31) where *M. flexuosa* accounted for 30% of the identified trees that might be classified as the *Mauritia flexuosa* swamp wood type. However this was an exception in the area and because of its isolation it was classified as forest type 4 since the species composition also showed resemblance to this forest type.
The other one is forest type 3 (Figure 5.1), which coincides with the *Pterocarpus officinalis* swamp wood, where a very specific structure became apparent. These forests tend to be almost monospecific as was found in almost all plots of this forest type except for plot 41 (that contained 7 different species) and have a very high stem density (Alvárez-Lopez, 1990). Fanshawe (1952); Koponen et al. (2004) found that *P. officinalis* tends to form small hummocks by litter accumulation between its buttresses (Koponen et al., 2004; Imbert et al., 2000). This was confirmed here by the clustering that became apparent from the L-function and the pair correlation functions of these plots. In these plots a lot of moko-moko (*Montrichardia*

arborescens (L.) Schott (Araceae)) can be found (Figure 5.1), as was previously noted by de Granville (1986); Janzen (1978); Koponen et al. (2004); Lindeman (1952).

In the *P. officinalis* forests in Guadeloupe a mean of 6 species and a maximum of 16 per plot were reported (Imbert et al., 2000). However, this study included lianas so it is to be expected that the number of species per plot was lower in this study. In Mexico, Costa Rica and Guadeloupe canopy heights of respectively 16-17 m, 17 m and 11-23 m were reported, which is similar to what we observed (Imbert et al., 2000; Pool et al., 1977; Weaver, 2000). A lot more variation has been found for the basal area figures: in French Guiana this was between 60 and 80 $m^2 \cdot ha^{-1}$, in Guadeloupe basal areas between 35 and 87.5 $m^2 \cdot ha^{-1}$ were reported and in Mexico basal areas between 58-61 $m^2 \cdot ha^{-1}$ were reported (Alvárez, 1982; Koponen et al., 2004; Migeot and Imbert, 2011; Weaver, 2000). In this study a mean basal area of only 33.59 $m^2 \cdot ha^{-1}$ was found. This can probably be related to the stem density that was considerably lower than reported in French Guiana (1,100 $stems \cdot ha^{-1}$ compared to 2,300 $stems \cdot ha^{-1}$) (Koponen et al., 2004). While the evenness index assessed in our study was very similar to the results from the study in French Guiana, the Simpson index was lower, probably because there was a second abundant species in the French Guiana study (*Malouetia tamaquarina* (Aubl.) A. DC. (Apocynaceae), which was absent in our plots) (Koponen et al., 2004). The low swamp forests found in our study site are thus a classic example of the *Pterocarpus forests* found in the greater Caribbean region in terms of species composition, species diversity and the typical hummock structure, but were considerably lower stocked than most *P. officinalis* forests in the region. A probable explanation for this might be the forest fires that affected the region or that in Suriname this type of forest develops into the high swamp climax vegetation while this is not the case in Guadeloupe (Imbert et al., 2000).

Figure 5.1: Left: A *Pterocarpus officinalis* dominated plot. Right: moko-moko that typically grows in and around the *Pterocarpus officinalis* dominated low swamp forests.

High swamp forest

This climax vegetation of which the soils never completely dry out, has a canopy of at least 20 m high that is composed of two or more storeys (Beard, 1944; Lindeman and Mori, 1989). However, when the soils dry up, there is a danger of forest fires that will set back the succession (Bubberman, 1973; Planatlas, 1988; Teunissen, 1993). Lindeman (1952) called these forests marsh forests. As in the low swamp forests, only specialized species occur here and thus species with buttresses and stilt roots are common, but contrary to the low swamp forests, palms are an important aspect of these forests (Beard, 1955; de Granville, 2002; Oldeman, 1969). They are often so prevalent that this type of forest is labelled as *pinotière* in French Guiana, after the local name for *Euterpe oleracea.* In this study *E. oleracea* has the highest IVI in forest type 4, despite the small dbhs of these palms, which demonstrates that *E. oleracea* has the same importance in the high swamp forests in Suriname as in these forests in French Guiana (Figure 5.2).

Teunissen (1993) subdivided this forest type into 3 types: the species poor, deeper (water levels up to 3.5 m) *Crudia-Macrolobium* forest where no palms are present and the species rich *Virola surinamensis-Symphonia globulifera-Euterpe oleracea* forests that appear on shallow swamps (water levels up to maximum 80 cm). The *Virola-Symphonia-Euterpe* forests can also locally be dominated by a particular species such as *Hura crepitans*, *Virola surinamensis* or *Pentaclethra macroloba* which may lead to the use of the names Posentri forest, Mataki forest and Pentaclethra forest. Forest type 4 in our study belongs to the second forest type: *Virola-Symphonia-Euterpe* forest.
In the three swamps in Guyana that were studied by (van Andel, 2003), two swamps suited this description, one where *E. oleracea* was the dominant species together with *Pentaclethra macroloba* and *S. globulifera* and one where *Tabebuia insignis*, *Symphonia globulifera* and *Virola surinamensis* where the dominant upper canopy species and *E. oleracea* could be found in the shrub layer. Although the species composition differs from the ones present in

Figure 5.2: Left: Typical views in the palm dominated high swamp forests.

this study, the indicative species are present and the described environmental characteristics match. The number of species per hectare, mean diameter and canopy height also fall in the same range as found in the Guyana study.

5.2.2 Seasonal swamp forests

General observations

Seasonal swamp forests or marsh forests grow on seasonally waterlogged soils and thus have alternating moisture conditions. They have a canopy height around 25 m and are composed of two or more storeys. Palms are often, but not necessarily an important component of the floristic composition and some of the trees that occur in this forest type will have stilt roots. However, the number of species with stilt roots is reduced compared to the swamp forests (Beard, 1944, 1955; de Granville, 1986; Lindeman and Moolenaar, 1959). The biodiversity was indeed a lot higher in the seasonal swamp forests than in the swamp forests featuring in this study. The amount of canopy layers, canopy height, the importance of palms and the lessened share of tree species with stilt roots are all typical attributes of the measured plots.

Marsh forests

This periodically inundated forest type can be found on clay flats with poor drainage that are slightly higher than the surrounding landscape (Planatlas, 1988). The canopy is composed of two storeys or more and the upper storey reaches heights between 25-30 m (Lindeman and Moolenaar, 1959). This type of forest is often regarded as the transition between the (high) swamp forests and the evergreen tropical forests and should accordingly have a higher biodiversity than the swamp forest but lower than the rainforests (Beard, 1955; Planatlas, 1988). According to Lindeman and Moolenaar (1959), some of the characteristic species for this forest are a variety of palms (*Attalea maripa*, *Euterpe oleracea*, *Oenocarpus bacaba*, *Mauritius flexuosa*) and the following tree species: *Carapa guianensis*, *Alexa wachenheimii*, *Copaifera guyanensis*, *Eschweilera* spp, *Trichilia quadrijuga* and *Simarouba amara*. Most of these species where indeed present (and often in significant proportions) in forest type 4 in this study (which coincides with this forest type) (Figure 5.3). However, *M. flexuosa*, *A. wachenheimii* and *S. amara* were completely absent in this forest type while they all could be found abundantly in forest type 1.

The stem densities between 700-900 stems·ha^{-1} that was found by Koponen et al. (2004) in the higher and drier swamps are slightly higher than the density found for this forest (a mean of 670 stems·ha^{-1}). This was also the case for the Simpson index and the evenness. The basal area ($m^2 \cdot ha^{-1}$) was higher in two plots and lower in one plot (where it was only 20 $m^2 \cdot ha^{-1}$). The species composition showed similarities but some of the species that were important in the French Guiana plots were not encountered in this study and vice versa (Koponen et al.,

Figure 5.3: Left: Typical views in the seasonal high swamp forests on clayey soils (marsh forests).

2004). This may be caused by the greater biodiversity that can be found in this forest type and the sample size of the plots, which are small in both studies.

Ridge forest

Arguably, this forest type can be regarded as not belonging to the seasonal swamp forest types since its main distinguishing characteristic are the sandy ridges on which it is located. As such it could be labelled as an edaphic forest determined by soil type instead of the water status. However, temporary inundation is a common event so it can be regarded as seasonal swamp forest (Van der Eyk, 1957). Lindeman and Moolenaar (1959) found that this forest type typically has 2 or more storeys and is over 30 m high while de Granville (1986) found that these forests on ridges of intermediate age are only between 15 and 25 m high in French Guiana (where they are called *cordon sableux*). Forest type 1, which coincides with the ridge forests, in our study has a canopy height of 21.1 m and more than 2 storeys (Figure 5.4). Other than this the forest type is mostly determined by its species composition which varies with the age of the ridge as older ridges are further removed from the influences of the sea and generally higher and thus drier. In Suriname *Hura crepitans* is often a characteristic species on the young ridges, while the older ridge in the eastern part of the country are better characterized by *Parinari excelsa* (which is the 18th most important species in the measured plots according to its IVI) (Planatlas, 1988). Other important species are *Oenocarpus bacaba*, *Attalea maripa*, *Hymenaea courbaril*, *Cedrela odorata*, *Simarouba amara*, *Protium* spp. and *Inga* spp. (Lindeman and Moolenaar, 1959), which mostly correspond to the species composition found in French Guiana by de Granville (1986). The IVI of these species in this study are respectively 9.40%, 8.70%, 3.03%, 0%, 15.56%, 5.72% and 5.72% for *Inga rubiginosa* and 5.18% for *Inga alba*. The species composition of the ridges in this region thus concur with the existing literature (de Granville, 1986; Lindeman and Moolenaar, 1959).

These forests are also less diverse than the marsh forests that can be found on flats, which has also been assessed in this study.

Ecosystems on abandoned forest plantations and farmlands

A remarkable appearance are the four plots of forest type that are classified as "Ecosystems of Urban Areas, Farmlands, Meadows, Mining areas and Abandoned Forest Plantations and Farmland". These forests have a higher rarefied species number, Simpsons index, Shannon index and evenness than the other forest types and the mean diameter, mean tree height and basal area per hectare show similarities to the other drier forest types (Figure 5.5). The dissimilarity matrix shows that the floristic composition is similar to forest type 2, the marsh forests. Thus when not taking the deviating diversity into account it could be supposed that this forest type should actually be classified as marsh forest, which also happens to be the dominant forest type that surrounds these plots.

What explains the higher biodiversity? One explanation could be the intermediate disturbance hypothesis and that these plots, because of the disturbance by humans in the past, have not yet reached their equilibrium state and thus have a higher species richness (Connell, 1978). Another possible explanation might be that the human disturbance changed the nutrient status in the soils. Both a more nutrient rich or a nutrient poor soil are possibilities as slash and burn techniques are used in Suriname which might enrich the soil but it might also be possible that the soil nutrient status has been depleted by agricultural activities. Fires initially cause the quantity of organic matter to drop but in the long term it generally exceeds the original organic matter levels and the base saturation increases (Certini, 2005). Because these plots are still surrounded by forest there is no seed dispersal limitation and the open space inside the forest might even attract more animals which would cause the species that

Figure 5.4: Left: Typical views in the seasonal high swamp forests on sandy soils (ridge forests).

use zoochory as dispersal method to have a better chance of establishment (Ruiz-Jaen and Mitchell Aide, 2005).

5.2.3 Comparison of the forest types

The composition of the most important species of the forest types indicated that the low swamp forests (forest type 3) and the high swamp forests (forest type 4) have a lot of species in common. However, when analysing the total floristic composition, there are some clear differences since the high swamp forest consist out of a lot more species. The diversity indices as well as the height and the aboveground biomass also indicated similarity between these forest types. These similarities in composition and dissimilarities of the dimensions and spatial patterning can be explained as some low swamp forests, such as the *P. officinalis* forests (forest type 3), are an earlier stage in the succession to the climate swamp forest type, namely the high swamp forests (in this case the *Virola surinamensisSymphonia globuliferaEuterpe oleracea* forest (forest type 4) (Beard, 1944; Teunissen, 1993). The latter features a greater diversity in species but also especially in dimensions, as this forest type has a longer development history.

In between the patches of these two types of swamp forest the three other, drier, forest types (the seasonal swamp forests) can be found. Except for the importance of *E. oleracea* in all forest types not much similarities are shown between the swamp forests and the seasonal swamp forests.
While the drier forest types do show similarities in floristic composition and diversity, they do show (slight) differences in the dimensions of trees and in the number of trees per hectare. These differences are caused by the different soil types. The ridge forests (forest type 1) grow on sandy soils, while the marsh forests (forest type 2) and the forests growing on old forest plantations and farmland (forest type 5) grow on clay soils. More species could be found in

Figure 5.5: Left: Typical views in the seasonal high swamp forests that were previously human ecosystems such as plantations or farmlands.

the seasonal swamp forests growing on clay soils than in those growing on sandy soils and a larger basal area and a higher AGB could be found on the clay soils. This might be explained by the ridge forests grow on nutrient poor soils while other two forest types grow on more nutrient rich soils (Van der Eyk, 1957). The forests growing on old forest plantations and farmland (forest type 5) could been regarded as a special case of the marsh forests (forest type 2), namely "heavily disturbed seasonal swamp forests on clayey soils".

5.3 Classification of the forests

Over the years many different classifications have been proposed for the forests in the Guiana Shield and the Amazonian region, which led to confusing terminology (such as marsh forest- swamp forest- seasonally swamp forest- *igapo* forest) (Beard, 1944, 1955; de Granville, 1986; Fanshawe, 1952; Lindeman and Moolenaar, 1959; Prance, 1979; Teunissen, 1993). Because some species might be locally abundant this also led to numerous subtypes based on floristic composition that might be valid for one part of the country but completely useless elsewhere. An example is the Mora forest that can be found in West-Suriname and parts of Guyana but not in the east of Suriname or French Guiana (Beard, 1955; Lindeman, 1952; van Andel, 2003). We propose the following classification for the edaphic forests caused by inundation for the Guianas:

- **Permanent swamp forests:** edaphic tropical forests that are waterlogged and have a year-round ground water table at ground level. The water can be slightly brackish or fresh. These forests are species poor compared to the evergreen or semi-deciduous tropical forest.
    - Low permanent swamp forests: permanent swamp forests that are dominated by only one or two species, have a single storeyed canopy of maximum 20 m and are densely stocked (they have a high number of trees per hectare). The presence of palms is rare.
    - High permanent swamp forests: permanent swamp forests that are dominated by more than one species, but are still species poor and have a canopy with two storeys that has a maximum height of 30 m. The presence of palms is common.
- **Seasonal swamp forests:** edaphic tropical forests that are waterlogged and have a ground water table at ground level, but not year-round. The water can be slightly brackish or fresh. These forests are species poor compared to the evergreen or semi-deciduous tropical forest but more species rich than the permanent swamp forests.

- Low seasonal swamp forests: seasonal swamp forests that are dominated by only a few species, have a single storeyed canopy of maximum 20 m and are densely stocked.
- High seasonal swamp forests: seasonal swamp forests that are not necessarily dominated by a few species, and are more species rich that the other edaphic forest types of this series. They have a canopy that is higher than 20 m and composed of more than 2 storeys.

This general classification still allows for subdivisions based on floristic composition, time and depth of inundation and soil type.

5.4 Comparison with remote sensing classification

In the parallel thesis "Structural and spatial characterization on the forests in swamp forests in northeastern Suriname via remote sensing techniques" (Feyen, 2016), four vegetation types could be distinguished: the open herbaceous swamps (which were easy to recognize in the field and which are outside the scope of this study) and three forest types, which (Feyen, 2016) names (1) *Virola-Symphonia* forest; (2) low forests and (3) mixed high forests. The first forest type coincides with the high swamp forests (forest type 4) encountered in this study, while the second forest type coincides with the low swamp forests (forest type 3) and the third type coincides with the seasonal swamp forest on sandy soils (forest type 1: ridge forests), the seasonal swamp forests on clayey soils (forest type 2: marsh forests) and the forests that grow on abandoned human ecosystems (forest type 5). Thus the remote sensing classification could distinguish between the swamp forest types, but not between the drier seasonal swamp forests. In this study the differences between these forest types could mostly be encountered in the tree species composition, tree density and tree height.

5.5 Evaluation of the sample method

The unsupervised classification in combination with the knowledge of the inhabitants of the region already gave a good first impression of the different forest types and their location. Koponen et al. (2004) and van Andel (2003) mentioned that one hectare sample plots give quite a complete view of species composition in these species poor forests and that small plots are useful to assess the local variation in composition and structure in these kinds of forests. van Andel (2003) also stated that more than one plot is needed to estimate the local diversity, even if it has a large size. The size of the plots was useful to be assessed in a fast way and to get a general idea of the species composition, especially in the species poor forest types.

However, the sample size might have been too small for some of the analysing techniques during the processing even though they did already give a good indication. When the rarefied species richness was calculated, they did not reach the asymptotic rarefaction curves meaning the sample size was not large enough. The same is true for the mark correlation functions and mark variograms which are expected to find an equilibrium around at a value of 1 (or sill) for a long enough distance which is called the range (Pommerening and Särkkä, 2013; Szmyt and Stoyan, 2014; Wälder and Stoyan, 1996). The plots also appeared to be too small for usage in the remote sensing analysis of the region. This might be solved by larger plots or satellite or aerial images with a higher resolution (companion work by Feyen, 2016).

