Lutz Fehrmann, Alina Kleinn and Christoph Kleinn

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What scientific information are policy makers really interested in?

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Edited by
Lutz Fehrmann, Alina Kleinn and Christoph Kleinn

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This volume contains the proceedings of the 6th DAAD funded international workshop on "The science policy gap regarding informed decisions in forest policy and management: What scientific information are policy makers really interested in?". The workshop was organized by the Chair of Forest Inventory and Remote Sensing at the Georg-August Universität Göttingen (Prof. Dr. Christoph Kleinn) together with the Instituto Bosques y Sociedad, Facultad de Ciencias Forestales y Recoursos Naturales, Universidad Austral de Chile, Valdivia (Prof. Dr. Victor Sandoval).

A preparatory seminar with guest lectures given by Thomas Enters, PhD (UNEP Bangkok), Friedrich Schmitz (BMEL, Bonn), Dr. David Morales (FAO, Rome) and Ragna John (GIZ, Eschborn), was held in November 2016 at the University of Göttingen. The workshop took place along the ForestSAT conference from 13 to 19 November in Santiago de Chile.

Adress of the Editor:

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Preface

The sustainable management of forest resources became an indispensable prerequisite for any policy addressing the actual and future challenges of globabl development. Forests and other tree resources are essential for the provision of ecosystem services and contribute largely to future food security, livelihoods and ecosystem stability. Forests and any other trees outside the forest play a relevant role all three great UN conventions (on Climate Change, on Biodiversity, and on Combatting Desertification). The policy processes to implement the measures in these conventions on sub-national, national, regional and international level are extremely complex. This complexity comes, among other factors, from a blend of different sectoral and national interests, from a large number of scientifically not yet entirely resolved issues and a wide range of different biophysical, social, cultural and political conditions all over the world.

It is a challenge for academia to educate the future decision makers (who are our students today) in a way that they are enthusiastic about the overall relevance of these processes. It is a challenge to integrate this education into regular curricula because various dimensions need to be covered in a field that is rapidly further developing. On the other hand, these processes offer a unique possibility to illustrate the important – and sometimes somewhat neglected – science-policy interface.

The Faculty of Forest Sciences and Forest Ecology started in 2010 to implement a new format of what we would call “long-term / sustainable national capacity building”: we organize a workshop on actual forest related topics for master-students and professors (alumni of German universities) and integrate into that that workshop a visit to an international conference. This time it was the ForestSAT conference in Santiago de Chile. Our students were intensively prepared for the visit of this conference and had the opportunity to visit one of the largest events with focus on remote sensing applications and forest inventories; an excellent opportunity for our students to extend their knowledge on how information on forest resources can be produced by remote sensing technologies and how this information might be used in policy processes and forest management – and actively practice networking.

This year, thanks to the support from DAAD, we were able to invite 42 attendees from 19 different countries to our workshop in Santiago de Chile, from Nepal, Indonesia, Ghana, Phillipines, Ecuador, Ethiopia, Uganda, Paraguay, Germany, Mexico, Colombia, Chile, Brasilia, Argentina, Costa Rica, South Africa, Italy, Peru and Bolivia. We believe that this workshop and the visit to the ForestSAT conference was an equally rewarding and instructive experience for all participants, both in scientific-technical terms and also in terms of international networking.

Organization of this workshop was only possible through the active and comprehensive support by many. Our greatest thanks are due DAAD and to Kira Urban for coordination and implementation. We thank Mrs. Magdalena Benecke for accounting and administration. We are grateful to MSc Alina Kleinn for a thorough language review and editorial support when

finalizing this proceedings volume. Workshop implementation and all logistics in Chile were organized excellently by Prof. Dr. Victor Sandoval from the Instituto Bosques y Sociedad, Facultad de Ciencias Forestales y Recoursos Naturales, Universidad Austral de Chile, Valdivia. Without his committment it would have been hardly possible to solve all the small and larger challenges! And great thanks to the participants of this workshop who all supported the implementation.

We hope that this volume does equally serve as a memory to the workshop and also as a useful reference for a variety of topic in the field of the “Science policy interface”.

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Chair of Forest Inventory and Remote Sensing

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Prof. Dr. Christoph Kleinn opening the DAAD ForestSAT workshop in Santiago de Chile.

On this volume

This proceedings volume contains the seminar papers as presented at the DAAD funded international workshop on “The science policy gap regarding informed decisions in forest policy and management: What scientific information are policy makers really interested in?”

Contributions from 1st semester Master students are mixed with those senior scientists. As student contributions are considered as assessed assignment with credit points they have to comply with the examination regulations of the Faculty of Forest Sciences and Forest Ecology at the Georg-August Universität Göttingen. We motivated the participating early semester Master students to review scientific literature on their respective topics and to make use of actual scientific findings. In context of this coursework we therefore accept that some contributions make use of figures from published sources if they are cited and referenced correctly. The manuscripts are formatted and language-edited, but they did not undergo a scientific review. The editors took the academic freedom to adapt and harmonize some of the provided figures and tables during final review and formatting.

We hope that this volume does serve as a memory for all participants and is a contribution to strengthen the established scientific networks among students and scientists from 19 different countries. Great thanks to all who provided their contributions in compliance with the very tight deadline and who made it possible that this proceedings volume could be produced only a few weeks after our workshop.

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Chapter one

Conservation & Biodiversity

Inventory and assessment of ecosystems with relict tree species as a tool for establishing criteria for public forest policy

by Eduardo Javier Treviño-Garza

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Abstract

In subtropical regions, there is a presence of fragmented ecosystems which are considered as relict since they contain forest species endemic to genera of boreal distribution. The management of natural resources has evolved from criteria based on the use of wood and sustainable production of the same to criteria of sustainability of the ecosystems considering the conservation of ecosystem services and biodiversity. These public policies related to biodiversity conservation, prevent the use of relict species so it is necessary to carry out an analysis of their structure, diversity and ecological aspects in fragmented ecosystems in order to take the right decisions for their management.

1 Introduction

When we think about forest areas we think of the products that are provided to us. These are materials like wood or some environmental services like those of the hydrological kind. Of all types of vegetation, forest areas are presented as the most complex ecosystems that, in order to be developed require special climatic, soil and physiographic conditions.

Throughout history man has used the natural resources, thereby obtaining food and materials necessary for his subsistence. In the beginning the first humans made a moderate use of the resources; they used only what was necessary for their daily consumption due to their nomadic lifestyle. The interaction with nature changed drastically when the first human settlements were established. Before land ownership appeared, the cultivation of edible species began in deforested areas. Construction materials and fuel wood were obtained from around the village areas because they had no owner and in this land everyone could make use of the forest vegetation.

2 Public forest policies

In first instance, the land that belonged to no one was credited as state property. The regulations imposed by the public forest policies were shaped during the medieval age in the forest permanencies. At the beginning of the industrial revolution the need for raw materials increased. Public policies in this regard were shaped at this time to try to obtain a continuous non-declining production, with the maximum possible extraction (sustainable production). The search for technical options to achieve this led to the creation of forestry schools that would lay the scientific basis for forest production.

At present time the constant growth of the human population and the demand for products of all kinds has had a strong impact on the environment. The paradigms in forest policies have changed from regulating the technical interventions to the forest in order to obtain wood to trying to conserve the ecological functions of the forests and their diversity, as well as to maintain the environmental services that they provide. This later paradigm also includes carrying out activities for the restoration or rehabilitation of degraded areas or with diminished resources (Jardel et al., 2008, Jardel 2012).

3 Biodiversity use

The term "biodiversity" - a jargon contraction of "biological diversity" - has been particularly contentious or misunderstood, giving rise to conflict and confusion at high levels of policy and science and among the public. Is however one of the aspects that are considered important in maintaining the stability of forest ecosystems, which does not only concern the diversity of species within ecosystems, but also the diversity of ecosystems and genetic diversity within populations of the same species.

This genetic diversity manifests itself within the same population or within the same species in different environmental gradients. Maintaining this genetic diversity is important for the persistence of species. Reducing this diversity would increase the vulnerability of the species.

The use of biodiversity in the forest sector has served to identify the best native populations of a species in order to migrate some individuals within their range of distribution from less favorable environments to those with better conditions for their development, and in this way, improve wood production. These studies of origin have been the basis for the development of forest plantations and of timber species in the world.

4 Biodiversity conservation policies

The conservation aspect of maintaining biodiversity in forests is meant to foster ecosystem connectivity, maintain the heterogeneity of the landscape, the structural complexity of forests and aquatic ecosystems (Holmgren P. and R. Persson 2002).

Strategies have been put in place to conserve biodiversity at the regional level, at the landscape level or at the forest ecosystem level. At the regional level, the establishment of large ecological reserves such as national parks or natural protected areas is proposed.

At the landscape level, it is being considered to conserve areas without forest production, to maintain areas of influence along the aquatic ecosystems, to properly design the road network, and to maintain an adequate special and temporary arrangement of the forest product harvesting units, as well as improving proper fire combat practices.

With respect to forest management, it is pertinent to maintain the structural complexity of ecosystems with rotation of harvest areas over longer periods and of adequate silvicultural practices. In this respect, the Mexican regulation to allow forest management provides for the classification of areas into areas of conservation and restricted use, production areas, restoration areas, protection areas and other uses.

The classification into an area of conservation and restricted use is considered when the property where the forest management plan is elaborated belongs to a protected natural area. The land-use is restricted in the same way in areas of protection along the rivers, on slopes greater than 100% or 45 degrees, in mountainous areas with altitudes higher than 3,000, in areas with mangroves or fog forests or in areas that are habitat of species or subspecies of flora or fauna that are at risk or are protected.

In order to determine which species are at risk, international or national criteria are used. The international level used corresponds to the World Union for Nature (IUCN) criteria, established in the Red List and at national level, the Official Mexican Standard NOM-059 are used. The first considers the criteria Extinct (Ex), Extinct in the wild (EW), in critical danger (CR), endangered (EN), Vulnerable (VU), near threatened (NT) and little concern (LC) (IUCN 2016). In the Mexican Standard, the following classifications are used: Probably extinct in the wild, in danger of extinction, threatened and subject to special protection (SEMARNAT, 2010).

5 Forest tree species at risk in Mexico

In Mexico, we can find the southern distribution of tree species from the Neartic ecozone, these grow in extreme climatic conditions (low humidity and high temperature) and are in some cases endemic for a region. These species have been logged for their timber by local sawmills. This use is now being discouraged for conservation reasons. The spruce species are distributed in northern Mexico as shown in figure 1, in northeast Mexico we find Martinez's Spruce (*Picea martinezii*), in the same forest ecosystem with others species in risk categories like Vejar's Fir (*Abies vejarii*), Mexican Yew (*Taxus globosa*) and Douglas Fir (*Pseudotsuga menziesii*.).

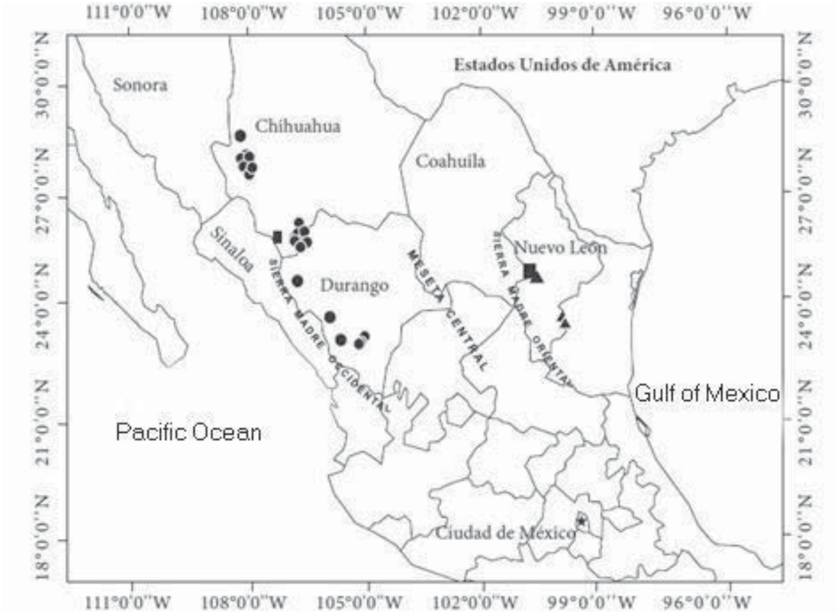

Figure 1. Distribution of spruce populations (Picea martinezii ▲), (P. mexicana ■) & (Picea chihuahuana ●) (Mendoza-Maya et Al. 2015).

Although wood of species of the genus Picea is used all over the world, in Mexico all species are protected by law. In the case of Martinez's Spruce (Picea martinezii), the species is on the Red List Category of the NICU and in the category of danger of extinction. In the NOM-059 it is registered as endemic. It is distributed between 2155 and 2990 above sea level. At present it occupies 48 ha in four localities, and the population is severely fragmented as a consequence. The population is likely to decrease due to forest fires and pests.

Figure 2. Martinez's Spruce (Picea martinezii)

Globally, more than 40 species of Abies (Pinaceae) grow in boreal forests. In Mexico Eguiarte and Furnier (1997) mention that there are eight species of Abies, six of these endemic, distributed in the highlands of the country. All of them are protected.

The Vejar's Fir (Abies vejarii) is endemic to northeastern Mexico, it is extended over 144 km2, at elevations ranging from 1,900 to 3,300 meters and is found in mixed pine forests. It is considered by Mexican law as threatened and internationally as Near Threatened (IUCN). The population is likely to decline because of forest fires and deforestation and is considered severely fragmented.

Figure 3. Vejar's Fir (Abies vejarii).

The Mexican Yew (Taxus globosa, Schltdl.) is located in an approximate area of 2,000 km 2, in small and severely fragmented populations, in an altitudinal range between 1,000 and 3000 meters above sea level. At national level it falls under theprotection category and at the international level it is considered as threatened. It has recently been studied due to the medicinal qualities of Taxol that it contains (García & Castillo, 2000, Shemluck et al. 2003, Barrios et al. 2009).

Douglas Fir (Pseudotsuga menziesii, (Mirb.) Franco) is a species of tree with a wide distribution and many subspecies: from sea level in the north to the high mountain in the south. It is the tree with the best logging performance in North America. In Mexico it is protected by law; subpopulations are often isolated and have been described as distinct species. This variety is present in many protected areas, including some national parks.

The current distribution of these species is influenced by climate change, not only the one that has appeared in the last century. The last glacial period changed the landscape of the Earth. Even though many of the plants and animals of the Quaternary Period are virtually the same as those living today, there are some important differences in their distribution. The vegetation was displaced by the ice and returned to the same location when the ice melted, leaving some isolated species in latitudes south of their original distribution, leaving fragments of vegetation with an affinity to the boreal forests in the mountains.

Table 1. IVI Values of trees in ecosystems with relict species in northeastern Mexico. (González Cubas, 2015).

Species	Altitude in m			
	2400	2500	2600	2700
Abies vejarii	29.4%	29.5%	16.9%	18.4%
Cupressus arizonica		31.5%		
Quercus affinis	18.5%	8.6%	24.1%	24.7%
Quercus mexicana	17.2%			
Quercus polymorpha	9.2%			
Picea martinezii	8.7%		22.6%	
Taxus globosa	8.7%	2.2%	13.1%	
Pseudotsuga menziesii	1.9%	11.7%		
Zanthoxylum fagara	1.6%			
Pinus ayacahuite	1.6%	14.4%	14.3%	20.9%
Ulmus craassifolia	1.6%			
Arbutus xalapensis	1.5%			12.7%
Pinus pseudostrobus		2.3%	9.1%	
Pinus teocote				18.2%
Quercus fulva				5.1%

In order to establish the horizontal, vertical and floristic structure of these communities, as well as to know their ecology, a network of permanent forest research sites were established. Following the scheme proposed by Corral et al. 2009, the sampling sites have an area of 2,500 square meters. In these plots, the dendrometric variables and the position of each tree were recorded. Each tree is numbered to perform measurements every 5 years in order to see its increase in diameter and height. Soil samples are taken for physical, chemical and biological analysis. This analyzes the seed bank of the forest species of interest. The seedlings of the forest are quantified and the phenology of 25 trees in each site is recorded monthly for two years to determine the periods of leaf renewal, flowering and fruiting. Samples were taken from the spruce leaves and transported to the laboratory for genetic analysis.

As an example, the analysis of four forest ecosystems with Northern exposure at altitudes of 2400, 2500, 2600 and 2700 meters above sea level is presented. The four populations are close but do not form a continuum. Taking the importance value index (IVI) to describe the floristic structure, Table 1 shows that *Abies vejarii, Quercus affinis* and *Pinus ayacahuite* are present in the four localities. The IVI values for Abies are between 20% and 30% when decreasing the altitude, the oak is dominant as second order in all localities and pine values decrease with altitude. The Mexican yew is found in the three lower altitudes, Douglas fir in the two smaller ones and spruce in two 2400 localities with low values and at 2600 with values of 23%

6 Conclusions

The concept of biological diversity has been particularly controversial or misunderstood, leading to conflict and confusion at high levels of policy, science and among the public. In many cases, the public reacts poorly to alarming information, with or without scientific knowledge, on issues such as climate change, habitat destruction or loss of biodiversity. The environmentalists present initiatives to the political authorities in order to create public policies without sufficient scientific information. As a consequence, their good intentions produce negative economic impacts for the owners of the resources or negative ecological impacts in the ecosystems, because the regulation avoids management actions that assure the permanence of the ecosystems.

In the case of relict tree species, these may be rare in one region but abundant in others. The information about these ecosystems will allow us to determine the genetic richness, the distribution of the species, the possible uses and its resilience, which presents limitless possibilities for the management of biodiversity.

The study of these highly fragmented populations has shown that despite being under pressure, these ecosystems still preserve their biological richness and their reproductive capacity. It is necessary to present this information in an organized way to change some of the conservation policies, and to manage the species communities in order to expand their distribution and connectedness.

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Zoning of an Agroforestry System: Organic Coffee Production in Santa Cruz Island – Galápagos

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Abstract

In the Galapagos Islands, the agricultural land was abandoned due to the explosion of tourism activities, having the spread of invasive species as a consequence. One of the crops that still exist on the island is coffee. One coffee farm produces certified organic coffee under the shade of endemic forest species, and is recognized by tourists and locals as a high quality coffee. One of the most important characteristics of coffee production in the island is that the optimum environmental conditions established in the literature are not met, so it is possible that other environmental factors influence the local success of the crop. This study focuses on the zoning of organic coffee to determine which areas are suitable for producing it. The study is based on the environmental conditions that favor the growing of organic coffee under the shade of native species in the reference farm. The data on environmental factors that influence the coffee production in the farm were obtained from thematic maps of soil, climate and elevation. The factors were reclassified in a range of zero to five, with five being the environmental factor present in the reference system. Then, the Raster Calculator tool was applied for multiplying the reclassified environmental factors and for indicating the suitable areas. Despite of the unfavorable environmental conditions of the Santa Cruz Island, the organic coffee farming is suitable and represents a viable approach to increase agricultural production on the island.

1 Introduction

A large number of small-scale coffee producers live in areas with fragile ecosystems and therefore they face big difficulties; however, they must comply the high market expectations and standards especially with regard to the coffee quality, which compromise their ability to compete against large scale coffee producers (Caswell y Méndez, 2012). This is also an issue in the production of coffee in the Galapagos Islands due to the special social and environmental conditions. In the Archipelago the production of coffee must be environmentally friendly and apply the best agricultural practices to ensure an efficient production; additionally, the farmers must confront and manage unusual environmental conditions that limit the production of coffee. For example: limited water, high temperatures and invasive species. Moreover, farmers face the absence of people willing to work in agriculture and high salaries.

Agricultural zoning represents an opportunity for the farmers to identify the areas with the best suitability to improve the agricultural productivity of organic coffee inside a sensitive ecosystem. Furthermore, zoning allows the farmers to address some of the environmental and social challenges mentioned. According to Pineda and Suarez (2014) recent studies demonstrate the potential of zoning at the municipal level, not only for agricultural management but also to generate environmental protection strategies.

The zoning study that this paper is based on was conducted on the Island of Santa Cruz, where the abandonment of farmland resulted in an explosion of invasive species. An agroforestry system to produce organic coffee offers the possibility to respond to this problem and control the invasive species, besides coffee growing may be carried out under the shade of endemic species such as *Scalesias* (Chiriboga, Fonseca and Maignan, 2006). In one of the farms on the island the coffee also grows under endemic tree species like matazarno and palo santo.

According to FAO (1993), agroforestry is the deliberate growth and management of trees, along with agricultural crops and/or livestock, in systems that aim to be ecologically, socially and economically sustainable. In order to conduct the zoning, an agroforestry reference system was identified in the island, in the form of an existing farm.

This agroforestry reference system produces organic coffee with high quality; the system takes advantage of rains from January to April to collect water and irrigate shrubs, it also uses the natural shade of the native and endemic trees of the island. Forest tree species, in addition to providing shade, regulate temperature and are habitat for several species of unique birds.

The final product of the zoning is a map that identifies the areas with the greatest potential to implement an agroforestry system for the production of organic coffee, and thus replicates the system of organic production that is taken as an example. A zoning map is a support tool in the process of decision-making for farmers and local authorities.

2 Coffee production in the Santa Cruz Island

On the Santa Cruz Island currently 36 farms produce coffee; some of the coffee farms exceed 20 ha. In the low elevations cattle is raised while in elevated areas with deep soil coffee is cultivated. Coffee production on the island faces challenges such as the low prices and high labour costs; however, the quality of coffee is recognized, reason why the price has increased (Chiriboga et al., 2006).

2.1 Organic Coffee Production

The organic agroforestry reference system is the only one that has a certification from the United States Department of Agriculture (USDA), therefore this system was taken as a reference for the zoning. This system collects rainwater to manage activities of post-harvest, due to the lack of surface water resources. Under the agroforestry system of organic production, in 2015 the coffee production in the reference system was 4,545kg in an area of 10 ha. The production yield was 41% lower than the national level average, although Fireside (2014) states that the performance of organic coffee production is usually 70% lower than conventional coffee production and avoid the application of 281 kg of chemicals per hectare.

Through coffee crop the agroforestry system owners have managed to control several invasive species that affect the ecosystem. Under the special conditions of the Archipelago, it is impossible to abandon the farms to allow native and endemic vegetation to grow since invasive species are stronger and predominant (Guerra, 2015). The controlled cultivation of species such as coffee makes it possible to establish certain patches of native and endemic forest species. The aim of the agroforestry organic reference system is to use the production of coffee to improve the income, restore the native flora and attract fauna species. As a result of this initiative the system also counts with a Bird Friendly certification, this certification is specific for organic coffee that grows under shade and provides habitat for birds (IMO LATIN AMERICA, 2011). The forest species under which the coffee grows inside the reference organic system are mainly matazarno (*Piscidia carthagenensi)* and palo santo *(Bursera graveolens).* In the Figures 1 and 2 it is possible to observe some of the processes carried out in the farm, all of them under the shade of the native forest.

Figure 1. Coffee Nursery.

Figure 2. Prune of a coffee shrub.

2.2 Environmental conditions influencing the coffee growth

The agricultural production area, designated by the Galapagos National Park (GNP) in the Santa Cruz Island is 11,441 ha; the range of precipitation extends from 200 to 1,200 mm of rain per year. However, the maximum annual range of precipitation recommended for the production of coffee in Ecuador ranges between 990 and 3,000 mm per year, and the minimum range falls between 760 and 1,780 mm annually (Cofenac, 2003). Although, the range of rainfall on Santa Cruz Island is lower than the recommended range, there are nine coffee production systems that are located in the zone, characterised by a rain interval between 600 to 800 mm. This also includes the reference system.

The ideal temperature for coffee growth in Ecuador ranges from 18 to 21°C (Enríquez, 1993). However, the lowest temperature in Santa Cruz Island is 19 °C, and most of the coffee production systems are located in the areas with average temperatures from 22 to 23°C.

Cofenac (2003) reported that the best elevation to arabic coffee growing in the Ecuadorian ecosystems ranges from 800 to 1,200 masl, nevertheless in Santa Cruz Island the coffee crop grows from 156 to 453 masl.

The island is divided into three areas of fertility; the majority of the coffee systems and also the reference organic system lie in the most fertile area. Soil is considered fertile when it presents all the characteristics and nutrients for the growth of the plant within an acceptable range (Garnica, 2010). The degree of soil fertility is recognized as a very relevant environmental factor, because it determines the need to use additional fertilizers in the soil as well as the degree of soil productivity.

The island soil pH is generally acidic from 3 to 4, due to its volcanic parent material. Most coffee farms are located in soils with pH 4, which indicate that this is a better pH for coffee production. The pH is directly related to the degree of soil fertility that results from the interaction of a group of factors including availability of essential nutrients, pH and salts in the soils (Garnica, 2010).

The effective depth in the island is divided into four categories, most of the productive systems, including the agroforestry reference system, are located in the areas of effective depth grades of 2 and 3. The effective depth is defined as the space available for roots of a plant to penetrate without resistance (Ibáñez, 2007).

The texture of the soil refers to the content of soil particles of different sizes. The soil texture can be classified as fine and coarse and is related to the amount of water and air that soil is able to retain, and the speed with which the water flows through soil layers (FAO, 2006). In the island the texture is classified into three values, the reference organic system is located in the higher texture value.

The taxonomy of the soil is classified into several categories. For this study the soil order classification feature was considered, most of the agricultural area of the island is classified within the soil orders alfisol and inceptisol.

3 Methodology: Application of GIS for Zoning Agricultural Systems

Zoning is a system that regulates the type and intensity of the land use inside a community, and allows planning the future based on the goals and local policies (Kruft, 2011). Agricultural zoning is a specialized type of zoning applied in a community to preserve and maintain the agricultural production, the aim is to protect the crop land against non compatible uses that in the long term affect in a negative way the economical capacity of the area (Kruft, 2011). Geographical Information Systems (GIS) represent a strong tool for agricultural zoning of big land extensions. The zoning of the agricultural land extension established by the GNP was made with the use of GIS and the data from the agricultural system of organic coffee production in the island. In the following map (Figure 3) it is possible to see the agricultural land for which the zoning was applied.

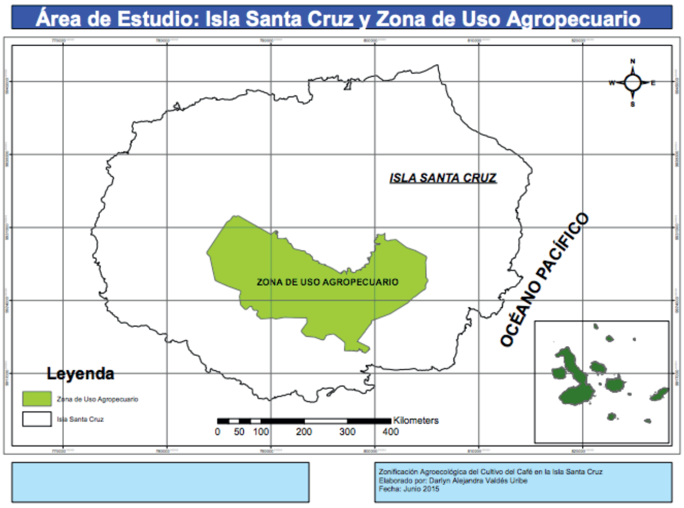

Figure 3. Agricultural area assigned by the GNP.

The coffee zoning consisted in the mapping of some of the most determining environmental factors for the growth of the coffee crop. These factors are: Soil taxonomy (order), precipitation, temperature, elevation, texture, effective depth, fertility and pH. The zoning was conducted with the use of the ArcMap component in the ArcGis software that belongs to ESRI. The use of ArcMap allows representing the spatial data through a group of layers that can be explored, created and edited (ESRI, 2012). The layers for the zoning were shared by the Urban Planning Department of the Santa Cruz Municipality and the SIG Tierras program boosted by the Ecuadorian Agriculture Ministry (MAGAP). Most of the relevant data for the zoning was extracted from these layers; it is important to say that, some of the data as texture, fertility and effective deep were previously classified, reason why the study does not have access to the original data with measurement units.

Each environmental factor was reclassified, and new values between zero to five were assigned, with zero representing the less suitable environmental factor and five representing the most suitable ones (Figure 4). The value five was set for the environmental factors corresponding to those identified in the reference agroforestry system. The following map exposes the result of the reclassification of two of the environmental factors considered for the zoning.

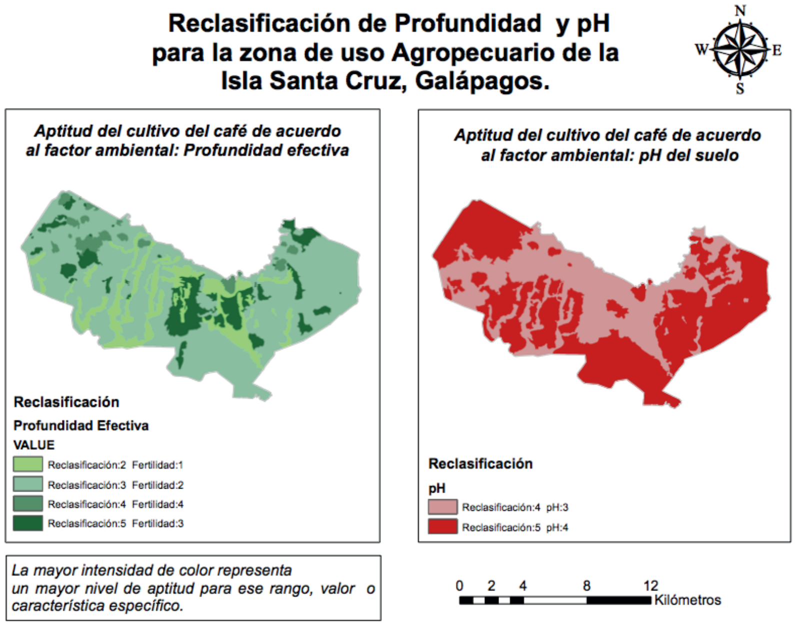

Figure 4. Example of environmental factors reclassification.

Following the reclassification, the *Raster Calculator* tool was applied to all of the raster layers containing the newly reclassified environmental factors. With this tool the environmental variables were multiplied and as a result a single raster map with a cell size 10 x 10 m was obtained, in the map is possible to identify the most and less suitable areas according to the result of the multiplication. A model of the process followed in this study is presented in Figure 5.

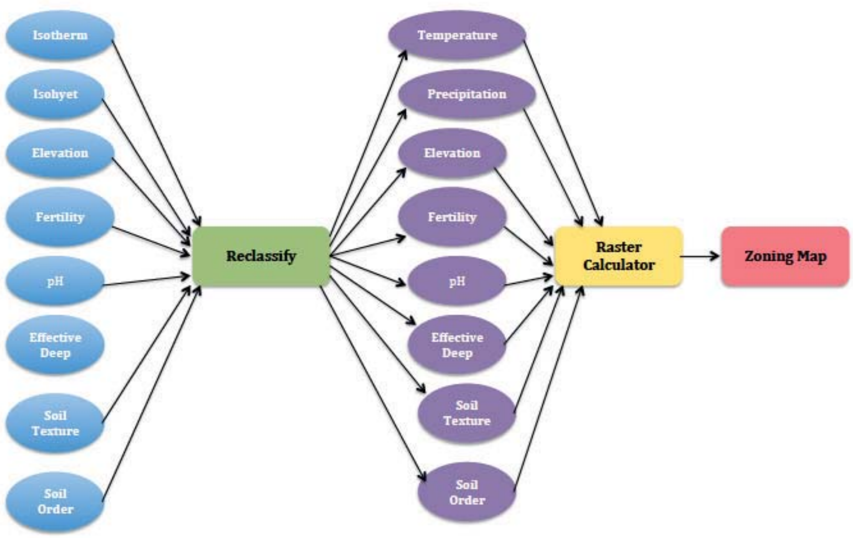

Figure 5. Model of the process followed in this study.