5.6 Value of the forests in the study area

Until recently, the economic value of forests was mostly determined by the wood that could be obtained. Nowadays a more holistic approach is gaining popularity: the concept of ecosystem services, defined by Sukhdev et al. (2010) as "the flows of value from nature to human societies as a result of the state and quantity of natural capital". Four categories are defined: provisional services, regulating services, cultural services and supporting services (Assessment, 2005).

Provisional services are ecosystem services that describe the material outputs from ecosystems (Assessment, 2005; Sukhdev et al., 2010).
In the study site several sources of food could be found such the fruit pulp and palm heart of *Attalea maripa*, the fruits of *Duroia aquatica*,*Genipa americana*, *Mauritia flexuosa*, *Oenocarpus bacaba*, *Hymenaea courbaril* and the acai berries that grown on *Euterpe oleracea*. The *Euterpe oleracea* palms (which are abundantly present) might even be harvested with a more commercial purpose in mind and could be exported as happens in Brazil. The forests also provide proteins such as the larvae of *Rynchophorus palmarum* that live on *M. flexuosa*, the fishes and turtles that are caught in the waters running through the forests and the iguanas (known in Suriname as tree chicken) and agoutis that are hunted by the forest people.
Raw materials could be found as well. 59 of the 1770 trees reached harvestable dimensions (as presented in Comvalius (2010)), which is 28.6 trees$\cdot$ha^{-1}. As selective logging (with often only 7 m^3 harvested per ha) is widely used in Suriname (Mohren and van Kanten, 2011), it is possible to exploit them. However, the (almost) year round wet grounds will complicate the extraction process and thus increase the costs significantly. The low number of specimens that reached harvestable dimensions might be explained by the age of the forest, as it is regularly destroyed by forest fires (Bubberman, 1973; Koponen et al., 2004; Weaver, 2000) or by the site quality, as there is a lack of oxygen in the soils, which impedes the growth of less specialized species (Beard, 1944). Many encountered species are suited as fuel wood and some produces oils that can be used for illumination: *Carapa guianensis*, *Carapa procera* and *Ceiba pentandra*. Other raw materials that could be harvested from this forest are kapok (from *Ceiba pentandra*) and fibrous materials from *Eriotheca globosa* and *Mauritia flexuosa*.

These forests are also a great medicinal resources as many plants are often used by the local people for this purpose. Examples can be found in Section 4.4.

Regulating services are services that ecosystems provide by acting as a regulator for its surroundings (Assessment, 2005; Sukhdev et al., 2010). Wetlands such as the swamp forests are know to help moderate floods by soaking up portions of the excess water and influence air quality (Russi et al., 2013).
The swamp forests, which grow quite fast, are able to sequestrate carbon (through photosynthesis). It are however the anaerobic conditions in the soil (which result in peat formation) that cause swamp forests to be large carbon sinks (Page et al., 2011; Pan et al., 2011).
Other regulating services such as waste water treatment and the influence on the climate need more research. Because of its location close to the Amazon rainforest it is possible that the effects on the climate might be negligible compared to the huge influence that the Amazonian rainforest has on the climate (Nepstad et al., 2008; Shukla et al., 1990).

Cultural services include the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual and psychological benefits (Assessment, 2005; Sukhdev et al., 2010).
The recreation value of this area is low thanks to its inaccessibility and more established nature parks and reserves such as Brownsberg and Bigi Pan are preferred by tourists. However, these forests are used to gather plants that are part of spiritual and ancestral rituals by the forest people and the inhabitants from the surrounding villages. Examples can be found in Section 4.4.

Supporting services underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals (Assessment, 2005; Sukhdev et al., 2010).
The Guianas have plenty of endemic species and some of these are typical for the coastal swamp forest and the endangered tree species *Virola surinamensis* is quite common here (IUCN, 2016). More research is needed in the swamp forests of this part of Suriname to elaborate on the supporting services that these forests provide.

CHAPTER 6

Conclusion

The goal of this study is to obtain a rapid assessment that reflects the structure and compositon of these forests. Very high resolution imagery (and a simple unsupervised classification in a preparatory step prior to field work), and the knowledge from people who know the area well allowed to set up an adapted field protocol. Although not applied in this study, the use of satellite images can also contribute to the characterization and mapping of the distribution of the forests in the area (companion work by Feyen, 2016).

The size of the sample plots allowed for logistically advantageous information gathering, and the somewhat smaller sample size enabled for a better spatial spread in the field, to capture differences within the same forest types. The classic 1 ha plots, used for long term biodiversity monitoring were outside the scope and limitations of this work anyway. However, we acknowledge that larger plots should result in a more thorough knowledge of the tree species composition in the drier forest types. In the swamp forests (as classified above) such an increase in area would only yield a few more identified species. Another argument in favour of a slightly larger sample plot size is that they are somewhat small for analysis via satellite remote sensing. This should become feasible when technology is able to render images with a resolution smaller than 10 cm. This would also be useful for the point pattern analysis, which in this study often did not reach the expected values yet because of the short inter-tree distances that could be evaluated.

The floristic composition and general structure of the explored plots mostly coincided with the findings of earlier studies in the Guiana Shield region. Even the point pattern analyses were able to sketch an image of the forest structure within a plot level. That was however not possible on a larger level as the absolute coordinates for the trees were lacking (because of the large inaccuracies of the GPS location measurements) and the small size of the plots. The existing knowledge and data on these forests is often lacking in terms of quantitative measurements and information concerning the biodiversity, structure and the dimensions of the trees present. Often the existing data date back a considerable time, but this does not necessarily renders them useless, since the general characteristics will continue to apply to the wider region. On the other hand, these are forests that are subject to more dynamics than many other forests in the region due to i.a. forest fires and shifting agriculture. These phenomena frequently set them back in time, with a diversity of succession patterns as a result. The abundance of forest classification systems for the Guiana Shield and its individual countries were overwhelming but all represented more or less the same forest type, although the many forest types are named after an abundant species which may not necessarily always be that abundant. Thus when the forest types based on floristic composition were filtered out and the physiognomic characteristics of these forests were listed more consistently, an overarching classification could be proposed. It is possible to list the forest types based on floristic composition as subtypes under the proposed forest types, although caution is desirable for forest types dominated by one or two tree species, as these are often (but not always) a very local appearance and might be classified under a larger floristic association.

The wetter swamp forests are low in diversity both on floristic and size level. However, as an edaphic ecosystem it is able to harbour many habitats for fauna as they are found on the transition between the coastal and marine habitats and the rainforests. The drier seasonal swamp forests feature a higher diversity, both in floristic composition and in dimensions of trees. The patchwork of forest types occurring in this region thus shows a diversity in its own peculiar way, thanks to the rapid alternation between the different forest types and the large number of habitats that they create.

From the more conventional silvicultural point of view, these forests may appear to be less valuable as prized timber species are sparse and their dimensions are small. However, they are not absent and with the technological evolution where particle boards, fibre boards and pulp and its applications gain importance, it might become more interesting to introduce logging activities in these regions since the more valuable wood species and species with less specialized applications could be harvested together. Nonetheless, the environmental conditions may prove another hurdle to overcome for mechanical and at the same time profitable extraction. Because of this, more alternative uses and valuations of the forest should be considered. The variety of NTFPs that this forest delivers such as acai berries, palm hearts, hunting and fishing grounds and the plethora of locally used ritual and medicinal tree species, is of great value to the forest people and the inhabitants of nearby villages. They might have potential to contribute to the economic growth of Suriname, if managed and marketed carefully.

While the mean aboveground biomass is lower than the average rainforest (as far as these exist), the peat formation and relatively undisturbed (by humans) occurrence of these forests may also prove to considerably contribute to carbon sequestration.

Thus the swamp forests in Northeastern Suriname demonstrated to be interesting, if not fascinating forests with a great intrinsic value which contributes to both the flora and fauna of Suriname and its inhabitants.

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APPENDIX A

Extra tables and figures

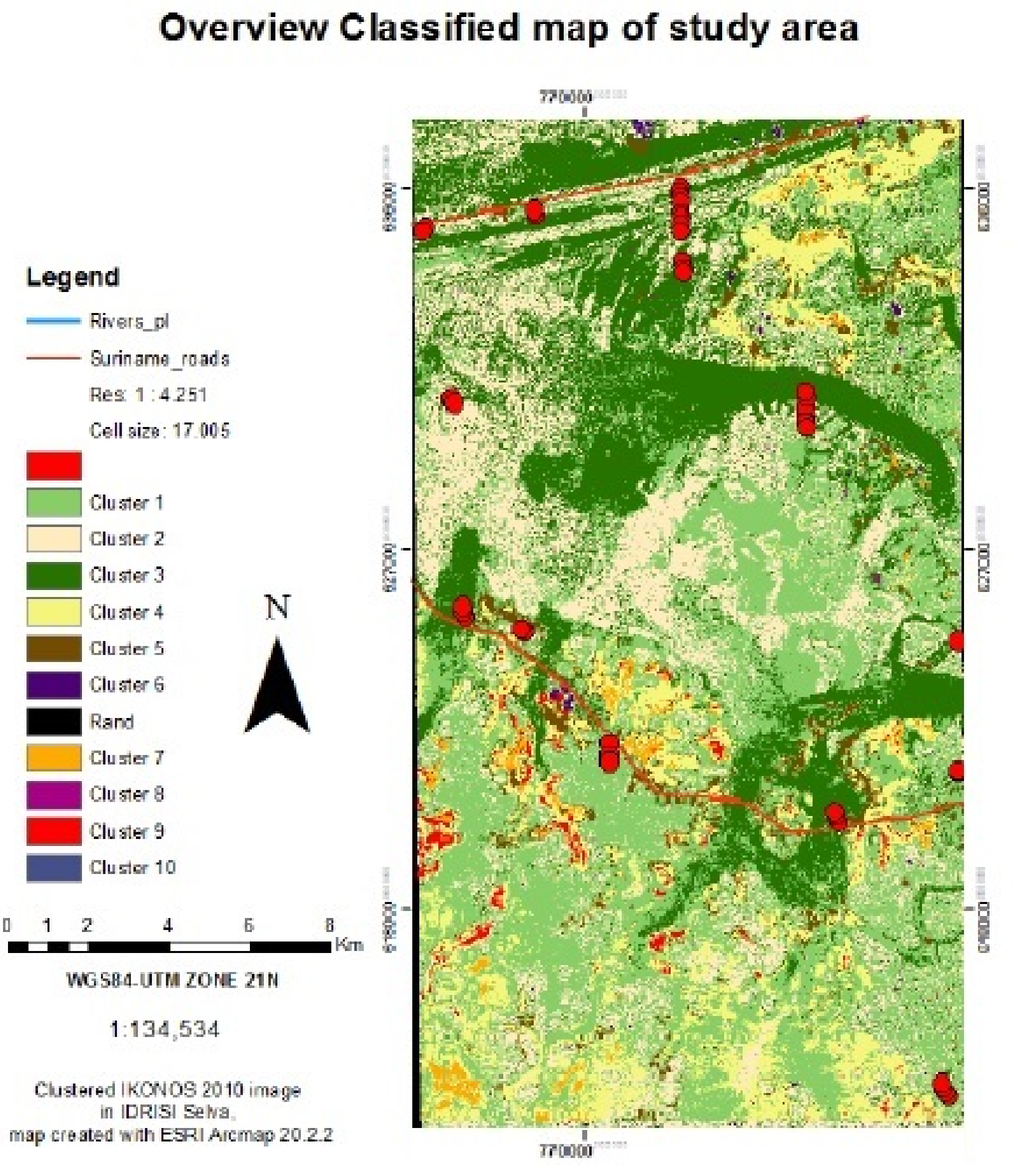


Figure A.1: Locations of the measured sample plots on the unsupervised classification of the study site.

Table A.1: Summary characteristics for the plots in forest type 1. D' is the Simpson index, H' is the Shannon index, J' is the evenness, AGB is above ground biomass, CE is the Clark-Evans index.

	11	12	13	14	33	34	35	36
Area (ha)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of trees measured	51	22	22	18	18	21	14	20
Number of species	17	15	12	11	14	16	9	14
Number of genuses	17	14	12	11	13	13	7	13
Number of families	15	10	10	9	11	13	7	10
Rarefied species number	7.21	8.93	7.97	7.41	5.9	6.16	4.86	5.73
D'	0.79	0.85	0.83	0.79	0.71	0.60	0.62	0.52
H'	2.17	2.40	2.19	2.03	1.65	1.75	1.31	1.61
J'	0.52	0.59	0.51	0.85	0.38	0.73	0.38	0.39
Average dbh (cm)	17.30	22.95	27.28	18.83	27.33	21.92	26.92	26.42
Basal area ($m^2 \cdot ha^{-1}$)	27.94	21.23	36.32	11.88	24.5	20.86	24.25	36.01
Average height (m)	15.9	15.0	17.9	15.0	19.0	15.2	16.2	16.9
Canopy height (m)	16	15.1	21	21.3	26.4	20.3	23.5	25.4
Above ground biomass ($Mg \cdot ha^{-1}$)	175.47	148.87	304.78	75.63	220.48	137.23	200.62	336.35
Density ($trees \cdot ha^{-1}$)	1020	440	440	360	360	420	280	400
CE	0.731	0.897	0.883	0.89	0.949	0.849	0.845	0.769

Table A.2: Summary characteristics for the plots in forest type 2. D' is the Simpson index, H' is the Shannon index, J' is the evenness, AGB is above ground biomass, CE is the Clark-Evans index.

	6	7	8	9	10	15	16	25	26	29
Area (ha)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of trees measured	36	39	44	30	46	38	26	20	26	30
Number of species	9	10	11	11	9	18	19	13	11	14
Number of genuses	9	10	9	10	9	15	15	13	11	14
Number of families	8	10	8	10	9	12	10	13	10	12
Rarefied species number	7.04	6.4	6.82	7.52	4.92	8.31	9.06	6.8	6.13	6.85
D'	0.85	0.75	0.8	0.85	0.61	0.87	0.85	0.71	0.74	0.75
H'	2.07	1.86	2.02	2.17	1.44	2.45	2.52	1.9	1.82	2
J'	0.5	0.45	0.47	0.91	0.42	0.72	0.61	0.56	0.44	0.84
Average dbh (cm)	20.88	17.52	18.4	19.37	15.49	21.38	20.2	25.83	21	24.72
Basal area ($m^2 \cdot ha^{-1}$)	30.69	22.94	28.62	24.65	21.3	34.51	24.09	32.27	23.87	43
Average height (m)	14.2	13.3	13.5	17.4	14.1	18.7	17.8	18.7	14.0	14.5
Canopy height (m)	19	16.4	22.7	24.6	20.3	24.9	33.6	27.2	21.9	21.5
Above ground biomass ($Mg \cdot ha^{-1}$)	237.96	127.34	224.03	183.37	133.33	387.24	351.28	362.15	188.6	311.11
Density ($trees \cdot ha^{-1}$)	720	780	880	600	920	760	520	400	520	600
CE	0.887	0.57	0.96	0.898	0.594	0.834	1.006	1.087	0.851	0.743

Table A.3: Summary characteristics for the plots in forest type 3. D' is the Simpson index, H' is the Shannon index, J' is the evenness, AGB is above ground biomass, CE is the Clark-Evans index.

	19	20	21	22	23	24	27	28	30	41
Area (ha)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.0125	0.05
Number of trees measured	48	57	76	71	85	89	47	37	25	54
Number of species	5	5	4	2	4	2	5	5	4	7
Number of genuses	5	5	4	2	4	2	5	5	4	7
Number of families	5	5	4	2	4	2	5	5	4	7
Rarefied species number	4.94	4.37	3.86	2.67	3.45	2.56	3.87	3.71	4.48	5.27
D'	0.76	0.7	0.65	0.44	0.5	0.4	0.63	0.63	0.67	0.75
H'	1.6	1.43	1.26	0.77	1.02	0.72	1.24	1.21	1.37	1.67
J'	0.67	0.42	0.3	0.19	0.24	0.3	0.3	0.28	0.4	0.4
Average dbh (cm)	16.73	17.39	16.87	14.54	16.24	17.78	19.67	23.79	15.86	16.23
Basal area ($m^2 \cdot ha^{-1}$)	23.18	30.09	37.33	24.59	40.35	48.44	33.15	37.63	43.59	24.99
Average height (m)	11.8	13.8	12.3	12.9	11.2	13.3	15.1	16.1	14.2	15.3
Canopy height (m)	15.6	16.8	16.1	16.2	15.6	16.6	20.1	22.7	18.2	18.3
Above ground biomass ($Mg \cdot ha^{-1}$)	100.54	136.93	155.82	101.22	157.71	205.77	181.13	208.65	279.11	145.36
Density ($trees \cdot ha^{-1}$)	960	1140	1520	1420	1700	1780	940	740	1667	643
CE	0.817	0.72	0.818	0.78	0.774	0.746	0.879	0.799	0.553	0.573

Table A.4: Summary characteristics for the plots in forest type 4. D' is the Simpson index, H' is the Shannon index, J' is the evenness, AGB is above ground biomass, CE is the Clark-Evans index.

	4	5	31	32	37	34	35	36
Area (ha)	0.1	0.1	0.05	0.05	0.05	0.05	0.05	0.05
Number of trees measured	96	100	41	40	78	36	45	33
Number of species	12	8	8	6	6	10	7	5
Number of genuses	12	7	8	6	6	9	7	5
Number of families	9	7	6	6	6	8	6	5
Rarefied species number	5.07	4.24	5	4.52	2.83	4.99	5.05	4.07
D'	0.64	0.61	0.73	0.71	0.51	0.68	0.72	0.63
H'	1.56	1.32	1.60	1.48	0.94	1.56	1.58	1.28
J'	0.65	0.39	0.39	0.36	0.23	0.36	0.66	0.38
Average dbh (cm)	15.61	14.60	21.62	18.31	13.08	19.19	18.38	16.39
Basal area ($m^2 \cdot ha^{-1}$)	20.93	18.62	40.25	23.87	23.66	25.47	27.7	17.33
Average height (m)	12.1	10.1	15.9	15.6	13.4	14.6	16.6	11.7
Canopy height (m)	16	15.1	21	21.3	17.4	20.4	22.6	15.1
Above ground biomass ($Mg \cdot ha^{-1}$)	104.43	79.25	246.86	145.34	107.21	161.69	185.72	70.26
Density ($trees \cdot ha^{-1}$)	960	1000	641	800	1560	720	900	660
CE	0.579	0.93	0.731	0.832	0.592	0.702	0.755	0.923

Table A.5: Summary characteristics for the plots in forest type 5. D' is the Simpson index, H' is the Shannon index, J' is the evenness, AGB is above ground biomass, CE is the Clark-Evans index.

	1	2	17	18
Area (ha)	0.1	0.1	0.05	0.05
Number of trees measured	54	73	26	38
Number of species	22	21	19	24
Number of genuses	17	20	18	21
Number of families	14	16	14	16
Rarefied species number	8.68	8.36	8.71	9.36
D'	0.84	0.88	0.85	0.88
H'	2.54	2.54	2.48	2.73
J'	0.62	0.59	0.61	0.63
Average dbh (cm)	20.23	22.48	18.5	20.22
Basal area ($m^2 \cdot ha^{-1}$)	24.72	36.47	17.91	31
Average height (m)	13.9	14.5	16.2	17.6
Canopy height (m)	21.5	21.5	26.2	25.3
Above ground biomass ($Mg \cdot ha^{-1}$)	251.95	289.81	173.52	311.63
Density ($trees \cdot ha^{-1}$)	540	730	500	760
CE	0.658	0.948	0.852	0.892

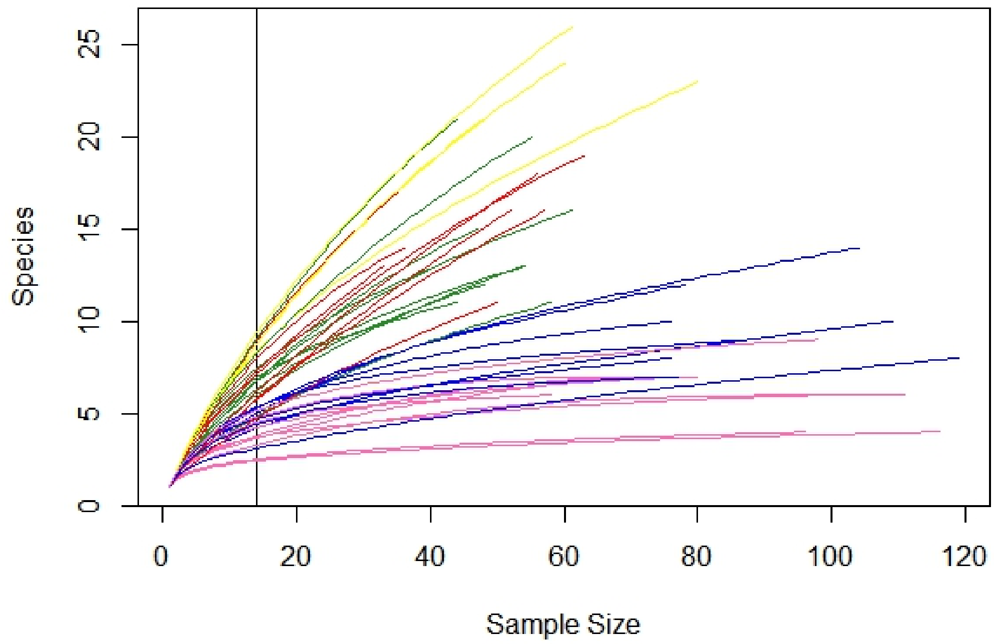


Figure A.2: The rarefaction curves for every sample plot with the rarefied species number at sample size 14. The red lines represent forest type 1, the green lines forest type 2, the pink lines forest type 3, the blue lines forest type 4 and the yellow lines forest type 5.

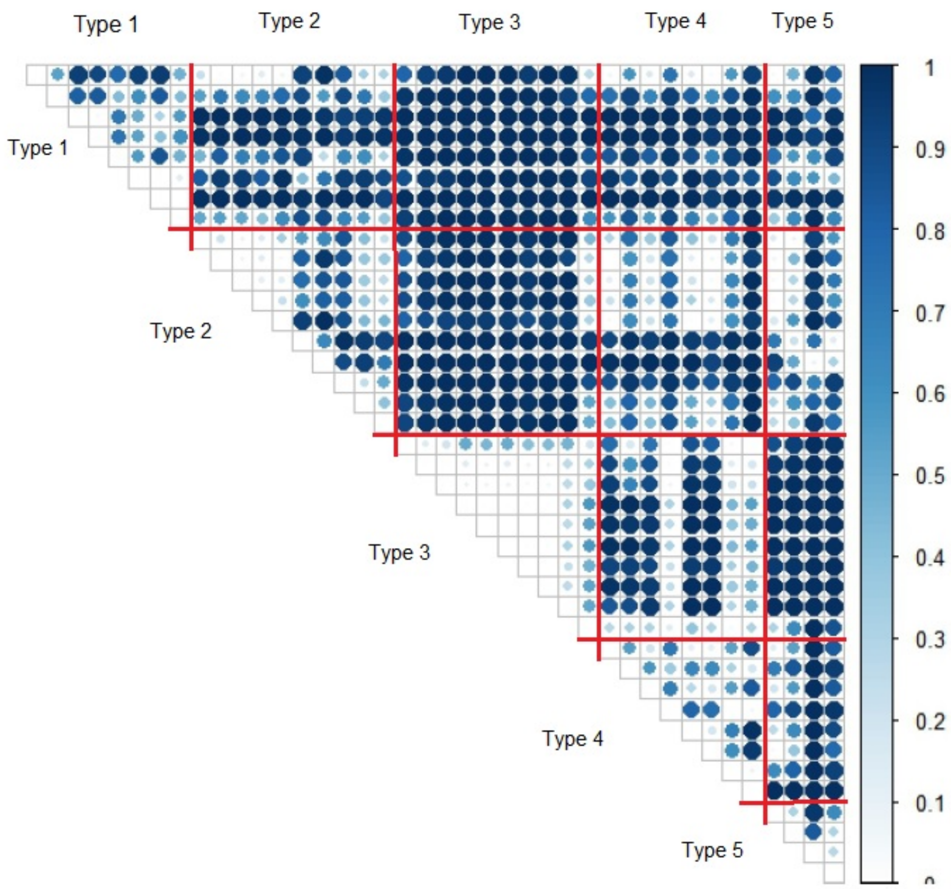


Figure A.3: The Morisita dissimilarity matrix for all the sample plots. The darker the shade and the larger the size of the circles the more dissimilar the composition of the vegetation is.

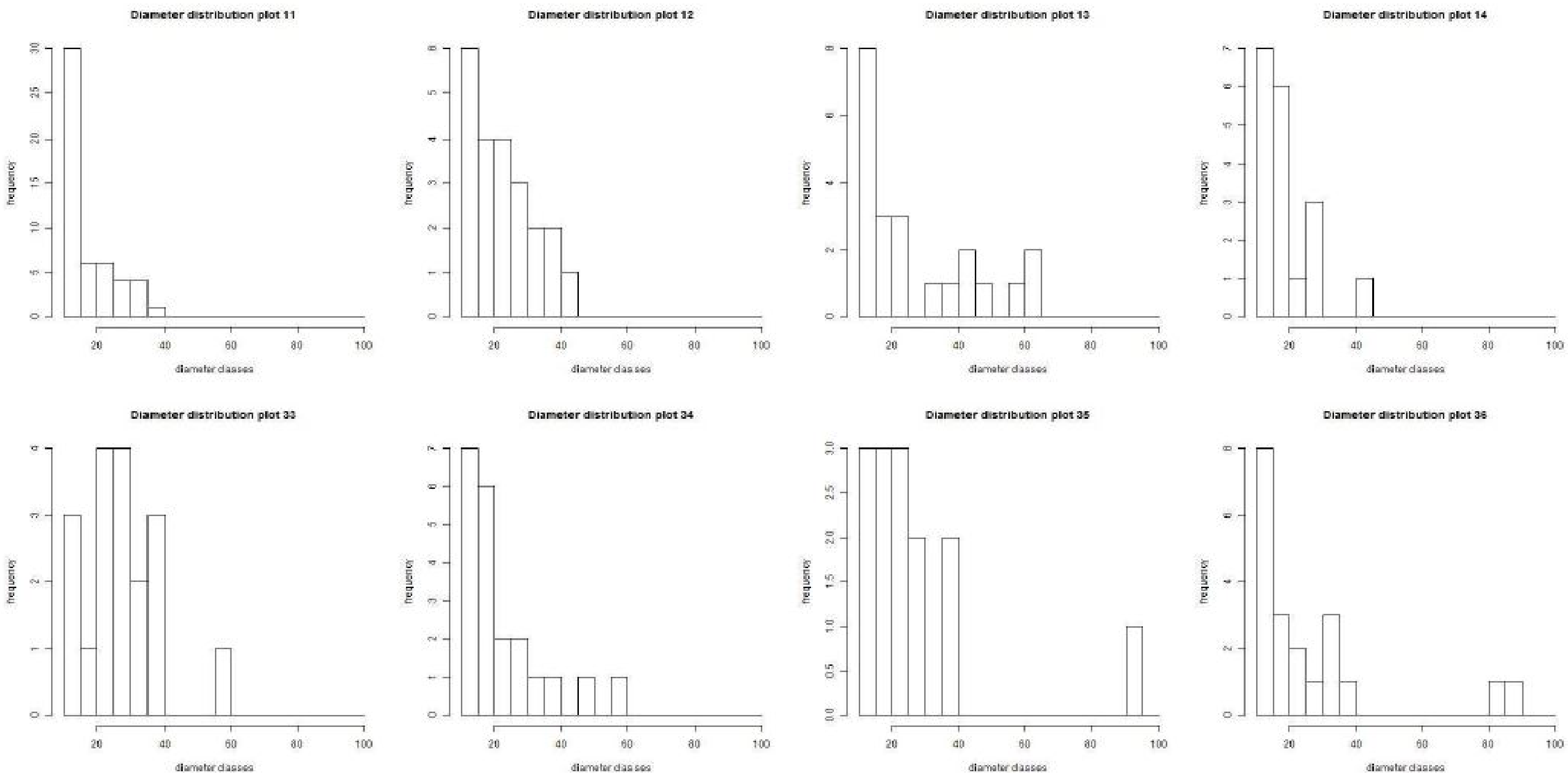


Figure A.4: The diameter distributions for the sample plots that belong to forest type 1.

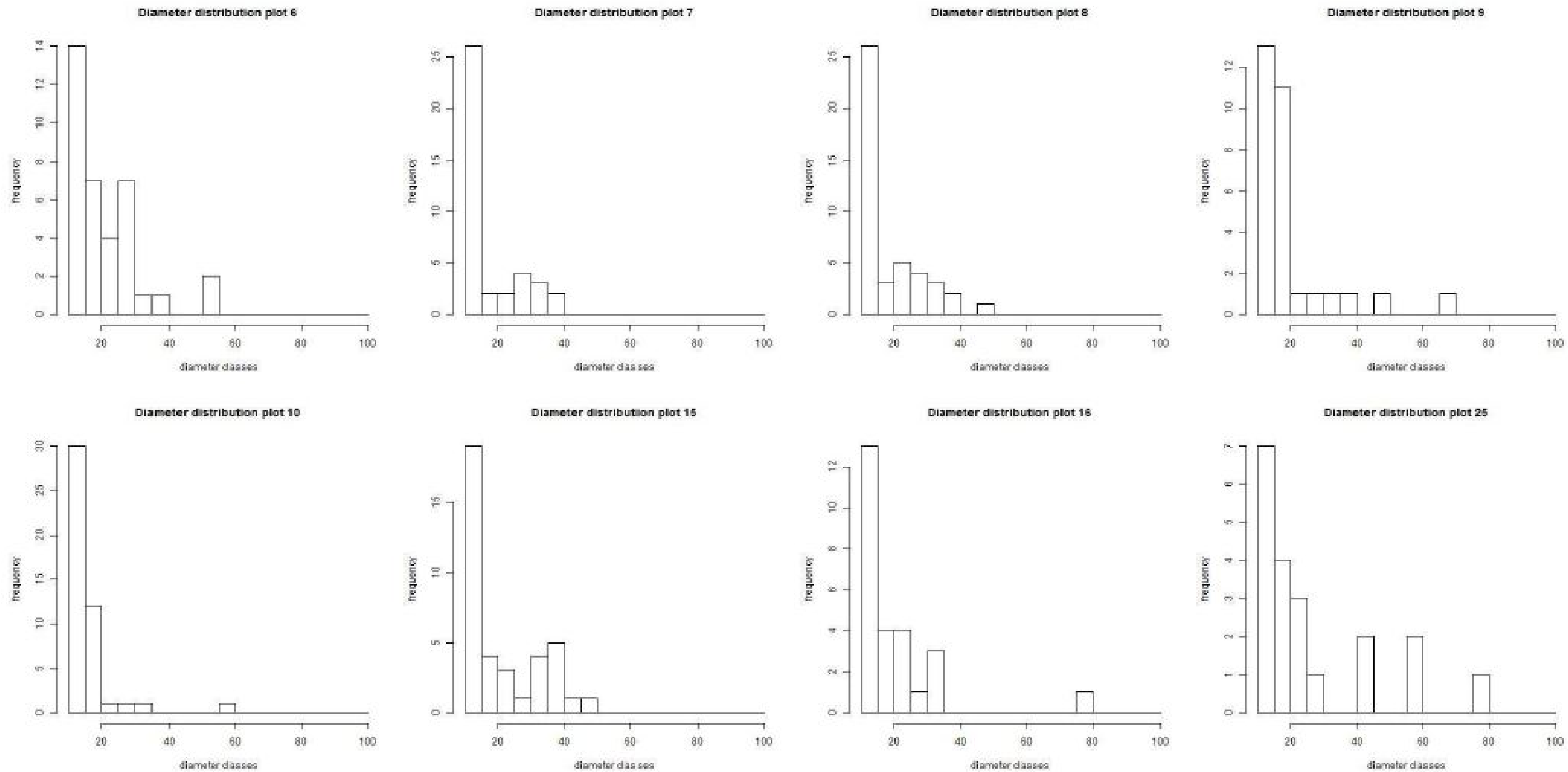
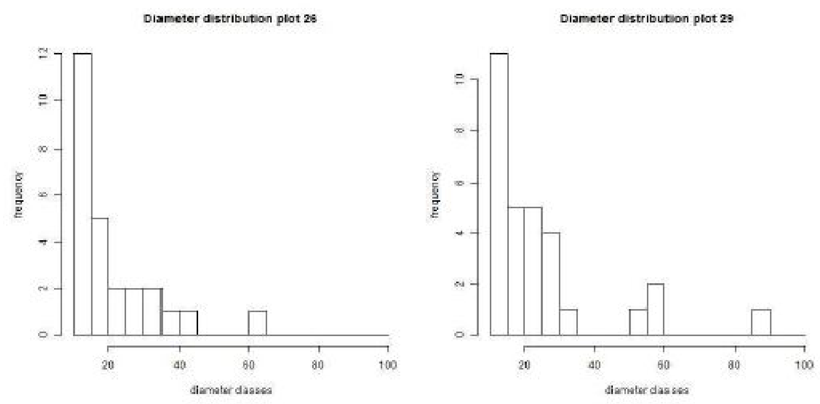


Figure A.5: The diameter distributions for the sample plots that belong to forest type 2.