4 Results

With the purpose of facilitating the visualization of the results, in this section two maps are presented. Both maps show the same zoning result, but each one with different additional information.

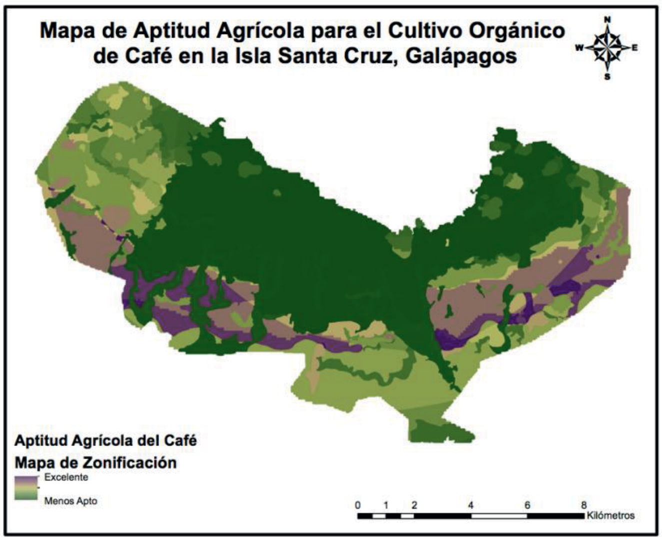

Figure 6. Zoning map for organic coffee in the Island of Santa Cruz.

In the map (Figure 6) the suitable areas for the agroforestry system are clearly visible in purple and lilac, these areas are mainly located in the south east and south west of the agricultural zone. The dark green area that occupies a big portion of the central zone of study is less suitable for the proposed system.

In order to determine the area that corresponds to the suitable and non-suitable locations for organic coffee growing, the results of the zoning map were classified in five categories. The classification was made according to the natural break method called *jenks*. This method is based on the own natural grouping of data, that best fits the similar values and maximizes the differences among the data ESRI (2015).

Table 1. Area in km2 of the different suitability classes

Suitable	Area (km^2)
Not Apt	50.45
Marginal	13.78
Apt	11.82
Very Apt	34.47
Excellent	28.27

The Not Apt and Marginal area for the agroforestry system of organic coffee is 64.23 km^2, this represents 46.3% of the total agricultural area. The main reason that explains why the Not Apt and Marginal category is so broad is due to the soil structure that is mainly of the Inceptisol type. This type of soil occupies an area of 41.2 km^2 and covers 30% of the total area. The Inceptisol order is a young soil that requires fertilizers in order to be productive, this is why this soil was reclassified with a value of zero, and as a result when the *Raster Calculator* was applied each cell with this characteristic received a null value. Nevertheless, the Apt, Very Apt and Excellent area for the organic crop is 74.56 km^2, that is to say more than 50% of the agricultural area labeled by the GNP.

Current coffee growing systems in the island are located randomly inside the survey area. The next map (Figure 7) shows the coffee crop systems in the zoning map. The reference organic system is also outlined.

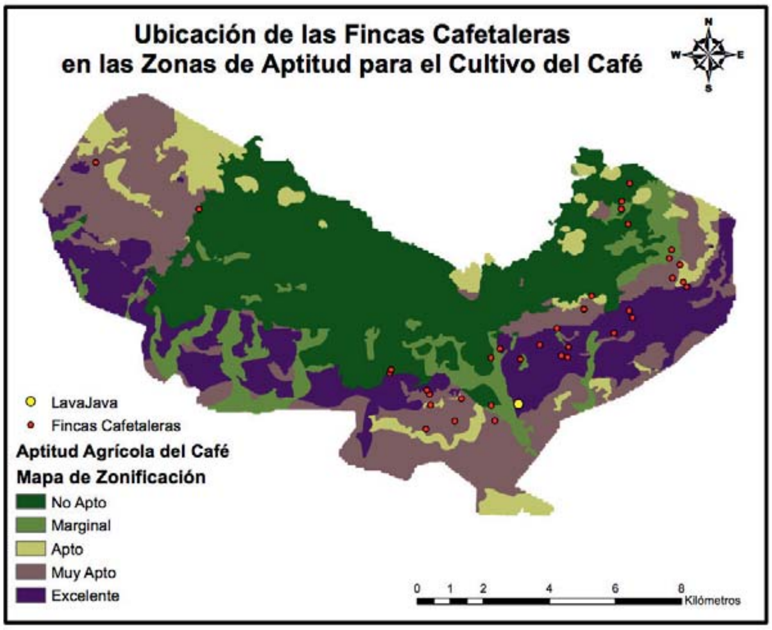

Figure 7. Location of the coffee crop systems in the zoning map.

In the displayed map it is straightforward to identify that 12 of the 36 existing production systems are set in the Not Apt and Marginal areas for growing organic coffee under the shade of forest species. The remaining 24 systems are located in the Apt, Very Apt and Excellent zones. It is important to say that the results do not suggest that coffee growing is not possible in the Not Apt and Marginal zones. Regardless of the location these systems are currently producing coffee. It is however possible that these systems will not be able to produce organic coffee under the conditions and considerations taken into account for this survey, this means that probably these systems need fertilizers to improve the soil.

The Excellent and Very Apt zones are randomly located in the study area. Throughout all the elevation ranges, between 40-640 masl, it is possible to find apt zones. This exemplifies that elevation is not a factor that limits the coffee growth, although elevation certainly plays an important influence in the physical characteristics of the coffee bean: The altitude coffee shows a green-blue bean, while the lowland coffee bean is less dense and clear green (Santoyo, Díaz, Escarilla y Robledo, 1996). Most of the coffee production systems in the island are located in the highest altitude range, 24 systems are set between 200 – 430 masl, but the capacity to produce good quality organic coffee in association with forest endemic species is apparently not related to elevation. The organic reference system for this study, located at

176 masl is an example of this. Environmental factors such as soil order, fertility, texture and shade appear to make the difference between conventional coffee growing and organic systems in the Santa Cruz Island. The map above is a good guide for small coffee farmers that want to change from a conventional system to agroforestry plantations.

As mentioned, the precipitation and temperature intervals in the island are not proper for coffee growing according to literature. Nonetheless, additional factors act as agents to regulate climate. One of these agents is the shade of forest species that create a fresh microclimate with enough humidity (Pérez y Suárez, 2011). The MAGAP technician in Santa Cruz Island, asserts that the island presents special physical and biotic conditions that generate a broad variety of microclimates that are believed to favor some crops (Vásquez, 2015). This variety of microclimates is a local phenomenon that is not detected in the temperature and precipitation maps, and might be the reason why it is possible to grow coffee, even when the typical standard growing conditions are not fulfilled. Coffee growing under arboreal species contributes to the improvement of physical and chemical soil properties, erosion protection, raise of biodiversity and environmental quality (Pérez y Suárez, 2011). Additionally, an outstanding improvement of the coffee quality has been shown when it grows under shade; for example, higher cherry weight, larger size, better acidity and coffee body (Muschler, 2001).

5 Conclusions

The zoning map shows that 74.56 km^2 are suitable to implement an agroforestry system with organic coffee, this represents 53.7% of the area assigned for agricultural use in Santa Cruz Island. The environmental conditions under which coffee grows in the island are barely similar to the conditions established in the literature. Instead, the organic agroforestry reference system develops at temperatures between 22 °C and 23 °C, precipitation interval from 600 to 800 mm and in lowlands. This could be understood to indicate that environmental factors such as climate and elevation do not determine the development of coffee in the island. However, for a future research it is priority to look into the influence of these factors on the coffee growth, not only referring to the development of the crop but also to the bean quality.

46.3% of the land is qualified as Not Apt due to the predominating soil order inceptisol. This type of soil is not fertile and requires fertilizers to be productive, resulting in small chances to replicate the agroforestry reference system on it. Nevertheless, the fact that currently some coffee crops are located in this soil type indicates that it is feasible to grow coffee under a conventional system. However, the activities in a conventional system may threaten the sensible ecosystem of the island, the quality of underground water and soil. In order to prevent harm to the ecosystem, this study emphasizes the organic coffee production in combination with forest local species in Santa Cruz Island.

The zoning analysis tends to demonstrate that the most predominant environmental factors are soil texture, soil order, effective depth, pH and fertility. The combination of these variables have been effective during the last eight years for the agroforestry reference system, resulting in the production of high quality organic coffee, with an annual production rate of 282 kg of roasted coffee per hectare. The crop yield mentioned is above the typical productivity values for organic systems that according to literature produce a 70% less than the conventional crop systems, but in the case of the reference system is 41% less than conventional ones.

The lack of sweet superficial water in the island does not restrict the coffee production, the effects of this issue in bean quality are not well known. Furthermore, the effects of the forest shade as temperature regulator, water captor and humidity retainer agent are unknown. However, the success of organic coffee production in the reference framework suggests that a complex climate regulation system takes place and benefits the coffee growing under shade, in spite of the not common conditions in the study area.

Taking into account the percentage of the area suitable for the implementation of an agroforestry system with organic coffee identified in the zoning map, it is acceptable to conclude that with the increasing market of organic products and the coffee prices it is possible to obtain significant profits for the island. Moreover, this represents an opportunity to raise the local population incomes and improve the economy. Supporting the local farmers is indispensable to move from a conventional crop system to an organic sustainable production model.

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Chapter two
Participatory forest management

Integrated Naranjilla Round Table: a space of concertation for farmers

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Abstract

Since June 2013, the Napo Provincial Decentralized Autonomous Government (GADPN) in Ecuador has been promoting the Integrated Naranjilla Round Table, a space for dialogue about the utilization and marketing of the Naranjilla fruit (*Solanum quitoense)* involving institutional representatives from the public sector; Non-governmental organizations, and farmers in the canton of Archidona. The main objective is to innovate the joint and integral management of the naranjilla value chain to find a balance between productivity, sustainable use of natural resources and increase incomes of farmers.

1 Introduction

The Integrated Naranjilla Round Table of the Sumaco Biosphere Reserve, created in February 2013, through strategic alliances, seeks to promote the production of clean naranjilla in the province. The spaces for horizontal dialogue which deals with the cases or subjects which concern a group of producers for the benefit of its social, cultural and natural state, constitutes an alternative for good governance. This space for dialogue possess a distinct quality due to the active participation of producers, public and private organizations, non-governmental organizations, etc. to deal with problems, share knowledge or take decisions which tend to improve definite situations.

With the leadership of the Decentralized Autonomous Government of the Napo Province, Ecuador, the Integrated Naranjilla Round Table was launched to support the strengthening of the organizations and improve the production of naranjilla in the Hatun Sumaku Parish of Canton Archidona. This parish consists of seven indigenous Kichwan communities which are the major producers of the naranjilla (Solanum quitoense). The development of this species demands high quantities of organic materials and due to its monoculture character, it is vulnerable to attacks by plagues and diseases. This situation obliges the producers to widen the agricultural frontier which in turn threatens the high biodiversity of this territory which merited the pronouncement by UNESCO declaring it as the Sumaco Biosphere Reserve. A further problem associated with the production of naranjilla is the indiscriminate use of agricultural chemicals; in addition, the instability of the price of the fruit and the low prices which the intermediaries pay do not contribute to improving the producers' economic situation.

As a consequence, the change in the use of the soil results in harvested fruits with high indices of chemical residues which makes them unapt for human consumption. The lowered state of health of the producers and non-sustainable agricultural practices are the threats which demand intervention in order to change these negative effects.

Due to these, the articulated actors, through the spaces of dialogue, formulated a strategy to search for an integrated production of naranjilla and in an associated manner protect the biodiversity of this important biosphere reserve.

2 Who forms this space for dialogue?

Institutional representatives of the public sector: Napo Provincial Decentralized Autonomous Government (GADPN), Hatun Sumaku Parochial Decentralized Autonomous Government (GADPHS), Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP), National Institute of Agricultural Research (INIAP) Ministry of Public Health (MSP), State University of Amazonia (UEA), Ministry of Public Health, Ministry of Public Health, Ministry of Public Health, Ministry of Public Health, Ministry of Public Health, Ministry of Industry and Productivity (MIPRO), Institute for Amazon Regional Ecodevelopment (ECORAE), Ministry of Environment (MAE); Non-governmental organizations: Rainforest Alliance, Environmental Law and Management Corporation (ECOLEX) and Maquita Cushunchic (MCCH); (Solanum quitoense) from the communities of Wamaní, Sumaco Wawa, Sumaco Volcano, 10 de Agosto, Challwayaku, Pucuno Chico, Pacto Sumaco, Cotundo, Pachakutik and Pakchayaku communities.

Most of the farmers belong to the Hatun Sumaku parish, located in the buffer zone between two biologically and culturally important areas, the Napo Galeras Sumaco National Park and the Sumaco Biosphere Reserve, declared by UNESCO in 2000 as one of the 380 biosphere reserves in the world. The coordination of the Roundtable is in the charge of the Provincial GAD of Napo and counts on the advice of Rainforest Alliance. "Together with all the actors and with the approval of the farmers, we have designed a strategic plan, aimed at fulfilling the dream of producing clean naranjilla, to access markets that allow the commercialization of both naranjilla in fruit; As well as derived products, such as juices, jams, pulps, among others, "says Guido Farfán Talledo, coordinator of the GAD Provincial Production Unit.

3 Main achievements to 2014

The process of formulation and implementation of the strategy has been very participative which led to the empowerment of the actors by the process and in each area of competence gave impulse to the realization of the objectives of this strategy:

- Developed the training plan by UEA, Rainforest Alliance, MAGAP, AGROCALIDAD, INIAP, ARCSA, MSP and the GADP of Napo.

- AGROCALIDAD carried out residual analyzes of agrochemicals to ensure that the naranjilla complies with the parameters accepted by current regulations.
- ARCSA inspected the food processing laboratory of the Bilingual Technical College of Wamaní to identify the missing requirements to obtain the corresponding sanitary permits.
- The Rainforest Alliance selected 14 demonstration plots and seven pilot farms in the seven communities of Hatun Sumaku Parish, which are used as training sites for good agricultural practices.
- With the participation of about one hundred farmers of the producers' organizations of Papanco, Pacto Sumaco, Challwayaku, Diez de Agosto and Wawa Sumaco, and with the support of MAGAP, plots of naranjilla and vegetables have been built.
- ECOLEX and IEPS initiated the legalization process of the "ASOPROBISUM Association".
- With the help of IEPS, the Sacha Larán Producers Association was legalized.
- In February 2014, the Provincial GAD of Napo and Rainforest Alliance promoted the participation of the Wamaní producers in the Expo Napo Provincial Fair, which allowed them to market, for the first time, the clean orange juice in the city of Tena.

4 Strengthen local capacities, key to improving production

The production of naranjilla (Solanum quitoense), demands fertile soils and when becoming a monoculture, it is more susceptible to attack of pests and diseases, which has caused that the producers extend their agricultural border and use high doses of agrochemicals, that in the majority of cases are banned by the World Health Organization, because of their degree of toxicity. "The incorrect handling of agrochemicals has caused that most producers of the Hatun Sumaku parish (70%) have suffered cases of intoxication, most cases of eye irritation are reported" (López, F .; Paredes, D. 2013).

The indiscriminate use or inappropriate handling of agrochemicals affects the health of producers and consumers, contaminates water, soil and air. In addition, the high production costs and the low prices paid by the intermediary for the fruit do not contribute to improve the farmers' economic situation.

This is why, based on the analysis of this information, the members of the Naranjilla Round Table elaborated a training plan that addresses the needs of farmers, and in which four components were prioritized: socio-organizational, sustainable management and Implementation of good agricultural practices, post-harvest, good practices of manufacturing, value added and commercialization.

Training farmers on these issues is key to their sustainable development, improving their sanitary conditions, conserving natural resources, consolidating their organizational process, and developing value-added products.

Within the framework of the Andean Amazon Conservation Initiative, supported by the United States Agency for International Development, the Rainforest Alliance trains socio-organizational components, sustainable management and implementation of good agricultural practices; Post-harvest, good manufacturing practices and added value as well as marketing, issues in which this organization has much experience.

"An organized group will have greater commercial opportunities, will be able to negotiate and establish its own conditions. Organized producers have greater advantages than the individual producers because they can buy together and thus obtain better prices, which is why in September, together with the State University of Amazonia (UEA), we started the training process on strengthening issues Organizational," says Christian Velasco, forest program manager for the Rainforest Alliance in Ecuador.

At the same time, in coordination with MAGAP, the first workshops on sustainable management and good agricultural practices were held. To date, 27 producers (8 women and 19 men) have been trained in the communities of Wamaní, Pacto Sumaco, Challwayaku, Diez de Agosto, Wawa Sumaco, Pucuno Chico and Pachakutik.

Through training, the Rainforest Alliance seeks to raise the awareness of naranjilla farmers about the importance of adopting agricultural practices that improve the socio-cultural, health, environmental and economic conditions of agriculture through sustainable and economically viable production methods. Thereby, farmers manage to both increase their income, as well as adequately manage natural resources.

The application of good agricultural practices entails a social challenge that overlaps with the technical activities that are implemented in the area, therefore it is necessary that institutional actors and support entities continue to join efforts to positively influence the organizational culture of the producers. "With the support of the Rainforest Alliance I have been able to learn about some issues that can improve the economy of my family, communities and the parish to offer better products to naranjilla consumers," said Francisco Huatatoca, a member of the Challwayaku community; While saying that from now on he wants to be a leader in charge of teaching this subject to the organizations.

5 Where are we going?

By 2014, the Naranjilla Roud Table constitutes a space for legitimate dialogue for coordination, coordination and accountability that promotes the sustainable development of producers and the conservation of natural resources. Public organizations responsible for local agricultural development develop and implement a specialized technical assistance program that promotes the adoption and application of GAP in naranjilla cultivation.

- By 2015 the naranjilla producers consolidated their organizational process and identified the products with added value to offer as well as the market potential at national level and the strategies of penetration.
- By 2016 farmers in the Hatun Sumaku parish produced clean naranjilla and positioned their primary and value-added products in major local and foreign markets.

Training and strengthening farmers' capacities will enable naranjilla production to be a viable economic alternative for the residents of the Hatun Sumaku parish.

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The implementation of community based forestry as REDD+ activity: Comparative study in Indonesia and Ethiopia

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Abstract

Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+) is presented by the United Nations Framework Convention on Climate Change (UNFCCC) as climate change mitigation concept and many developing countries including Indonesia and Ethiopia have been actively participating in the implementation of REDD+. Ethiopia and Indonesia have different characteristic in what concerns drivers and agents for deforestation and forest degradation but both countries face the similar condition of vulnerability of poor forest-dependent communities. Community around forest is important stakeholder that has to be taking into acccount to achieve effective, efficient and equitable outcome of REDD+ not only through safeguards concept but also in designing the activities. CBFM (Community Based Forest Management) as REDD+ activity has the potential to engage and provide benefit for communities beside addressing the drivers of deforestation and forest degradation. Indonesia has three legal CBFM mechanisms that have the potential to be adopted under REDD+, meanwhile Ethiopia has developed a PFM (Participatory Forest Management) program that also has the potential to be improved as REDD+ activity.

Keywords: CBFM, Ethiopia, Indonesia, REDD+

1 Introduction

Since the early 1990's the United Nations Framework Convention on Climate Change (UNFCCC) has debated how forest protection and restoration should be included in global efforts to reduce atmospheric greenhouse gasses (GHG)) concentrations. UNFCCC is known as the main international regime for climate change that brought about climate change mitigation concepts such as Reducing Emissions from Deforestation and Forest Degradation Plus (REDD+). There are various intergovernmental agenda to address sustainability issue nowadays, and climate change is one of the main issues (Skutsch and McCall 2012). REDD+ has raised awareness of fact that greenhouse gasses (GHG) emissions from tropical deforestation contribute 17% of global emissions (IPCC 2007).

REDD+ is a milestone of climate change policy development through the use of forest protection and restoration for the reduction of atmospheric GHG concentrations. REDD+ achieves this goal through one or a mixture of several forestry strategies (Skutsch and McCall 2012). The scope of REDD+ has been addressed in many discussions. Forest degradation was included in 2007 and the other three elements (biodiversity, sustainable forest management and forest carbon stocks enhancement) were added later to accommodate different interest. This wide scope is meant to reflect each country's different forest situation and allow them to benefit from an international REDD+ regime (Angelsen *et al.* 2012).

REDD+ has the core idea of providing rewards for individuals, communities, projects and countries that contribute to reducing GHG emissions from forests. It was assumed that this would reduce emissions at a low cost within a short time frame while contributing to reducing poverty and sustainable development at the same time (Angelsen 2008).

REDD+ safeguards are the way to address and avoid direct and indirect impacts of REDD+ on communities and environment. According to Angelsen *et. al* (2012), discussions on REDD+ readiness initiatives focus primarily on carbon monitoring, reporting and verification (MRV), paying little attention to other core issues such as safeguards, however. Meanwhile, considering communities and environment in the REDD+ policy and project design is critical to achieving effective, efficient and equitable outcomes. Against this background, Community Based Forest Management (CBFM) has the potential to be a form of REDD+ activity that engages communities and allows for them to benefit.

This paper reviews the potential of CBFM as REDD+ activities to combat deforestation and forest degradation, with a especially focus on how the local community can be engaged and be beneficiaries, taking Indonesia and Ethiopia as examples.

2 Characteristic of Drivers and Agents of Deforestation and Forest Degradation in Indonesia and Ethiopia

Among the proximate or direct drivers of deforestation and forest degradation are human activities and actions that directly impact forest cover and thereby result in a loss of carbon stocks. Agriculture is estimated to be the proximate driver of around 80% of deforestation worldwide (Skutsch and McCall 2012).

Commercial agriculture is the most important driver of deforestation. In Africa and subtropical Asia it accounts for around 1/3 of deforestation and is of similar importance to subsistence agriculture. Mining, infrastructure and urban expansion are important but less prominent. Commercial timber extraction and logging activities account for more than 70% of total degradation in sub-tropical Asia. Fuel wood collection, charcoal production and, to a lesser extent, livestock grazing in forests are the most important drivers of degradation in large parts of Africa (Skutsch and McCall 2012).

The figure below, developed by Kissinger et al. (2012), shows the distribution of the dominant scale of agriculture and the dominant driver of forest degradation worldwide. In Ethiopia and Indonesia (highlighted in red) commercial or large scale agriculture is dominant over subsistence agriculture. in Ethiopia, the study by Kissinger et al. (2012) shows that the subsistence drivers of forest degradation such as fuel wood collection, charcoal production and to a lesser extent livestock grazing in forests, is more dominant than commercial degradation. In Indonesia, however, the commercial degradation is dominated mostly by timber extraction and palm oil plantations. This shows that both countries have the same agent characteristics but face different dominant drivers of forest degradation.

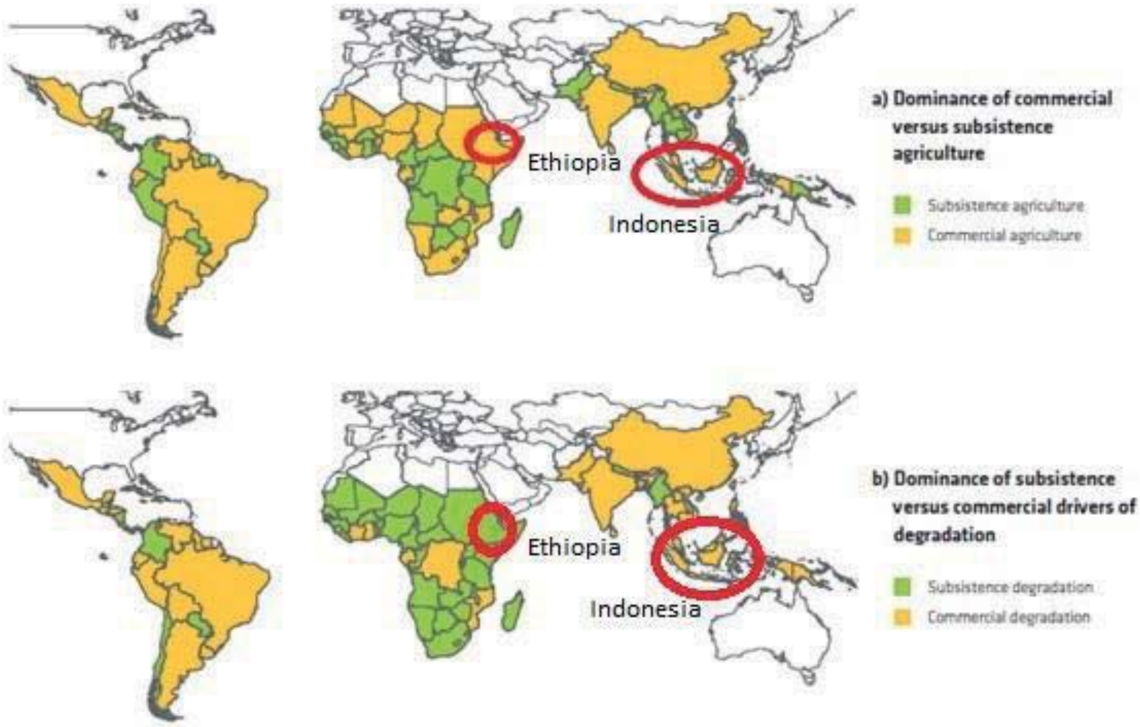

Figure 1: Subsistence vs. commercial agents and drivers of forest degradation (Source: Kissinger et al. 2012).

An extensive list of the different drivers of deforestation in Indonesia and Ethiopia is presented in Table 1, below.

The forest area in Indonesia is decreasing due to its legal or illegal utilization that leads to deforestation and forest degradation. As a result, 56% of the country's emissions come from deforestation, degradation and peatland conversion (MoE 2010). According to a study by Madeira *et al.* (2010), there are two predominant agents of deforestation and forest degradation in Indonesia, the first are industrial-scale agents and the second are smallholders or communities.

Table 1: Main drivers of deforestation behind the local community

Country	Direct drivers	Underlying drivers
Indonesia	Large scale commercial agriculture Forest area encroachment Uncontrolled forest fire	Poverty Tenure insecurity
Ethiopia	Extensive large-scale agriculture Fuel wood Overgrazing Uncontrolled forest fires	Population growth Tenure insecurity Neglect community in participation Weak law enforcement

The forest management in Indonesia is under the authority of the Ministry of Environment and Forestry (MoEF) but the forest is also an important livelihood source for a huge number of people in the country. Sunderlin et al. (2000) mention that 6 to 30 million Indonesians are estimated to be directly dependent on forests and most of those people are categorized as poor. The life of communities around the forests is directly or indirectly dependent on the forest area. But unclear tenure rights between the state forest area and the communities lead to many issue related to community activities that are claimed to be 'illegal' in forest areas, such as encroachment for shifting cultivation and illegal logging. And the motivation of communities to do those 'illegal' activities is simply to maintain their livelihoods. Even though the dominant drivers and agents of forest loss in Indonesia are at commercial or large scale, the community in Indonesia has a high dependency on the forest that needs to be taking into account.

Direct drivers of deforestation in Ethiopia include forest clearance for both subsistence and large scale agriculture, illegal and unsustainable extraction of wood, mainly for charcoal and firewood, overgrazing and periodic forest fires. According to Bekele *et al.* (2015), rapid population increase and associated growing demand for land and energy; extensive legal and institutional gaps including lack of stable and equitable forest tenure; less stakeholder participation in forest management and benefit sharing schemes and weak law enforcement are the main underlying causes of deforestation.

3 Community Forestry as REDD+ Project activity tool

The concept of Payment of Environmental Services (PES) adopted by REDD+ promises a win-win scenario, assuming that the local forest users will choose forest conservation if the compensation they receive is higher than what they would obtain from alternative forest uses. Household survey results of a study by Angelsen *et al.* (2012) showed that local people conceive REDD+ as being primarily about forest protection while the people's main hopes and worries concerned income and livelihoods. The success of REDD+ depends not only on local support, but also on interventions being targeted at areas with high levels of deforestation and forest degradation where they can yield substantial emission reductions. In order to make REDD+ activities more effective however, it is better to consider co-benefits to livelihoods.

But according to the study by Sills *et al*. (2014), there are several constraints related to REDD+ implementation on the ground level, including tenure and social safeguards.

The COP 21 Paris decision no 16 on 'Alternative Policy Approaches, such as Joint Mitigation and Adaptation Approaches for the Integral and Sustainable Management of Forests' (UNFCCC 2016) gives more potential to support the indigenous and community rights on REDD+ activities. During the discussions, UNFCC recognised that alternative policy approaches, such as joint mitigation and adaptation approaches for the integral and sustainable management of forests, are one of the alternatives to results-based payments that may contribute to the long-term sustainability of the implementation of the activities (UNFCCC 2016).

Against this background, community based forest management (CBFM) is a potential concept to address several issue related community engagement in REDD+ activities in the Indonesian and Ethiopian context. It could ensure tenure rights, encourage participation from the community, establish coordination on the ground level, ensure benefit sharing and provide livelihood alternatives for the community. A study in the Philippines by Lasco *et al*. (2011) showed that depending on which REDD+ activity is implemented, communities under CBFM areas would have varying roles and potential benefits but it was still the approach that give the most.benefit to communities

According to Robinson et al. (2013), Tanzania has adapted CBFM as a form of participatory forest management to be a model for the implementation of REDD+ pilot programs, and because it was likely to succeed. Tanzania's CBFM was implemented because key drivers of forest loss are shifting cultivation, local expansion of smallholder farming and local extraction of forest products. The program has two key objectives that link very closely to REDD+: to reduce the loss of forests and forest degradation, and to thereby increase ecosystem services and improve the livelihoods of local forest-dependent villagers. Since Tanzania faces similar community-related drivers of deforestation and forest degradation as Indonesia and Ethiopia, the implementation of CBFM can be an example for these two countries.

Indonesia and Ethiopia have both established a National REDD+ Strategy. REDD+ strategies outline a set of programs and policy actions to reduce deforestation and forest degradation by addressing the key drivers. In both countries, community engagement is not explicitly mention in the pillars and strategy but there is an implicit concern for it in the scope of the strategy.

The strategic framework for REDD+ in Indonesia has been developed and one aspect is the focus on the increase of the value and sustainability of the forest's economic functions. One out of three strategic programs is "sustainable management and landscape" that includes the focus on the expansion of sustainable alternative livelihoods and management of multi-functional of landscape (Satgas REDD+ 2012).

By now, Indonesia has participated in several REDD+ initiatives such as Forest Carbon Partnership Facility (FCPF), United Nations REDD Programme and Forest Investment Program.

However, a study of the preliminary typology of REDD+ pilot project in Indonesia by Madeira *et al.* (2010) showed that only 2 out of 17 observed projects aim to address deforestation and forest degradation by ‘illegal’ community activities. Madeira (2009) also provided the finding that the dominant type of REDD+ interventions in Indonesia seeks to prevent large-scale conversion to plantations by outside actors. It was argued that although these kind of projects fit the definition of PES at the scale at which the environmental service is transacted, PES characteristics are not a primary component of on-the-ground implementation. Smallholder or community actors are recognize as essential to the long-term success of the intervention, but they are not the main focus.

According to finding by Jurgens et al (2013) there are REDD+ relevant programs that include small grant programs that focus on rural community development in Indonesia. Indonesia has numerous of such programs that are largely run by non-state institutions, several of which have natural resource management components. Small grants programs have the benefit of being community-driven, bypassing local bureaucracies, and are able to support a variety of REDD+ related activities.

Ethiopia’s REDD+ strategy has four pillars categorized under strengthening institutions, legal regulatory frameworks, stakeholder engagement and strategic actions. Under the third pillar, community based forest management is used as a tool to foster forest conservation (FDREMoFE 2015).

An intervention that has proven successful in Ethiopia is Participatory Forest Management (BERSMP 2010) in which community based organizations associate with governmental and non-governmental institutions. Since community groups are given rights and responsibilities in the forest area, this creates a sense of ownership which motivates the protection and conservation of the forest resource. This ongoing program has the potential to be developed to support REDD+ implementation in the country.

4 Policy Implications and Implementation constraints

To adopt CBFM as REDD+ activity, it is important to review the implementation opportunity and constrains from existing policy and program in both country.

Since REDD+ implementation in Indonesia is designated within the state forest area, there are three community based forest management mechanism that could be implemented according to Ministry of Forestry regulation No.6/2007: Community Forests (Hutan Kemasyarakatan/Hkm), Village Forests (Hutan Desa/HD) and forest partnerships. Implementation of community REDD+ activities within the legal mechanisms will ensure the sustainability of the program or project because of clear authorization.

Although detailed regulations for HKm and HD arrangements were well defined, these require complicated procedures of proposal verification, site designation and approval. According to Jang et al. 2015, procedures for HKm and HD need to involve both local and central government agencies, which can take years. This may therefore become a constraint even before the implementation of the project. Forest partnership is more flexible in terms of implementation because the community can collaborate with existing forest managers, for example a company with concession or local government, to manage an existing designated forest area. Current initiatives by the Forest Investment Program try to adopt the forest partnership mechanism into their REDD+ program in West Kalimantan, Indonesia. The partnership is basically multilevel forest enterprise coordination but in practice the community will do the collaborative forest management together with the Forest Management Unit (an institution under the Ministry of Environment and Forestry of Indonesia for site level forest management).

The constitution of the Federal Democratic Republic of Ethiopia (FDRE) recognizes that the people have the right to directly participate at local level development initiatives as an exercise of the sovereign power of the people. Moreover, people have the right to participate in the formulation of policies and projects in relation to any development activity and the government is duty-bound to ensure people's participation. There are also forest policies and proclamations at the federal level and in some regional states (Oromia and SNNPRS) that provide the legal basis for PFM implementation.

According to the result of a study on the analysis of the legal basis for PFM implementation in Ethiopia (Melesse 2011), the concept of the PFM approach is a recent phenomenon and is getting more emphasis over time as one of the most viable options for sustainable forest management worldwide, and particularly for Ethiopia, there are provisions and established principles in the legal frameworks that allow the application of PFM both in state as well as community owned forests. As mentioned above, an intervention that is proven successful in Ethiopia is Participatory Forest Management. The important challenge for Ethiopia is to improve the PFM with clear and equitable benefit sharing mechanisms before adopting it as activities on REDD+ project.

The significance of the REDD+ Program in Ethiopia is that it is part of a national strategy. It is referred to as Climate Resilient Green Economy (CRGE) strategy and aims at the main sectors of the economy in order to develop an environmentally sustainable and climate resilient economy, which is meant to bring the country to a middle income status with net zero emission by 2030 (MoEF 2014). The REDD+ Secretariat has completed the required REDD+ management arrangements at federal level and as per today regular meetings are being held within the REDD+ Readiness M&E framework with members of the REDD+ management including the Steering Committee, Technical Working Group and 3 Task Forces (MoEF 2014). As local communities are also part of the REDD+ readiness project, they must take part in regular meetings and decision making processes.

5 Conclusion

The dominant drivers of deforestation and forest degradation in Indonesia are commercial or large scale actors but the dependency of communities on the forest for livelihood is high. Meanwhile in Ethiopia, subsistence or small-scale actors are the most important drivers. It could be assume that CBFM as REDD+ activity has the same potential to be implemented in both countries in order to engage and provide benefits for communities beside addressing drivers of deforestation and forest degradation. Indonesia has three legal mechanism of CBFM that may also potentially be implemented as REDD+ activities. These are community forests (hutan kemasyarakatan), village forests (hutan desa) and forest partnerships. Forest partnership is the most potential mechanism to be implemented because it will not lead to administrative constraints as the two other mechanisms. In the Ethiopian case, the ongoing Participatory Forest Management (PFM) program has the potential to be developed and improved as CBFM activity for REDD+. The most important challenge within PFM in Ethiopia is to define the clear and equitable benefit sharing mechanisms.

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Community Forestry in Nepal and México: Concept, Lessons, Challenges and way forward

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Abstract

The role of community forestry all over the world in affecting the livelihood of people is strongly discussed within the field of sustainable forest management. We present two scenarios from very different countries, Nepal and Mexico, and the community forestry development in each country. This paper makes a comparison of community forestry in both countries. There is a great complexity of situations on the ground and there are various weaknesses in the process which need to be addressed, especially the big inequalities between CFUG´s (Community Forestry User Groups) from Nepal and the Ejidos (Groups of settled land owners) from Mexico and how the implementation of community forestry is developing in both countries, the challenges and ways forward to reaching social participation and a sustainable forest management.

1 Introduction

Forest resources have always been important for food security and the improvement of livelihoods; they provide fundamental support to human well-being, and they are the main targets of Sustainable Community Forestry Development (FAO, 2016). The use of forest resources in a judicious way, fulfilling the needs of current society without compromising the future needs of goods and services is therefore the base of sustainable forest management (Aguirre-Calderón, 2015). However, Sustainable Forest Management, includes many other important elements, including social, economic and ecologic factors, community forestry is one approach to achieve sustainable forest management. It has an important role in reversing processes of deforestation, sequestering carbon, and management of the natural capital of countries. In general, natural resource management through community mobilization is one of the more successful programmes of its type around the world.

To reach a good development, the Community Forestry needs support and requires social investment, technical assistance, and training in the administration of natural resources (Klooster & Masera, 2000). Among the various forms of community based forest management in the world, Community forestry in Nepal has a good reputation and is considered as role model in the forestry sector. During a period of over 4 decades, learning by doing became the major theme in the implementation of Community Forestry in Nepal. Multi-stakeholder involvement, efficient policies and improvised institutional arrangements are the backbone of Community Forestry programme that achieved reputation all over the world (Oli *et al*, 2014). Mexico has confronted many changes during its 10 decades as an independent country, since the settlers started to work in their own lands and natural resources. One of the most important role models in the Mexican Community Forestry development is the investment and support to Ejidos and communities through the CONAFOR (Comisión Nacional Forestal – National Forest Commission), as a decentralized member of federal government, who brings support to forest communities, giving technical assistance for sustainable natural resource usage (CONAFOR, 2015).

In order to highlight the Community Forestry development in Nepal and México, a comparison between both countries can help us to understand and identify strengths and main issues in order to reach a conclusion on good management of Community Forests.

2 Background and Concept

Background in Nepal

The development phase of forestry in Nepal started before 1760 when forests were handed over as a gift to army personnel, government officials and nobles. These forests were often deforested and converted to agricultural lands by the new owners. This activity continued till 1957 when government nationalised private forest in the country under the State Control Enforcing Private Forest Nationalization Act. After nationalization, government could not control the public resources resulting in massive deforestation of the nationalized forest. In the late 70's, when the government accepted its inefficiencies in managing the forest, community participation, control and management of the forest was prioritized. A new national forest policy was enforced to give the legal support for community participation in forest management. The policy was implemented in 1978 by handing over the national forests to local communities and also empowering them (Pandey & Paudyall 2015). A master plan for the forestry sector (MPFS) in 1989 and the people's movement of 1990 were the key elements for the formulation of the Forest Act of 1993 and Forest Regulation of 1995. The Forest Policy and Regulation institutionalized the community forest user group (CFUG) as a autonomous bodies for the protection, utilization and conservation of the forests.

The local communities were legitimised as self-dependent and self-governing forest institutions. The act made provision to hand over any accessible part of the national forest to the community for the period of 5-10 years, whenever they were willing to manage by preparing forest management operational plan themselves.

Background in Mexico

As a Biodiversity richness country, Mexico is between the five countries called “megadiverse”, next to Brazil, Colombia, China and Indonesia. Mexico represents 12% of the earth´s diversity (CONABIO, 2008b), its location and relief, its climates and its evolutionary history have resulted in the great wealth of ecosystems, ranking eleventh in diversity of birds, fifth in vascular flora and amphibians, third in mammals and second in reptiles (CONABIO, 2016).

During its history, Mexico as an independent country, has confronted many changes, one of the most important in forest management, was the sharing out of lands to settlers under the war of the Mexican Revolution that promised to give, "Tierra a quienes la trabajan” – Lands to whom works (Trujillo Bautista, 2009).The Forest Management did however not start as participative and as Community Forestry, using and improving the landscape or thinking about sustainable forestry development. The main aim was the economic profitability, to obtain major possible advantages without using a forestry technique. The unique requirement was to obtain bigger and healthier trees. But the land owners were not taken under consideration in decisions, only land workers of private enterprises from the USA were considered (Vargas Larreta, 2013). The consolidation of Ejidos as a consequence of the Mexican Revolution of 1910, represents the rural triumph, according to Trujillo Bautista, (2009) for settlers, who thereby became land owners. But it was not until 1970, that the use of many silvicultural treatments was started and became the main aim of what is nowadays known as sustainable forest management. Under this scheme in 1990 the System of Conservation and Silvicultural Development was established, it can be applied to conditions of regular or irregular forest, and, as fundamental basis of Forest Management it established a series of reforms to the Forestry Law (FAO, 2004).

In Mexico, the community forest is defined as the cultivated forest, including the participation of the owners who benefit from it. , Conceptually, the forest exists in a common used territory in the hands of a community (CONAFOR, 2015), community forestry includes natural, environmental and human resources, its purpose is to establish shared interests between owners (Luján Álvarez et al., 2016), forest management has been considered since some decades, as a decision-making process, focused on economic, social and ecological factors, mainly oriented on the harvest, in accordance with the ecosystem’s production capacity (Aguirre-Calderón, 2015), community forestry promotes organization and social participation, with the purpose that Ejidos and communities establish sustainable management practices for ecosystem goods and services that contribute to improving their life quality.

2.1 Development phase of Community Forestry

Nepal

In the first decade of establishing the community forestry, environmental protection of the mountainous region was the main concern, primarily to stop the deforestation of the mountainous forests. For four decades through the enactment of specific policies, community forest management succeeded in the forest protection of the mountainous areas.

In the last decade, livelihood improvement, good governance, social inclusion and private sector involvement were the main concerns of community forestry. Currently, new agendas like climate change adaptation, ecosystem services, REDD+, etc. are being addressed at different levels. These adaptation processes show how community forestry is adopting to different paradigm shifts. The whole concept started with the fulfilment of daily firewood and timber products supplies for the local people and later came to include community development, livelihood improvement, climate change adaptation, ecosystem services and biodiversity conservation. This is a classic example of bottom-up forest management, originating from a concept of need-based local forest management practices and extending to global sustainable and conservative approach of forest management.

Mexico

Approximately 80% of the forest cover and rain forest are property of Ejidos and Communities (CONAFOR, 2015). According to the census of Ejidos ran by INEGI (Instituto Nacional de Estadística y Geografía –National Institute of Statistic and Geography) of 196.4 million hectares that belong to the Mexican territory, 105,948,306.16 hectares are distributed in 31,514 Ejidos and Communities. Out of the total of Ejidos and Communities 3,014 Ejidos use their land for forest community activity. (INEGI, 2009).

To strengthen the forest development CONAFOR was created in 2001 and its operations are based in highlight the social participation.

Under the development strategies to achieve a sustainable forest management, priority is given to the strengthening of community forestry. The Community Forest Enterprise strategy (CFE) was established as an essential tool for forest resources management and social capital formation (CONAFOR, 2015). One of the key elements in CFE’s development has been a rich endowment of social capital, based mainly on social capital relation and traditional social institution (Bray & Merino-Pérez, 2002).

The CONAFOR has generated diverse programs designed to promote community forestry. One of the most important ones is the PROCYMAF, (Programa de Desarrollo Forestal Comunitario –Community Forestry Development Program), which considers fundamental aspects:

1. Support different population groups, mainly indigenous groups.

2. Promote leadership for institutional sector development.

Thereby the Community Forestry Development programs are destined to strengthen the community institutions though social and human capital consolidation and by developing their management skills to maximize the benefits that can be derived from natural resources management (CONAFOR, 2009).

2.2 Institutional development and Good governance

Nepal Government in Community Forestry

There are three levels of institutional arrangement for community forest implementation in Nepal. At the national level is the Ministry of Forest and Soil Conservation, consisting of the Department of Forests, the Community Forestry Division, the Regional Forest Directorate & the Federation of Community Forest User Groups. The district level includes the District Forest Office and the District Level Federation of Community forest User groups. The lowest level, is the Range Post level consist of the Range Post Office and Community Forest User Groups (Dahal, G. R., & Chapagain, A. 2008).

Mexico Government in Community Forestry

The Forestry legislation is an indirect factor of big importance to understanding forest management. In Mexico the forest sector regulation depends basically of national legislation. Since its beginnings, the legislation was designed and modified with the main objective of making the regulation of forest management more effective, in accordance with advances in scientific research.

This way the LGDFS (Ley General de Desarrollo Forestal Sustentable - General law on sustainable forest development), as the most important forestry regulation in the country established its main objective to regulate and promote the conservation, protection, restoration, production, harvest, management and use of the country's forest ecosystems, the main purpose being the promotion of sustainable forest development (LGDFS, 2016).

Another important law in Mexico, is the LGEEPA (Ley General de Equilibrio Ecológico y Protección al Ambiente –General Law of Ecological Balance and Protection to the Environment) which is based mainly on the public order and social interest, which refers to the preservation and restoration of the ecological balance, and establishes the basis to guarantee the right of everyone to live in a healthy environment (LGEEPA, 2016).

2.3 Lessons

Lessons from Nepal

A total of 1.8 million hectares of forested land (30 percent of the total land area) has so far been handed over to 18,960 CFUGs which constitute about 2.4 million households, representing about 44.08 % of the total households of Nepal (MFSC,2016).

Community forests are more frequent in hilly regions which constitute about 65% of the total land handed over CFUGs. The average household community forest area is 0.76 hectare (Oli et al,2014).

Overall forest improvement has been shown in 86 % of community forest users groups (MPFS 2011). Degraded hills have been successfully rehabilitated. The reason behind this includes regular monitoring of community forests by users, controlling forest fire, management of open grazing and control of illegal felling. The growing stock, forest cover and biodiversity have increased more in community forest than in the national forest. Various studies have shown the positive impact of community forestry in biodiversity conservation (Dangi 2009).

The network of community forests has been contributing to the conservation of flagship species such as the tiger, rhinoceros, elephant and red panda. The community forests in the Terai arc landscape have been restored in 5 years and have been working as an important wildlife corridor. Similarly, the incident of human-commons-leopard conflict in the mid hills has been increasing which also shows that there is increment in forest resources (Oli *et al*, 2014).

Community forestry has been providing support for the development of education, health, transportation and other physical structures of the community. The Community Forest Development Guideline 2009 has made the provision of spending 40% of the total income from the forests in community development. MFSC 2011 reported the expenditure of 40% on education, 28% on health, 17% on poverty reduction and 16% on road and infrastructure projects. In this way community forestry is helping local development and skills development due to the provision of utilizing money for the community.

Community forestry is mainstreaming local institutions and governance at the local level. The networking in community forestry is helping local people to develop their social capital. Equity, participation, inclusion, responsibility, accountability are basic social responsibilities which are improving at local level. A study of the community forestry programme in 50% of the CFUGs in the last three decades shows that 47 % of CFUG actively participated in social auditing and that there was a decrease in social discrimination (MFSC, 2011).

Community forestry is developing local leadership for the people. The provision of 50 % of women in the executive committees of community forestry in the 2016 guideline is promoting women’s leadership. Community forestry is also a platform for the development of a political career. More than 200,000 people are in leading positions of forest management in community forests out of which 60,000 are women (MFSC, 2016).

Lessons from Mexico

The community forestry in Mexico is based mainly on the development of the CFE´s, which allow the landowners to work and take advantage of the natural resources that belong to them. A CFE belongs to a Community or Ejido and works through elected members by assemblies. The elected members could stay in office during one, two or more years, the Ejido or Community will determinate the time. The CFE must own forest lands and must be authorized to extract (Bray et al., 2003). Like any established company, a CFE must at least meet the following requirements: have a good organization of people working in the forest and lead an orderly and transparent administration and accounting of the money obtained from the sale of forest products, and together with the CONAFOR, reach a Sustainable Community Forestry.

2.4 Challenges and Way forward

Nepal challenges and way forward

Community forestry has been confronted with various issues and challenges from its inception but improved to present day condition by overcoming these issues and challenges. Planting the degraded hilly areas was the challenge in the initial days where involvement of the community forest users group was crucial.

Community forestry programs have started to define inclusiveness, promote livelihoods, install benefit sharing mechanism, and encourage good forest management but they were not able to reach the expectations. Various programs and project have been implemented to address these issues (Kandel, 2004).

In due course of time, issues and challenges of community forestry are changing. Mitigating human wildlife conflict, ignorance of environmental aspect while doing development work, improving social inclusion and the participation of women in decision making, encroachment on community forest and good governance in community forestry are the current issues to be addressed in community forest. To overcome these issues various strategic development has been carried out such as the development of the Gender and Social inclusion strategy 2008, the national biodiversity strategy and action plan 2014, the forest encroachment control strategy 2002, Wildlife Damage Relief guidelines 2012 and the revised Community Forestry Development Guideline 2016(Oli *et al*, 2014).

Mexico challenges and way forward

The biological capital development of forests as a source of variety of products and services, as well as recreation and educational opportunities, are equal or more important than the resource of wood, for this reason establishing strategies of management of the resources, taking into account the present value of the forest in the conservation of biodiversity and provision of ecosystem services should be the focal point in sustainable forest development (Aguirre-Calderón, 2015).

After the sixteenth session of conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC), held in Cancun in 2010, Mexico started the national strategy of REED+ (Reducing Emissions from Deforestation and Forest Degradation Plus) known as ENAREDD+, in which the main achievements are the 30% reduction of the country’s emissions towards 2020 (Pukkala & Gadow, 2012). This national Strategy, will be the basis for the recovery of forestry areas, together with community forestry, which has allowed to maintain the forest resources in good condition, (Chapela, 2012). Together, these two essential elements will lead to a sustainable use of the great biodiversity that the country harbours.

Mexico has recognized the importance of sustainable natural resources management through conservation, management and ecosystem restoration thereby promote better opportunities, emphasizing the climate change challenges (CONAFOR, 2014).

3 Comparison between Nepal and Mexico

Community forestry in Nepal and Mexico are renowned in the world for their successes of protecting forest as well as sustaining the rural communities who are involved in its management because of the user-rights which are handed over to communities. Mexico which has approximately 80% of forest cover and rain forest that are property of Ejidos and communities has shown a better increase of forest coverage since the 1970´s where the silviculture techniques helped landowners to achieve proper management of natural resources. Similarly in Nepal forest cover increased after the concept of community forestry emerged in late 1970’s which is now considered as a global innovation in community forestry.

The Mexican community forestry is based on CFE´s and the government who helps them develop the community. Comercial harvesting was established in forest management plans to use the natural resources in an apropiate way and to achive community development. In contrast in Nepal where the need of CFUGs is for fodder, timber and fuel wood and commercial harvesting is minimal and is controlled through approved management plans a share of the total income of community forests are spent on community development and pro poor activities.

In Nepal communities have rights for protection, conservation and utilization of forests resources but the land tenure is with government, whereas in Mexico the law recognizes land ownership by the communities.

CFUG are the main decision making bodies in Nepalese community forests, which decide how community forests should be managed and how executive members should be punished as per the approved forest operational plan, whereas in the Mexican general assembly of Ejidos is the main decision making body, with an assistant in forest extraction activities who is called forest technical service provider, but the general assembly is who take the last decision.

In Nepal, The CFUG´s must prepare the Forest Management Operational plan for the period of 5 to 10 years and submit it to the district forest office for its approval before carrying out forest management activities, and similarly in Mexico with European influence, the forest management plan is made for a period of 10 years by the technical service provider who helps the Ejidos in decision making.

4 Conclusion

Community Forestry in Nepal and Mexico are the result of long support and legal backing of legislation that has been transformed in due course of time according to the changing context. Community Forestry in both countries is governed at local level in the form of Community Forest Users Groups, Ejidos and communities. The basic feature of community forestry in both countries is that the income from the use of resources are spent on the development of communities and for the people living there, community forestry in Mexico is more commercialized and seeks sustainability regarding the use of resources and helps community groups to be more entrepreneurially sustainable, community forestry in Nepal is more focused on fulfilling the basic needs of fodder, timber and fuel wood and improving socio economic issues such as governance, livelihoods and sustainable forest management rather than commercialization, but the introduction of scientific forest management of the community forest could be the stepping stone for commercialization.

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Recognizing the ancestral land and biodiversity conservation efforts of indigenous people in Quinchao municipality using GIS- and a participatory 3D-mapping tool

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Abstract

The Chiloé archipelago is located in the south of Chile, in the tenth region called "Los Lagos", and forms the province of Chiloé. It is characterized as isolated community due to its distance from the main land. Thus, less attention from external entities is being given and the community is often left behind during the planning process pertaining to its own land. Because of this, few local economic activities allow the inhabitants to generate work. Therefore, as means of livelihood, the native forests are being replaced by agricultural land-use or forestry plantations with exotic species. One possible way to help the community is combining arts, which local people can easily understand; and science, which experts and other external entities can offer, in order to solve the issues of isolation, lack of recognition and respect in Quinchao Island. One such combination is the application of a participatory 3-dimensional and GIS-generated map. The main interests in employing this participatory technique is to encourage participation of all stakeholders in the planning process; to create shared vantage points and offer a common visual vocabulary among stakeholders; and to facilitate peaceful negotiations for bridging communication barriers. Obviously, this tool enables the government sector and other stakeholders to understand the current situation of local communities. Hence, these tools have high potential to help Quinchao Island, especially its indigenous communities,

Key words: participatory 3-D mapping, GIS, managing protected area, native forest management, indigenous communities

1 Introduction

Since ancient times, the forest has provided Chilean indigenous communities with many benefits such as construction material, food, medicinal products or burning material. However in the last century these communities have faced many challenges causing a loss of their ancestral relationship with the forest. One of the most important issues in Chile resulting from the problem mentioned above has been the loss of forested areas in this region. The main causes of this can attributed to two factors. Firstly, human activities have provoked the deforestation, erosion and over exploitation of the soil and secondly, there has been little government involvement aimed at strengthening the relationship between indigenous people and their forest (Smith, 1998). As a result of this, the communities are often encroached upon or threatened by external users, or even by community members under increased economic pressure (GIZ, 2012). In this line, a study conducted by J.J. Armesto et al. (2010) revealed that, "the distribution of Chilean temperate forests has been greatly disrupted by human activities, mainly through logging, land clearing for agriculture, and replacement of native forests by extensive commercial plantations of exotic trees." The Pehuenche and Huilliche are examples of indigenous communities who have close connection with the forest in south-central Chile but have been forced to leave the land. They were transferred to land with low productivity which resulted in even more problems. At the same time their ancestral lands were reassigned to private or industrial landowners where the native tree species were replaced by exotic ones for timber and pulp production. The results of these transfers of land were conflicts between indigenous people and risks to the conservation of highly biologically valuable species.

J.J. Armesto, et al. (2010) proposed that, "solutions to the conflicts between conservation goals and indigenous communities can be found in the combination of community-based initiatives and government incentives approaches to land management." Another recommendation is promoting a participatory approach to ensure the harmonization of ideas of indigenous people with those of existing government policies which is supported by the study of International Fund for Agricultural Development (2009). Recently, the most commonly used approach is so-called participatory 3D-mapping and GIS-mapping. They are believed to be effective tools to help indigenous communities to document their customary territories, institutions, and customary laws and ensure that indigenous peoples approve the related processes. Making and displaying a 3D model allows for interpersonal communication that facilitates learning and negotiation. To use the model as a channel for interaction, insiders and outsiders have to physically gather around it (Rambaldi, 2010). Meanwhile, all the information displayed on 3D maps has to be portable by integrating the 3D map data with a GIS-software which makes it possible to be reproduced and shared with other stakeholders.

Several initiatives that promote participatory planning were cited in the paper review of International Fund for Agricultural Development (2009). There are case studies from Lassen, B., et. al. (2012) related to recognizing the rights of indigenous people are the project by German Development Cooperation (GIZ) with Conservation International (CI). This project supports the government of Ecuador in giving rights to Chachi indigenous communities in Esmeraldas for conserving 7, 200 hectares of forest under Conservation Incentive Agreements (Lassen, B., et. al. 2012).

2 Brief description of Quinchao municipality

Quinchao municipality is located in the Chiloé archipelago, in the southern sector of Chile (between latitudes 41°45'S and 43°30'S) almost 1.000 kilometers from Santiago de Chile, the capital of the country. This archipelago is located in the tenth region called “Los Lagos” and the province of Chiloé, one of the 4 provinces of the region. The archipelago is composed of a main island, the “isla grande” of Chiloé which represent 90% of the archipelago and a series of smaller islands (Uribe & Castillo, 1969). Figure 1 shows the province’s location.

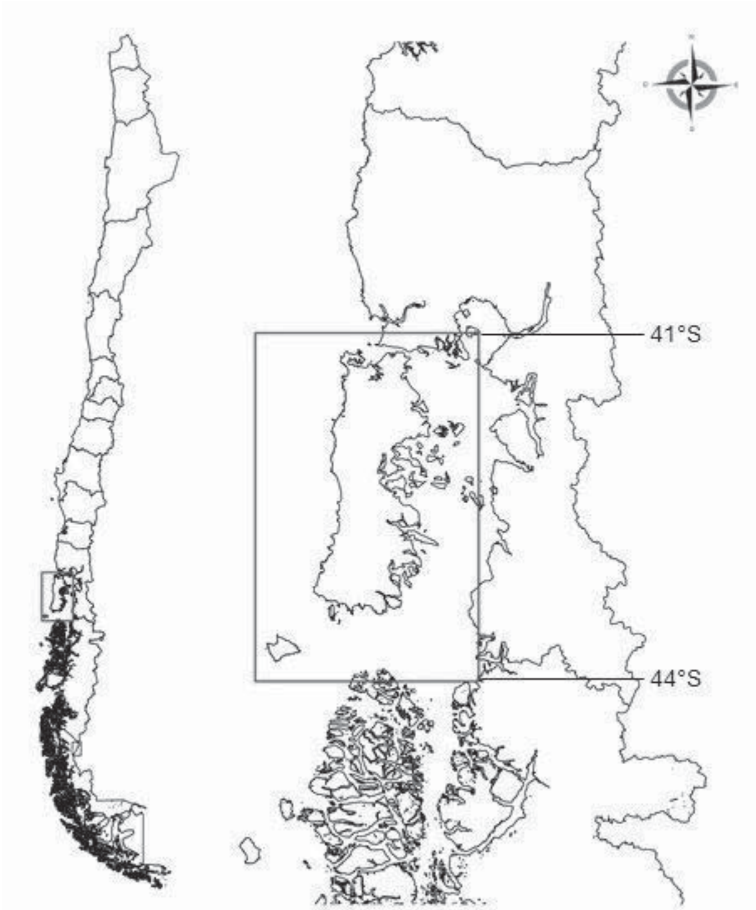

Figure 1. Chile extension and Chiloé island location (source: prepared by the authors).

The territory is characterized by insularity because of its distance from the continent. While this particularity allows the development and preservation of one's own culture, is also synonym to isolation (Arenas et al., 1999). In Chile, according to Arenas et al. (1999) “within the public policies, there is a lack of management instruments and development programs that can capture the territorial disparities that are adapted to the physical, social and economic characteristics of the territories defined under some common trait such as isolated territories”. It therefore appears necessary to introduce instruments for territorial organization.

In the Chiloé archipelago, the economic activities in all the 10 municipalities are principally associated with the primary sector as shown in Table 1. The data can partly explain that the native forest is gradually being reduced for the profit of agricultural land-use or forestry plantations with exotic species. Since 1974, the forested resources in Chiloé have changed and evolved (Troncoso & Torres, 1974).The ultimate appraisal presented that more than 10.000 hectares of native forest have been modified to other land-use between 1998 and 2013 (CONAF & UACH, 2014).

Table 1. Chiloé communities by economic activities, poverty rate and incomes. Extracted from Osses et al., 2006.

Province	Municipality	Agricultural Community	% Agricultural	Tourism community	% Tourism	Transport community	% Transport	Fishery community	% Fishery	Impoverish community	% Impoverish year 2001	Incomes year 2000
Chiloé	Castro	753	1.9	365	0.93	816	2.07	1,438	3.65	4,601	1.69	$355,154
	Ancud	1,662	4.16	247	0.62	687	1.72	2,071	5.18	8,537	21.37	$338,759
	Chonchi	525	4.18	62	0.49	209	1.66	693	5.51	1,949	15.5	$269,881
	Curaco de Velez	92	2.7	3	0.09	23	0.68	248	7.29	153	4.51	$351,617
	Dalcahue	526	4.92	50	0.47	154	1.44	776	7.26	731	6.84	$334,968
	Puqueldón	81	1.95	13	0.31	40	0.96	376	9.04	0	-	-
	Queilen	209	4.07	13	0.25	34	0.66	441	8.58	0	-	-
	Quellón	404	1.85	182	0.83	337	1.54	2,708	12.41	0	-	-
	Quemchi	416	4.79	11	0.13	48	0.55	777	8.94	1,500	17.26	$282,355
	Quinchao	318	3.54	26	0.29	43	0.48	603	6.72	985	10.97	$365,610

In this provincial context, this article will analyze Quinchao (Figure 2), one of the most isolated municipalities of the archipelago. As the classification by Arenas et al. (1999) shows, this territory is qualified as the one with the third most critical isolation of Chiloé province, or the twentieth of Chile (Table 2). Due to this isolation in Quinchao the problems associated with Chiloé's insularity are further amplified.

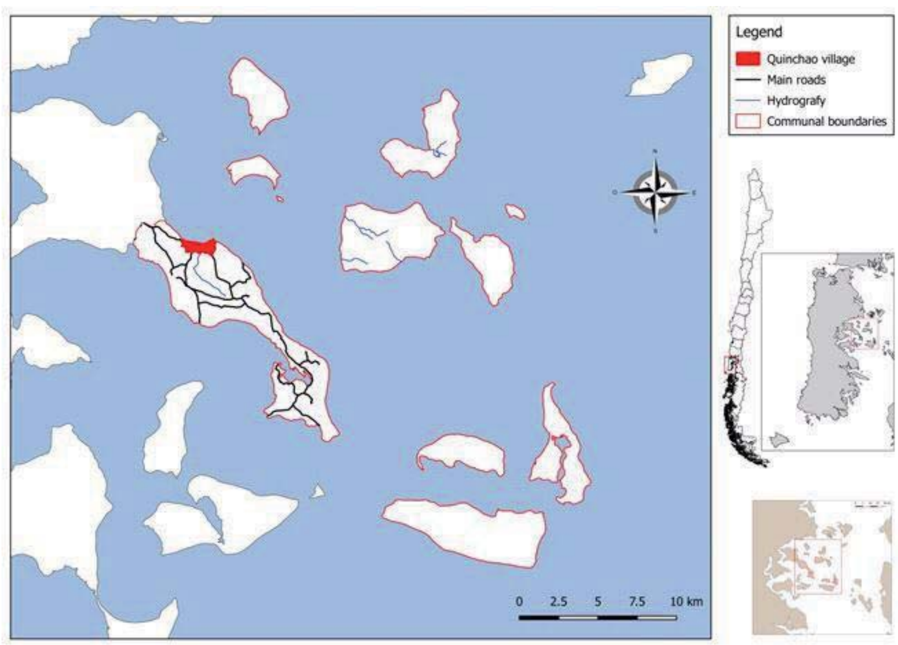

Figure 2. Quinchao municipality location (source: prepared by the authors).