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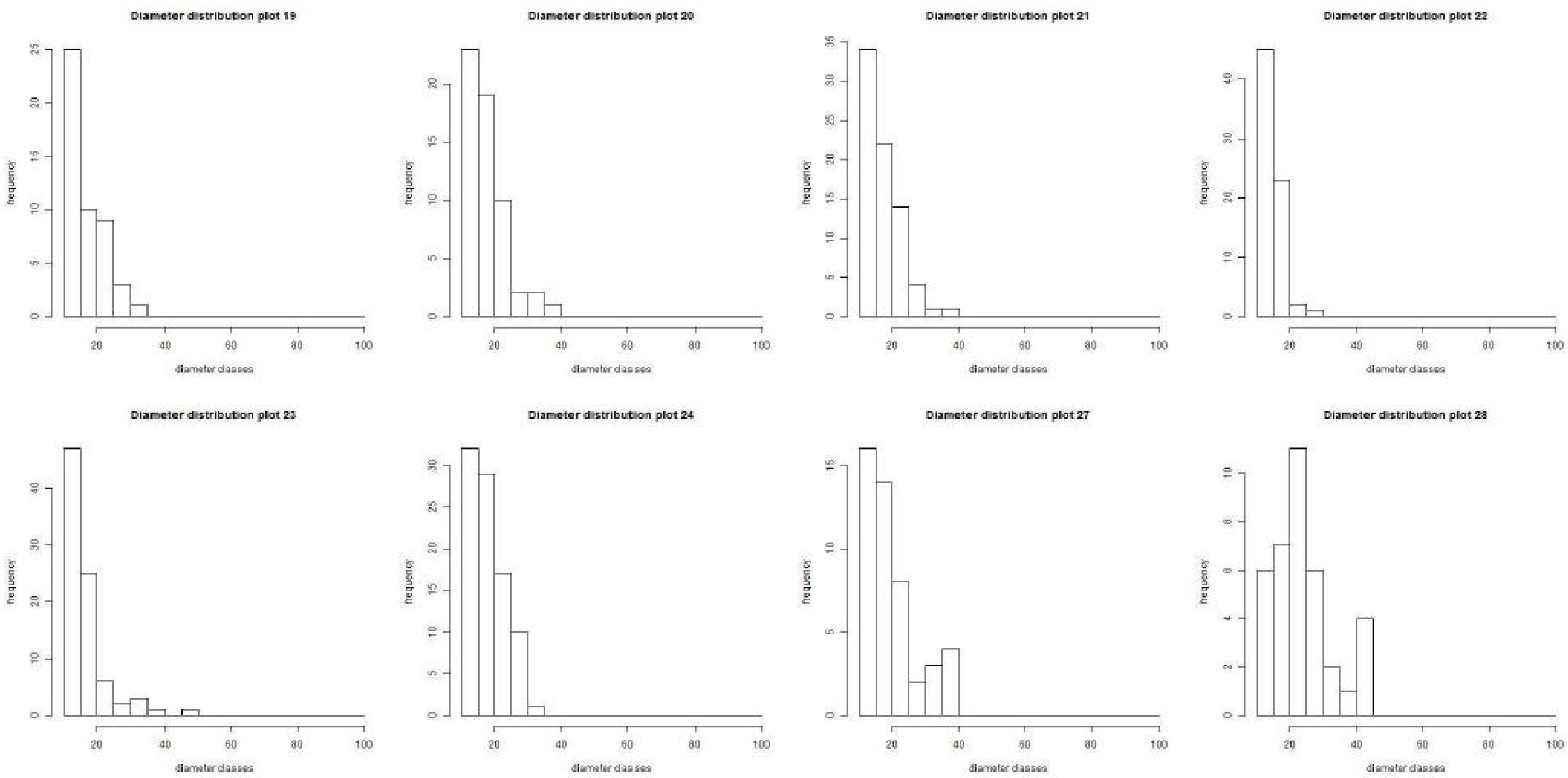
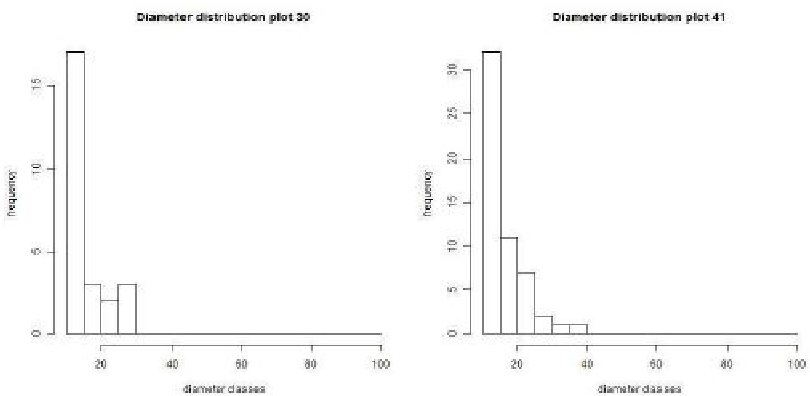


Figure A.6: The diameter distributions for the sample plots that belong to forest type 3.



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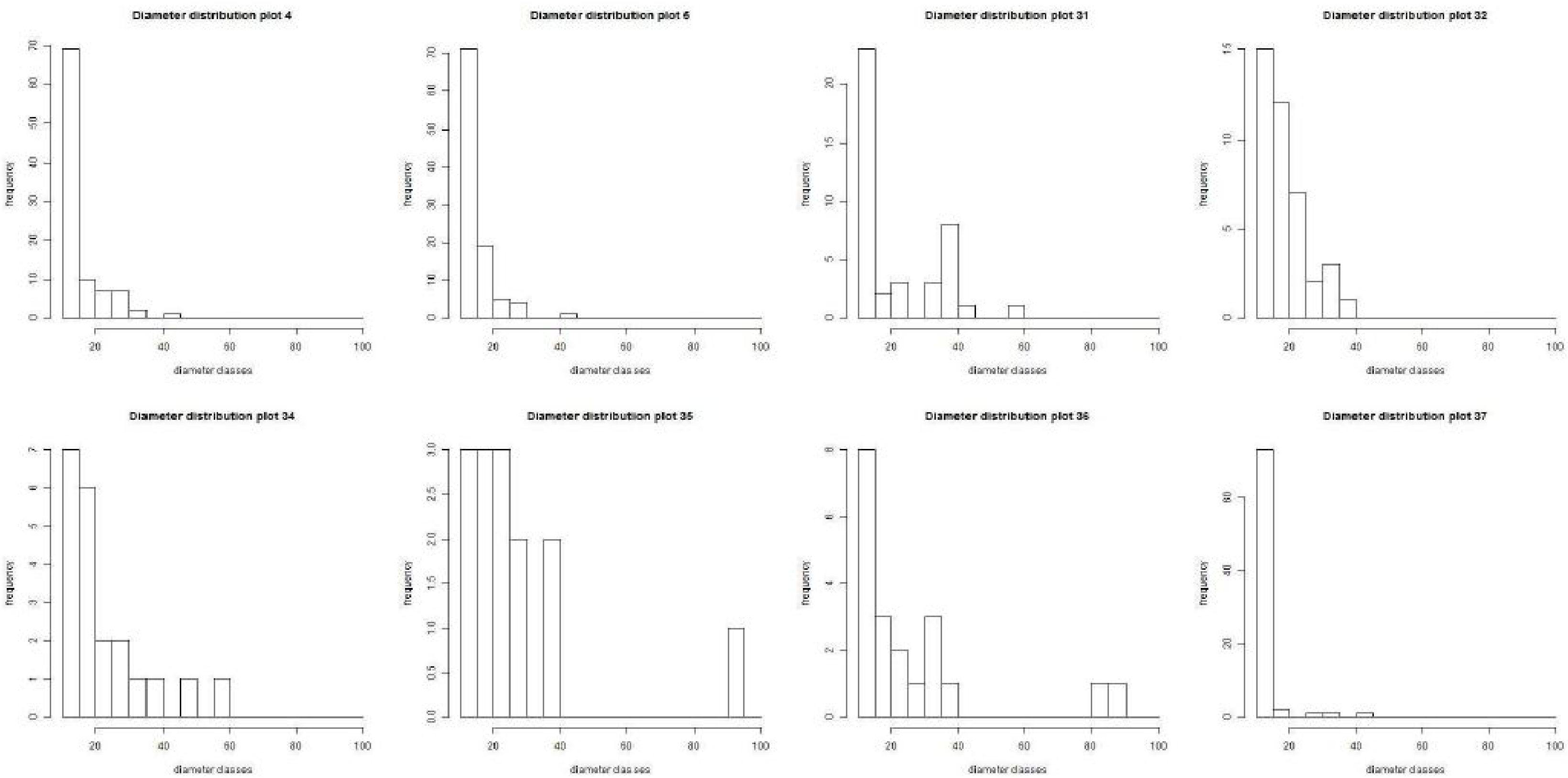


Figure A.7: The diameter distributions for the sample plots that belong to forest type 4.

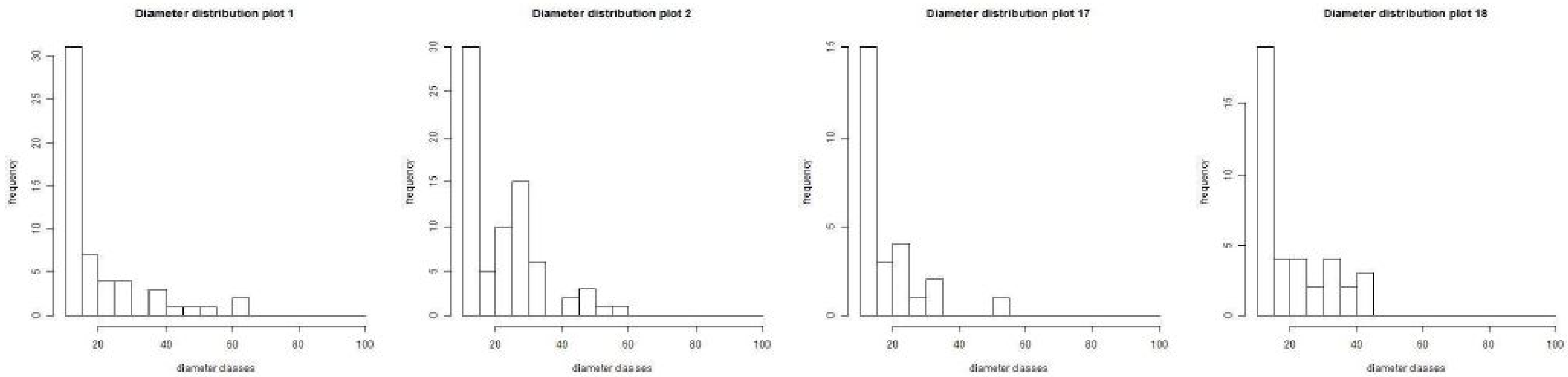


Figure A.8: The diameter distributions for the sample plots that belong to forest type 5.

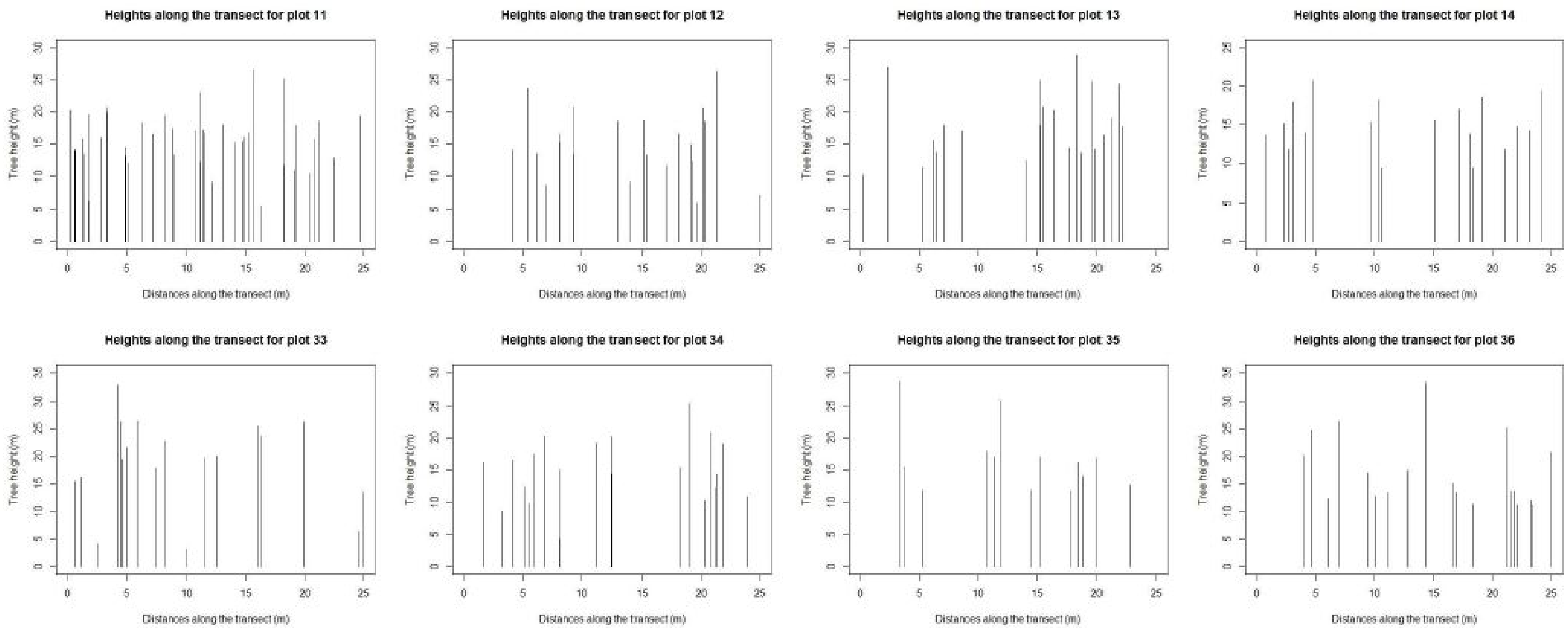


Figure A.9: The tree heights along the transect for the sample plots that belong to forest type 1.

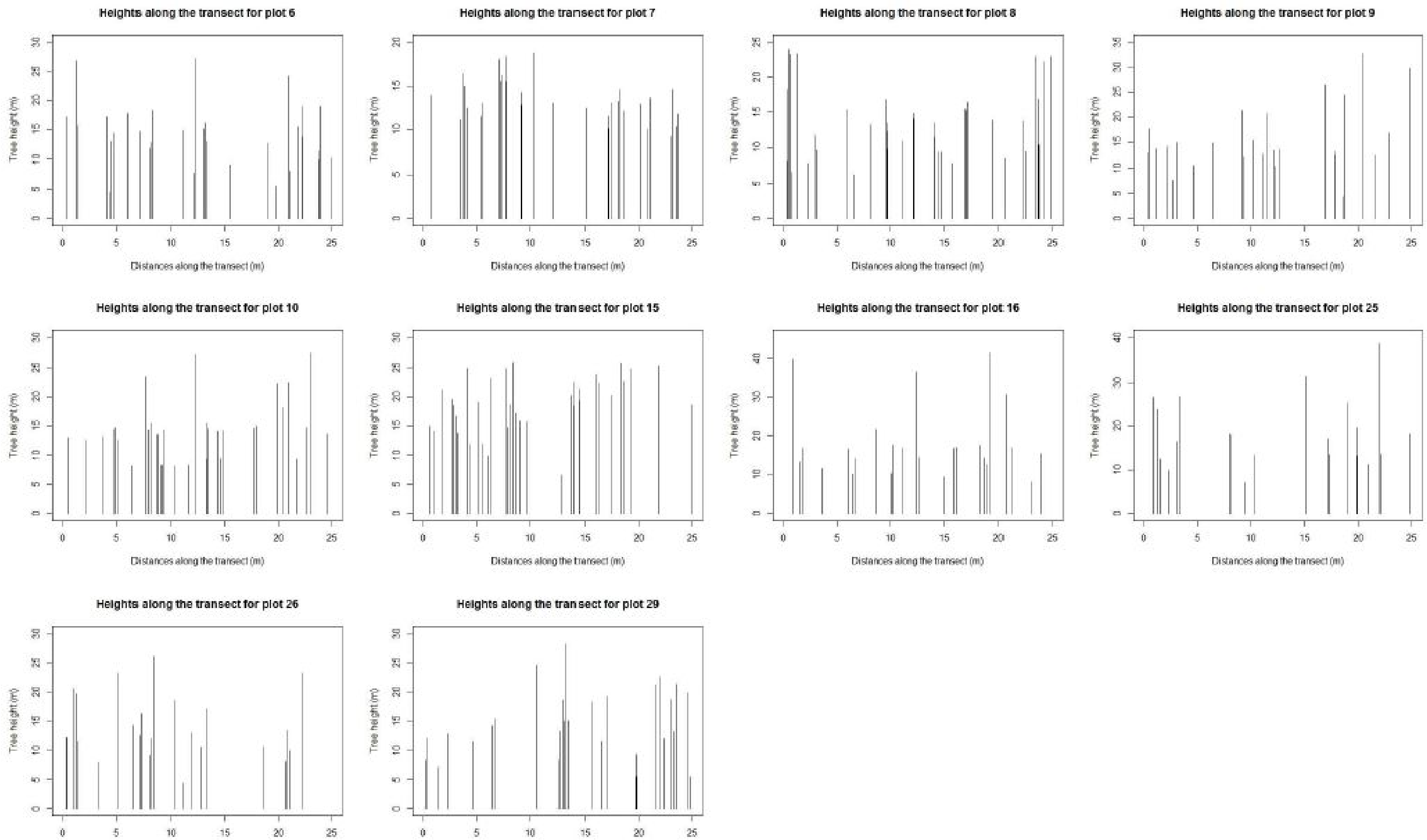


Figure A.10: The tree heights along the transect for the sample plots that belong to forest type 2.