Table 2. Municipalities with crucial isolation. Rating, Municipalities, Scores of isolation, Region. Extract of Arenas et al., 1999.

No.	Comunas con aislamiento critico		
	Comunas	Puntaje	Region
1	Guaitecas	7.4	XI
2	Tortel	7.3	XI
3	O'Higgins	6.7	XI
4	General Lagos	6.7	I
5	Futaleufu	6.5	X
6	Timaukel	6.4	XII
7	Palena	6.4	X
8	Curaco de Velez	6.3	X
9	Juan Fernandez	6.3	V
10	Colchane	6.3	I
11	Navarino	6.2	XII
12	Rio Ibanez	6.2	XI
13	Lonquimay	6.2	IX
14	Curarrehue	6.2	IX
15	Putre	6.2	I
16	Lago Verde	6.0	XI
17	Queilen	6.0	X
18	Hualaihue	6.0	X
19	Isla de Pascua	6.0	V
20	Quinchao	5.9	X
21	Puqueldon	5.9	X
22	Cochamo	5.8	X
23	Chaiten	5.8	X
24	Ollague	5.8	II
25	Alto del Carmen	5.6	III

3 Relevance of integrating Indigenous People of Quinchao Island in national conservation policies

In the most recent official census, in 2002, Quinchao registered 8.932 inhabitants in which 1.576 pronounced themselves as belonging to an ethnic group (in 99,4 % Mapuches). In the municipality, 17.6 % of the population considers themselves as indigenous peoples. Another important element is that in this territory, few local economic activities allow the inhabitants to generate work. These facts, associated with the rural character of the island, connected with rare public or private investment in the municipality territory, hardly allows for the Quinchao's inhabitants to project themselves into the future. So, in order to ameliorate the quality of life of the people, and specifically of the indigenous communities, one of the solutions is to, as Arenas et al. (1999) explain, "improve the low attractiveness of isolated communities which corresponds to one of the responsibilities of the State". If the Chilean government creates a natural conservation area as a means to make the territory more attractive, it may resolve partially the issues previously described.

Smith, (1998) mention that “the inhabitants of [indigenous] communities have many large areas of native forests, which extract a wide variety of products that maintain their subsistence economy”. Taking into account the previous point, the natural conservation area needs to integrate different approaches; one of them would be using the product of the native forest without leaving aside the significant value that the natural environment has for the community. Another important point is the necessity of respecting the traditional culture of indigenous communities, in a way that they can have free access to the forest in order to develop sustainable activities in this area (Smith, 1998). Integrating and involving the indigenous community during the whole process of creating conservation areas will permit to improve the government's relations with indigenous communities.

Nowadays there are various types of protected areas in Chile: National Park, National Reserve, National Monument, Natural Sanctuary, Marine Park, Marine Reserve, Marine Coastal Protected Area. According to Sierralta L. et al. (2011), these areas represented 30.209.408 hectares. It is essential to value Chilean territory because as Ormazabal, (1993) said “the isolation of some parts of the Chilean territory due to glaciers and marine channels in the south, and the Pacific Ocean in the west, have caused the country to develop many biological aspects characteristic of an island, wherein many of the terrestrial species and ecosystems are unique to the country”. It appears important as well to consider the population living within. The purpose and advantage of managing natural areas in which communities reside can help to reduce the “threats to natural terrestrial ecosystems in Chile such as forest fires, mining, fuelwood collection in dry lands, pollution, logging, and land use changes” (Ormazabal, 1993).

There are already studies that set an example for the application of the suggested tool in Quinchao Island. Ecuador has already applied it with the Chachi indigenous communities (Scherl & Edward, 2007). As Oltremari & Guerrero, (2003) mentioned, “the local population can be regard as an associate in the protection of biological diversity, and in turn, the communities acknowledge the officials who manage the areas as partners in the search for sustainable development options”.

To help the community of Quinchao, especially indigenous people, to be respected and minimize the issues and concerns of their locality; as well as to recognize their effort in maintaining the remaining native forest in the area, we therefore propose that one of the most interesting techniques would be to apply a creative tool called participatory 3D-mapping and GIS mapping technique.

4 Participatory 3D-mapping (P3DM)

The participatory 3D-mapping is the construction of a physical 3D model created jointly by a large group consisting of different stakeholders, especially people who have deep knowledge of the locality (Figure 3). Rambaldi (2010) mentioned that "P3DM can support collaborative natural resource management initiatives and facilitate the establishment of a peer-to-peer dialogue among local stakeholders and external institutions and agencies." The P3DM approach also enables everyone to appreciate and understand their biophysical environments, territories and provides stakeholders with a powerful tool for land-use management and serves as an effective community-organizing tool.

According to Rambaldi, G. (2010), "the P3DM process helps reclaim lost memories about the traditional ways of living. It facilitates intergenerational knowledge exchange and raises awareness across generations about the status of the environment" This tool is even more useful for people who cannot read and write and to those who cannot understand scientific methodologies.

Figure 3. Participatory 3D mapping in Samar, Philippines. (Photo credits: Gaillard, J.C., 2013).

Further, the 3D map is easier for the local people to understand because they are the one who created the map. Introducing high technology resources can be hard for the local people to understand, most especially for indigenous people. In spite of the many benefits of this tool, there are also limitations for this activity. The process requires large space; location and extent of the elements are based only on knowledge of the participants; the availability of all involved stakeholders cannot be guaranteed; and the final map needs a secured place for storage.

To start the process of making the P3DM, gaining trust with the community is considered the most important element. The participation of the community depends on how the facilitator establishes the relationship with them. It is also important to ensure the good relationship between communities and other stakeholders in order to facilitate peaceful negotiations. Partnership with organizations that already have good relationship with the community can foster this process.

The identification of participants should be carefully assessed to identify individuals that have influence in the area. The facilitator must ensure the relationship between each stakeholder and the communities to avoid their hesitation to participate in the process. Identifying the past issues and conflicts in Quinchao is significant to getting an idea of an appropriate facilitation process and to establish the criteria for the information to be included in the map. There are several participatory methodologies that can be used to gather information from the local people such as key-informant interviews and focus group discussions. Often, the kinds of criteria that were included in many P3DM initiatives according to Gaillard (2010) are physical (e.g. topography, watershed, sub-watershed, location of infrastructure, roads); administrative (e.g. buffer zones); environmental (e.g. ecosystems, habitats); cultural (e.g. ethnicity, ancestral rights, values, customary tenure); socio-economic (e.g. settlements with associated resource-use areas, harvesting or grazing areas); and territorial (e.g. conflicts, disputes, causes and effects). Stakeholders should be the ones to identify the areas on the topographic map using a combination of these criteria. The ancestral lands are being included on the map, thus enabling the area of the indigenous people to be recognized. The status of the native forest that indigenous people are protecting can also see from the map so that their contribution to nature protection is also acknowledged.

In addition, it is important to secure all the materials needed. This process is very cheap because it only uses local materials such as the following (Gaillard, J.C., 2013):

a. Local people, their knowledge and skills;
b. A venue to conduct mapping activities and store the map;
c. A strong table made of local materials;
d. A base (topographic) map;
e. Mapping materials, e.g. carton/Styrofoam/cork, paint, yarns, pushpins, glue, nails or local equivalents; and
f. Training materials, e.g. markers, flip charts, masking tape, and scissors.

The size of the map and scale depends on the provided topographical map (Figure 4). Based on Gaillard (2013), the scale can be as small as 1:1000, as long as the necessary information can still be depicted without congesting the pushpins, yarns and paints in the 3D map. However, a large area would also mean a large size of the actual 3D map. For the thickness, a recommendation of 1 cm per 10 meters contour interval is suggested.

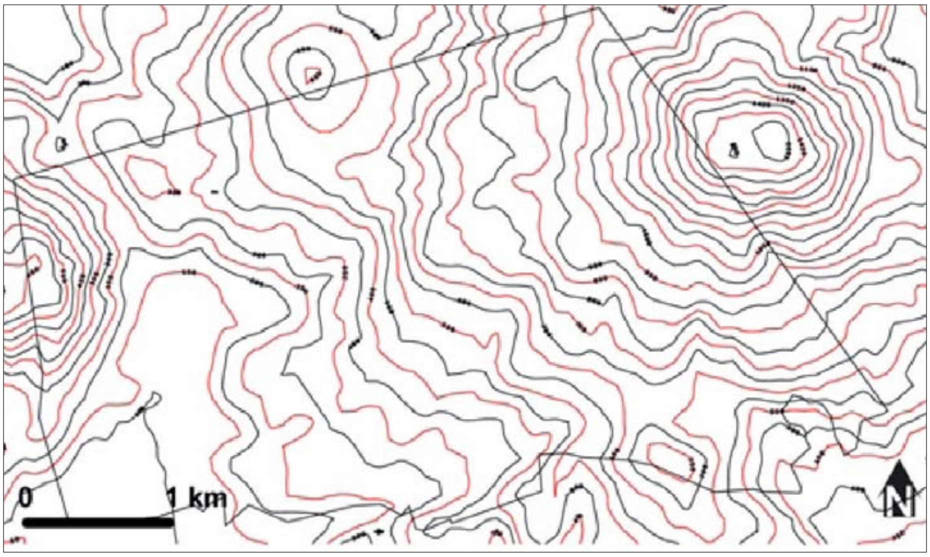

Figure 4. Sample base map with the basic elements required such as contours, scale and orientation by Gaillard, J.C. (2013).

The process is composed of the following steps (Rambaldi, G., 2010):

a. Construct a base table with exactly the size of the base map.
b. Glue one base map on the table.
c. Stick the second base map on a carton board with carbon paper in between using clip, staple wire or adhesive tape.
d. Using a pencil, trace the first contour line with solid line then broken line for the second contour line starting from the lowest elevation in one corner (reference corner).
e. Cut out the layer using scissors, cutters or coping saws. Each contour is traced and cut separately.
f. Each contour cut out is pasted on top of the previous layer.
g. It is also desirable to independently assemble the selected portions of the model then join them afterwards. The initial output is the plain or blank 3D model as shown in Figure 5.
h. For labeling and adding information on the map, sort first the colors according to agreed symbollogy.
i. Identify the elements that are agreed to depict in the model. Using color-coded yarns, push pins and paints, start labelling the 3d model.
j. Place grid on the model using yellow yarn starting from the reference corner. Note that for 1:10,000-scale model, 10cm-interval is used, corresponding to 100 hectares.
k. Label the grids using number and letter to symbolize the coordinates. (See Figure 6)
l. Adding additional information from existing cartographic maps is included by georeferencing using the base map.
m. Identifying the coordinates on the base map corresponding on the grids on the 3D model.
n. For finishing touches, the legend is finalized, numerical scale, bar scale, north arrow, acknowledgement plate and date at which the model was last updated are included.

Figure 5. Sample blank 3d model (Photo credits: Rambaldi, G., et.al., 2010)

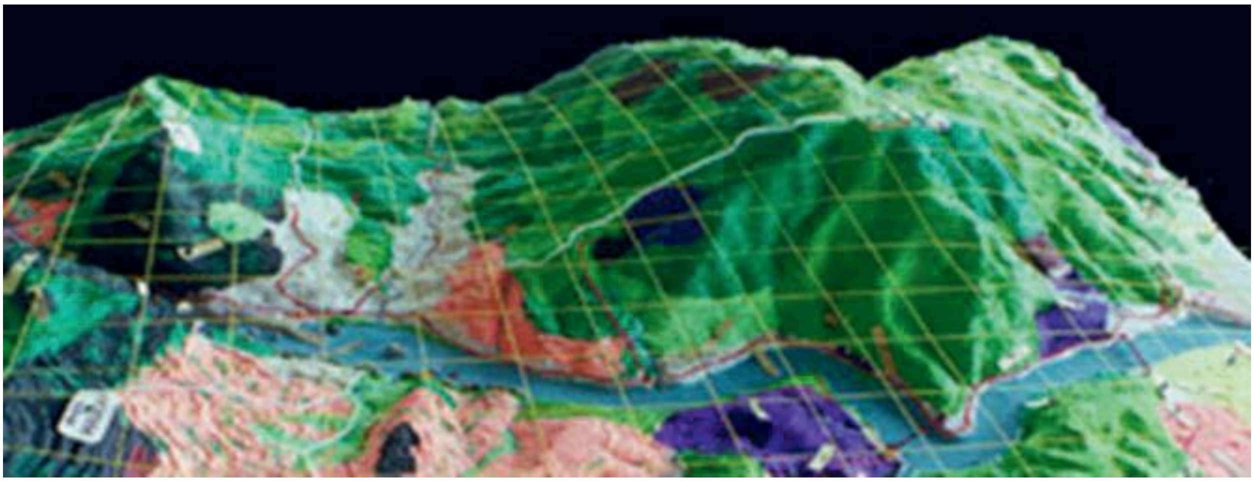

Figure 6. Final 3d map with grid lines using yellow yarn (Photo credits: Rambaldi, G., et.al., 2010)

The processes are discussed in detailed on the manual by Gaillard, J. C., et.al. (2013) entitled, "Participatory 3-Dimensional Mapping for Disaster Risk Reduction: A Field Manual for Practitioners". Usually, the P3DM process alone takes 7 to 10 days depending on the size of the area, but the whole process including the preparatory phase for the community, takes 3 to 6 months. To expedite the process, it is advisable to divide the group by activity. For example, there is group for tracers, cutters, gluers, etc.

5 Participatory mapping using GIS software

The P3DM data is integrated with a GIS-generated map. It is still participatory because it still requires participation of all stakeholders that were present during the creation of the P3DM. The benefits of integrating GIS to achieve our objective in this study are to create a digital map that is easier to distribute and store. However, the method is time consuming and laborious and will require additional training for the use of GIS software. It is flexible only to those who master the technology and the data is stored externally, not with the concerned community.

The process of transferring data from P3DM to GIS software starts with taking photographs of the 3D model. The appropriate way to do this is by tilting the model by 90 degrees, setting up a high resolution camera in a known distance (suggested distance is 4 meters away from a 1:10,000 scale-model), and consecutively capturing images of the model from left to right and top to bottom with 60% overlap. To make sure that you are in a consistent position, the facilitator can use yarn and place it in the floor as guide for the photographer. These processes are shown in Figure 7, 8 and 9, respectively.

All these images will serve as vector data of the 3D model that can be entered in the GIS software. Afterwards, digitizing and georeferencing of the elements in the 3D model will follow as shown in Figure 10.

Figure 7. Taking photographs of the3D model (Photo credits: Rambaldi, G., 2010).

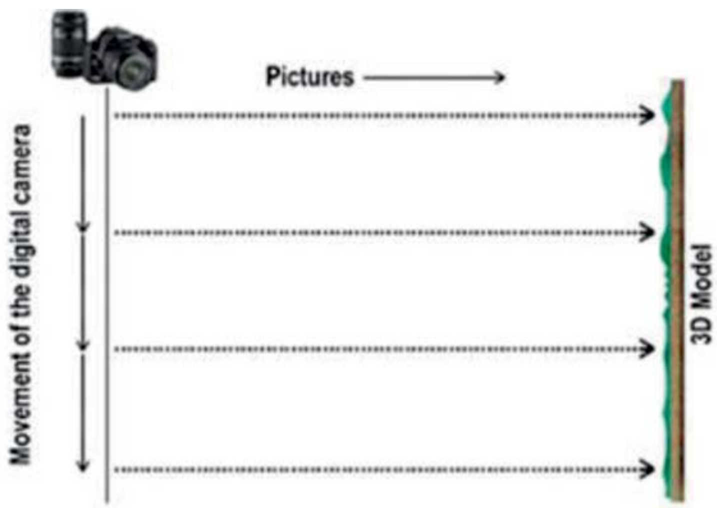

Figure 8. Direction of capturing images of the 3D model (Photo credits: Rambaldi, G., 2010).

Figure 9. Capturing images with 60% overlap as indicated in white dotted line (Photo credits: Rambaldi, G., 2010).

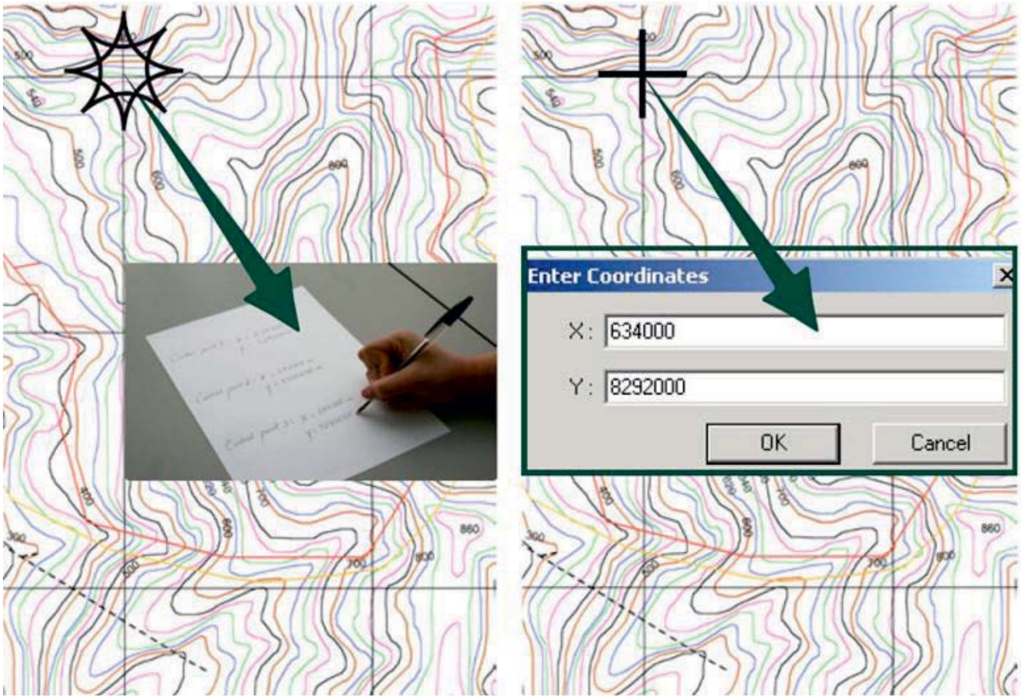

Figure 10. Taking notes of the coordinates of the elements from 3D model using the base map (left) and entering the coordinates in GIS software (right). (Photo credits: Rambaldi, G., 2010).

The output for this is a GIS generated map which can be compared with other existing spatial data or cartographic information, as well as remote sensing images. Integration of other information obtained from official and other sources like administrative and political boundaries can also be included. In case of inconsistencies, the participants will negotiate and try to reconvene around the 3D model. It should also keep in mind that the legend to be used is still based on the agreement of the participants.

6 Conclusions

The P3DM and GIS mapping tools often require skills or creativity. They are created by all stakeholders with influence in the area so everyone is well informed about the content of the models. Everyone contributes, thus, bias is reduced and communication barriers are minimized. The process also encourages negotiation between stakeholders so they can discuss what steps or solution to be chosen. Therefore, there is the possibility to prevent, mediate and resolve local disputes and to strengthen communities in dealing with their management. It might be time consuming than other tools, but it is the easier means for the local community to understand the map and be involved with the decision making process over their land, especially for people who cannot read and write.

Furthermore, a holistic view of the whole conservation area enables the government sector and other stakeholders to understand the current issues of Quinchao Island. It can give the external stakeholders a better perspective of the indigenous communities' territory and their contribution to the resources in Quinchao Island. Hence, these tools can help Quinchao Island, especially indigenous communities, to be recognized, respected and alleviate their problem of isolation in the Chiloé province.

P3DM and GIS-generated maps are also a useful tool for other purposes such as vulnerability and disaster management, forest management planning or forest land use planning, watershed planning and many more.

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Chapter three
Forest inventory and decision support

Effect of timber enumeration and cost accounting errors on forestry profitability and decision making

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Abstract

There is currently a strong focus on emerging forest growers in South Africa. Often these growers lack technical and financial skills to assess the profitability of their operations. Profitability is a product of timber volume, timber price and costs. Errors in timber volume assessment and cost accounting could potentially lead to mistakes being made in assessing profitability. The question remains how these errors will impact on financial decision making. A simulated 10 ha stand of *Pinus patula* was developed and “enumerated” to test the effect of random and systematic sampling techniques on mean height determination as well as the impact of plot sampling on diameter and stocking estimates. The estimated volumes were incorporated into a financial analysis. Results indicated that factors such as volume models used and sampling methods could lead to either the rejection of financial projects or the overestimation of profitability. Errors in volume estimation had a greater effect on financial decision making than errors in cost accounting.

1 Introduction

The South African forestry sector is based on fast growing pine, eucalypt and *Acacia* plantations. It is dominated by pulp and paper and the sawmilling industries which consum about 10 million m^3 and 4.4 million m^3 of timber, respectively, per annum. The sector contributes approximately R 21.4 billion/annum to the national economy and was a net exporter of goods to the value of R 14.9 billion in 2011. The total plantation area is 1 273 357 ha, consisting of 650 880 ha pine softwood and 622 477 ha hardwood (eucalypt and Acacia) (FES, 2012).

The South African government has identified forestry as a high growth potential sector of the economy which could contribute substantially to economic development (DTI, 2009). Forestry and value adding industries such as sawmilling and furniture manufacturing have a place in local development programmes in many rural districts of South Africa (DWAF, 1996). This development focus includes the introduction of new black owned enterprises into the sector (DTI, 2009).

It must however be considered that many of these emerging forestry entrepreneurs do not have formal forest management and operation training. They are also restricted by a lack of information about forestry operations that prevent them from estimating profitability and business sustainability. In short, they might be able to manage forestry operations but lack the business skills, information and funding required for operating successful enterprises (Banks, 2001). There is a risk that a basic lack of skills in forest inventory, enumeration and cost accounting could prevent these entrepreneurs from assessing their enterprise profitability.

Profitability in its simplest form is a function of i) the amount of stock expressed as tree volume/ weight, ii) the price paid for the stock and iii) the costs associated with maintaining and harvesting the timber stock. Forest owners have little control over the external market price of timber but good silvicultural stand management practices can influence timber volume (Theron 2000), proper inventory systems can capture accurate volume estimates (Bredenkamp 2000) and well maintained cost accounting system can help to record, manage and reduce costs (Openshaw 1980). Profitability is therefore not only a function of good tree growing but also of proper management of information.

Unless detailed cost and inventory information is recorded and analysed, forward planning and budgeting does not have a proper basis (Openshaw, (1980). But considering the management skills of new forest owners the question remains how accurately costs and timber volumes should be recorded to ensure proper forest enterprise management? What will be the effect of errors made in inventory and cost accounting on the decisions made by these entrepreneurs? Based on a simulated scenario of a 10 ha stand of pine pulpwood, this study explored the effect of enumeration errors and poor cost accounting on the profitability of the stand.

2 Methodology

The study was based on the “enumeration” of a simulated stand of pine trees where the position, diameter at breast height (DBH) and tree height (HT) of every tree were known (See Van Laar and Akca, (2007) for a description of these parameters). The total stand volume based on the sum of individual volumes estimated for all trees (i.e. a full population inventory) was compared to the inference of stand volume estimated using different sampling techniques/scenarios. This information was used to investigate the impact of volume difference on the Internal Rate of Return (IRR) of this 15 year pulpwood rotation stand.

2.1 Construction of a model compartment

The R system for statistical computing (R Core team, 2015) was used to generate a “simulated forest” with 11 000 data points (or “trees”), each with an X- and Y-coordinate, a DBH and a HT. This represented a 10 ha stand of *Pinus patula* trees planted at spacing of 3 x 3 m (1 100 stems per hectare). Data points were randomly removed to represent a final stand density of

418.9 stems per hectare (SPHA) at age 15 as illustrated by figure 1. The method followed to generate DBH and HT for each tree is presented in Appendix 1.

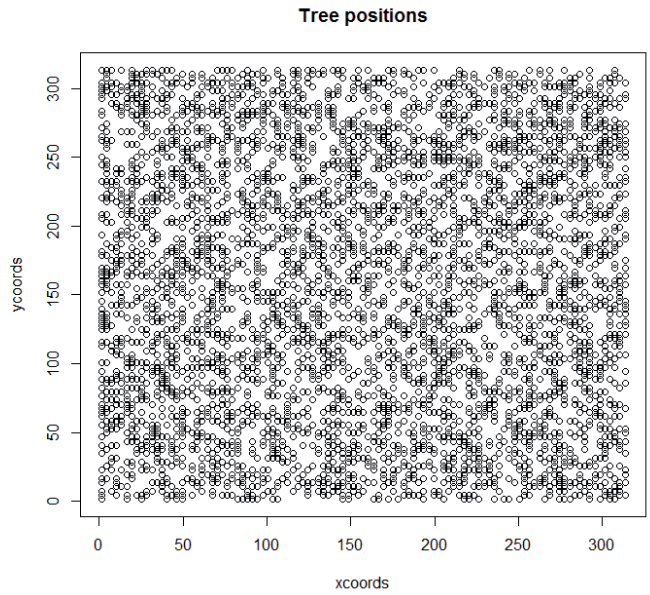

Figure 1. Position of data points representing live trees at age 15 (38% survival rate).

2.2 Plot sampling of simulated compartment

Forest managers rely on sampling procedures to estimate stand volume and associated quantitative information rather than on full inventories (Van Laar and Akca, 2007; Howard, 2012). A 3 x 3 sample grid was overlaid on the stand to give nine sample plots of 500 m^2 each for a sample percentage of 4.5% (figure 2).

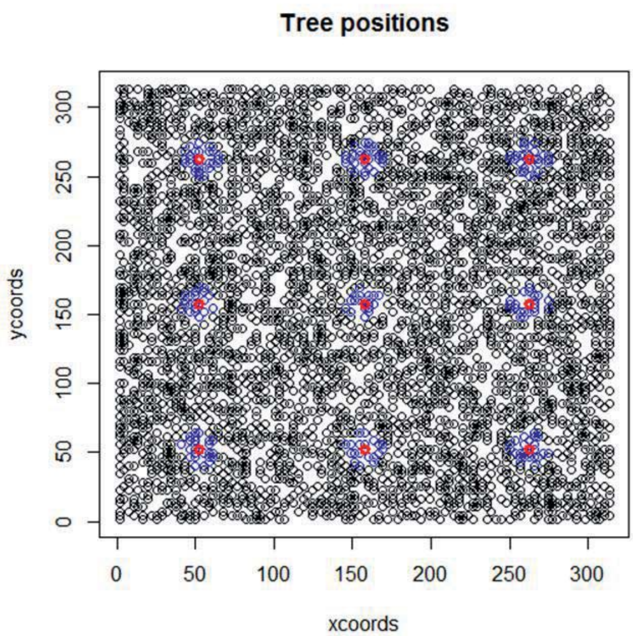

Figure 2. Trees included in sample plots.

According to Howard (2012) the measurement of 25 to 30 DBH/HT pairs per compartment is adequate to determine the relationship between DBH and HT of the trees in the whole compartment. From the sample plot data, random samples of 30 trees were therefore selected as 30 DBH/ HT pairs for the estimation of mean tree heights (mHT). A total of 31 repetitions (of simulated plot samples) were made to assess the sampling error (observed - predicted %) for the full DBH sample (with all heights) and the DBH/ HT samples. Finally, three sets of 30 DBH/HT pair samples were drawn from the nine sample plots for inclusion in the volume prediction exercise.

2.3 Full stand individual tree volume estimates

The total volume of the 10 ha compartment was estimated from the sum of the individual tree volumes. The individual volumes were calculated by means of the Max and Burkhart (MB) individual tree volume function as described in Kotze (2010) with coefficients for *Pinus patula* developed by Kotze (1996).

Segmented polynomial functions such as MB have been shown to describe stem form well, but have the disadvantage of being relatively complex to use (Bredenkamp, 2012). The equation most frequently used in standing volume determination in South Africa is the Schumacher and Hall (SH) function (Bredenkamp, 2012). This function was also used to estimate the individual tree volumes and resulting total volume of the compartment for *Pinus patula*. In addition, total compartment volume was estimated by means of the SH function with coefficients for *P. elliottii*, *P. taeda*, *P. radiata* and *P. pinaster* (Bredenkamp, 2012). The objective was to compare the total volume estimations between the different species

The total compartment volume estimated from individual tree volumes by means of the SH function for *P. patula* was taken as the benchmark volume (hereafter referred to as the *benchmark volume*). Deviations from this volume were calculated for the other functions.

2.4 Sampling volume estimates

A sampling estimation of stand volume/weight involves the prediction of individual tree (merchantable) volumes/weights and the summation of these quantities to obtain a per hectare stand volume/weight (Clutter et al., 1983). The underlying principle of sampling methods is to accurately estimate stem content which is a function of diameter, some measure of height and an expression of tree form (Clutter et al., 1983) and number of stems per hectare (Bredenkamp, 2000).

Enumeration analysis according to Bredenkamp (2000) calls for the estimation of quadratic DBH (DBHq) and SPHA from an analysis of sample plot data and the estimation of mean HT (mHT) from a regression analysis ($\ln Ht = bo + b1DBHq^{-1}$) of at least 30 DBH/ HT pairs. The volume estimates of various methods of sampling were tested against the *benchmark volume*.

The first analysis was done by using the DBHq and SPHA estimated from all the trees in the stand (estimated at 27.26 cm and 418.9 SPHA respectively) and mHT calculated from the regression analysis of DBH/HT pairs obtained by means of different sampling methods to calculate stand volume. This include a mHT estimation based on a DBH/HT regression of all trees in the stand, different systematic sampling method to draw a sample of at least 30 trees from all the trees in the stand and three random sample methods where 30 DBH/HT pairs were selected from trees in the sample plots (table 1).

Table 1. Different sampling methods to select DBH/HT pairs for mean HT regression analysis and volume calculations

Method	DBH/HT pair sample size	Remark
All-Pat-mHT	4189	Used all tree data from stand in DBH/ HT regression
Sys-DBH138-mHT	30	Sorted all trees on DBH and selected every 138th tree for DBH/ HT regression
Sys-HT138-mHT	30	Sorted all trees on HT and selected every 138th tree for DBH/ HT regression
2STDV-HT-mHT	3990	Sorted all trees on HT, estimated mean HT and Standard Deviation. Exclude all trees outside 2 standard deviations from mean in DBH/ HT regression
Median-mHT	32	Use all tree data and selected the median HT value for every DBH cm class for DBH/ HT regression
3-tree-mHT	3	Use all tree data and selected the smallest and largest DBH trees as well as the tree closest to average from these two. Use average HT from three trees. No regression analysis.
Sample-1-mHT	30	Randomly select 30 DBH/ HT pairs from plot sample
Sample-2-mHT	30	Randomly select 30 DBH/HT pairs from plot sample
Sample-3-mHT	30	Randomly select 30 DBH/ HT pairs from plot sample

A second set of volume estimates was conducted by using the mHT calculated from the DBH/HT pair regression analysis (All-Pat-mHT, Sample-1-mHt, Sample-2-mHt, Sample-3-mHt) in combination with the DBHq and SPHA from sample plots. This analysis included adjustments for hypothetical slope to estimate the effect of (erroneously) not taking slope into account when calculating SPHA and the subsequent total volume (table 2). Slope corrections are often left out in field enumerations but horizontal land is implicit in most stand characteristics and although slope errors are negligible for slopes up to 10 percent, plots should be corrected for slope (Husch et al., 1982).

Table 2. Different sampling methods where sample plot data was used to calculate DBHq and SPHA (mHT from regression analysis was kept constant in volume calculations)

Model	Number trees from sample plots	Remark
All-Pat-Plots	202	Mean HT from All-Pat-mHT regression with SPHA and DBHq from sample plots
All-Pat-Plots-10%-slope	202	Mean HT from All-Pat-mHT regression with SPHA and DBHq from sample plots, adjust for 10% slope
All-Pat-Plots -20%-slope	202	Mean HT from All-Pat-mHT regression with SPHA and DBHq from sample plots, adjust for 20% slope
Sample-1-Plots	202	DBHq, SPHA from sample plots and mHT from randomly selected 30 DBH/HT pairs in sample plots (Sample-1-mHT)
Sample-2-Plots	202	DBHq, SPHA from sample plots and mHT from randomly selected 30 DBH/HT pairs in sample plots (Sample-2-mHT)
Sample-3-Plots	202	DBHq, SPHA from sample plots and mHT from randomly selected 30 DBH/HT pairs in sample plots (Sample-3-mHT)

The effect of a 0.5 ha over or under estimation in compartment area was also tested on the *benchmark volume*. In total 23 methods were used to estimate stand volume. All these methods were compared against the *benchmark volume*.

2.5 Cash flow analysis

A cash flow table (Ham and Jacobson, 2012) for a 1 ha *Pinus patula* pulpwood project with a 15 year rotation was constructed from South African industry benchmark data (FES, 2014) (Table 3) to test profitability. The gross revenue obtained from clear felling in year 15 was a function of standing value (mill delivered timber price minus harvesting and transport costs) and clearfelling volume as determined from the 23 different methods of estimating stand volume. In the cash flow analysis it was assumed that forest owner’s cost of capital is 5% and that a project with an IRR below the Minimum Acceptable Return (MAR) of 5% will be rejected downright (Ham and Jacobson, 2012).

A sensitivity analysis (Cullen and Frey, 1999) was conducted whereby the clearfelling volume was decreased from the *benchmark volume* by 0% to 20% to determine when the IRR of the project will fall below the MAR. This was also repeated for a 0% to 20% increase in harvesting and transport costs and establishment costs. The sensitivity analysis gives an idea of how much profitability is influenced by a decrease in volume or an increase in costs.

Table 3. Cash flow table for 1 ha of Pinus patula pulpwood grown on a 15 year rotation with benchmark volume (cells in grey were manipulated for the cash flow analysis)

Age	Activity	Direct Costs	GAC	Total Cost	Gross Revenue	Net Cash Flow	Present Value
		R/ha					
0	Land	R 13 444					
0	Establishment	R 5 501		R 5 501		-R 18 945	-R 18 945
1	Tending	R 574	R 2 108	R 2 682		-R 2 682	-R 2 553
2	Tending	R 574	R 2 108	R 2 682		-R 2 682	-R 2 432
3	Tending	R 574	R 2 108	R 2 682		-R 2 682	-R 2 316
4			R 2 108	R 2 108		-R 2 108	-R 1 734
5			R 2 108	R 2 108		-R 2 108	-R 1 651
6			R 2 108	R 2 108		-R 2 108	-R 1 573
7			R 2 108	R 2 108		-R 2 108	-R 1 498
8			R 2 108	R 2 108		-R 2 108	-R 1 426
9			R 2 108	R 2 108		-R 2 108	-R 1 358
10			R 2 108	R 2 108		-R 2 108	-R 1 294
11			R 2 108	R 2 108		-R 2 108	-R 1 232
12			R 2 108	R 2 108		-R 2 108	-R 1 173
13			R 2 108	R 2 108		-R 2 108	-R 1 117
14			R 2 108	R 2 108		-R 2 108	-R 1 064
15	Clearfelling		R 2 108	R 2 108	R 78 212	R 89 548	R 43 074
	Land				R 13 444	NPV	R 1 700
						IRR	5.37%

3 Results and discussion

3.1 Volume estimates

For the 10 ha stand the average DBHq was 27.26 cm, average height 16.62 m and SPHA 418.9. The total stand volume estimated for the different volume functions differed between -0.47 to 179 m^3 from the *benchmark volume* (1 501.19 m^3) (Table 4). There was a difference of 179 m^3 (or 17.9 m^3/ha) between the SH and MB volume functions for *Pinus patula*. Kotze (1996) differentiates between total stem volume functions such as SH which produce good results for predicting total stem volume and taper functions such as MB which are used for predicting merchantable volume.

The two individual tree volume functions for *P.patula* exhibited similar trends for different strata (age, DBH, Site index, crown classes and South African regions), with the same magnitude biases varying between 11% under-estimation to 22% over estimation (Kotze (1996). While MB is used in the development of yield tables for utilisable timber in South Africa (Kotze et al., 2012) this study will continue to use the SH function (Bredenkamp and Loveday, 1984; Bredenkamp, 2000) as it is more likely to be used by emerging contractors with no access to sophisticated yield prediction software.

The stand volume estimated with the SH function with coefficients for *P. elliottii* and *P. patula* differed by less than 1 m^3 but there was approximately -174 m^3 difference between these two species and *P. taeda*. The differences between these three species were much smaller when the MB function was used (*P. Patula* – 168.2 m^3/ha, *P.elliottii* – 166.4 m^3/ha and *P. taeda* 165.9 m^3/ha). Poynton (1977) reported large variation in growth between different growing sites and provenances of these species, planted in South Africa. This could have impacted on the development of coefficients for the MB and SH functions in South Africa by Kotze et al. (1994), Kotze (1996), Kotze and Groenewald (1995) and Loveday (unpublished in Bredekamp, 2000), emphasising the need for the updating of coefficients to keep up with tree breeding and improved silviculture.

Table 4. Full stand volume calculated from sum of individual tree volumes (SH-Patula is benchmark volume)

Model	Vol/ tree (m^3)	Vol/ha (m^3)	Vol/stand (m^3)	Δ Vol/stand (m^3)
SH-Patula	0.36	150.12	1 501.19	0.00
MB-Patula	0.40	168.02	1 680.19	179.00
SH-Elliottii	0.36	150.07	1 500.72	-0.47
SH-Taeda	0.32	132.64	1 326.43	-174.75
SH-Radiata	0.37	153.53	1 535.32	34.14
SH-Pinaster	0.32	135.80	1 358.04	-143.15

The total volume estimated with the mean height derived from regression analysis of all 4 189 trees in the stand (All-Pat-mHT) is 43 m^3 lower than the *benchmark volume*. The Sys-HT138-mHT, 2STDV-HT-mHT systematic sampling methods returned approximately the same volume estimate as the All-Pat-mHT estimate. The Median-mHT and 3-tree-mHT systematic sampling estimates were very close to the benchmark volume. The Sample-2-mHT and Sample-3-mHT random sampling methods had the largest variation from the full volume estimate (Table 5).

According to Husch et al. (1982) such systematic sampling methods provide reliable estimates of population means and totals by spreading the sample over the entire population. In large forest areas where greater variation can be expected a systematic sample might give a better estimate of the mean than a completely random sample as illustrated in this study. As homogeneity increase the estimates from a random and systematic sample will tend to agree (Husch et al., 1982).

Table 5. Full stand volume calculated from sum of individual tree volumes (SH Patula is benchmark volume)

Model	HT (m)	Sample size	Vol/ tree (m^3)	Vol/ha (m^3)	Vol/stand (m^3)	Δ Vol/stand (m^3)
SH-Patula				150.12	1 501.19	
All-Pat-mHT	16.588	4189	0.35	145.81	1 458.11	-43.08
Sys-DBH138-mHT	16.687	30	0.35	146.96	1 469.60	-31.59
Sys-HT138-mHT	16.590	30	0.35	145.83	1 458.28	-42.91
2STDV-HT-mHT	16.593	3990	0.35	145.86	1 458.61	-42.57
Median-mHT	16.979	32	0.36	150.38	1 503.78	2.59
3-tree-mHT	16.999	3	0.36	150.62	1 506.18	4.99
Sample-1-mHT	16.792	30	0.35	148.19	1 481.86	-19.33
Sample-2-mHT	16.084	30	0.33	139.96	1 399.65	-101.54
Sample-3-mHT	15.719	30	0.32	135.77	1 357.73	-143.46

The All-Pat-mHT and 2STDV-HT-mHT models had similar slope, y-axis intercept and r^2 values with nearly identical volume prediction (Table 6). The All-Pat-mHT model was based on 4 189 data points while the 2STDV-HT-mHT model was based on 3 990 data points with all data points more than 2 standard deviations from the mean HT value truncated. Sample-1-mHT had the lowest r^2 fit of 0.005 but returned a value of 1481.86 m^3 for the stand volume which is 19.33 m^3 less than the *benchmark volume*. The Median-mHT model (based on 32 data points) had a r^2 fit of 0.884 and gave a volume of 1 503.78 m^3 for the stand which was only 2.59 m^3 less than *benchmark volume*.

Avery and Burkhart (1994) warn that a strong correlation between two variables (e.g. r^2 of 0.90) implies only that the variables are closely associated and are not necessarily the result of a cause and effect relationship. It is important, when assessing models for accuracy, not only to consider goodness-of-fit (e.g. coefficient of variation) but also to test biased-ness in terms of slope and intercept (Tedeschi, 2006).

mHT from the regression analysis (see table 6) was used to estimate stand volume together with DBHq and SPHA derived from plot data. DBHq calculated from the plot data was 27.27 cm compared to 27.26 cm from the full stand data. Most of the variance in volume between the sample plot based models can thus be attributed to differences in SPHA from the plot data. The sample plot data overestimated SPHA by 32.2 trees per ha. When the plot size is adjusted for slope the SPHA increase to 458.1 for a 10% slope and 480.1 for a 20% slope. The models with SPHA estimated from sample plots all overestimated the total stand volume when compared to the *benchmark volume*, except for Sample-3-Plot that underestimated due to a lower tree height (Table 7).

Table 6. Difference in volume, r2 and coefficients for the lnHt = b0 + b1DBHq-1 models

Model	b0	b1	r^2	Vol/stand (m^3)	Δ Vol/stand (m^3)
SH-Patula			-	1 501.19	
All-Pat-mHT	3.243	-11.837	0.137	1 458.11	-43.08
Sys-DBH138-mHT	3.0262	-5.7679	0.072	1 469.60	-31.59
Sys-HT138-mHT	3.614	-21.947	0.244	1 458.28	-42.91
2STDV-HT-mHT	3.1714	-9.879	0.127	1 458.61	-42.57
Median-mHT	3.211	-10.332	0.884	1 503.78	2.59
3-tree-mHT			-	1 506.18	4.99
Sample-1-mHT	2.9064	-2.3319	0.005	1 481.86	-19.33
Sample-2-mHT	3.3746	-16.265	0.312	1 399.65	-101.54
Sample-3-mHT	2.8734	-3.2302	0.009	1 357.73	-143.46

Bredenkamp (2000), emphasises that stand density is one of the most sensitive parameters estimated from plot samples. Plots must therefore be established according to horizontal distance and measured accurately. Mistakes are magnified by the reciprocal of the sampling percentage per hectare. If one tree is miscounted in a plot at a 5% sample it will lead to an error of 20 SPHA.

Table 7. Volumes estimates based on SPHA and DBHq from plot data

Model	SPHA	HT (m)	Vol/tree (m^3)	Vol/ha (m^3)	Vol/stand (m^3)	Δ Vol/stand (m^3)
SH-Patula	418.9			150.12	1 501.19	
All-Pat-Plots	451.1	16.59	0.35	157.18	1 571.84	70.66
All-Pat-Plots-10%-slope	458.1	16.59	0.35	159.61	1 596.09	94.91
All-Pat-Plots-20%-slope	480.1	16.59	0.35	167.27	1 672.72	171.53
Sample-1-Plots	451.1	16.79	0.35	159.75	1 597.55	96.36
Sample-2-Plots	451.1	16.09	0.33	150.95	1 509.47	8.29
Sample-3-Plots	451.1	15.72	0.32	146.38	1 463.76	-37.42

A reduction in stand area to 9.5 ha and increase to 10.5 ha lead to a 75 m^3 under and over prediction compared to the *benchmark volume*, respectively (1 426.13 and 1576.25 m^3).

3.2 Financial analysis

It was assume that the *benchmark volume* was correct and that therefore the gross income at clear felling and IRR based on this income was the correct project profit and return. The IRR estimated from the base volume was 5.37% which was higher than the minimum acceptable return of 5% thus indicating a profitable project (Ham and Jacobson, 2012). A model volume that returned an IRR below 5% could lead to a wrong rejection of the project while a model volume that returned an IRR above 5.37% could overestimate profitability. Only eight of the 23 models used to estimate stand volume presented an IRR that fell within the 5 to 5.37% band (Table 8). The majority of models could thus have led to wrong financial decision making.

Table 8. Effect of model volume variation on clearfelling income and project profitability (compared to 5% MAR)

Model	Vol/ha (m^3)	Value/ha	IRR	Δ MAR	Reject project	Over predict
SH-Patula	150.12	R 78 212	5.37%	0.37%		
MB-Patula	168.02	R 87 538	6.26%	1.26%		X
SH-Elliottii	150.07	R 78 187	5.36%	0.36%		
SH-Taeda	132.64	R 69 107	4.39%	-0.61%	X	
SH-Radiata	153.53	R 79 990	5.54%	0.54%		X
SH-Pinaster	135.80	R 70 754	4.57%	-0.43%	X	
All-Pat-mHT	145.81	R 75 967	5.14%	0.14%		
Sys-DBH138-mHT	146.96	R 76 566	5.20%	0.20%		
Sys-HT138-mHT	145.83	R 75 976	5.14%	0.14%		
Sample-1-mHT	148.19	R 77 205	5.26%	0.26%		
Sample-2-mHT	139.96	R 72 922	4.81%	-0.19%	X	
Sample-3-mHT	135.77	R 70 738	4.57%	-0.43%	X	
2STDV-HT-mHT	145.86	R 75 994	5.14%	0.14%		
Median-mHT	150.38	R 78 347	5.38%	0.38%		X
3-tree-mHT	150.62	R 78 472	5.39%	0.39%		X
All-Pat-Plots	157.18	R 81 893	5.73%	0.73%		X
All-Pat –plots-10%-slope	159.61	R 83 156	5.85%	0.85%		X
All-Pat-Plots-20%-slope	167.27	R 87 149	6.23%	1.23%		X
Sample-1-Plots	159.75	R 83 232	5.86%	0.86%		X
Sample-2-Plots	150.95	R 78 644	5.41%	0.41%		X
Sample-3-Plots	146.38	R 76 262	5.17%	0.17%		
SH-Patula-area-0.5-less	142.61	R 74 295	4.96%	-0.04%	X	
SH-Patula-area-0.5-more	157.62	R 82 110	5.75%	0.75%		X

3.3 Sensitivity analysis

When the effect of a one percent reduction in the *benchmark volume* of 150 m^3 was tested on profitability (0% change represented the standing timber price of R 78 212 derived from 150.12 m^3 x R 521/m^3) it was found that a volume reduction of more than 4% would decrease IRR to below MAR. A 20% reduction in volume would lead to a 1.75 percentage point reduction in IRR.

If harvesting volume was kept constant at the benchmark volume of 150.12 m^3 but the harvesting and transport cost increased by a percentage (0% change represented harvesting costs of R 129 m^3) the effect was an incremental reduction in profitability brought about by a decrease in standing value. An 11% increase in harvesting and transport costs would result in an IRR below the MAR and a 20% increase in costs would led to a 0.73 percentage point decrease in IRR.

When the harvesting volume was kept constant at 150.12 m^3 but the establishment costs increased by a percentage (within a 0 to 20% range from R 5 501 /ha at 0%) the effect was an incremental reduction in profitability brought about by an increase in costs. The effect was however small with at least a 30% increase in cost resulting in an IRR below MAR.

3.4 Effect of enumeration and costing errors

The fact that trees differ in size and shape, and that stands are not a homogenous collection of even spaced trees can introduce errors in sampling. These errors can be either random due to stand density and microsite variability within the stand, or biased due to systematic deviations of sample estimates from the true values. Bias errors could be introduced by the operator, instruments or mensuration and statistical analysis (Van Laar, 1987).

The cash flow analysis illustrated the effect that these errors in enumeration can have on financial decision making. If a timber farmer has to assess the return from a forestry investment against the rate at which he/she has to borrow money, wrong volume estimates could lead to the rejection of a project. Similarly and even potentially more disastrous could be a situation where wrong volume estimates lead to the over prediction in returns. In such a case a farmer could pay too much for a project, only to realise at a later stage that the returns are lower than expected.

The sensitivity analysis illustrated that mistakes in volume estimates have a larger effect on financial returns than when costs are reported wrongly. It is, however, also necessary to recognise that while inventory processes can influence profitability through errors in stock volume, poor cost accounting methods can also over or underestimate costs and profits. When costs are generalised or captured under wrong cost objects it becomes easy to miscalculate profitability of an enterprise or individual product lines (Horngren *et al*., 2003). This is especially the case for harvesting and transport costs which are presented per m^3 and will also have a larger cumulative effect when multiplied with timber volume than establishment costs which is recorded per ha.

4 Conclusion

Smaller growers and non-traditional forestry owners and contractors are already a significant part of the forestry landscape in South Africa and are important to the long term sustainability of the industry. Profitability and enterprise sustainability of new entrants into the industry have necessitated a focus on providing tools and measures to test the viability of forestry operation before investments are made. These tools such as financial simulators (see for instance www.forestsim.com) mostly focus on financial analysis. Critical to financial analysis is, however, an accurate estimate of timber growing stock obtained from inventories.

This study has shown that errors in inventory can have a detrimental effect on financial decision making. Errors in volume estimation have a much larger effect on profitability estimates than for instance mistakes in cost accounting.

While enterprise support has increasingly become the focus of industry bodies such as Forestry South Africa (FSA, 2013), extension officers and companies' technical support in inventory, mensuration and cost accounting is required to keep track of forestry wealth in the form of timber resources (Klemperer, 1996). As with any investment, good decisions cannot be made if the true and accurate value of such investment is not known.

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Appendix 1

Calculation of tree parameters for simulated stand

Stand level variables were simulated to assign an individual DBH and HT value to each tree based on the following parameters:

Site Index:	20
Site Index Reference Age (si.ref):	20
Age:	15
SPHA (survived at age 15):	418.9

Dominant height (HD) of the stand was simulated based on the Pienaar and Harrison (1989) function and coefficients (Equation 1) and estimated at 16.75 m.

HD = SI*((1-exp(b1*Age))/(1-exp(b1*si.ref)))b2 1

Where:
b1 = -0.0583
b2 = 1.0669

From SPHA, Age and dominant height, Basal Area and quadratic DBH was estimated with the use of Pienaar and Harrison (1989) multiple linear regression coefficients (Equation 2). Basal area was estimated at 24.35632 m^2 and DBHq at 27.20857 cm.

Basal Area ={exp(b0 + (b1/Age) + b2*log(TPH) + b3*log(HD) + b4*(log(TPH)/Age) + b5*(log(HD)/Age))} 2

Where:

b0 =	-0.6512
b1 =	-25.0905
b2 =	0.22550
b3 =	0.9789
b4 =	3.06600
b5 =	0.86360

With the use of SPHA, Basal area and Dominant height the diameter distribution was simulated. To simulate the normal distribution, Dmin (minimum diameter) (Equation 3), Dmean (mean diameter) (Equation 4) and Sdev (standard deviation of the diameter) (equation 5) were modelled according the dminhwk function (Kassier 1993) and estimated to be 16.91397 cm for dmin, 26.96507 cm for dmean and 3.631983 cm for sdev.

dmin =	(b0 + b1*rsd + b2*(tph/length(data1$DBH)) + b3*Age)*dmean	3
dmean =	sqrt(dq2-sdev2)	4
sdev =	b4 + b5*Age + b6*ba	5

where:

b0 =	0.875567
b1 =	-2.04057
b2 =	-0.172085
b3 =	0.002205
b4 =	1.319673
b5 =	0.06841
b6 =	0.052806

From these inputs a normal distribution was simulated (figure 1).

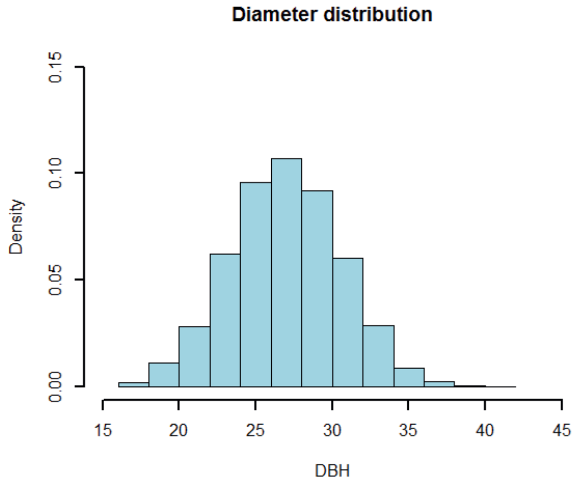

Figure 1. Normal distribution of simulated stand.

Tree heights were simulated from DBH with Pienaar's height equation, htdbh_dd (Equation 6) (Pienaar, *et al.*, 1988)

Formula: {b0*Hmean*(1+b1*exp(b2*Dbhi/Dq))} 6

Where:

b0:	1.405382
b1:	-0.807654
b2:	-1.028744

Variance was added within the normal distribution) as depicted in figure 2 and a normal distribution simulated around these values (with a sdev of 2) (figure 3).

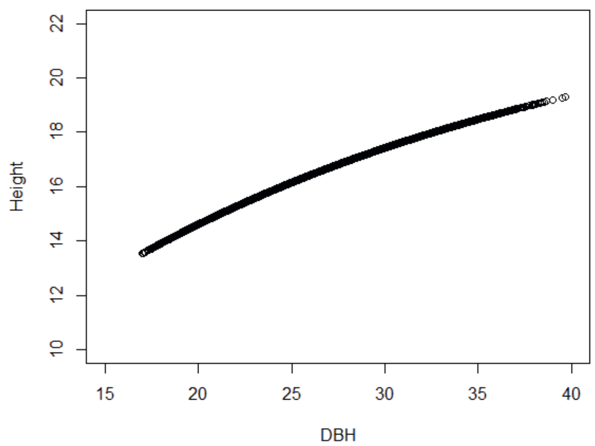

Figure 2. DBH and Height relationship.

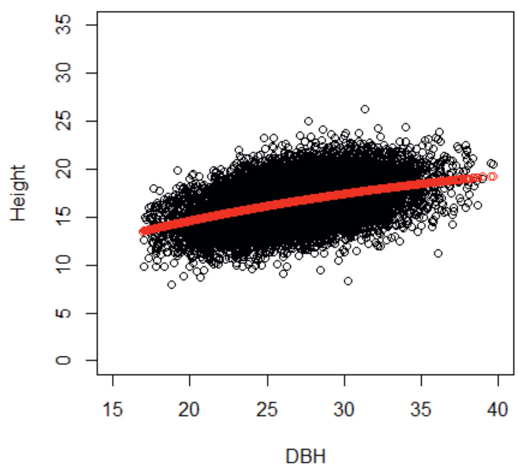

Figure 3. Simulated height values.

Investigating the effect of logging and the optimum sampling design in tropical forests of Papua New Guinea

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Abstract

Unsustainable exploitation of tropical forest resources is raising worldwide concern. In Papua New Guinea (PNG) timber harvesting has been identified as a major contributor to deforestation and forest degradation but few efforts have been carried out to assess its impact on biodiversity. Two recent studies used data from a 135 one-hectare permanent sample plot network to investigate the effect of selective logging on tree biodiversity of PNG forests and to define the optimal plot and sample size needed to estimate these characteristics. Significant differences in taxonomic composition were found between logged-over and unlogged forests, while no differences were found in richness, diversity and evenness. Stem density and, sometimes, basal area were greater in unlogged forests. Furthermore, positive trends were detected in taxonomic richness, diversity, stem density and basal area with elapsed time after logging. The establishment of a network of 319 permanent sample plots between 0.2 and 0.3 ha in size was defined as an efficient sampling scheme in the lowland forests of PNG. These results improved the knowledge of PNG tropical forests and will support the development of strategies for their conservation and sustainable management.

1 Introduction

The forests of Papua New Guinea (PNG) extend for about 33 Mha and represent half of the third largest tropical rainforest on the planet after the Amazon and the Congo Basin (Keenan et al., 2011). They account for an estimated 6% of world's flora (Kinch et al., 2010), providing habitat for approximately 11 000 plant species currently described, and some 9 000-14 000 yet to be discovered (Supriatna et al., 1999). They also play an important role in carbon (C) sequestration, with an uptake of 1.1 ± 3.4 and 0.2 ± 1.6 MgC ha-1 y-1 in logged-over and unlogged forests, respectively (Fox et al., 2011a).

In PNG, logging operations have suffered in the past from poor performance and a high level of corruption (Filer and Sekhran, 1998) and, despite the promulgation of regulations for a more sustainable supply of timber (PNGFA, 1991), logging of native forests in PNG is still criticized for a host of unsustainable practices (Laurence et al., 2010; Lindemalm and Rogers, 2013). Previous studies addressed this issue without achieving unanimous agreement as for the rate and extent of deforestation and forest degradation. Shearman et al. (2008; 2009) highlighted a net loss of 15.0% of primary rain forest – at an annual rate of 1247 km2 – and a degradation of 8.8% to secondary forest between 1972 and 2002. Filer et al. (2009) criticized the former and reported the lower deforestation rate by Bellamy and McAlpine (1995) – 392 km2 per year – as more reliable. Nevertheless, they acknowledged the complex long-term effects of timber harvesting on forest carbon stocks.

In order to address such issues, the quantification of and remuneration for carbon sequestration capacity under the Reducing Emissions from Deforestation and forest Degradation (REDD+) scheme has generated much interest in PNG, particularly as an alternative income source to large-scale timber harvesting (Fox et al., 2011b). Useful data will be provided by the forthcoming multipurpose National Forest Inventory (NFI), which is expected to become the basis for all planning activities in the forestry sector. It will also be a key element to the National Forest Monitoring System that PNG is required to establish under the arrangements for REDD+ (Grussu et al., 2014).

2 Permanent sample plot network

One hundred and thirty-five PSPs (Fig. 1) were established and measured by the PNG Forest Research Institute (PNGFRI) between 1992 and 2008, to assist planning of forest management options (Alder et al., 1999) and to provide a ground-based estimation of forest carbon and carbon flux associated with selective logging (Fox et al., 2010; 2011b). Most PSPs were located in lowland tropical forests (<1000 m a.s.l.) distributed throughout PNG where most harvesting activities take place. Only ten plots were established in montane tropical forests.

The plots were established in pairs, usually within 1 km of each other, according to the procedures adapted from Alder and Synnott (1992). Each plot is 1 ha (100 × 100 m) in size and subdivided into 25 subplots of 20 × 20 m, where all stems ≥ 10 cm diameter at breast height (DBH) are mapped and identified to genus or species level, for a total of 527 taxa. Measurements taken on trees included DBH and height. A total of 122 plots were established in selectively harvested forests, usually 0-4 years after logging (YAL) (although 7 PSPs were established from 6 to 13 YAL), and were specifically intended to monitor forest recovery and re-growth. Only 13 PSPs were located in unlogged forests.

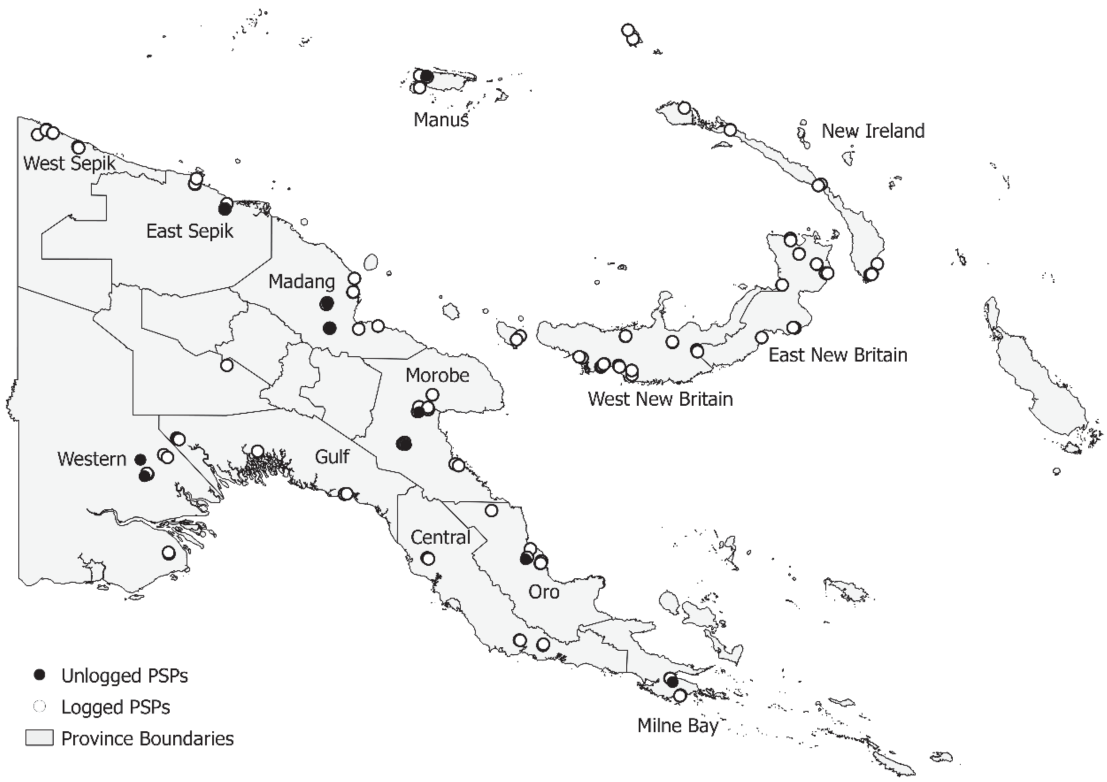

Figure 1. Map of PNG showing PSP locations across the country. Empty circles represent 122 logged-over PSPs, while 13 unlogged PSPs are represented by black circles. Province boundaries as well as province names are shown (from: Testolin et al., 2016)

3 The effect of logging on tree biodiversity and structure

Deforestation and forest degradation are listed among the main causes of species loss in biodiversity hotspots (Stork 2010), particularly in tropical areas. Testolin et al. (2016) analyzed data from the existing set of PSPs to shed light on the impact of selective logging on PNG's forest structure and tree taxonomic diversity. The sampling scheme of such a PSP network was not meant to provide an precise assessment of the effect of forest management on biodiversity in such a wide and heterogeneous area as PNG. However, their study represents the first extensive preliminary study at the national scale.

3.1 Materials and methods

The analyses were carried out on a set of 101 plots distributed in two different lowland vegetation types (VTs): 49 PSPs (6 in unlogged forests) in low altitude forest on plains and fans (P type), and 52 PSPs (4 in unlogged forests) in low altitude forests on uplands (H type) (see Testolin et al. 2016 for further information on data selection).