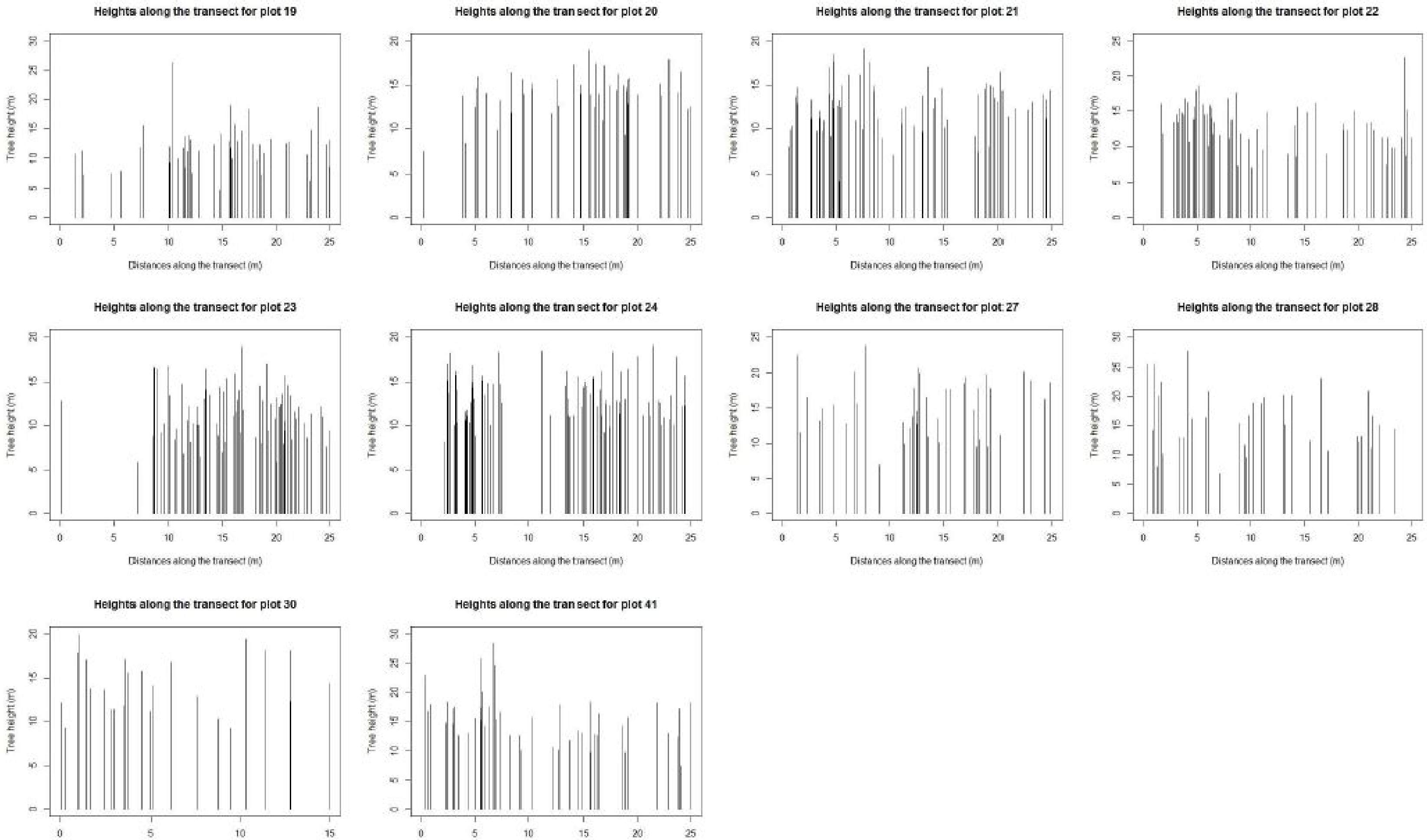


Figure A.11: The tree heights along the transect for the sample plots that belong to forest type 3.

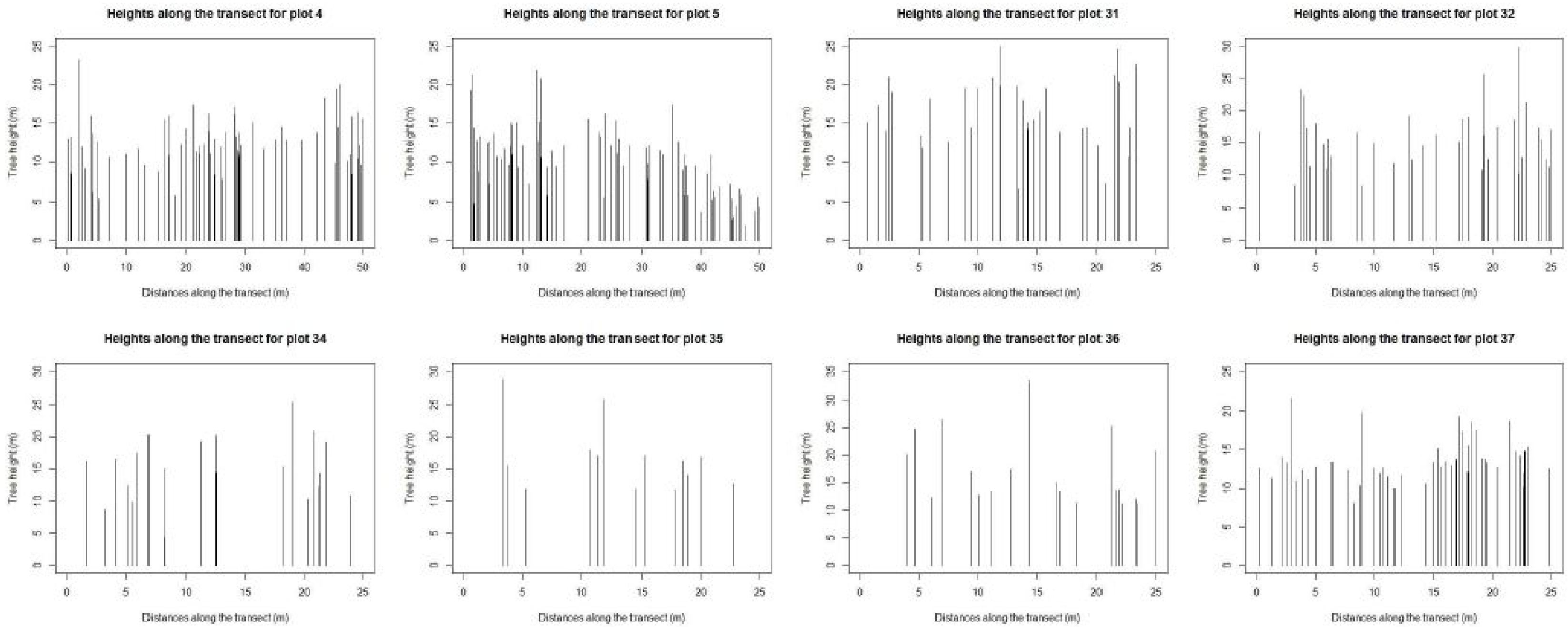


Figure A.12: The tree heights along the transect for the sample plots that belong to forest type 4.

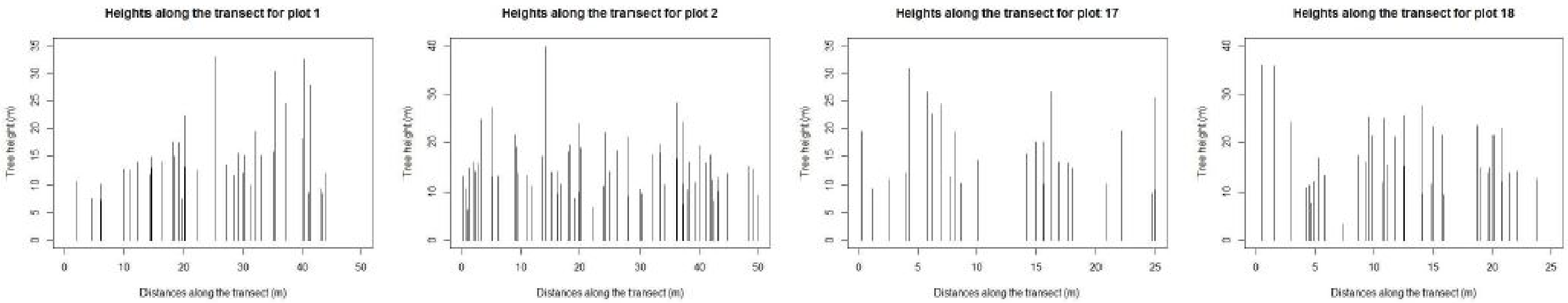


Figure A.13: The tree heights along the transect for the sample plots that belong to forest type 5.

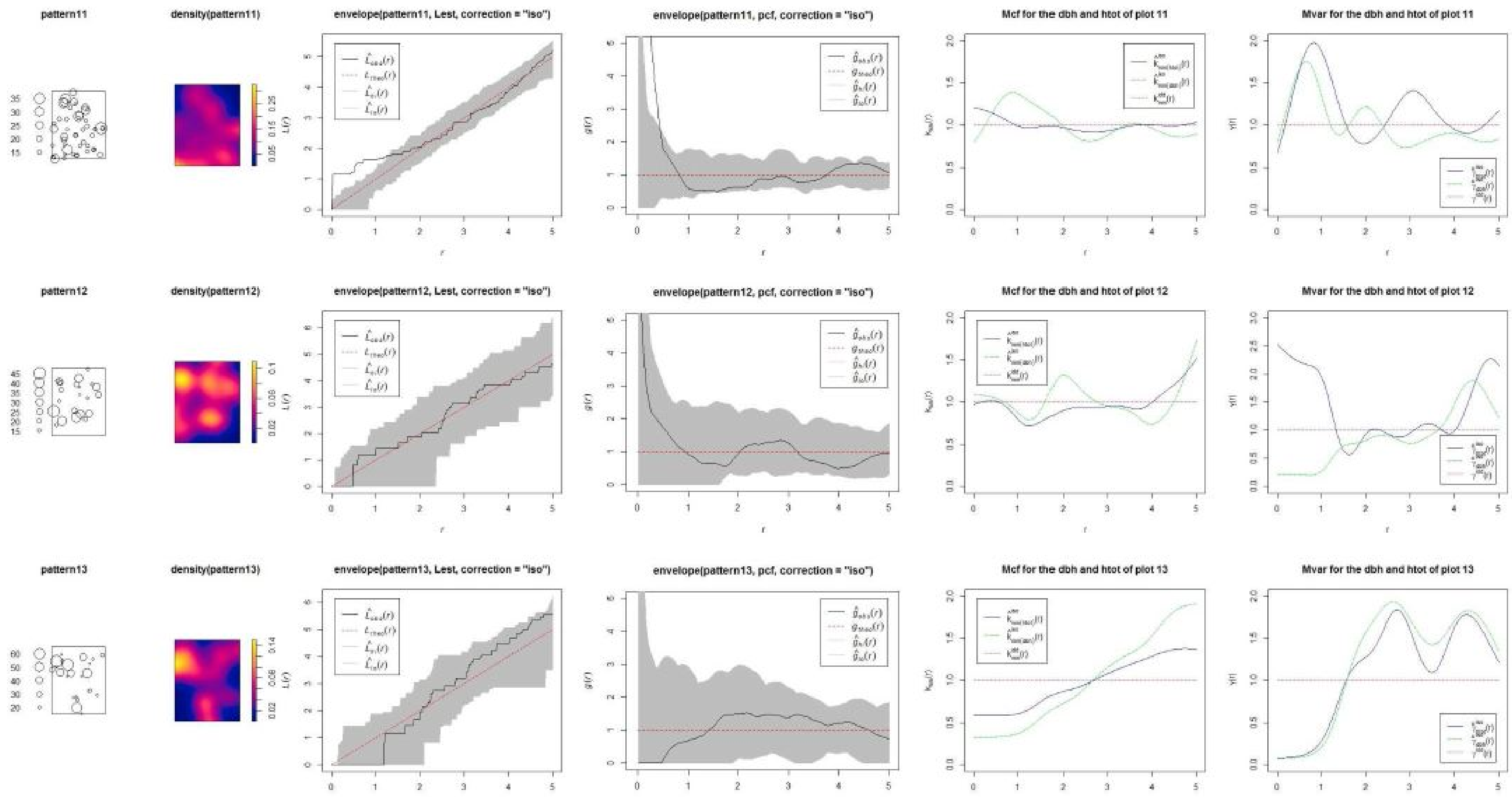
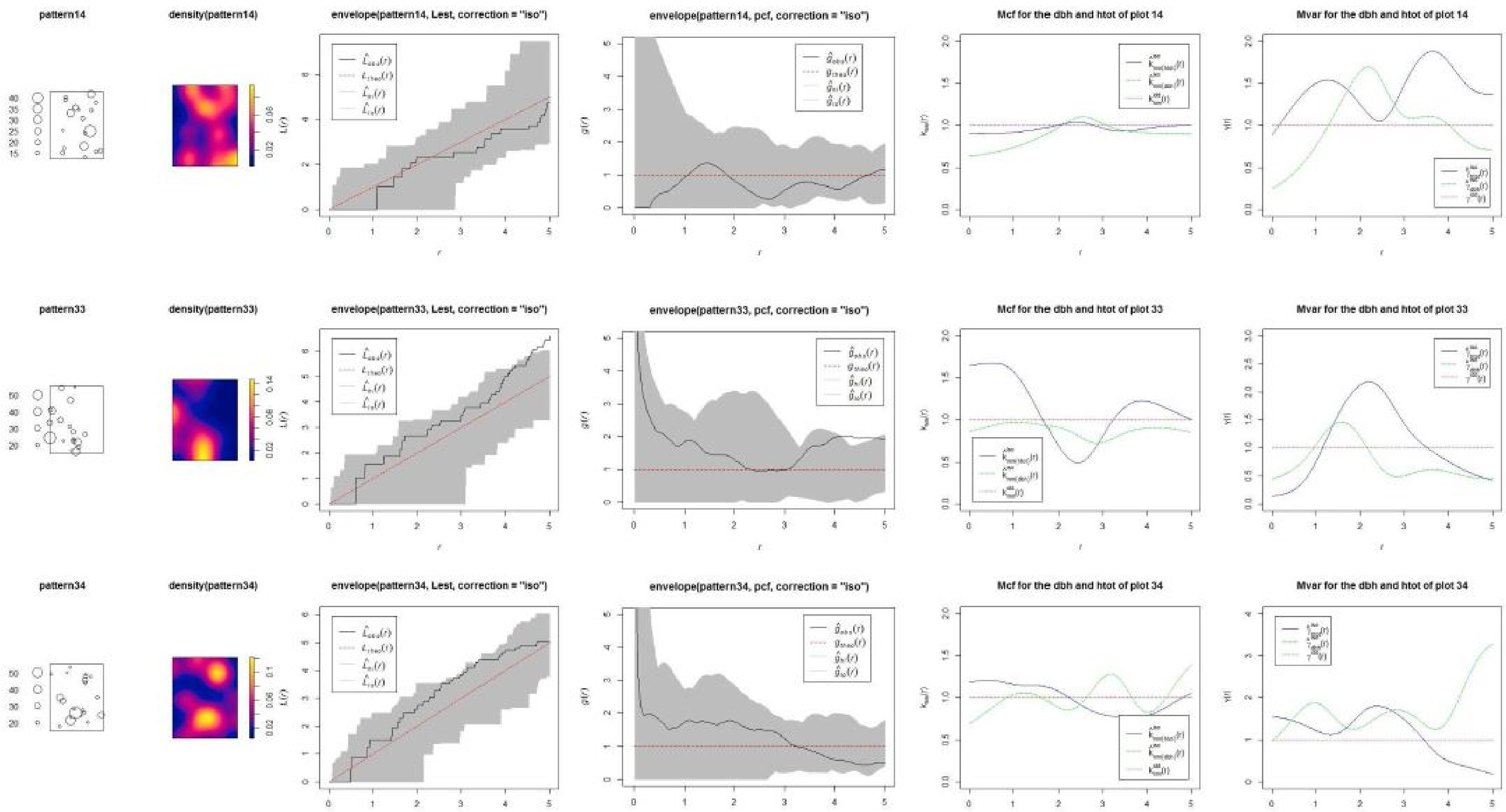


Figure A.14: The point pattern, density, L-function, pair correlation function, mark correlation function and variograms for the diameter and height for every plot of forest type 1.