The taxonomic composition of unlogged and logged-over (0-4 YAL) PSPs was compared using canonical analyses of principal coordinates (CAP), ordination method (Anderson and Willis, 2003) and PERMANOVA (Anderson, 2001). The Pearson correlation coefficient of tree species with the CAP axes was calculated to determine which taxa were responsible for the tested differences. To examine the effects of logging on forest diversity, Shannon's diversity index (Shannon, 1948) and Pielou's evenness measure (Pielou, 1966) were calculated for each plot. Additionally, total basal area (BA) and the number of stems for each plot were calculated as a measure of tree cover and density. Differences in richness, diversity, evenness, total BA and stem density between unlogged and logged-over forests (0-4 YAL) within the two VTs were tested with two-way ANOVA on the first census of the PSPs. Pairwise Student's t-tests were carried out when appropriate. To observe trends of the aforementioned indexes with elapsed YAL in both VTs, five multiple linear regression models were fitted.

3.2 Results and discussion

Significant differences in taxonomic composition were found between logged-over and unlogged forests of the H type (t = 1.29; p = 0.04). CAP ordination was consistent with this result (Fig. 2). The taxa which are responsible for the identified differences within vegetation type H were identified according to their correlation with CAP axis 2 (Tab. 1). All the taxa - the majority of which belonged to the primary species group - showed negative correlation with the axis, meaning that they were less abundant in logged over forests (with *Calophyllum europhyllum*, *Dillenia papuana*, *Litsea firma* and *Myristica subalulata* showing the strongest correlation to the axis 2). Interestingly, even some non-commercial taxa (*Euphorbia spp. And Symplocos spp.*) were less abundant in logged over PSPs, probably because of the relatively low selectivity of logging practices that are usually carried out in PNG. Indeed, accidental damages during felling of other trees or skidding and construction of logging roads are frequent (Shearman et al., 2008) and have a significant impact on all tree species, regardless of their commercial value.

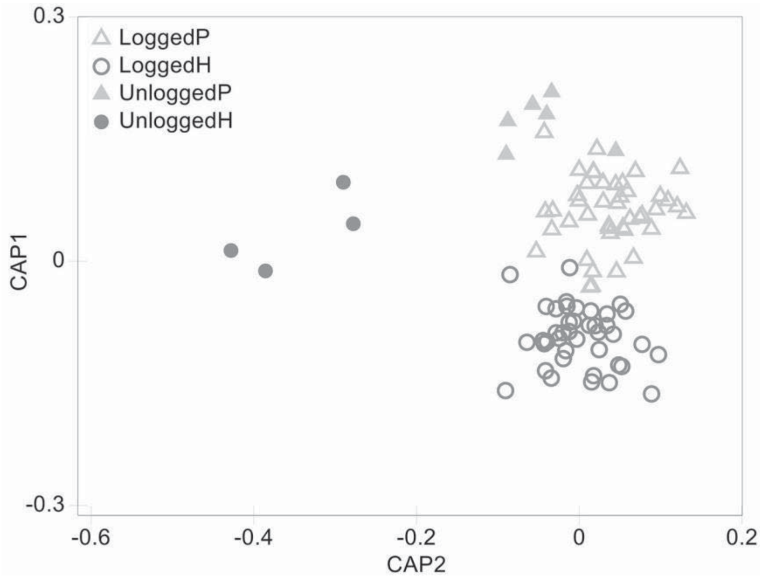

Figure 2. CAP ordination of PSPs. Logged-over and unlogged PSPs belonging to different vegetation types are grouped according to their tree taxonomic composition. (P): Lowland forests on plains and fans; (H) lowland forests on uplands (from: Testolin et al., 2016).

Table 1. Pearson's correlation coefficients of species with CAP axis 2. Average abundances and standard deviations are reported for logged-over and unlogged forest plot of the H type (from: Testolin et al., 2016).

Taxon	Correlation	Logged (stems 100ha^{-1})	Unlogged (stems 100ha^{-1})	W	LHS
Alstonia scholaris [c]	-0.35	39 ± 97	475 ± 754	33.5 *	LS
Calophyllum europhyllum [c]	-0.64	39 ± 174	1900 ± 2248	43.0 **	LS
Dillenia papuana [c]	-0.56	110 ± 526	1325 ± 1552	24.5 ***	P
Drypetes spp. [c]	-0.36	2 ± 16	100 ± 141	42.5 ***	P
Euphorbia spp.	-0.35	2 ± 16	75 ± 96	42.5 ***	SS
Litsea firma [c]	-0.51	32 ± 133	850 ± 995	44.0 **	P
Myristica subalulata [c]	-0.62	78 ± 339	2700 ± 3156	120.0 **	P
Rhizophora spp. [c]	-0.48	5 ± 22	50 ± 58	45.0 **	P
Symplocos spp.	-0.58	7 ± 26	250 ± 332	44.0 **	P
Xylopia spp. [c]	-0.36	54 ± 182	275 ± 189	30.0 **	LS

(c): commercial species. (LHS): Life History Strategy codes; (SS) short lived secondary species; (LS): long lived secondary species; (P): primary species. (*): p < 0.05; (**): p < 0.01; (***); p < 0.001; (ns): not significant.

As for richness, diversity (*H'*) and evenness (*J*), no significant differences were discovered between logged-over and unlogged forest plots. This is consistent with several previous studies, which compared logged-over undisturbed forest within a relatively short period after logging (e.g., <20 years – Hall et al., 2003; Bischoff et al., 2005). Nevertheless, the small number of unlogged plots in this case might have led to an under-estimation of the actual tree richness and diversity. Higher stem density was found in unlogged PSPs (421 ± 153 stems ha-1) than in logged-over ones however (308 ± 110 stems ha-1). Regarding the BA, significant differences were found between logged-over (15.52 ± 4.04 m2 ha-1) and unlogged plots (30.28 ± 4.45 m2 ha-1) of the H type forests (*p* = 0.005).

The analysis of the richness trend with elapsed YAL highlighted a slight increase in the number of taxa (Fig. 3a), with a gain of about one new taxon per hectare every two years. Similarly, diversity showed some increase with time (Fig. 3b), while evenness remained roughly constant through the years (Fig. 3c). No significant trend in relation to the YAL was detected for stem density and BA in P type forests, while H type forests showed a gain of 9 ± 1 stems ha-1 yr-1 and 0.42 ± 0.06 m2 ha-1 yr-1 (Fig. 3d, Fig. 3e) and reached, after 24 years, values that are comparable to those of unlogged forests (481 stems ha-1 and 29.30 m2 ha-1).

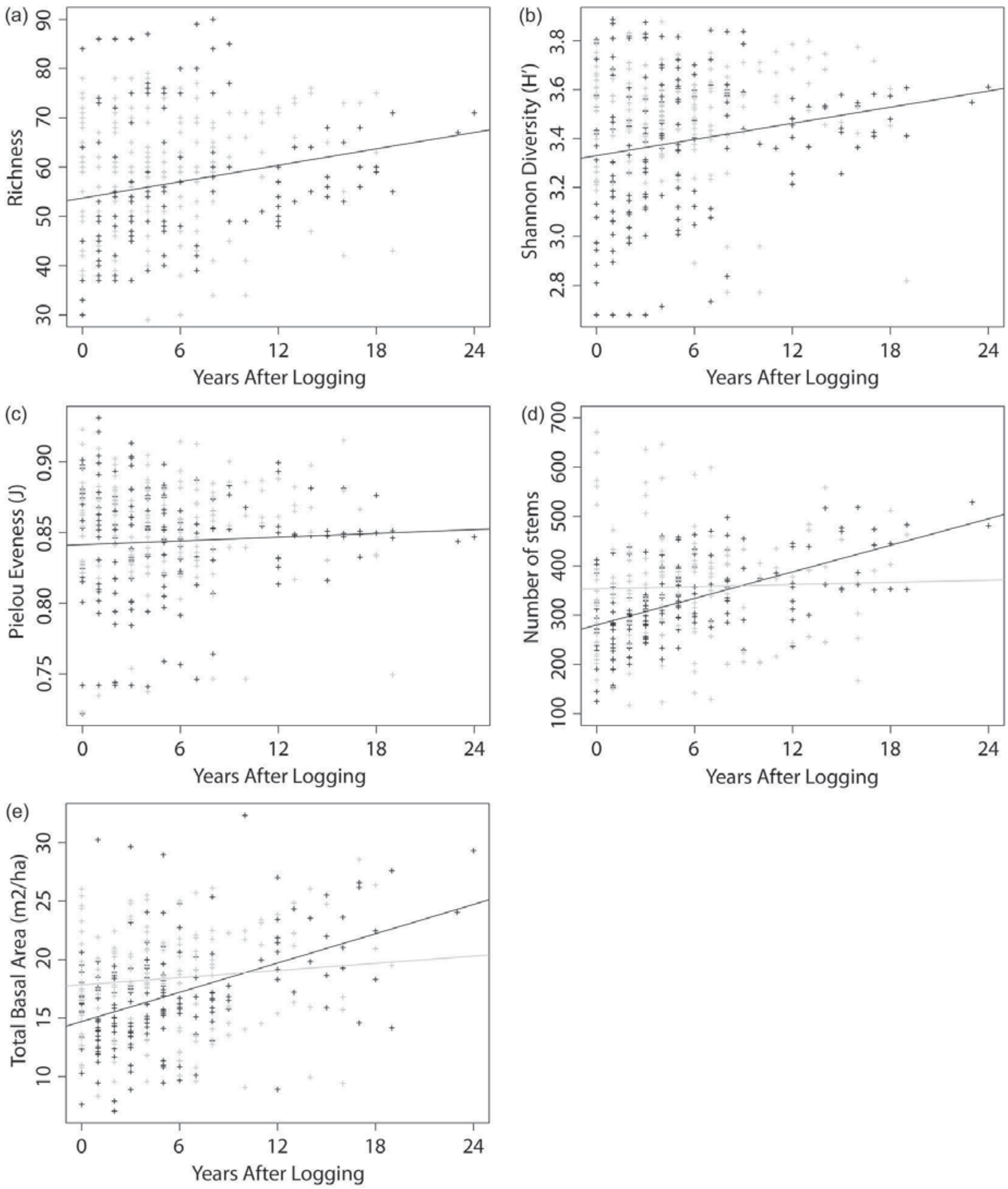

Figure 3. Scatter plots showing trends in stand features. The graphs report 322 censuses of 91 logged-over PSPs' belonging to two different vegetation types: H (black) and P (grey). Linear regression lines are shown. Richness (a) and Shannon diversity (b) showed significant increase in both vegetation types. Stem density (d) and BA (e), increased only in H type forests. Evenness (c) showed no significant change with years after logging (from: Testolin et al., 2016).

4 The issue of sampling design

Many studies have dealt with the topic of sampling design in forest monitoring programs, as the implementation of NFIs can be time consuming and it is important that they are designed to yield statistically representative data and make best use of limited resources (Evans and

Viengkham, 2001). A key element to accomplish this is the knowledge of the local variability in the sampled forest stand features.

Several studies from tropical forests have specifically focused on the issues of sampling error and spatial variation with respect to the estimation of biomass (e.g. Keller et al., 2001; Laumonier et al., 2010). However, few, if any, of these studies considered the variability of any biodiversity measure. To fill this gap, Grussu et al. (2016) carried out a study to identify the best survey design for an accurate assessment of both carbon stock and tree taxonomic richness of PNG tropical forests using the data from the PNGFRI PSP network.

4.1 Materials and methods

Two plots (one in logged-over and one in unlogged forests), which were measured only in 1997 and 1999, respectively, and reported as burnt in the database, were excluded from the analyses, which were carried out on a set of 133 PSPs, 12 of which were located in unlogged forests.

The aboveground living biomass (AGLB) for trees was estimated using the allometric model for wet tropical forests of Chave et al. (2005). The carbon fraction of biomass was calculated assuming that dry biomass is 50 percent carbon (Malhi et al., 2004) and is reported in megagrams of C ha21 (Mg C ha21).

The relationship between plot size and variation of carbon stock and tree taxonomic richness was investigated. Twenty-four different plot sizes (from 0.04 to 0.96 ha) were simulated by pooling 20 m×20 m (0.04 ha) subplots from 121 logged-over and 12 unlogged PSPs. The process was randomized 1000 times without replacement at each simulated plot size. For each of these simulated plot sizes, the number of taxa and the total carbon content was estimated. The coefficient of variation (CV) was calculated as a normalized measure of dispersion of richness and carbon estimations at each simulated plot size. The variation of CV with plot size was evaluated by fitting inverse-power models to the calculated CVs. The most efficient size is represented by the smallest size commensurate with the variability produced (Avery and Burkhart, 2015). The optimum plot size was chosen at the point beyond which the inverse-power function rapidly reduces its steepness; therefore, further increases in plot size will lead to a low increase in accuracy. The optimum plot size was rounded to the closest pool of 20 m×20 m basic units; the corresponding CV was used to determine the number of plots that need to be established to estimate the mean richness and carbon stock with 95 percent confidence level and a defined error of 5 percent using an equation from Philip (1994) (see Grussu et al., 2016 for further details on data selection and statistical analysis).

5 Results and discussion

As expected, carbon stock estimation showed high variability at small plot sizes, with a predicted CV of 62.3 percent and 51.2 percent in 0.04 ha plots in logged-over and unlogged forests, respectively. Richness appeared to be less variable, especially at small plot sizes, with a

CV of 43.5 percent in logged-over forests and 25.0 percent unlogged forests at 0.04 ha. As shown in Figure 4, the CVs of carbon stock estimation in both logged-over (4a) and unlogged (4b) forests exhibited an exponential relationship with an initial steep decline at small plot sizes and then a slower reduction starting at between 0.2 and 0.3 ha. Despite this decline, variability remained quite high even at large plot sizes. This result was expected, considering that tropical forests are known to exhibit high spatial variability in tree biomass (Laurance et al., 1999) across broad environmental gradients of moisture and temperature. The CVs of richness decreased in a similar fashion in logged-over forests (4c), while in unlogged forest plots (4d), the initial decline was much less pronounced.

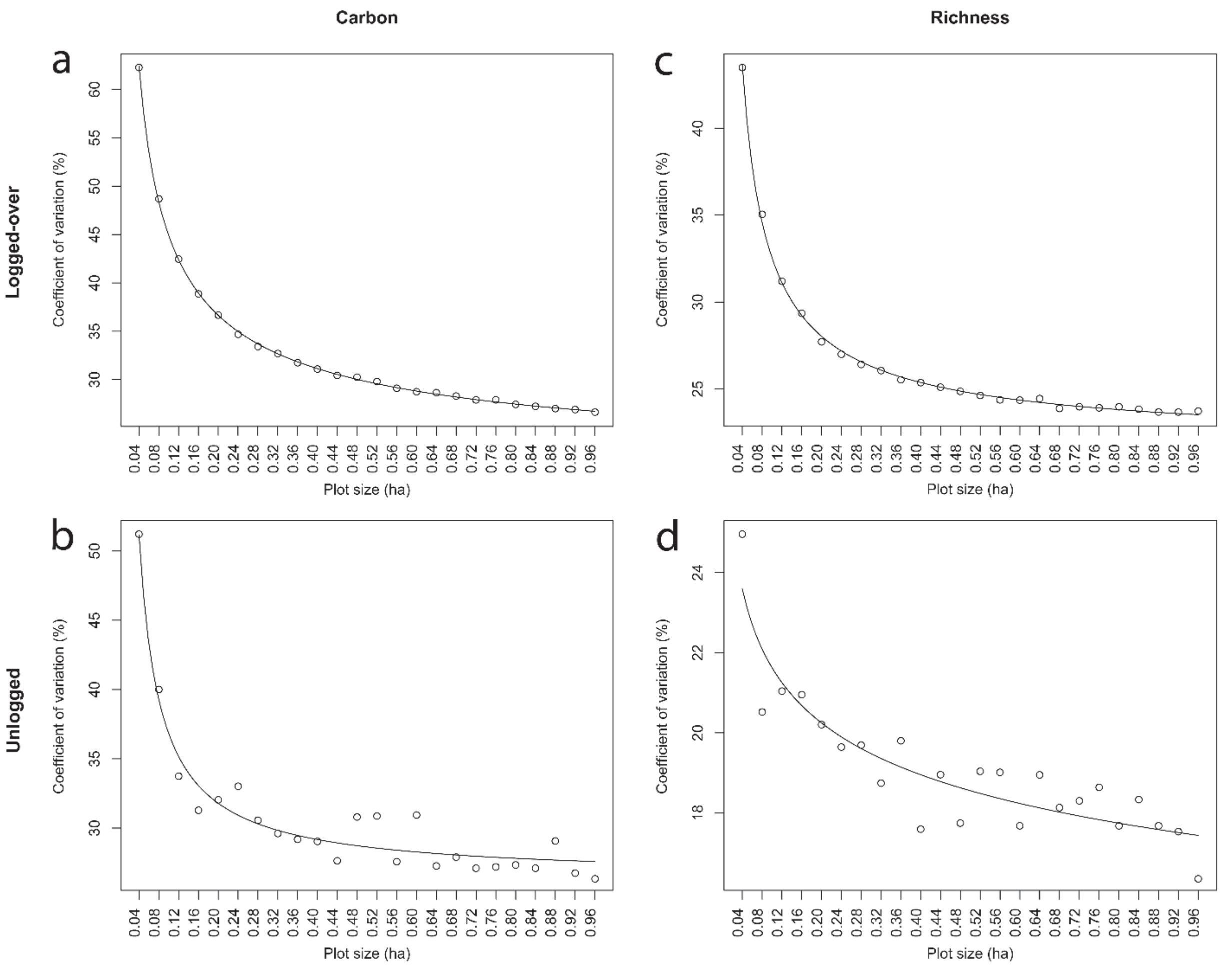

Figure 4. The observed CVs (empty circles) of the estimates of C stock and species richness with increasing plot size in logged-over (upper frames) and unlogged (lower frames) forests. The solid lines represent the fitted power models. The basic unit for plot size is the original 20 m×20 m (0.04 ha) subplot (from: Grussu et al., 2016).

The estimated optimum plot sizes with 95 percent CIs were rounded to the nearest integer (20 m×20 m subplot) and expressed in ha (Tab 2). Coherently with the trend in CVs, richness in unlogged forests appeared to require smaller plot sizes for an efficient estimation compared with logged-over forests and C stock, which conversely required similar plots sizes. The approximated optimum plot size for carbon stock estimation was 0.3 and 0.2 ha in logged-over and unlogged forest plots, respectively. Previous studies (Laurance et al., 1999; Keller et al., 2001; Laumonier et al., 2010) provided similar results identifying 0.2–0.25 ha as the optimum plot size to sample biomass in tropical forests.

As for richness, the optimum plot size dropped to 0.2 ha in logged-over forests and to 0.08 ha in unlogged forests. However, due to the current taxonomic limitation that characterizes forest inventories in PNG, it is likely that this analysis underestimated the actual tree species richness variability, especially in the case of unlogged forests where only 13 PSPs were available.

Given these optimum plot sizes, the corresponding number of plots and the total area sampled for an estimation of tree taxonomic richness and carbon stock (within 5 percent of the true mean; 95 per-cent confidence level) is reported in Table 2 and compared with the required number of 1-ha plots.

Table 2. Optimum plot size expressed in number of 20 m×20 m subplots with 95% CIs for carbon (C) and tree taxonomic richness (R) for logged-over and unlogged forests. The corresponding optimum sample size and total area sampled are provided and compared with the ones of the original 1-ha plots (from: Grussu et al., 2016).

Parameter	Opt PS [95% CI]	Rounded Opt PS (ha)	Opt SS (Opt PS) [Tot A (ha)]	Opt SS (1 ha) [Tot A (ha)]
CLogged	7.57 [7.48–7.64]	7 (0.32)	164 [52.48]	109 [109]
CUnlogged	5.10 [3.63–5.52]	5 (0.2)	155 [31.00]	117 [117]
RLogged	4.96 [4.69–5.05]	5 (0.2)	121 [24.20]	85 [85]
RUnlogged	2.09 [0.63–2.45]	2 (0.08)	75 [6.00]	46 [46]

Opt PS, optimum plot size; Opt SS, optimum sample size; Tot A, total area sampled.

It is clear that using a 1-ha PSP network would not deliver any benefits in terms of cost efficiency. On the other hand, the establishment of 164 0.3-ha plots in logged-over forests and 155 0.2-ha plots in unlogged forests – for a total of 319 PSPs – represents a better sampling design for both carbon stock and tree taxonomical richness.

6 Conclusions

Testolin et al. (2016) and Grussu et al. (2016) provided useful information on the effects of logging activities on tree biodiversity and structure of PNG forest, as well as on the spatial variation of carbon stock and tree taxonomical richness. Their results will be useful when compared with the new data that will be acquired with the NFI, which is being developed under the arrangements for REDD+. The establishment of a forest monitoring framework will be instrumental in assessing the impact of human activities and ecological factors on PNG forest biodiversity, and will support the development of sound strategies for the conservation and sustainable management of the nation’s biodiverse forest heritage.

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Geographic information system of urban forestry Pereira, Colobia

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Abstract

The SIAP is a management tool of urban trees in the city of Pereira, which enables online consultation of about 26 variables on each and every one of the trees on public space in the city of Pereira. Conducted at the end of 2015, the inventory covered 21,8682 arboreal individuals and registered them in an online system that allows citizens as well as the scientific community to run queries on data of interest. Systematization and geo-referencing of woodland yielded data and indexes of great value to the management of urban trees in the city of Pereira.

1 Introduction

The city of Pereira was founded 153 year ago. The municipality is a small city, in the center of the coffee region in Colombia. With a population of 396.487, the municipality has 60.552 hectares of which 3.040 hectares are in the urban zone; it is 1.411 m above sea level, has an average temperature of 26°C and 2.746 mm of annual precipitation3.

The municipality is in the middle of the gold commerce triangle between the three main cities of the Andes mountain chain, named Cali, Medellin and Bogota, the capital of Colombia. The city is cross by two rivers, the Consota river and the Otun river and another 27 little streams. The city has around 300 hectares of forestry; according to the urban forestry plan (PLAMSUP) of 2015, and has 21.868 trees in the public space. The urban forestry plan is therefore a very important tool for the planning in the near future.

Pereira has been characterized as a civic city that have developed part of its infrastructure thanks to strength of its citizens, such as the football stadium, or the Olympic Village, which is called HERNAN RAMIREZ VILLEGAS. Even the airport is part of the civic achievements of the city.

Pereira is a city that during the past decade has been concerned about the service it was providing to the city´s trees. By 2010 the administration published the Urban Forestry Handbook of the Municipality of Pereira, which was endorsed by the Municipal Decree regulation number 440 from 2011, and adopted as main handbook and management tool of urban trees. In 2015 in conjunction with the Botanical Garden of the Universidad Tecnológica de Pereira an Urban Forestry Master Plan of the Municipality (PLAMSUP) was built in the same way as the Forestry Handbook before it. It is a technical instrument of particular importance for the city as it develops, and aims for the integral management of urban trees in the city. Both initiatives are part of the same project and counted and characterized 21.868 trees in public space. This is significant data showing that for every citizen that exists in Pereira 0.05 exist, a figure very far from the 0.33 trees per person recommended by the World Health Organization (WHO).

One of the great contributions of PLAMSUP is the development of the Arboreal Information System Pereira - SIAP (Alcaldía de Pereira, 2016), this online system allows structured consultation of urban trees, providing 12 different data on each individual such as common name, scientific name, height, diameter at breast height (DBH), etc.

The application was released for consultation online and thereby to any citizen being connected to the internet, so anybody can view the general features (including a photograph from the inventory date) of each and every one of the specimens referenced on a recent google image (2016) of the city of Pereira. SIAP has also become the reference system and place of consultation of other municipal entities that are related to city trees such as the Operative Department of Parks and Greening, using the identification of each specimen that SIAP offers.

2 Urban forestry Pereira - GIS

The GIS - SIAP is a management tool that allows the municipal administration to obtain current and upgradeable georeferenced data that can be deployed in multiple platforms for the development of plans, programs and projects around the city trees.

Figure 1. SIAP http://sigper.pereira.gov.co/visor/arboladop/

3 Methodology

The methodology that allowed the development of SIAP had four basic stages

I. Development of data capture application for mobile devices.
II. Field data collection (inventory)
III. Paperwork, analysis and preparation of information
IV. Geographic Information System multi-platform.

Stage I Development of data capture application for mobile devices: The application was designed as a form for the use in the field, adapted for Android mobile devices. The form was structured with 26 variables and more than 30 sub variables. It was used to design the Android Memento Database application, and as a condition information can be collected offline if this is necessary by anybody as well as by using cell phones and media technology with the only requirement of having GPS on the device.

The variables finally published in the SIAP are:

- Collector Index
- Date Data Capture
- Numbering (Id)
- Geographical coordinates
- Location
- Common Name
- Development Status
- Height
- DAP
- Glass width
- Angle and direction of inclination of the trunk
- Conflicts infrastructure or roads
- Management needs
- Growth Habit
- Image

Stage II Data Collection Field (Inventory): The city has about 3,400 ha. To cover this area, 3 crews were established that collected field information georeferenced by using 3 cell phones. The crews worked for 180 days and synchronized data collected in the field once a day by WiFi connection. The information was then synchronized and matched with the Google Drive system using a Google Spreadsheets through a conventional gmail account. This way the data were available once synchronized and could be reviewed by desk work.

Stage III Paperwork, analysis and preparation of the information: Once the information was synchronized with google drive, it was available to the scientific world. The technical office was responsible for debugging the information, for data standardization and for clarifying doubts in relation to the taxonomic identification. Similarly, office staff prepared data for obtaining maps; initially the refined information in the tables was google processed by the fusion of tables on Google. This platform allows easy and functional mapping of the georeferenced information obtained through fieldwork.

Stage IV Geographic Information System Multi-platform: The approved and standardized data is connected and assembled for the google earth kml system and Esri shapefiles generic file format, the latter format feeds the information system's desktop platform under Arc GIS 10.2; finally an online template that allows online publication and consultation of the database is done.

4 Conclusions

In urban forestry processes censuses and inventories are necessary for the management of urban trees. There are low-cost technological tools available on the internet, for a census or an inventory of urban trees. Municipalities can appropriate these free tools and generate online GIS platforms. The associations between the academy and the municipalities are necessary, when the aim is to generate technical tools that contribute to the management of the trees of the city. Low-cost technologies do not mean inefficient processes; On the contrary, they are very profitable. However, when processes become more complex, governments and companies must scale their requirements towards paid technologies, just in case they exhaust the use of free technologies.

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Zoning organic management of Maqui (*Aristotelia chilensis*) in the region of Los Ríos, Chile

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Abstract

Maqui is a small native tree of Chile and Argentina the occurrence of which is associated with water courses and borders of forest. It produces a small edible berry, which has been used ancestrally by the Mapuche people and peasants as medicine for various diseases. Its high antioxidant content has been documented and has become a very attractive fruit for the pharmaceutical industry. The price of exported raw material has increased exponentially (168% in the last year) and still has potential for growth. Therefore, several attempts have been made to industrially produce Maqui with traditional agronomic methods and to patent the commercial varieties. However, since 1992 Chile is subscribed to the convention of biological diversity, which in its article 8j commits in general lines to protect and promote the ancestral knowledge of the original peoples. This protection also includes any benefit that is obtained of this knowledge and the use of the related products, including Maqui, and your use must be with the consent and benefit for these indigenous communities. In this context, it is necessary to have alternatives exploitation methods that promote the value of this product, generate a sustainable use of it for the benefit of the indigenous communities and are supported by the biological diversity agreement. Therefore, our proposal is to evaluate the region of Los Rios - Chile using the proposed methodology of organic management, taking into account mainly biophysical variables such as slope and distance to watercourses. In this way, it is possible to establish a zoning of intensity of use of the places where the Maqui is wild. In this first approximation it has been possible to estimate a potential of approximately 304 tonnes per year of fruit for the region, this is greater than the total currently exported at national level, indicating that the region of Los Ríos possesses all the characteristics necessary for organic management of the Maqui. This type of management provides a productive alternative to the indigenous communities and the small proprietors, could allowing them to obtain economic sustenance while at the same time diminishing the degradation of the resources.

1 Introduction

In recent years the demand for the consumption of Maqui has grown exponentially, according to the ODEPA (Bureau of Agricultural Studies and Policies of Chile) between 2014 and 2015 exports increased 168%, with the main destinations being Japan and Korea South. The Maqui's success is mainly due to its high levels of antioxidant production and its benefits as a medicinal plant (Hoffman, et al 1992, Alonso, J. 2012; Araya, et al 2006).

This increase in the demand for the Maqui fruit leads to an increase in the exploitation, and therefore to a potential degradation of this resource, because the Maqui is a native tree, which grows in the wild and currently has practically no silvicultural or agricultural management, since studies on its agronomic management are still in preliminary stages. The majority of Maqui production is through collection and has no major regulations. Due to these reasons, it is important to establish zones with different degrees of intensity in the management of the Maqui to obtain good yields and certifying an organic management of the Maqui that assures a sustainable exploitation of the individuals that exist in natural vegetation. In addition this type of organic management can serve as an incentive to local or indigenous communities to obtain an economic benefit through the collection of Maqui, thereby protecting not only the species but all the ancestral knowledge that these communities have developed in relation to the Maqui.

Therefore, we propose in this paper to establish an organic zoning of Maqui fruit productivity, following a proposal of organic management standard of the Chilean Agricultural and Livestock Service, which described in Silva (2016). Our proposal was to evaluate the region of Los Rios - Chile using the proposed methodology of organic management standard taking into account mainly biophysical variables such as slope and distance to watercourses, and this way it establish a zoning of intensity of use and method of harvest.

6 Characteristics of the Maqui

6.1 Geographic distribution

Maqui (*Aristotelia chilensis* Mol. (Stuntz)) is an endemic species of Mediterranean forests and a secondary or pioneer species in temperate rainforests of the evergreen forest type. In Chile it grows from Limarí (IV region) to Aysén (XII region), both in the Central Valley and in both Cordilleras (mountain ranges), from sea level to 2500 m.s.n.m. (Rodriguez et al., 1983). It preferably develops in ravines, slopes of hills or margins of forests. In addition, it has a high capacity invasion in ecosystems in which it is exotic like for example in Isla Juan Fernández. It's distribution is associated with other species like *Chusquea sp.*, *Lomatia hirsuta, Gevuina avellana, among other*, bordering forests, with humid places, it easily colonizes lands that have lost their vegetation cover, and is a pioneer species of newly burned or exploited soils (Silva, F. 2016).

6.2 Uses

Maqui is used in some types of folk crafts. The bark has fibers similar to that of hemp and is used in the production of ropes for binding. The Maqui also has medicinal uses and has been used by the Mapuche people and peasants for the treatment of multiple diseases (Silva and

Bittner, 1992). The powdered leaves are used for healing, in infusions against diseases of the throat, mouth ulcers and intestinal tumors, and in poultices against fevers and tumors; The fruits are also used in infusions against diarrhea, enteritis and dysentery (Andrés Bello Agreement, 1983 in Bonometti, 2000). Other uses are leaf juice against bronchial discomfort and intestinal tumors (Bonometti, 2000). The chemical analysis of the fruit of the Maqui has detected the presence of flavonoids with antioxidant capacity (Fauré et al, 1990) and low concentrations of alkaloids of the indole type, such as aristotelin, aristotelone, aristone and aristotelinin. Aristotelin has been identified as a secondary metabolite that has an antimitotic activity (Cespedes et al 1995). It has also been determined that in the Maqui fruits, anthocyanidins are found which would be responsible for the purple color characteristic of the fruits (Poblete 1997). Due to the intensity of its coloring matter, it has been used in the dyeing of handicraft objects and even to improve the coloring of red wines, a practice that is not allowed by the alcohol legislation in Chile (Poblete 1997).