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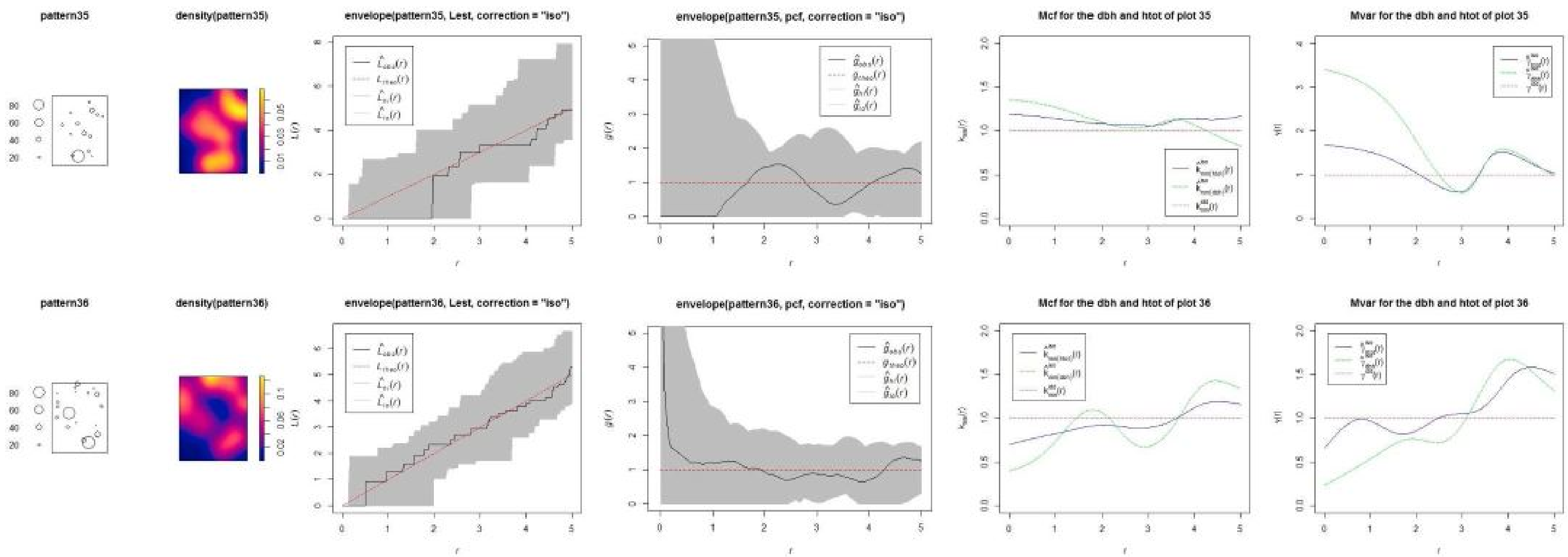

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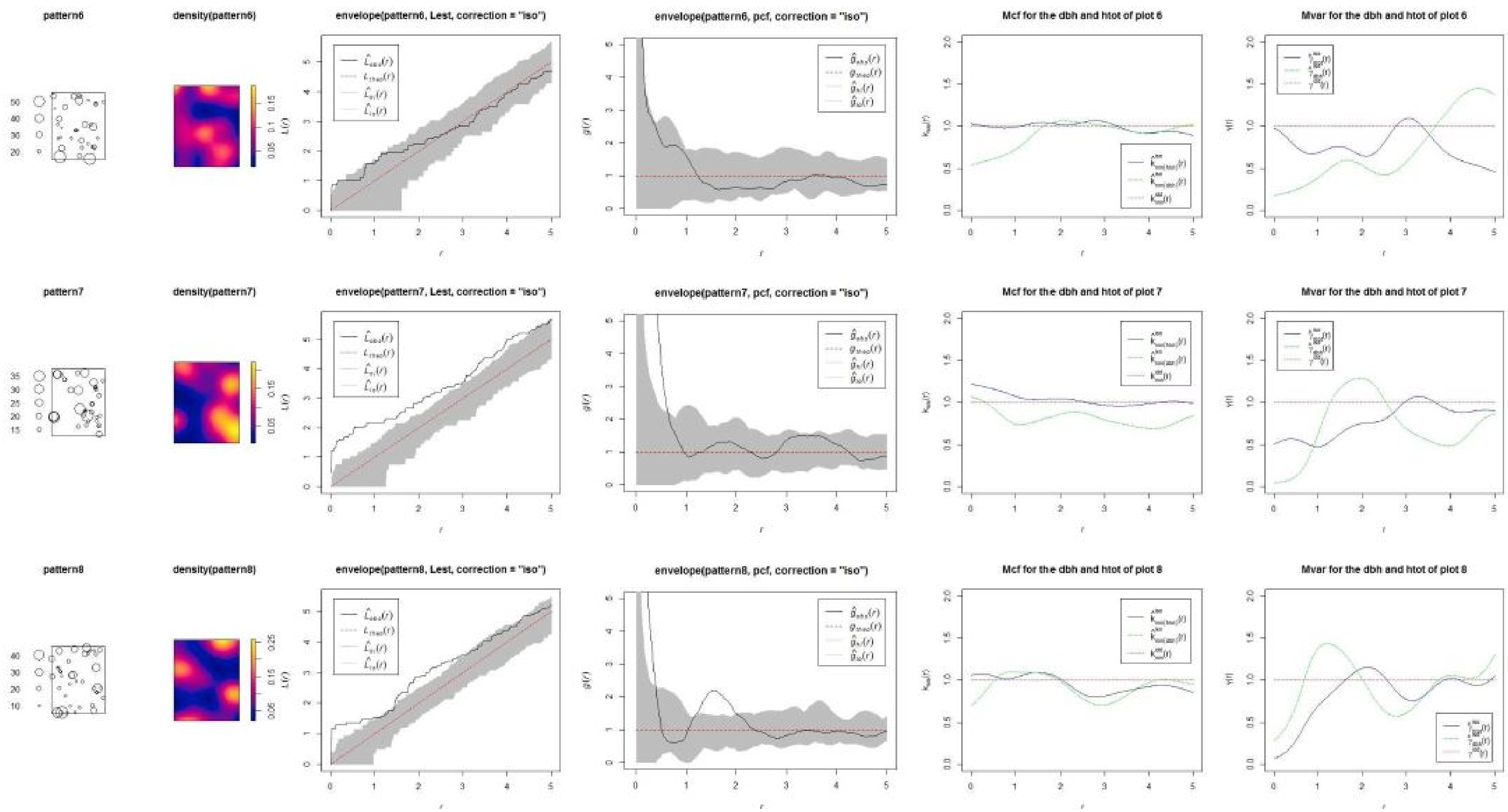
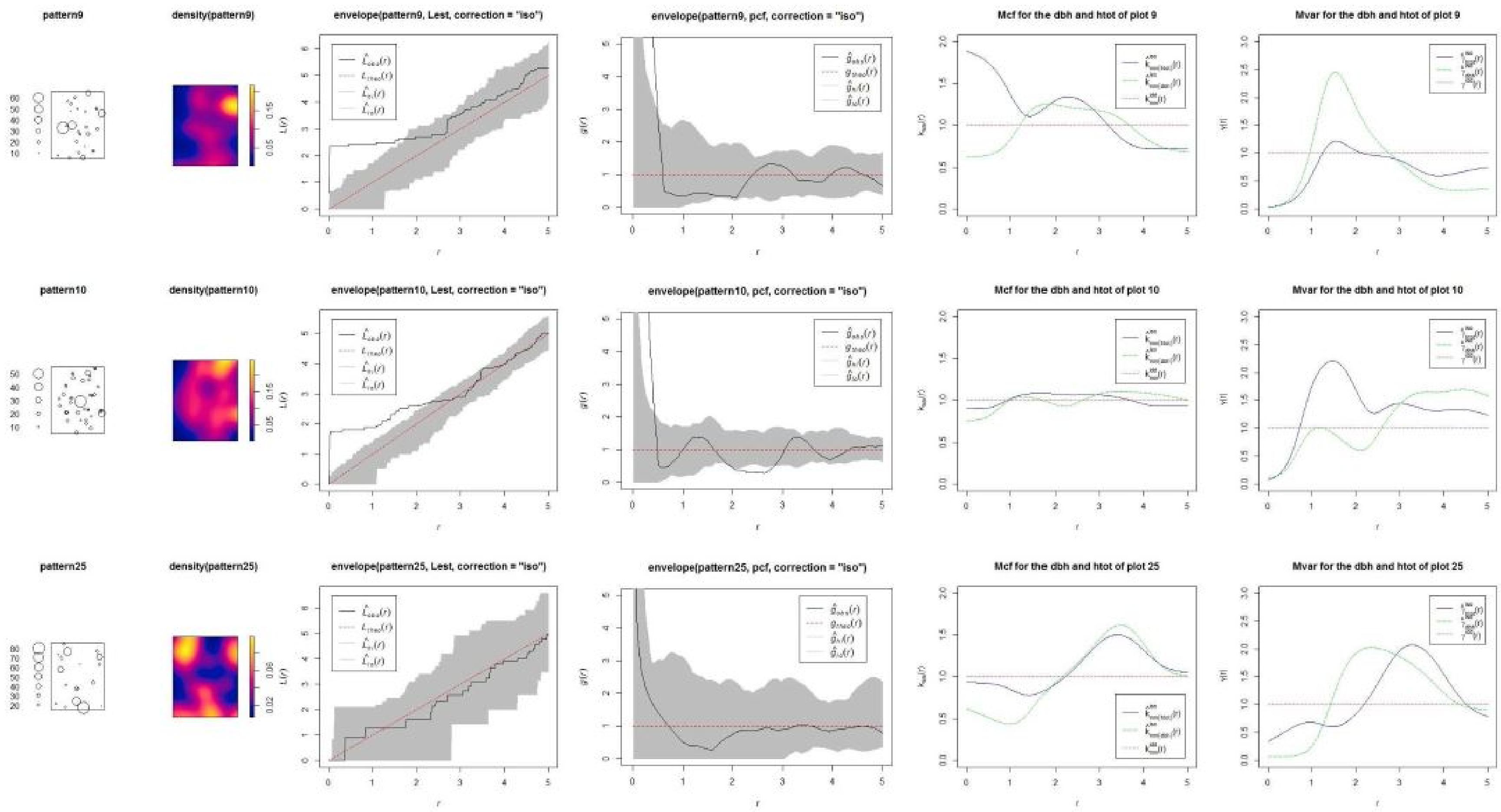


Figure A.15: The point pattern, density, L-function, pair correlation function, mark correlation function and variograms for the diameter and height for every plot of forest type 2.



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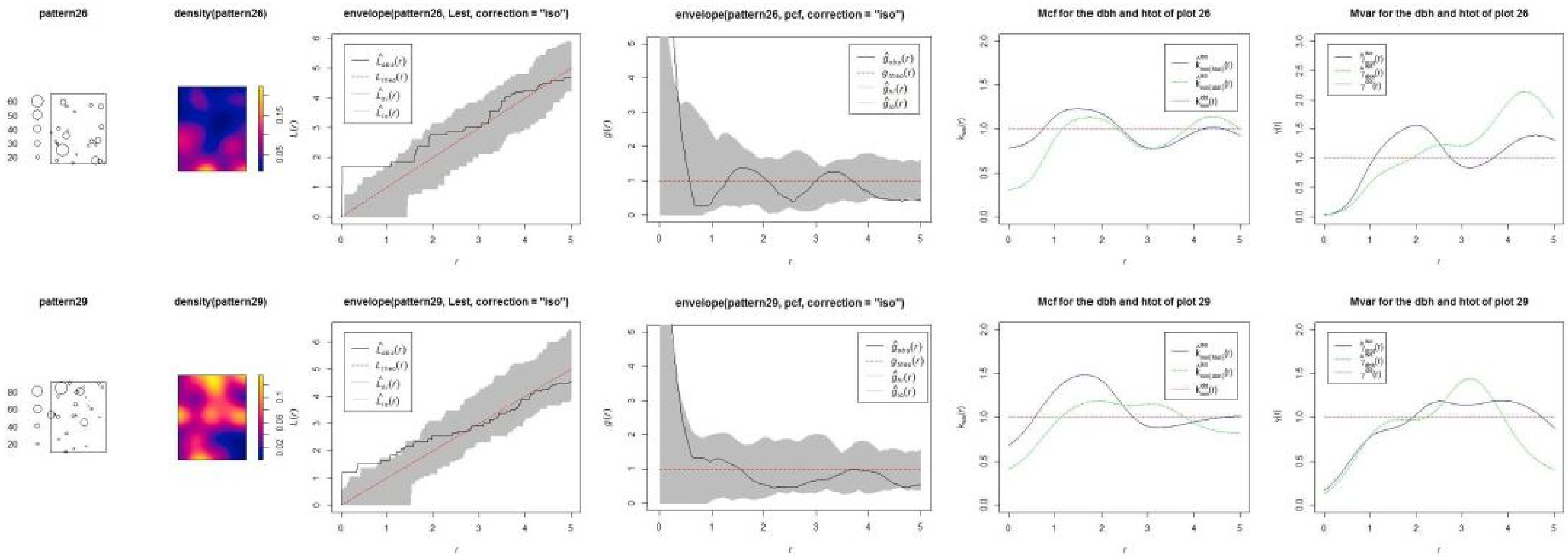

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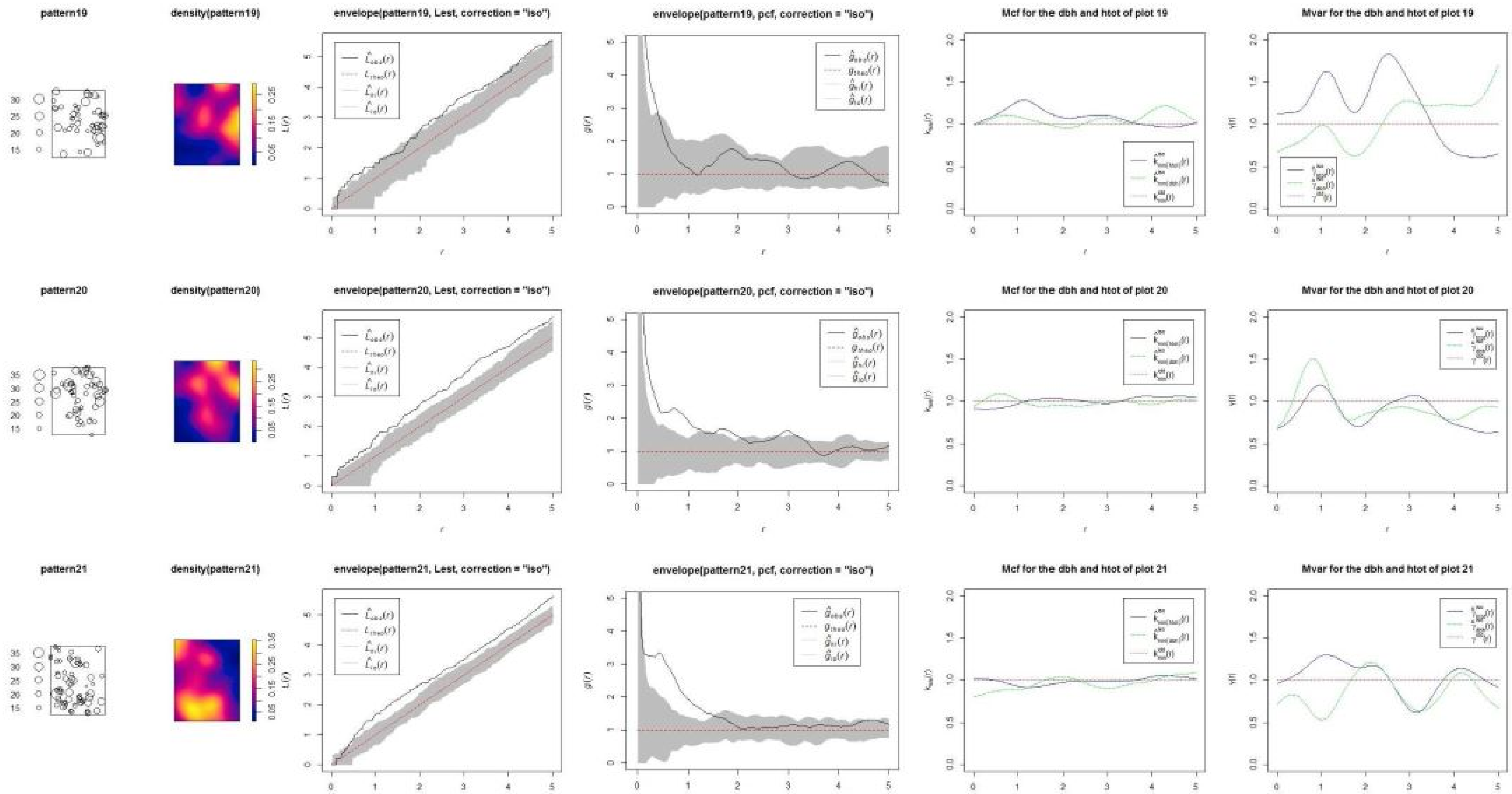
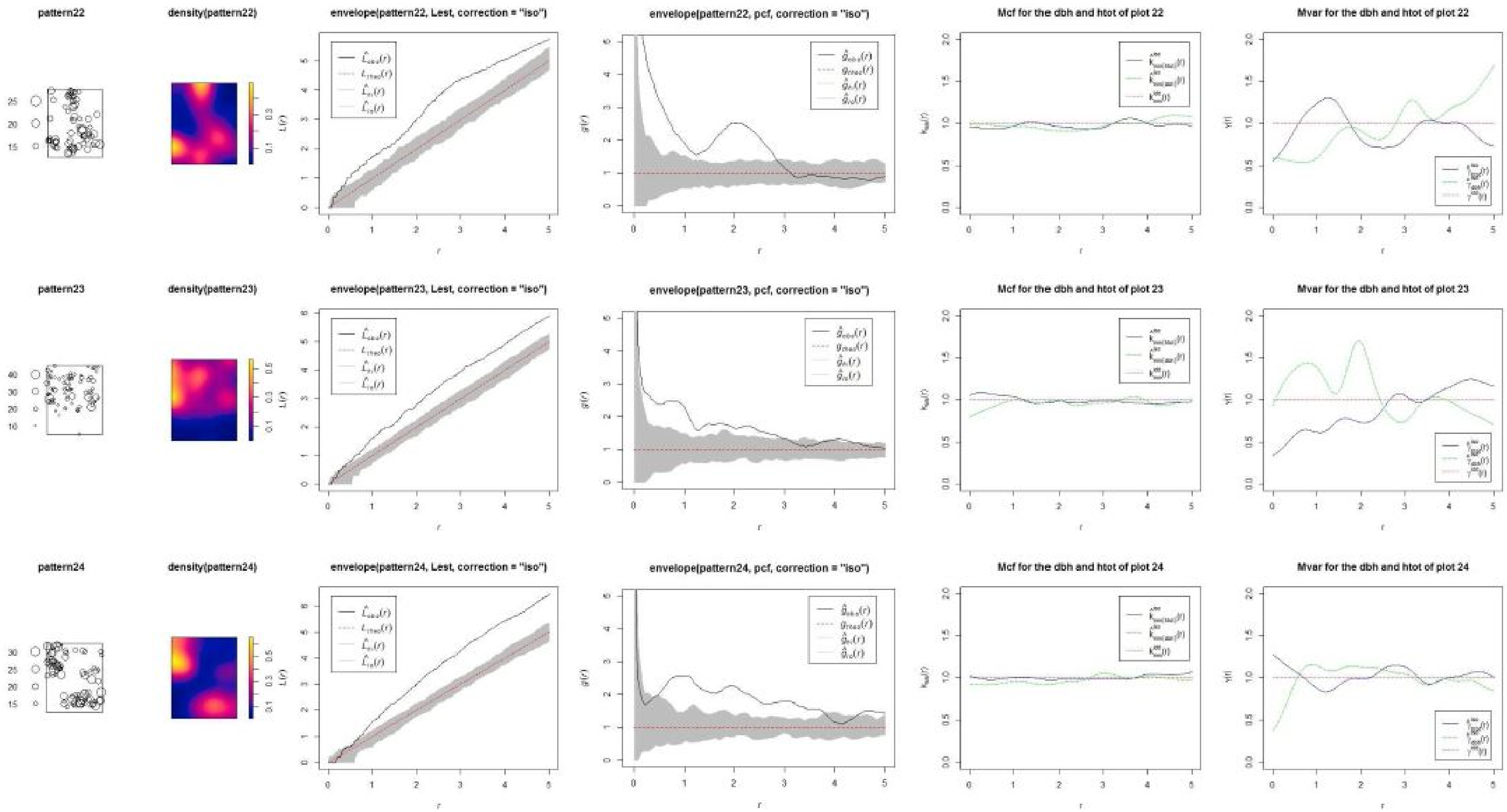


Figure A.16: The point pattern, density, L-function, pair correlation function, mark correlation function and variograms for the diameter and height for every plot of forest type 3.



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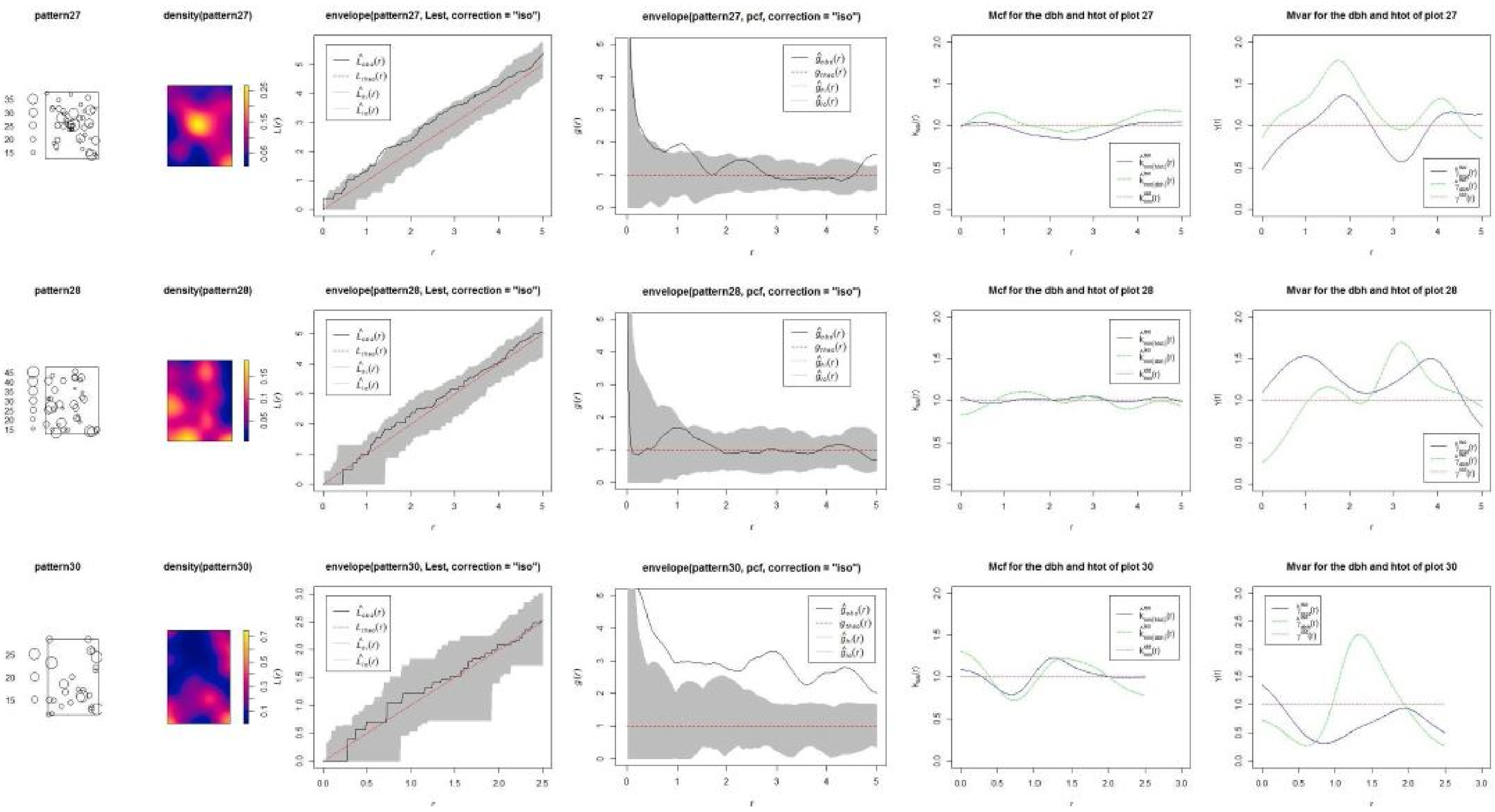

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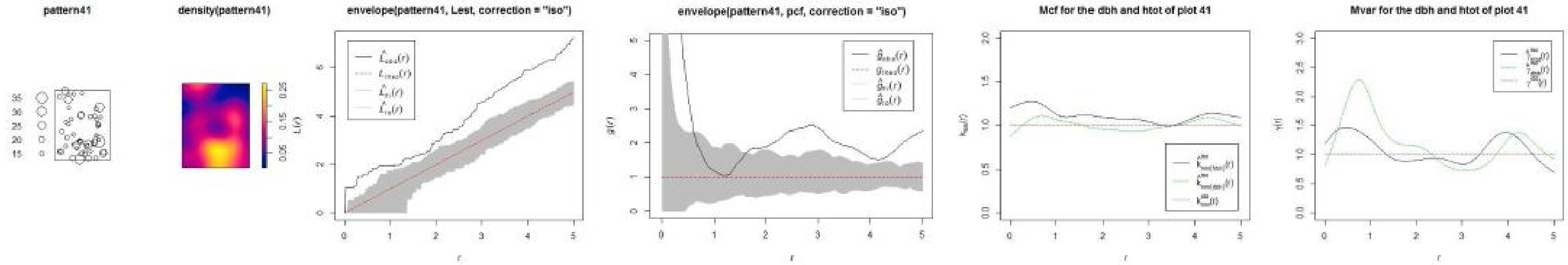

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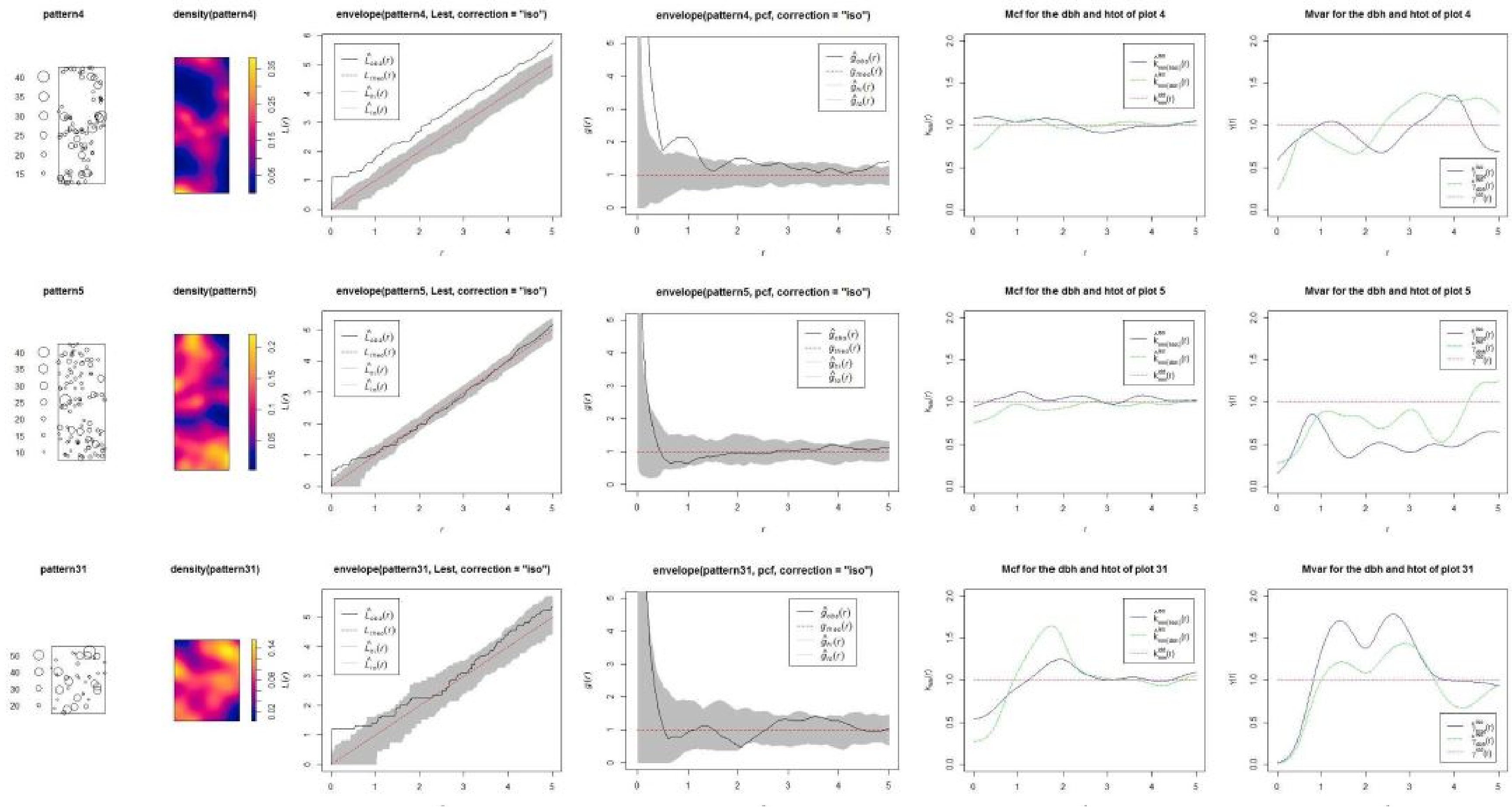
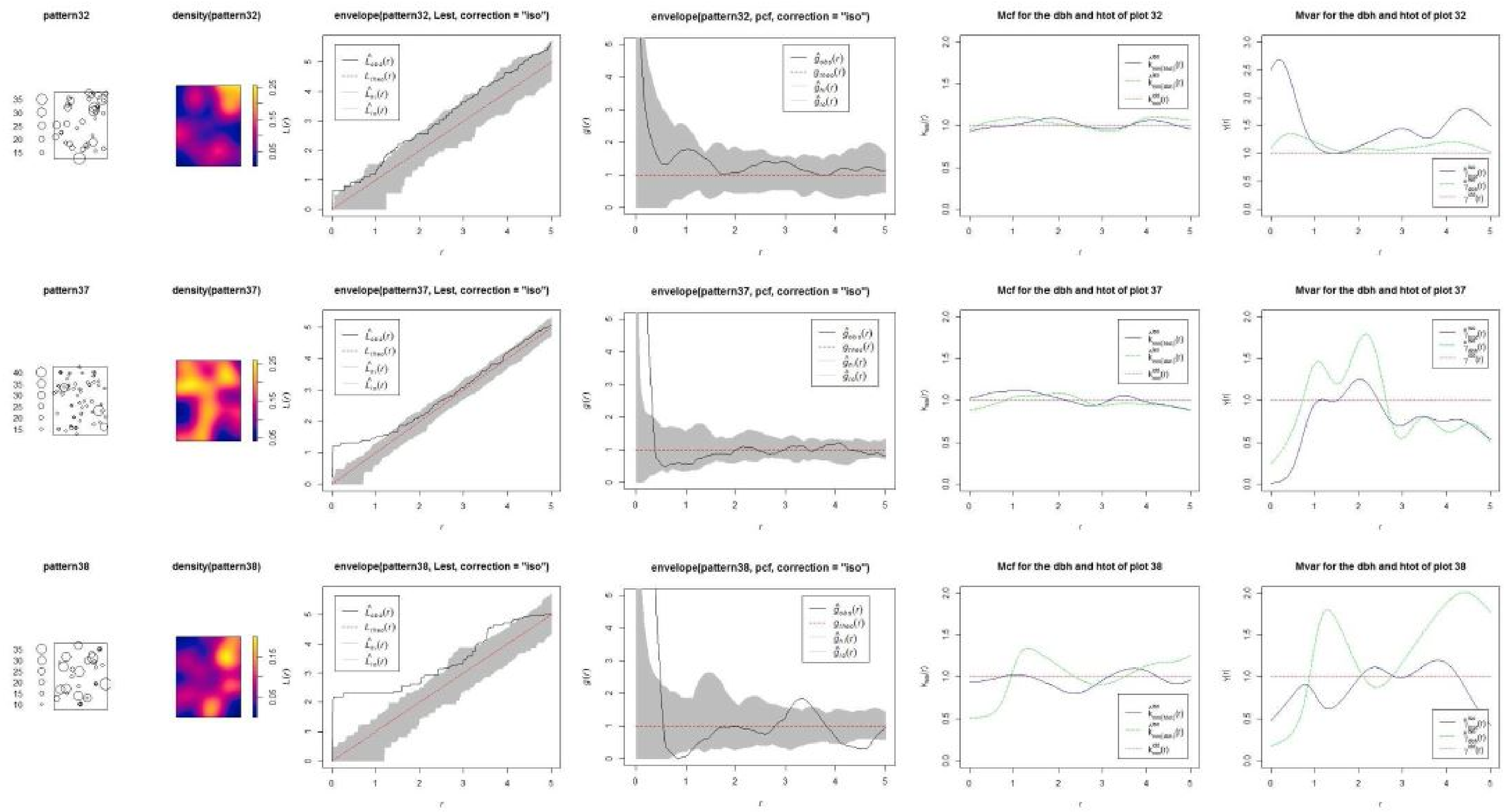


Figure A.17: The point pattern, density, L-function, pair correlation function, mark correlation function and variograms for the diameter and height for every plot of forest type 4.