7 Material and methods

7.1 Study area

The region of Los Rios is located between 39º15 'and 40º33' south latitude, it has an area of 18,429.50 square kilometers. The climate that characterizes this region is temperate or rainy, with the absence of a dry period (McKnight et al., 2000). The Los Rios region has approximately 1 million hectares of forest, 80% corresponds to native forest and 20% to forest plantations (CONAF, 2012). The total population of the region is 356,396 inhabitants according to the 2002 census, of which 11.3% is declared as belonging to the Mapuche ethnic group, making this the region with the second highest Mapuche population of Chile (INE, 2002).

7.2 Data collection and processing

The zoning of the management areas for Maqui in the Los Ríos region was elaborated through the organization of maps and slope information. To propose a zoning organic management of Maqui we used four different sources of georeferenced data (Table 1).

From the altitude data in software ArcGIS 10.1, we have created a slope file with spatial resolution of 30 m. We use as steepness levels in percent: 0-10, 10-30, 30-45, 45-60, 60-. With the data of water resources (water supply and water bodies), we did a buffer on both sides with a size of 15 m.

As a management criterion, we use 6 limitation of classes according to the characteristics of the sites as proposed by Silva (2016), see Table 2. This management proposal determines according to the biophysical variables the intensity of fruit exploitation and the way of harvesting (manual or machine).

Table 1. Data used to propose a zoning organic management of Maqui.

Data	Type	Coordinate System	Source
Altitude	Raster	WGS 1984 UTM Zone 18S	Alaska Satellite Facility (www.asf.alaska.edu/sar-data/palsar)
Lakes	Vector	WGS 1984 UTM Zone 18S	Ministry of Public Works of Chile (www.mop.cl)
Rivers	Vector	WGS 1984 UTM Zone 18S	Ministry of Public Works of Chile (www.mop.cl)
Spatial location of Maqui	Vector	WGS 1984 UTM Zone 18S	Ministry of Agriculture, National Forest Corporation (www.conaf.cl)

Table 2. Management levels defined as the characteristics of sites.

Class	Criterion	Management of Maqui	Intensity of fruit harvest
A	Sites on edges of rivers and lakes with 15 m buffer	No management	No harvest
B	Sites with slope less than 10%	No restrictions, it allows management plans for individuals and use of no woods forest products. The harvest can be by machine.	70%
C	Sites with slopes between 10 and 30%	Allows conservation management. It is suggested to maintain no less than 50% coverage. The harvest can be by machine.	50%
D	Sites with slopes between 30 and 45%	Conservation and protection. Coverage should remain above 70%, Not allowing the entry of livestock, only sanitary deforestation. The harvest can be by machine	30%
E	Sites with slopes between 45 and 60%	Just a manual harvest of fruits is allowed.	30%
F	Sites with slopes greater than 60%	Preservation and no use: intangible Maqui	No harvest

We analyzed the zoning production of Maqui fruits considering an average productivity of 24 $Kg.ha^{-1}$ (Valdebenito et al., 2003). These authors sampled the production of Maqui fruits on 10 communities during the production period. As the authors do not inform the reasons that can influence the production of the fruits. We decided to use this amount as an average. This productivity has a very conservative estimate, and can easily increase values.

8 Results

The area where there is Maqui occurrence is 45,676.3 ha, Figure 1.

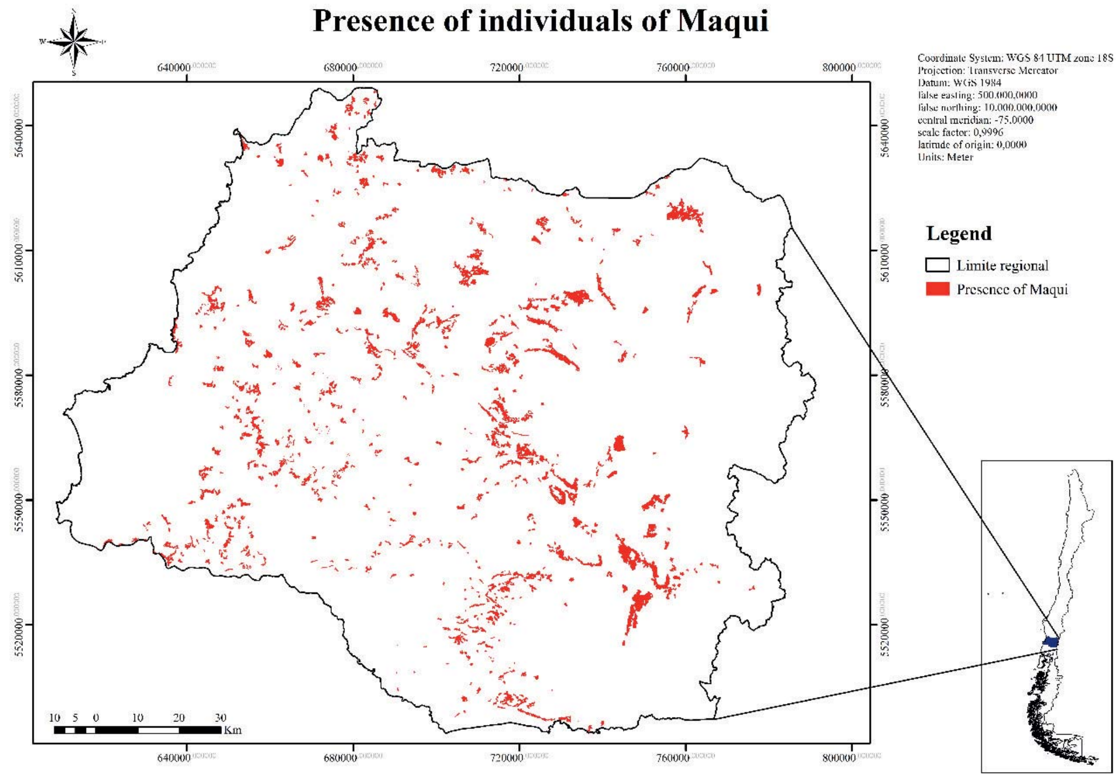

Figure 1. Spatial distribution of sites with occurrence of Maqui.

In the region de Los Rios – Chile, 90% of the area are characterized by low slopes of less than 30%, see Figure 2. In the fragments with occurrence individuals of Maqui the slope is similar like the region (Figure 3). The Classes B and C have the highest fruit yield in the region of Los Ríos – Chile (Table 3).

Table 3. Area in hectare of management class in total area and sites with Maqui

Class	Area (ha) Total	(%)	Area (ha) with Maqui	(%)	Production of fruit (kg.year^{-1})
A	138,374.78	7.41	1,205.984	2.52	No harvest
B	924,156.54	45.22	17,400.33	38.09	249,763.9
C	751,960.89	38.86	24,061.23	50.33	34,057.4
D	144,084.51	7.42	3,744.72	8.02	18,721.8
E	18,284.58	0.99	435.06	0.95	1,693.1
F	1,878.66	0.10	43.02	0.09	No harvest
TOTAL	1,840,367.17		45,676.3009		304,236

If the total region of Los Rios – Chile was managed, it would have a fruit production potential of 304 ton.year^{-1} (Table 3). The southeastern region of Los Rios accounts for most of this (Figure 4). As Maqui occurs mainly in low slope sites, even without the preserved areas, here defined without use for management (Classes A and F), the region of Los Rios - Chile has ample potential for management of the Maqui.

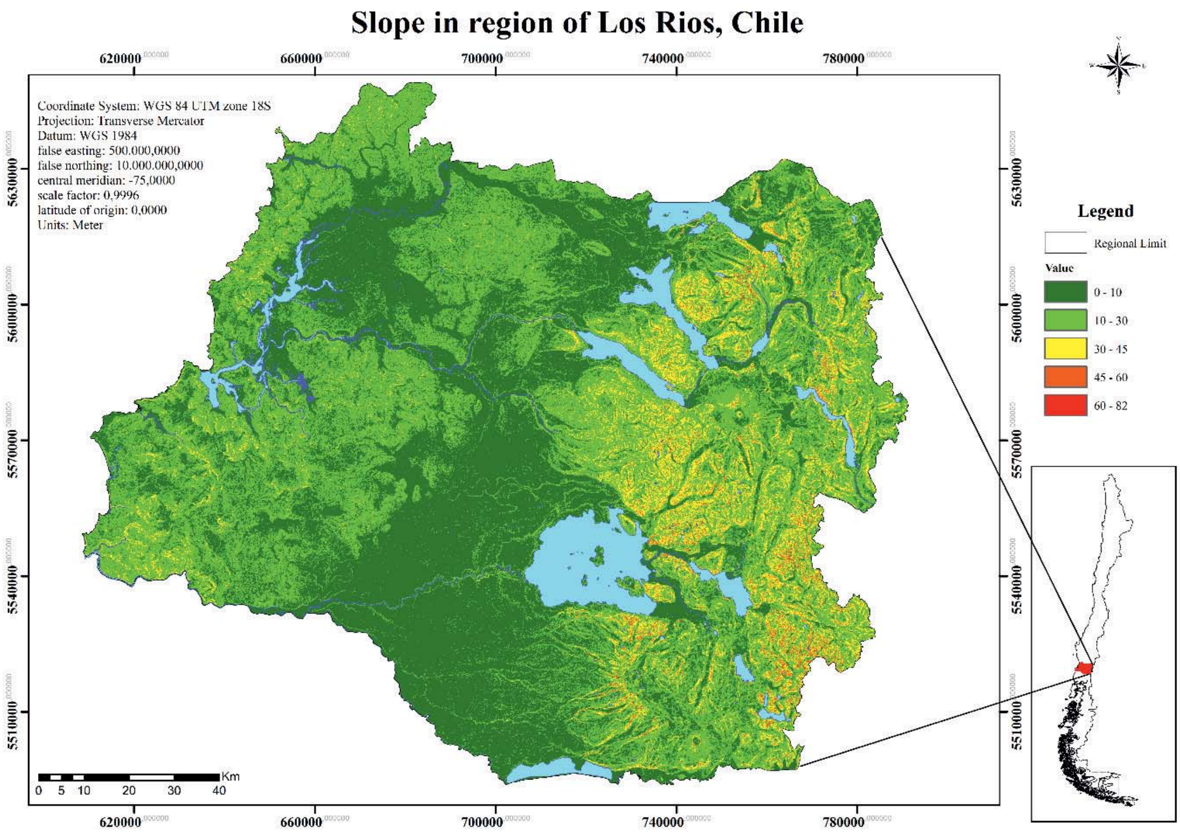

Figure 2. Slope in region of Los Rios, Chile

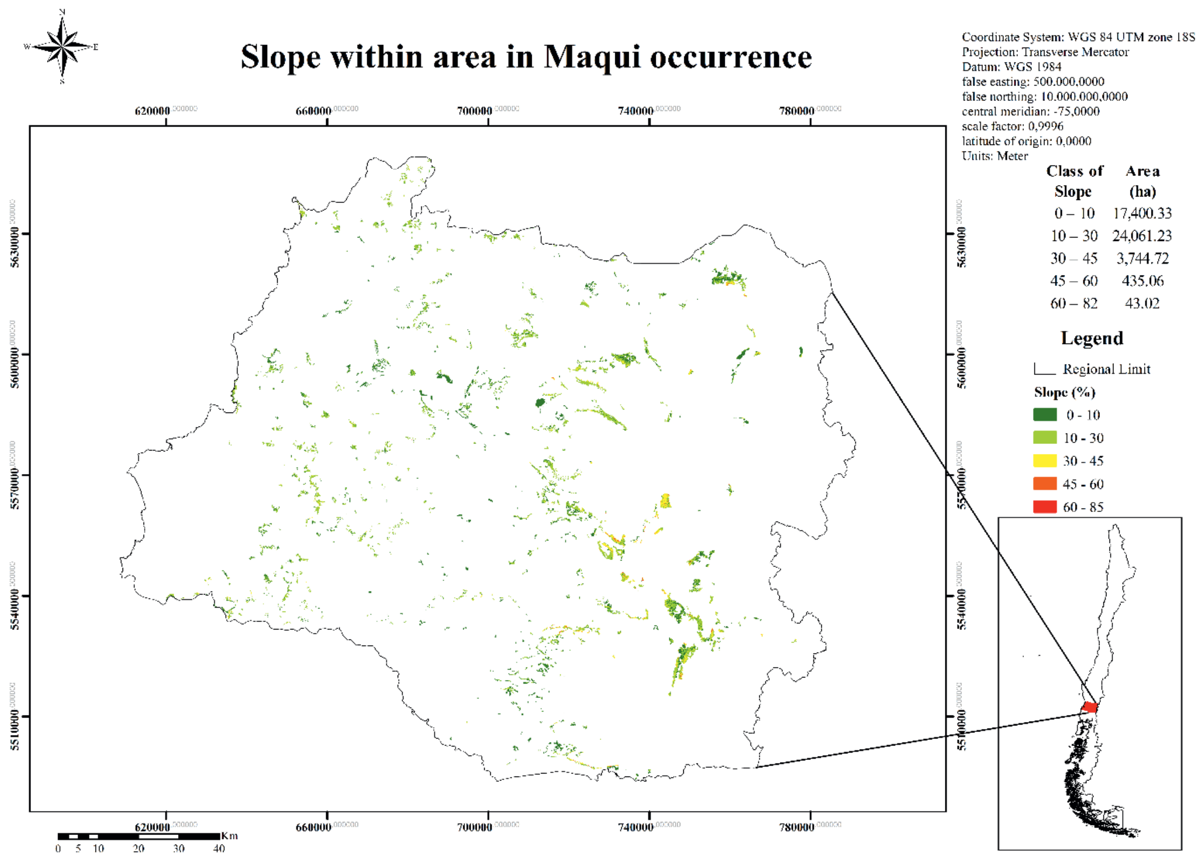

Figure 3. Slope in region of Los Rios, Chile with area in Maqui occurrence

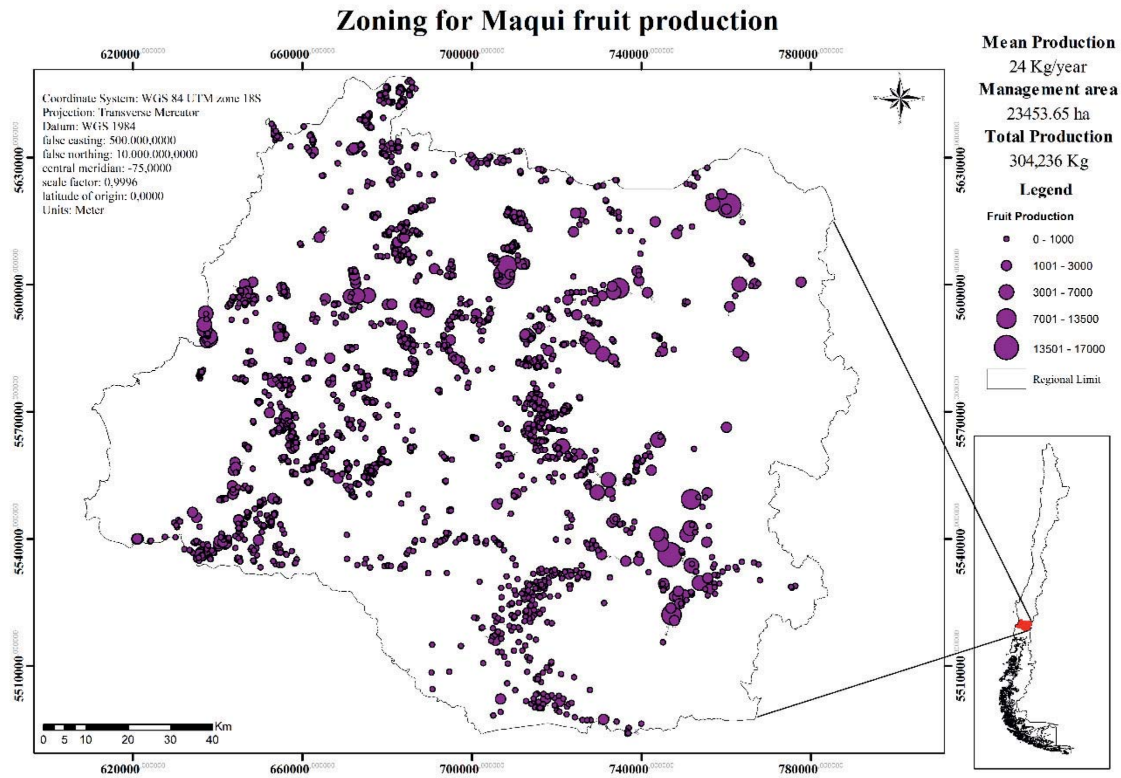

Figure 4. Zoning Maqui fruit production in region of Los Rios, Chile

9 Conclusions

The region de Los Ríos – Chile has high potential for Maqui fruit production, especially in the southeastern region which shows a greater production of fruits. Therefore, the sustainable management of Maqui is an excellent income alternative for the indigenous community. For, it is a non-destructive management of individuals due to being a non-timber product. The organic management of Maqui can help in the conservation of the native vegetation because it is not necessary to suppress the vegetation to use the same area. With the information of the organic zoning of Maqui can be defined the logistics for the implantation of factory of processing and transportation of the production of fruits and their derivatives. It is necessary that the governors encourage the local population to harvest and manage the fruits of Maqui to have a sustainable production to ensuring stable and durable production at low cost, respecting local environmental and cultural conditions.

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Chapter four

Land use conflicts

Land use and land cover change in forestry: A status quo of forest area and livelihood dependence in relation to land use policy changes

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Abstract

As a response to the increasing change in land use and decreasing forest cover, different countries worldwide have changed their environmental governance and forestry policies to increase the forest cover and attain sustainable development. The direction of this change varies between countries however, whereby some like Uganda concentrated on large scale plantations and others like Nepal concentrated on community forests and forest user groups. Such changes make various contributions in achieving increased forest cover. Additionally, they can have both positive and negative socio-economic impacts depending on the design and implementation of the policy. We argue that the analysis of different approaches to land use can support environmental governance and policy-making by increasing our understanding of the possible outcome of taking no action. Using Uganda and Nepal as examples of this transition, we argue that forest policies must explicitly address the forests' role in socio-economic issues. The integration and consideration of local people in policy formulation and implementation would create a visible positive change in forest utilization and management. Provisions for and acceptance of local communities' access to forest resources and markets backed up with capacity building and government support can enhance socioeconomic benefits.

1 Introduction

1.1 Land use and Land use policy:

Land use and land use change policy is a complex and interdisciplinary. This combines the social, economic, political, legal, physical and planning aspects of town and countryside land use (Pushkarev & Zupan 1977). It addresses the issues in geography, agriculture, forestry, irrigation, environmental conservation, housing, urban development and transport in both developed and developing countries (Pushkarev & Zupan 1977).

For both developed and under developed countries to make strategic decisions, foresee opportunities and cope with the future surprises, knowledge on the socio-economic and environmental drivers and knowledge on how to make them sustainable is crucial (Bryan B.A et al, 2016). Additionally, analysis of land use and sustainability issues increases understanding of the outcomes of taking no action which supports the different governments in policy-making and environment governance. This also helps in assessing the effectiveness of other policy designs, policy options under uncertainties including the outcomes and trade offs (Alcamo, 2008 as cited in Bryan at el, 2016). Forestry policies can't be implemented in isolation from other policies in energy, transport, investments and agriculture. This is because these sectoral policies may have both positive and negative impacts on each sector (Golub et al, 2013). Therefore, sustainable land management requires land-use policies and management actions that achieve the greatest environmental and socio-economic benefit at the least cost (Le et al; 2010).

1.2 Status quo of forest area

Globally, the world forest area has highly decreased from 4128 million ha of forest in 1990 to 3999 million ha by 2015. Additionally, there have been dynamics in forest gain and losses which are coupled with forest plantations and deforestation respectively (FAO 2015). These gains and losses differ highly and are concurrently related to national circumstances and forest types. For this reason, we have put emphasis on two different cases: Uganda and Nepal. Forest resources are strongly decreasing, mostly in low-income countries, in the tropics (Sandewall et al., 2015) and sub tropics due to different factors directly related to land use and cover changes such as; policy change, urbanization, settlement, and agricultural expansion hence leading to a continuous loss of forest cover (FAO 2016).

It is observed that a high proportion of forests globally are publicly owned although the proportion of privately owned forests has increased from 15% in 1990 to 18% as of 2010 (FAO 2010; FAO 2015). Furthermore, due to policy changes, management ownership of public forests by private companies in the case of Uganda and communities/forest user groups in the case of Nepal has increased significantly. Empirically, the forest plantation area has increased globally to 105 million ha since 1990 (FAO 2015).

1.3 Land cover policy change and Plantation forest

As stated above, change in government land use and land cover policy highly influences the extent of use and coverage of forest resources globally. The changes in policy are motivated by the urge for pursuing sustainable forest management (SFM) and economic development as well as infrastructure development (Fujita et al. 2007; Meyfroidt and Lambin 2008). In most countries in the tropics, the use of plantation forest is seen as a path to sustainable forest management by reducing pressure on natural forests, and promoting sustainable development through income generation, formal and informal employment and infrastructure (Obidzinski et al., 2013). These plantations require vast areas of land (Evans and Turnbull, 2004), unfortunately these large plantations are established in areas previously occupied and utilized by low income local communities. These areas are used for firewood, non-wood forest products, timbers, medicinal plants, and some wild foods (Heubach et al., 2011 and Persha et al., 2011). With the above evidence, it's necessary to specifically evaluate the change in forest coverage in relation to land use change policies and socio-economic impacts of land use policies in Uganda and Nepal.

1.4 Objectives

The objectives of this review are to assess:

i. the change in forest cover in relation to change of land use policy

ii. the socio-economic impacts on and forest dependence of marginalized groups using examples from Nepal and Uganda

2 Conceptual framework: Forest transition theory

In natural resource management like forest management, valuable information about future deforestation rates and for establishing baselines which allow reflecting national circumstances can be obtained by the use of forest transition theory (Leischner 2011). It's based on the formulated correlation by Mather (1992) and Mather and Needle (1998) showing the variations of deforestation with time. As seen in the Figure 1 below, the initial forest cover is deforested with time due to socio-economic and demographic development variations.

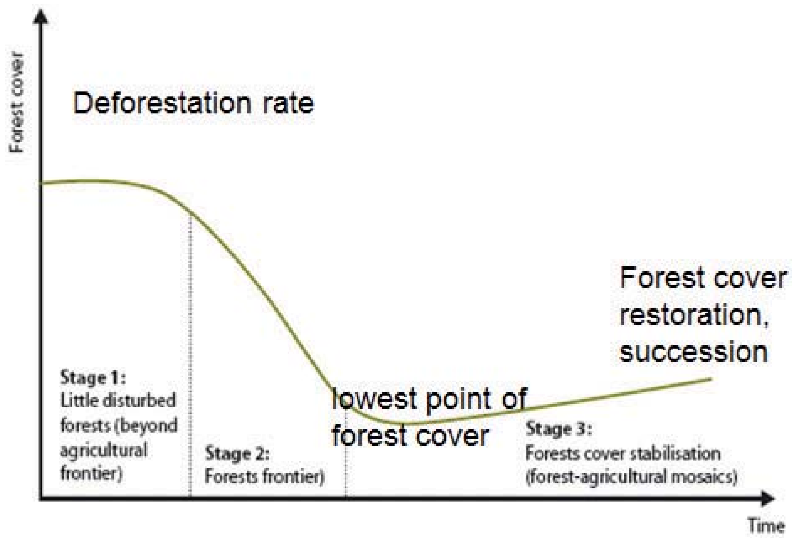

Figure 1. Forest transition curve. Source: Adopted from Angelsen 2007; Meyfroidt, Rudel, Lambin 2010.

This continues until the lowest point in the second stage when there are no more forests to supply the countries' needs are reached. Having reached this stage, different countries tend to start reforestation projects in order to recover the forest area as seen in the third stage of the transition curve. The recovery processes involves change in forest policies, plantation establishment and agro-forestry practices. Using this theory, the trend of forest deforestation and restoration of different countries can be assessed. We therefore use this theory in this paper to discuss the first objective regarding the forest coverage in Uganda and Nepal.

3 Methodology

3.1 Case study areas

For a critical review, two countries, Uganda and Nepal, where land use and forest policies have been changed and vast afforestation has been carried out were selected. Uganda is located between latitude and longitude 1° 00' N and 32° 00' E (Central Intelligence Agency, undated) (Figure 2). While a high percentage of the population depends on agriculture and forest products such as charcoal, timber and other non-timber forest products, 19.7% are clustered in the poor category, though not uniformly distributed around the country (Republic of Uganda, 2014).

Nepal is located between Latitude and longitude 280 00’ N and 84 00’, (Central Intelligence Agency, undated). More than 80% of the population is dependent on agriculture and fuel wood, timber and fodder with 38% living below poverty line (Regmi et al., 2008).

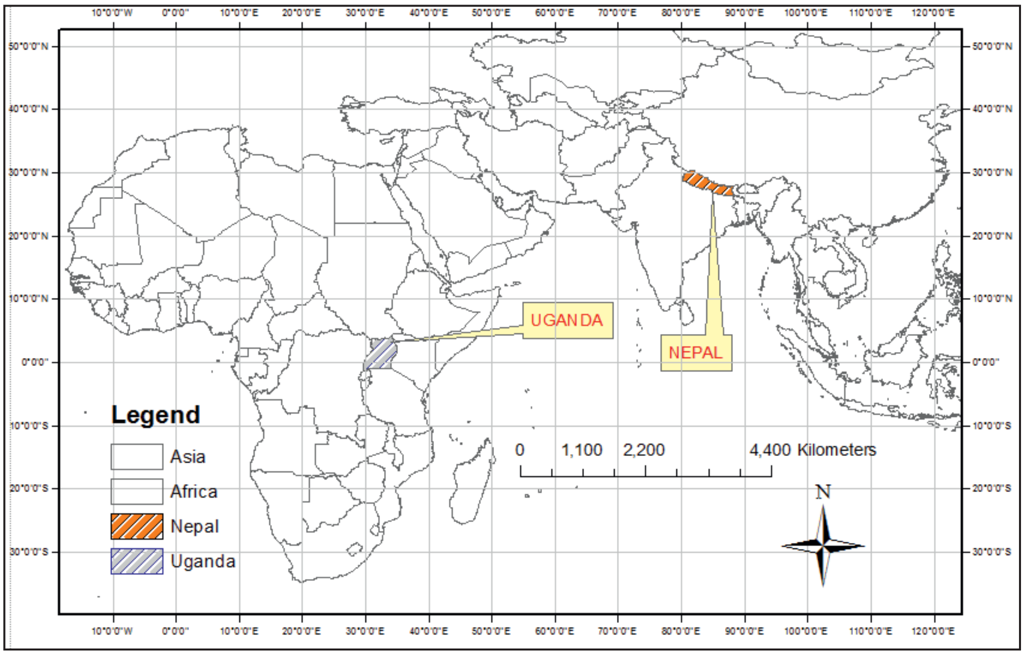

Figure 2. Map showing global forest cover change percentage and locations of Uganda and Nepal.

3.2 Data collection and Analysis

Using the FAO online data base, www.fao.org/forest-resourcesassessment, raw data on forest change globally and specifically for Uganda and Nepal was obtained. This platform was chosen since FAO has a reputable, well-established, consolidated, translucent and traceable reporting process making it easier for countries to provide data concerning their forest resources.

The obtained data was used to assess the change in forest cover from the onset/ implementation of forest policies in both Uganda and Nepal. To observe these changes, a descriptive analysis was carried out and results are presented graphically. Secondly, online literature and published reports were reviewed to obtain insights on the livelihood dependency, forest access and use, in areas where plantation forest/community forests were implemented. Only studies carried out between 2000 and 2016 were utilized since these give updated info. Additionally, they provide clear evaluation and impacts of the afforestation projects started more than 5 years ago.

4 Forest policy and forest cover changes in Nepal and Uganda

4.1 Policy change Uganda

In Uganda, plantation forestry and carbon offset activities have been enabled by numerous policies. These policies were mainly brought about with an aim of reducing deforestation; improving economic development, climate change mitigation and reducing pressure on natural forests (Government of Uganda, 2010b) and lead to increased land use and cover changes. Subsequent to the RIO conference in 1992 and Agenda 21, laws on forest resources and land laws reflecting government commitment to privatize public lands and attract foreign investment arose. As a result, acquisition of public lands was enabled within forest reserves to establish forestry plantations (Tree Planting Act 1993). Additionally, the Forestry Policy (2001) and the National Forestry and Tree Planting Act (2003) explicitly commit to the privatization of Uganda’s forestry sector. The New Land Policy (2011) also grants titles to citizen, thereby exercising private sovereignty over land (Lyons et al 2014; Lyons and Westoby 2014). With this in view, there are increased public and private collaborations, including related to forests and forest plantations, central to green development in Uganda with less involvement of local communities.

4.2 Policy change Nepal

In Nepal, afforestation was driven by the demand of forest resources such as fuel wood and started in 1976 in the National Forest Plan. As a potential mechanism for sustainable supply of basic forest products at a local level, as crucial route to poverty reduction and as a potential strategy of sustainable development , and improvement of ecological degradation, the government of Nepal implemented a community-based forestry program in 1978 (Kanel 2004; Department of Forest 2008; Gautam et al., 2004). Additionally, the Forest Act 1993 and laws, 1994 gave the community local user groups’ full responsibility to manage and carry out plantation activities with active involvement of local forest dependents (HMGN, 1993-1995). Since then, community plantations have become the major plantations in Nepal supported by District Forest Offices.

4.3 Change in forest cover in Uganda and Nepal after Policy changes

As can be seen in Figure 3, it is evident that there is a general negative trend in total forest area and natural forest areas for both countries. However, in 2005, while the trend becomes constant in the case of Nepal, there is a continuous rapid decrease in Uganda.

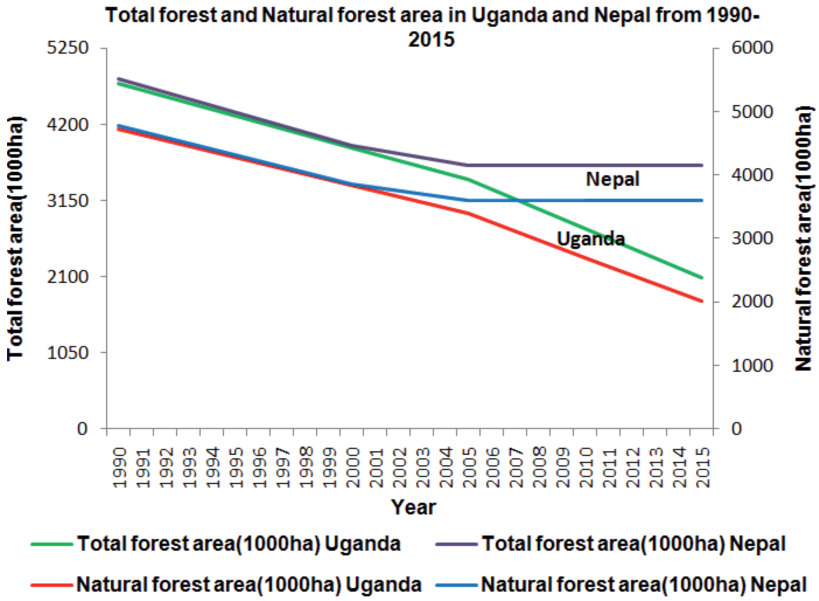

Figure 3. Trend of total forest area and natural forest area from 1990 to 2015 for both Uganda and Nepal.