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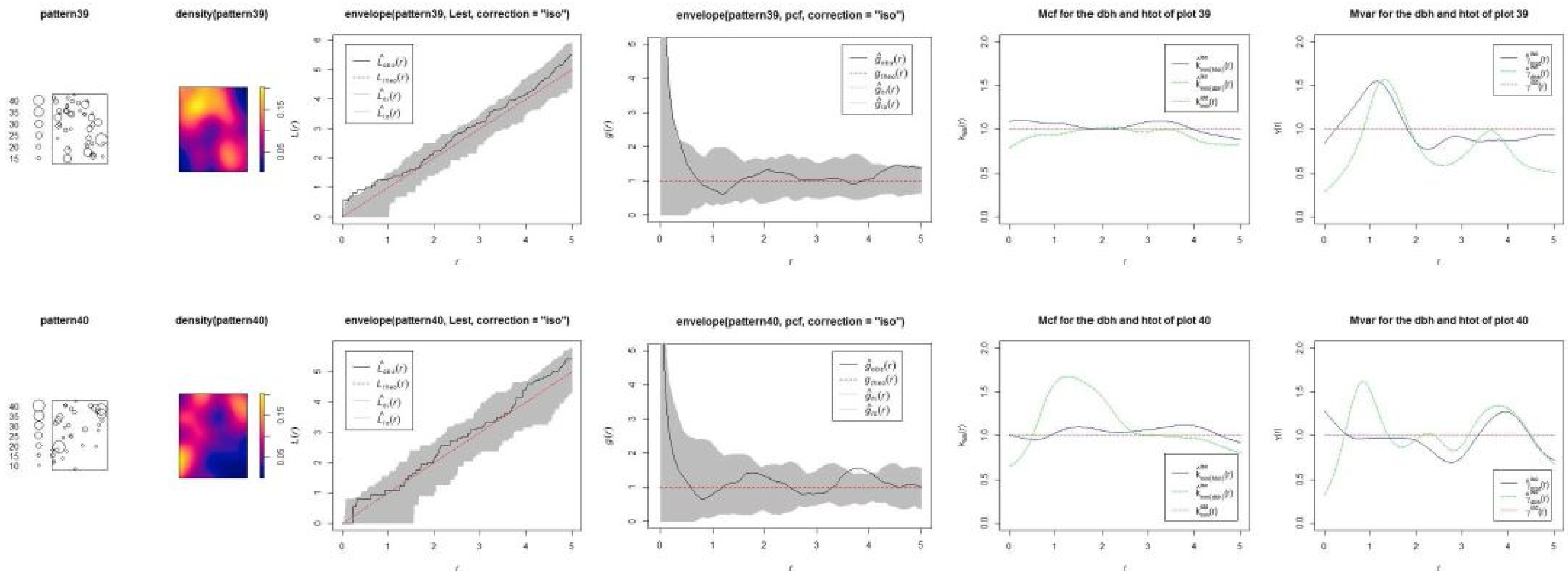

Figure A.17 (cont.)**:** First figure continued

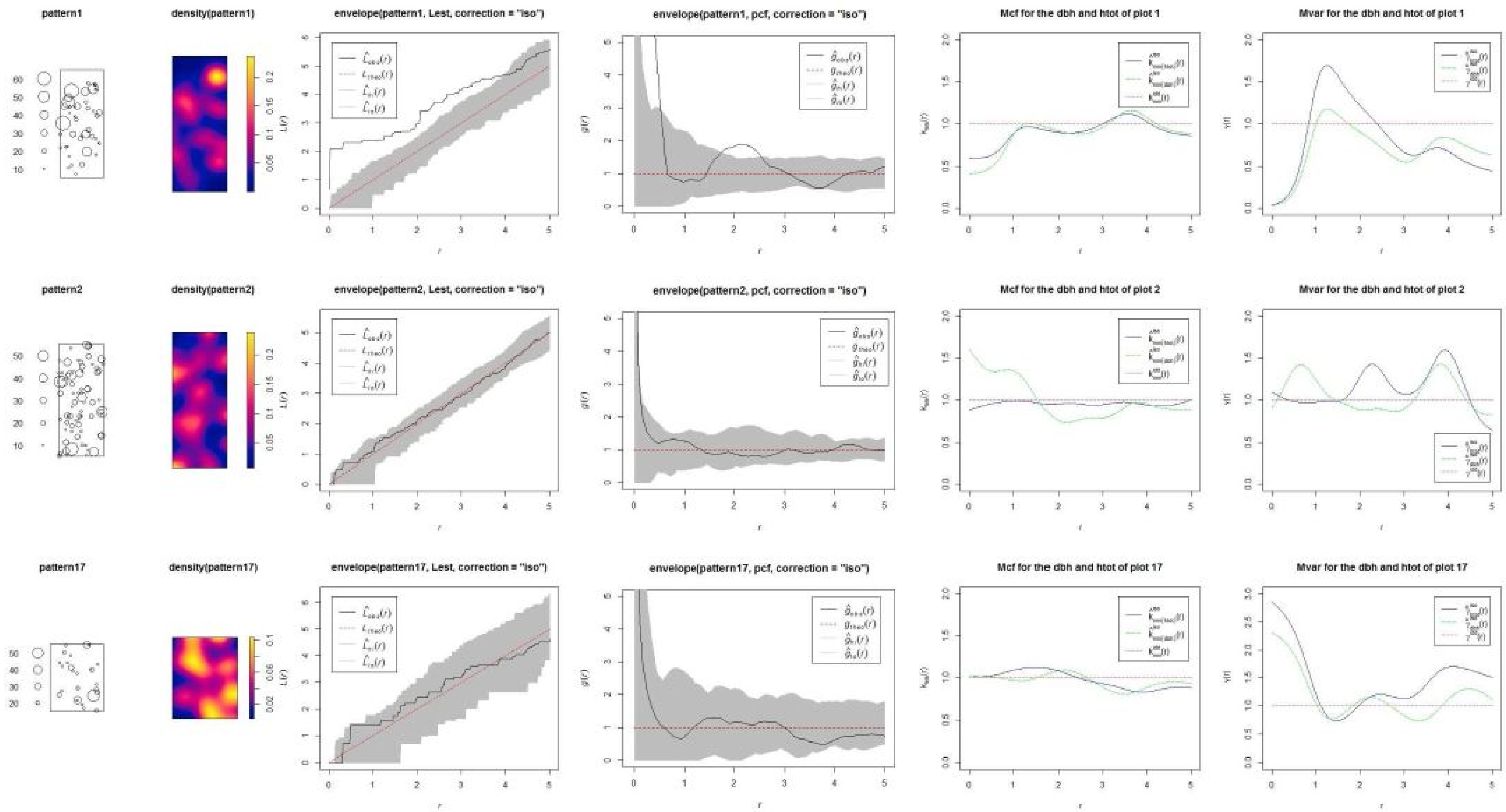

Figure A.18: The point pattern, density, L-function, pair correlation function, mark correlation function and variograms for the diameter and height for every plot of forest type 5.

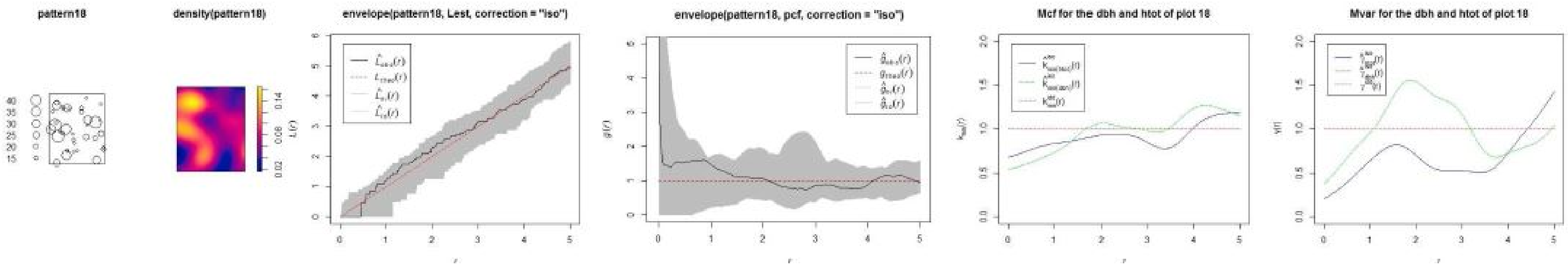

Figure A.18 (cont.)**:** First figure continued

APPENDIX B

List of the vernacular names used in the field and their scientific counterparts

Scientific name	Family	Vernacular name
Thyrsodium guianense	Anacardiaceae	Weti-udu
Annona densicoma	Annonaceae	Boszuurzak
Ambelania acida	Apocynaceae	Batbatti
Aspidosperma excelsum	Apocynaceae	Parelhout, witte
Geissospermum sericeum	Apocynaceae	Bita-udu
Schefflera decaphylla	Araliaceae	Kasaba-udu
Schefflera morototonii	Araliaceae	Morototo
Attalea maripa	Arecaceae	Mawrisi
Euterpe oleracea	Arecaceae	Pina
Mauritia flexuosa	Arecaceae	Maripa
Oenocarpus bacaba	Arecaceae	Kumbu palm
Handroanthus serratifolia	Bignoniaceae	Groenhart
Tabebuia insignis	Bignoniaceae	Panta, zwamp-
Crepidospermum rhoifolium	Burseraceae	Tingimoni, getande
Protium polybotryum	Burseraceae	Tingimoni, rode bast
Protium spp	Burseraceae	Tingimoni
Dendrobangia boliviana	Cardiopteridaceae	Yakanta, rode bast
Couepia guianensis	Chrysobalanaceae	Anaura, hoogland
Hirtella glandulosa	Chrysobalanaceae	Kwepi, rode bast
Licania densiflora	Chrysobalanaceae	Fungu, zwarte
Licania heteromorpha	Chrysobalanaceae	Anaura, zwamp
Licania macrophylla	Chrysobalanaceae	Sponshout
Licania majuscula	Chrysobalanaceae	Kwepi, harde bast
Parinari exelsa	Chrysobalanaceae	Fungu, Rode, Kleinbladige
Platonia insignis	Clusiaceae	Pakuli, laagland
Symphonia globulifera	Clusiaceae	Mataki, laagland
Tovomita secunda	Clusiaceae	Bosmangro, kleinbladig
Terminalia lucida	Combretaceae	Bosamandel

Tapura guianensis	Dichapetalaceae	Pakira tiki
Diospyros guianensis	Ebenaceae	Blaka-uma
Sloanea garckeana	Elaeocarpaceae	Rafrunyanyan, Kleinbladige
Alchorneopsis floribunda	Euphorbiaceae	Manbebe
Conceveiba guianensis	Euphorbiaceae	Panta, hoogland
Hevea guianensis	Euphorbiaceae	Hevea
Maprounea amazonica	Euphorbiaceae	Pikintiki
Goupia glabra	Goupiaceae	Kopi
Humiriastrum obovatum	Humiriaceae	Brofu-udu
Vismia cayennensis	Hypericaceae	Pinya, zwamp
Vismia macrophylla	Hypericaceae	Pinya, man-
Aniba taubertiana	Lauraceae	Pisi, waikara
Ocotea glomerata	Lauraceae	Pisi, kleinbladig, zwarte
Ocotea oblonga	Lauraceae	Pisi, papaya
Ocotea petalanthera	Lauraceae	Pisi, witte
Rhodostemonodaphne grandis	Lauraceae	Pisi, zwarte grootbladige
Rhodostemonodaphne praeclara	Lauraceae	Pisi, zwarte
Eschweilera congestiflora	Lecythidaceae	Umabarklak
Eschweilera coriacea	Lecythidaceae	Manbarklak, Hoogland
Eschweilera pedicellata	Lecythidaceae	Manbarklak, bergi
Eschweilera spp.	Lecythidaceae	Manbarklak
Gustavia augusta	Lecythidaceae	Konkoni-udu, laagland
Lecythis poiteaui	Lecythidaceae	Tete-udu, gele bast, grootbladig
Copaifera guyanensis	Leguminosae	Hoepelhout
Crudia glaberrima	Leguminosae	Watrabiri
Dicorynia guianensis	Leguminosae	Basralokus
Eperua falcata	Leguminosae	Wallaba
Hymenaea courbaril var. courbaril	Leguminosae	Lokus, rode
Martiodendron parviflorum	Leguminosae	Pintolokus, wite
Peltogyne venosa	Leguminosae	Purperhart, gewone
Sclerolobium melinonii	Leguminosae	Dyadidya
Alexa wachenheimii	Leguminosae	Neku-udu
Andira spp.	Leguminosae	Kabbes, rode
Diplotropis purpurea	Leguminosae	Kabbes, zwarte
Ormosia coccinea	Leguminosae	Kokriki, hoogbos
Pterocarpus officinalis	Leguminosae	Watrabebe
Swartzia benthamiana	Leguminosae	Bebe, hoogland
Abarema jupunba	Leguminosae	Sopo-udu
Inga alata	Leguminosae	Switbonki, witte bast

Inga alba	Leguminosae	Prokoni, rode
Inga disticha	Leguminosae	Switbonki, kapuweri
Inga heterophylla	Leguminosae	Switbonki, grootbladig
Inga pezizifera	Leguminosae	Switbonki, rode bast
Inga rubiginosa	Leguminosae	Switbonki, hoogbos
Parkia pendula	Leguminosae	Kwatakama
Parkia ulei	Leguminosae	Agrobigi, kleinbloemige
Stryphnodendron polystachyum	Leguminosae	Laksiri, hoogland
Hebepetalum humiriifolium	Linaceae	Yakanta, gele bast
Catostemma fragrans	Malvaceae	Barmani
Ceiba pentandra	Malvaceae	Kankantri
Eriotheca globosa	Malvaceae	Boskatoen, gewone
Sterculia pruriens	Malvaceae	Okerhout
Bellucia grossularioides	Melastomataceae	Mispel, eetbare
Mouriri grandiflora	Melastomataceae	Spikri-udu, drasbos
Carapa guianensis	Meliaceae	Krapa, rode
Carapa procera	Meliaceae	Krapa, witte
Cedrela odorata	Meliaceae	Ceder
Guarea guidonia	Meliaceae	Doifisiri, Rode Bast
Guarea kunthiana	Meliaceae	Doifisiri, zwarte bast
Trichilia quadrijuga	Meliaceae	Melisali, Sorosali
Ficus spp	Moraceae	Ficus
Iryanthera hostmannii	Myristicaceae	Srebebe
Iryanthera sagotiana	Myristicaceae	Brudu-udu
Virola michelii	Myristicaceae	Babun, hoogland
Virola surinamensis	Myristicaceae	Babun, laagland
Eugenia stictopetala	Myrtaceae	Kromoko
Minquartia guianensis	Olacaceae	Alata-udu
Agonandra silvatica	Opiliaceae	Kromantikopi
Chaetocarpus schomburgkianus	Peraceae	Foman
Pera bicolor	Peraceae	Pepre-udu
Hieronyma alchorneoides	Phyllanthaceae	Ayo-ayo
Triplaris weigeltiana	Polygonaceae	Mira-udu
Drypetes variabilis	Putranjivaceae	Fungu, witte
Cassipourea guianensis	Rhizophoraceae	Casepurea
Duroia aquatica	Rubiaceae	Marmeldoos, grootbladig
Faramea guianensis	Rubiaceae	Boskoffie
Genipa americana	Rubiaceae	Tapuripa
Palicourea longiflora	Rubiaceae	Kandra-udu

Casearia javitensis	Salicaceae	Uma-udu
Laetia procera	Salicaceae	Kaiman-udu, Pintokopi
Cupania scrobiculata	Sapindaceae	Gawtri, hoogbos
Melicoccus pedicellaris	Sapindaceae	Pintolokus, zwarte
Talisia mollis	Sapindaceae	Jankrapa
Vouarana guianensis	Sapindaceae	Tingimoni, hoogbos
Manilkara bidentata	Sapotaceae	Boletri
Manilkara huberi	Sapotaceae	Boletri, basra
Micropholis guyanensis	Sapotaceae	Riemhout, zwarte
Pouteria cuspidata	Sapotaceae	Pinto-boletrie
Pouteria guianensis	Sapotaceae	Yamboka, rode
Pouteria melanopoda	Sapotaceae	Yamboka, zwarte
Pradosia surinamensis	Sapotaceae	Kimboto
Simarouba amara	Simaroubaceae	Sumaruba
Siparuna decipiens	Siparunaceae	Asisi-udu
Gordonia fruticosa	Theaceae	Swa udu
Pourouma bicolor	Urticaceae	Granbusi-papaya
Pourouma guianensis	Urticaceae	Granbusi-papaya, Drifinga
Citharexylum macrophyllum	Verbenaceae	Krabasi udu
Paypayrola longifolia	Violaceae	Taya udu, gele bloem
Rinorea pubiflora	Violaceae	Manaritiki
Qualea coerulea	Vochysiaceae	Gronfolu, laagland
Vochysia guianensis	Vochysiaceae	Kwari, wiswis-
Vochysia tomentosa	Vochysiaceae	Wana kari