As a measure to reduce pressure on natural forests, plantation forestry increased in 2005 in both Uganda and Nepal as shown in Figure 4. While in Nepal there is a slight increase, forest plantation area coverage drastically increased in Uganda. Additionally, forest use in Nepal has stabilized, thus, there is no drastic deforestation as compared to Uganda where the increase in plantation forestry only plays a small role in reducing the unsustainable use of forest.

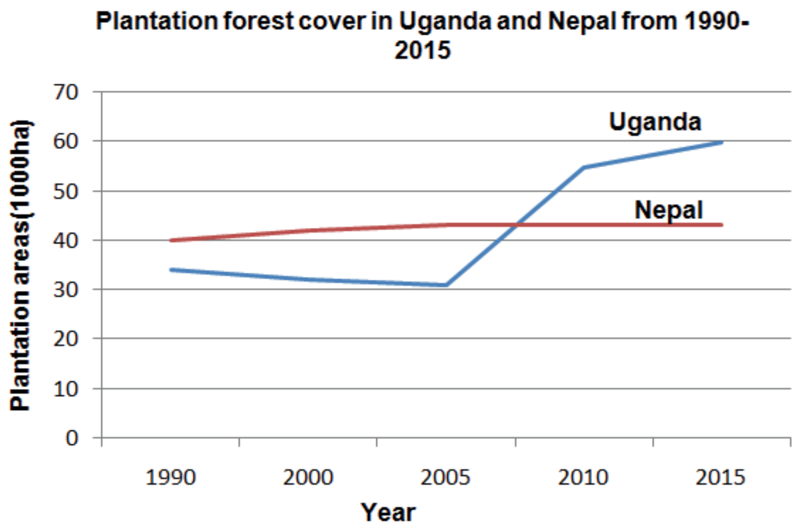

Figure 4. Total forest area and natural forest area from 1990 to 2015 for both Uganda and Nepal

5 Resource use and access by local communities

5.1 Resource use and access in Uganda

It was observed that due to the authority given by the government to the companies to evict people from their land, many have been forced out of their premises violently by policemen. During and after this eviction process, local people's homes have been burnt and destroyed. In addition, individuals have been harassed and some imprisoned. This has psychologically affected individuals which resulted in the reduction of their effectiveness and human capital. Besides these evictions, community members are denied access to their cultural sites and the forest reserve to collect firewood (Kill 2015; Peskett et al., 2010; Lyons et al 2014; Lyons and Westoby 2014).

Furthermore, a few individuals are called upon in meetings but their needs or ideas are never put into consideration. One respondent complained that, "We attend meetings, but our requests fall on deaf ears", hence there is no active participation of the community at large (Lyons et al 2014; Lyons and Westoby 2014). As a result, there is increased pressure on the natural forest reserves by local peoples through encroachment, settlement and establishment of agricultural patches.

Economically, forest companies provide jobs but only for migrant laborers. Local people who have managed to acquire jobs in these plantations work in poor conditions with inadequate training and experience with late or no payments in some instances (Nel 2014; Kill 2015; Lyons et al 2014; Lyons and Westoby 2014). Moreover, community members have observed that there is no fair benefit sharing, despite this being stated in the companies' management plans

As a consequence of plantation establishment, there is an acute land shortage for growing food and rearing animals. In areas where crops are planted, they are slashed and sprayed with chemicals or herbicides. In addition, animals are frequently confiscated for illegal grazing; carrying fines between 20,000 and 1 million Ugandan shillings~ ($7.50-$400) (Kill 2015; Lyons et al 2014; Lyons and Westoby 2014). Through the increased use of chemicals in the areas, there is loss of livestock which reduces the economic source of income for the affected people (Lyons et al 2014). These damages are never compensated by the companies, hence leading to the escalating rate of poverty.

5.2 The case of Nepal

Community forestry has led to a sustainable supply of forest products and has sustained the livelihoods of the poor in Nepal (Rasaily and Ting, 2012). There is also capacity building and participation of women and minority groups (Kanel 2006). Economically, community forest user groups financially support the local livelihood by providing loans to poor families and helping them in creating forest based activities to improve their income (Kanel and Niraula, 2004; Kanel 2004, Shrestha and Khadka 2004, Koirala 2007).

There are, nevertheless, bottle necks. There is a problem of exclusion of marginalized landless and ethnic local people from development opportunities, decision making, forest access and use (Baral 1993, Agarwal 2001, Lama and Buchy 2002, Adhikari 2005, DevDFID et al. 2003, Dhakal 2006, Paudyal 2008, Yadav et al. 2008). Additionally, Khadka (2009), states that these problems have persisted since the 1980s. Hence, income inequality among local individuals in Nepal has increased (Sunam and McCarthy 2010).

6 Discussion

The transition of forest coverage in both Uganda and Nepal had reached a second stage, according to the forest transition curve. This called for a change in forest policies in order to reverse the negative trend in forest coverage. With the onset of the policy changes, these countries would now be in the third stage, according to the forest transition theory.

The decrease in forest cover in Uganda, irrespective of the increase in plantations, is due to the following factors: land grabbing for palm oil and agricultural products, encroachment and settlements in natural forest reserves due to forced migrations, unsustainable utilization and illegal logging. With their inclusion in the land and investment policy, natural forest areas are increasingly destroyed to pave way for investors, urbanization and infrastructure development. In Nepal, there is sustainability in forest coverage since 2005 and this is attributed to the strong forest and land policies plus the involvement of local people in forest management.

The general decrease in forest area is attributed to an increase in demographic pressure such as household size and the high demand of fuel wood both for heating and cooking, illegal forest harvest, livestock grazing and forest fire (Chaudhary et al., 2015)

As an example, both the Ugandan Government and the Government of Nepal complemented their policies with the goal for sustainable development and sustainable provision of forest resources. Irrespective of the same goal, both countries followed different strategies to achieve Sustainable Forest Management (SFM). Uganda follows a pure large scale plantations strategy while Nepal follows a community plantation strategy. Involvement of the local people in Nepal helped the forest sector to avoid large deforestations and increase fair resource use. Additionally, this may be attributed to the opportunities generated for the poor from the grassroots policy interventions Hobley (2008) unlike in Uganda, where large scale plantation investors have sole rights and never involve the local communities.

In summary, tree plantations have a high potential to give benefits to local people in rural areas although this does not benefit the poorest groups as stated by Sikor and Nguyen (2007).

Failure of integrating the marginalized groups both in Uganda and Nepal is due to the fact that:

- Powerful interest groups are often close to national policy makers,
- Government control mechanisms are often weak to influence field reality,
- Patronage politics is common and;
- Lack of analysis and understanding of the hidden objectives of institutions in order to obtain a clear picture of institutional stakeholders' motivations (Mayers and Bass (1998).

7 Conclusions and Outlook

This paper has highlighted that the forest cover area is still decreasing in both cases although it remains higher in Uganda as compared to Nepal. In Nepal, the decrease has slightly stabilized, accompanied by a low increase in plantation forest. A high increase in plantation forest in Uganda was also observed but this contributes less to the total forest area. Socio-economically, the approach taken up by Nepal helped a lot in improving socio-economic aspects for the people although the marginalized ethnic group of people is still denied access to resource use and decision making. Large plantations in Uganda highly escalated poverty in the areas where these are established since people were evacuated and are denied access to the forest areas that have been providing the basis for their livelihoods since long time. As a consequence, land use conflicts on resource use have increased. Hence different households carry out illegal settlements and agriculture practices in protected natural forest reserves.

Since most of the local people in both tropics and sub tropics highly depend on forest resources, their integration and consideration in policy formulation and implementation would create a positive visible change in forest utilization and management as seen in Nepal.

Furthermore, forest policies must explicitly address forests' role in providing food, energy, high quality water and shelter. Provisions for and acceptance of the local communities' access to forest resources and markets backed up with capacity building and government support, is a powerful way to enhance socioeconomic benefits. Furthermore, out grower's schemes, agro-forestry and community woodlot plantations can be options to supply the nation's demand for forest products and revenues.

8 Acknowledgements

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Changes in coverage and land use in the Malleco Province in the Araucania Region, Chile

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Abstract

The degradation of native forests in the world is a phenomenon that has been increasing over the years. Latin America isn't exempt of this. Because of its geographic characteristics such as climate or edaphic characteristics, it had large extensions of surface with optimal conditions for agriculture, livestock farming and forests plantations. With the arrival of Europeans, a big part of the original vegetation has been overexploited by simple extraction or replaced by commercial interest species. It is fundamental to remember and keep track of the consequences of these changes of land cover and to monitor them by using several tools for spatial and temporal analysis, and to thereby make inferences about possible management or conservation strategies. In this paper, we analyzed the case of the forests in the Malleco Province in the Araucania Region of Chile, which had suffered an expansion of plantations of Pinus radiata and Eucalyptus sp., causing a negative impact on the ecosystem and the services that it provides, and even on the society.

1 Introduction

Currently, forests are under pressure from demographic expansion, which often leads to their conversion or degradation to states of unsustainable land-use. When forests are lost or degraded irreparably, they also lose some of their ecosystem services, such as their capacity as regulators of the environment, causing increased flood and erosion possibilities, reducing soil fertility and contributing to the loss of plants and animals (FAO 2001). Usually, the various factors that affect biodiversity loss are grouped into three categories: habitat modifications, introduction of exotic species and the overexploitation of species (CONAMA 2008) In Latin America's tropical areas biodiversity loss will be one of the most serious environmental disasters faced in the region (Magrin et al. 2007).

In Central and South America, forest cover was probably about 75 percent of the land area before the arrival of Europeans; deforestation in the 18th and 19th centuries reduced this to about 70 percent by the early 20th century. Deforestation generally increased in the tropical areas in the 20th century, especially in developing countries. In Latin America, for example, forest area declined to around 50 percent of the land area (FAO 2016). In the last two decades and especially since the 2000s, the South American region Great Chaco is being deforested with great intensity, in an unprecedented process of transformations of land uses (Zerda 2013).

The expression "soil cover" describes the type of biophysical cover observed on the surface of the earth. In contrast, the term "land use" is used to describe the set of activities that society carries out in a territory to produce, modify or preserve its state (Di Gregorio and Jansen 2005, Geist et al. 2006 quoted by Volante 1990). So-called "land use change" transformations, which in the first instance involve "changes in soil cover", currently act as one of the main controls of global change that can be seen at different scales of study (Duarte et al. 2006 quoted by Volante 1990).

The change of soil cover and land use is a dynamic process in which the role that man plays is fundamental. Continuous human intervention has modified the original vegetation, often as a cause of high population pressure; many native species have disappeared when areas were urbanized and others due to agricultural activities. These processes are increasing and occur rapidly, generating the loss of forest cover and negative effects on the quantity and quality of the water resources and soil.

Deforestation affects the amount of water in the soil, the groundwater and the moisture in the atmosphere. Forests influence the climate, support considerable biodiversity, provide valuable habitat for wildlife, forest foster medicinal conservation and the recharge of aquifers. Also, forests can extract carbon dioxide and pollutants from the air, thus contributing to biosphere stability and probably to the reduction of the greenhouse effect. In addition, forests are valued for their aesthetic beauty and as a cultural resource and tourism attraction (Gervet 2007)

The state of total forest cover gives a global impression, at national and regional or subregion levels, of the quantitative status of forest cover as a whole as an apparent continuous mass of tree vegetation located at a particular location. However, it is clear that within this supposedly continuous mass, there are specific spaces or ecosystems that need to be analyzed separately in order to establish the qualitative state of the different forest types that are reported together and mixed in the global statistics (FAO 2001).

2 Ecological and economic consequences of changes in land coverage

The changes in coverage bring important ecological and economic consequences. A big problem of this conversion is the change in the provision of ecosystem services. Among the consequences the following can be distinguished:

Increased surface runoff and surface temperature, air pollution caused by emissions from fixed and mobile sources, as well as the reduction of biological diversity. On land with agricultural use, modification occurs through the processes of soil erosion and sedimentation, acidification of aquifers resulting from the use of pesticides, fragmentation of ecosystems, loss of habitat for fauna and alteration in reproduction by overgrazing livestock or introduction of exotic species, for example (Alaniz 2014).

It is necessary to understand the effects of land use and land cover change at the ecosystem level. On a large scale, the destruction and fragmentation of native vegetation are part of a highly visible result of human soil uses (Bennett and Sanuders 2010 quoted by Alaniz 2014). At the global level, land use changes have been considered as one of the greatest threats to biodiversity because they cause not only the loss of vegetation cover but also the disruption of wild ecosystems into fragments of various sizes, hence the discontinuity and isolation of its biodiversity, which complicates each of the ecological functions and services of the ecosystem (Arriaga 2009 quoted by Alaniz 2014).

3 Importance of forest monitoring and remote sensing input

Forest monitoring is a major activity in today's forestry sciences, not only to gain knowledge of forest stocks and due to a modern perspective of inventories (Franklin 2001, Köhl et al. 2006 quoted by Zerda 2013), but also in order to relate research to the broad spectrum of other environmental sciences (Zerda 2007). The unique characteristics of remote sensing, a methodology that allows the simultaneous and repetitive observation of large territorial spaces, make the various available satellite databases a source of enormous value for the scientific community of various disciplines (Jensen 2007 quoted by Zerda 2013). El Chaco is the largest forest formation in Argentina, and it is under enormous pressure from the expansion of areas dedicated to extensive cultivation, with large losses of forest areas as a consequence (Argentina 2007 quoted by Zerda 2013). Currently, due to the advance of technology, it is possible to map and report on land uses, covering different countries and regions: There are initiatives that monitor deforestation, using satellite data of medium space resolution and based on visual methods (AVINA 2012 quoted by Zerda 2013).

Chuvieco (1995), quoted by Alaniz (2014), state that remote sensing offers a particularly effective tool for measuring changes in ground cover. Satellite image analysis is the most frequently used technique for mapping the changes in different covers, since it allows making observations of the terrestrial surface in a recurring way and to a very good scale, providing an alternative for more expensive methodologies such as aerial photography. In addition, large areas of land are covered with a single image.

The development of geographic information systems integrating data management programs, equipment and techniques, allows us to capture, manage, analyze and visualize spatial reference data, using information provided by satellites. These programs continue to be complex and constitute a fundamental tool to support natural resource management policies.

Many institutions offer free data which is useful for studies related to the forestry sector and one of the advantages is that they cover a fairly broad period of years. For example, the site Global Forest Watch, it lets explore the state of forests around the world using data layers.

It is possible to create customized maps of change, coverage and use of the forest. It is useful to continue to take advantage of these programs in a way that allows to improve the studies and to offer the society solutions to the current problems.

4 Malleco Province, Chile.

The Araucania Region is the IX region in Chile is located between the 37°35' and 39°37' southern latitude, from the border with Argentina to the Pacific Ocean.

According to the territorial information given by the Biblioteca del Congreso Nacional de Chile (BCN), the physical characteristics of the region are defined by the continuity of the principal units of relief of the country, i.e. the Andes mountains, an intermediate depression, the coastal range and coastal plains. The climate is defined by transitional characteristics from humid Mediterranean temperate climate to a rainy oceanic temperate climate. The vegetation is woody and abundant.

The Araucania Region has a surface of 3.180.347 ha. 30.3% of this surface is native forest, 19.88% are forest plantations (principally of *Eucalyptus sp.* and *Pinus radiata*) and 1.49% are mixed forests (CONAF, 2016). The region comprises two provinces: Malleco and Cautin. The Malleco province has 1.343.265 ha with 11 communes and the forestry industry is concentrated in it: Big national companies have been occupying and important part of the productive lands of the zone. The Cautin province has 1.837.082 ha with 21 communes and is its economic activity is principally characterised by trade focused on the services destined for the massive use of the population, such as the manufactured goods, and agricultural and livestock production (CNCA, 2015). In Figure 1 the distribution of the communes in the region is depicted.

Figure 1. Communes of Araucania region.

The climatic characteristics of the region allowed the development of a true southern jungle in the past, but following the intervention of man, it was replaced by grasslands for livestock and croplands. Real cleaning work was carried out in which trees were simply burned, which resulted in erosion problems in the Cordillera de Nahuelbuta (coastal range) and other sectors (BCN). "Currently, the forestry activity is the 2nd after mining" (Araya 2003). In figure 2 the land use of the region is depicted

In Chile, the Araucania Region is known for the "mapuche conflict" between mapuche people and the State of Chile. "This conflict began in the 1860s with the occupation of mapuche lands by the Spanish settlers also known as "Pacificación de la Araucanía (Araucania's Pacification)" to consolidate sovereignty in this area considered rebel" (Araus 2015)

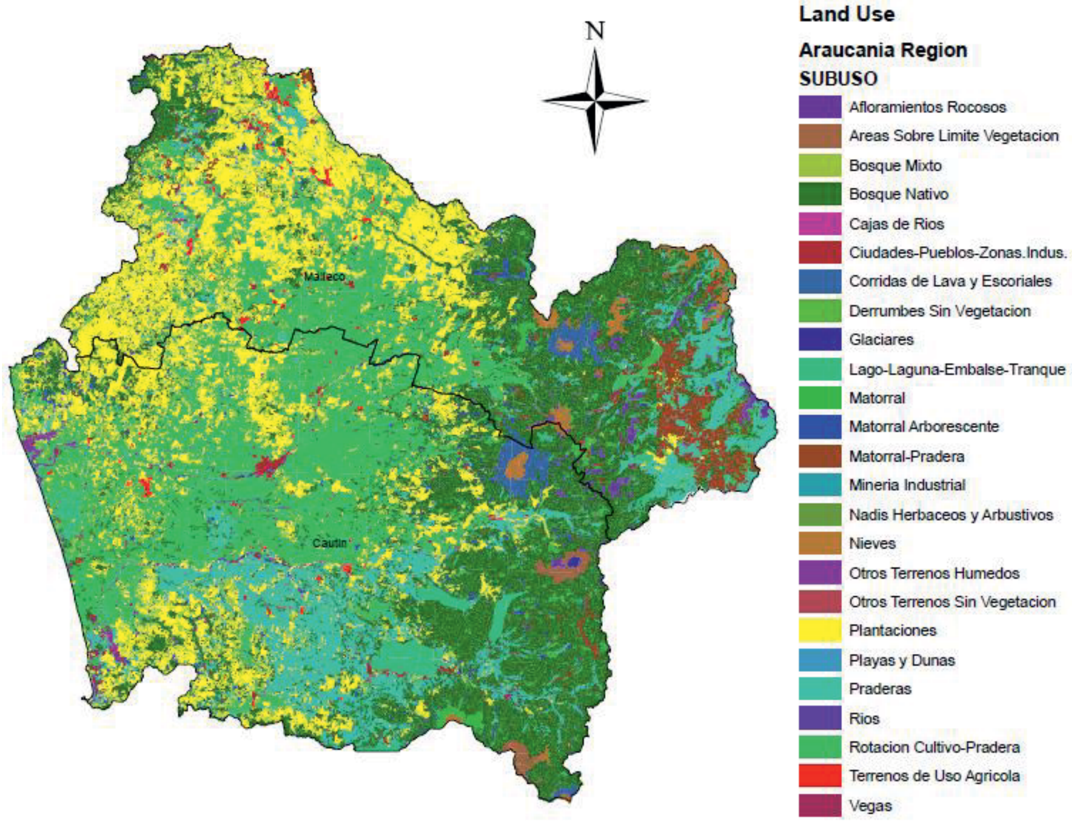

Figure 2. Land use of Araucania region (Based in the land use made by CONAF in 2013).

The Coastal range of La Araucania has suffered historically hard changes in the original coverage of the soil. The change in the land use began with the livestock farming Spanish. They initiated the destruction of native forests, for agriculture, timber and firewood extraction, and the production of carbon. Recently land use change has been caused by the impact of forests plantations. This situation has created a humanized landscape (Peña-Cortés et al. 2009).

Since 1931 there is a Forests Law in Chile that grants a tax incentive for natural or legal persons who reforest. However, despite this law, planting rates did not grow rapidly that's why in 1974 the Decree of Law N°701 (DL 701) on Forest Development was passed. Besides granting tax incentives for the ownership of forested land, it proposed to subsidize 75% of the net cost of afforestation. "This bonus accelerated the pace of plantations, especially in the

1980s, when plantations reached 1 million hectares with an average plantation rate of 80.000 hectares per year. This accelerated rate of growth of forest plantations rapidly began to cover large surfaces of land, especially from the IV to the X region" (Nazif 2014).

The main impacts that the above forest model legislation have caused in Chile have been, on an environmental level: native forest replacement, because a big proportion of exotic trees planted under the Decree of Law N°701 caused a decrease in the surface of native forest. In addition, forestry practices like clear felling of exotic species have caused the decreased of soil productivity because of the erosion associated with these practices (Andrade 2016).

Figure 3 shows the increase of forests plantations in Malleco between 1997 and 2013. The province has been covered by forests plantations in almost 65% except in the east because of the presence of the Andes mountain range. The most affected communes are Lumaco, Los Sauces, Ercilla, Collipulli and Angol.

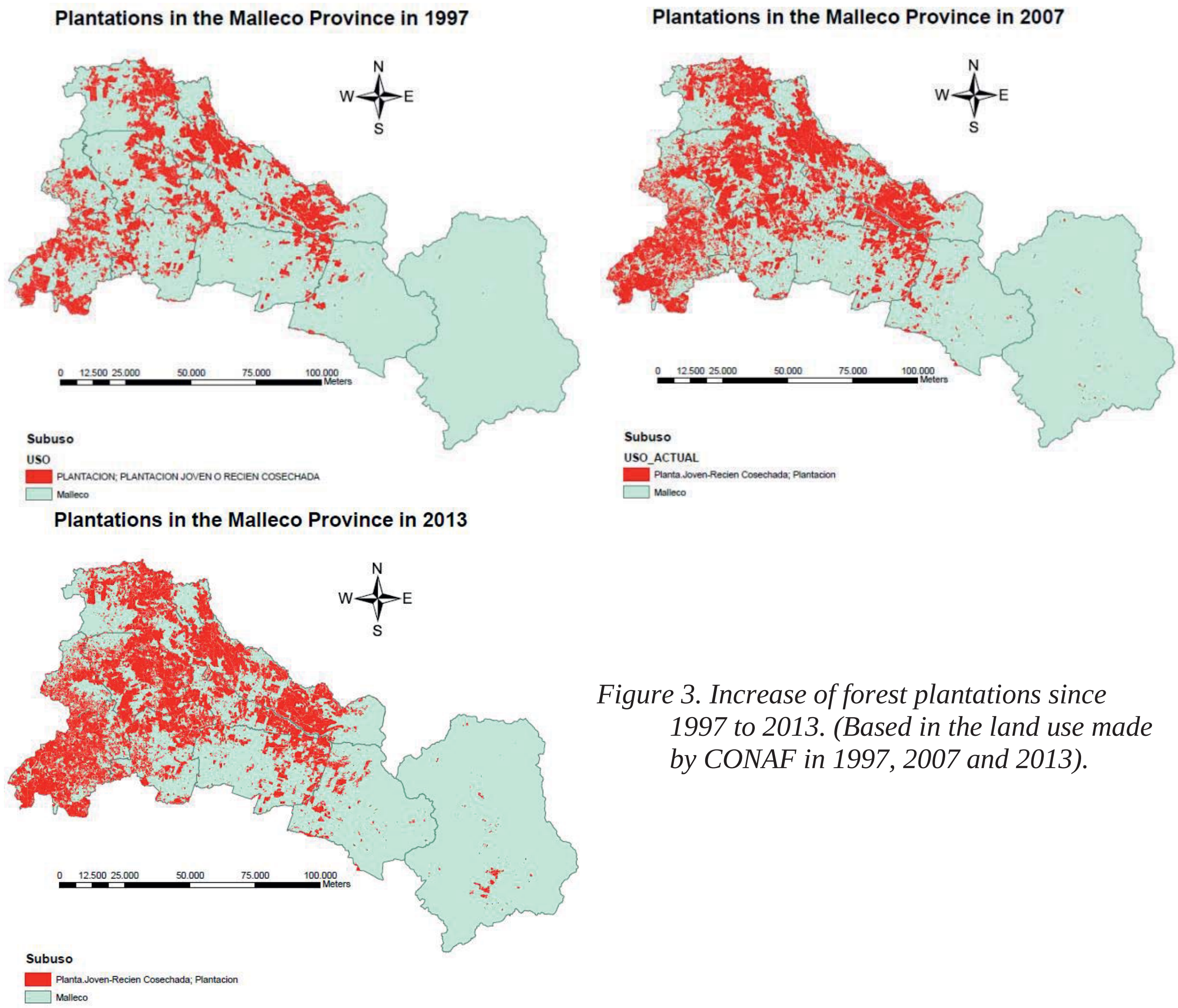

Figure 3. Increase of forest plantations since 1997 to 2013. (Based in the land use made by CONAF in 1997, 2007 and 2013).

The latest study realized by Sandoval et al. in 2014 shows that the forests plantations have increased by 9,3% in Malleco in a period of 6 years (Table 1), while in the whole country the increased was of 10,9%. This is due to the change of land use from agricultural lands, grasslands and shrubs and native forest.

Table 1. Land use surface balance, Malleco province (Sandoval et al. 2014).

Land use	2007		2013		Change	
	Surface (ha)	%	Surface (ha)	%	Surface (ha)	%
Plantations	317.994,92	23,5	347.510,52	25,9	29.565,54	9,3
Native Forests	492.210,17	32,1	431.195,29	32,1	1.985,12	0,5

5 Conclusions

The last decades, have seen a considerable change in land use. They territory has been changed for forests plantations or livestock farming, mainly to obtain the diverse products that the market demands. While the establishment of forestry plantations and areas destined for livestock in the region implies a greater economic increase allowing the obtaining of important products for the society such as wood, pasta cellulosic, meat, it is vital to continue implementing strategies by interdisciplinary groups where communities in the area in question can provide ideas and where specialized technicians contribute tools such as through remote perception for the monitoring, management or/and planning of such changes becomes clear. In this way, the analysis and decision-making can be enriched in order to achieve sustainability.

Latin America and other parts of the world, should try to detect the current challenges to the ecosystem and revert situations that contribute to reduce biodiversity and worsen soil conditions. It is necessary that every country has a land use to know exactly how to manage each part of it and obtain the maximum benefit without destroying the ecosystem.

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Chapter five
Methods in Remote Sensing

The role of Landsat time-series in forest dynamics research

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Abstract

Landsat time series of more than 30 years recently became available as the United States Geological Survey opened its archive in 2008. Therefore, research on ecosystem dynamics with Landsat time series have just begun in forestry research. This remote sensing time series is exceptionally long and offers a spectral, temporal as well as spatial resolution which is advantageous for researching into changes in forest structure, composition and cover. Methods on ecosystem dynamics can be differentiated into analyses on gradual change, seasonality, and disturbances. New methods on intra- and inter-annual analysis are being developed. Challenges like discontinuity due to cloud cover need to be overcome. Promising results offer algorithms using harmonic functions which can handle discontinuous time series and the fusion of the MODIS and Landsat time series. Future research on differences in reflectance values of the Landsat sensors and appropriate methods to model changes in seasonality and fine scale, low magnitude disturbances are needed. Analyses of Landsat time series give an exceptional opportunity to understand forest ecosystem dynamics and to relate them to current biodiversity patterns and the impact of ongoing global changes on forests.

Keywords: Landsat, times series analysis, forest dynamics, scales, forestry research

1 Introduction

Since the start of the Landsat missions in the 1970ies, Landsat images enrich ecosystem studies (Cohen & Goward 2004, Pasquarella et al. 2016, Wulder et al. 2016). Its spectral, spatial and temporal characteristics facilitate forestry research. Landsat data have been successfully used in different fields of forestry research, amongst others in forest inventory (Lefsky et al. 2001), resource assessment (Boyd & Danson 2005), forest cover mapping (Hansen et al. 2008) or change detection (Wulder et al. 2008).

However, the application of the complete Landsat time series, comprising over 30 years of data, has just been introduced into forestry research (Kennedy et al. 2010, Pflugmacher et al. 2013, Melaas et al. 2016 amongst others). The reason behind this is the opening of the Landsat archives by the United States Geological Survey (USGS) in 2008. Therefore, it is of current interest to further investigate long-term studies of forest dynamics with Landsat time series (Pasquarella et al. 2016, Wulder et al. 2016).

This project focuses on the question - In which way can the Landsat time series be useful for forest dynamics analysis. This shall be answered by a literature review and scientific experiences. Therefore, the study first gives an overview of the Landsat missions and characteristics. Secondly, Landsat time series analyses are discussed based on exemplary studies. This part is structured into the analyses of the time series components trend, seasonality, and disturbance.

2 Overview of the Landsat missions

2.1 Landsat history

The first Landsat sensor was launched by the National Aeronautics and Space Administration (NASA) in 1972 followed by seven further sensors until today (Table 1). The last successful Landsat missions were Landsat 5 in 1984, Landsat 7 in 1999 and Landsat 8 in 2013. The sensors evolved from the Multispectral Scanner (MSS) with 80 m or 40 m ground resolution and four or five spectral bands respectively (Landsat 1, 2 or 3), to the Thematic Mapper (TM) with a resolution of 30 m and seven spectral bands (Landsat 4, 5). The next sensor, the Enhanced Thematic Mapper Plus (ETM+) (Landsat 7), records eight spectral bands at a resolution of 30 m and the Operational Land Imager (OLI) used by the Landsat 8 mission has a resolution of 30 m and 9 spectral bands. The Landsat program is the longest running remote sensing mission covering the whole earth. In the USGS archive there are 1,988,982 images available for the TM, 1,858,501 images for the ETM+ and 385,345 images for the OLI sensor (status as of January 1, 2015) (Cohen & Goward 2004, Pasquarella et al. 2016, USGS 2016 a, b, Wulder et al. 2016).

Table 1. Comparison of the Landsat missions (Cohen & Goward 2004, USGS, 2016 c).

Landsat Mission	Sensors	Launch date	Spectral bands (in µm)								
			1	2	3	4	5	6	7	8	9
5	TM	1984	0.45-0.52	0.52-0.60	0.63-0.69	0.76-0.90	1.55-1.75	1.40-12.50	2.08-2.35		
7	ETM+	1999	0.45-0.52	0.52-0.60	0.63-0.69	0.77-0.90	1.55-1.75	1.40-12.50	2.09-2.35	0.52-0.90	
8	OLI	2013	0.43-0.45	0.45-0.51	0.53-0.59	0.64-0.67	0.85-0.88	1.57-1.65	2.11-2.29	0.50-0.68	1.36-1.38

TM= Thematic Mapper, ETM+= Enhanced Thematic Mapper Plus, OLI= Operational Land Imager

2.2 Landsat archives

The data recorded by the Landsat sensors were collected at International Cooperator Ground stations. The European ground stations owned by the European Space Agency (ESA) were located in Matera (Italy), Maspalomas (Spain) and Kiruna (Sweden). In South America, there were two ground stations located in Córdoba (Argentina) and Cuíaba (Brazil). The International Cooperators paid a fee to have the permission to collect and distribute the data (Wulder et al. 2016).

In 2010, the USGS (United States Geological Survey) started the Global Archive Consolidation (LGAC) initiative to join all Landsat data in one archive at the Earth Resources Observation and Science (EROS) Center in Sioux Falls (USA) to make it accessible to research. However, not all the Landsat data are available yet for particular regions at certain time periods. In Middle Europe for example, there are no Landsat images available in the USGS archive for longer periods in the 1990ies. These data are still owned by the ESA. The USGS archive stored 57% of the Landsat images by January 1, 2015 (Wulder et al. 2016).

Nowadays, the Landsat mission operations are in the hand of USGS with technical support of NASA. Therefore, the whole Landsat 8 data set is available in the USGS archive (Pasqurella et al. 2016, Wulder et al. 2016).

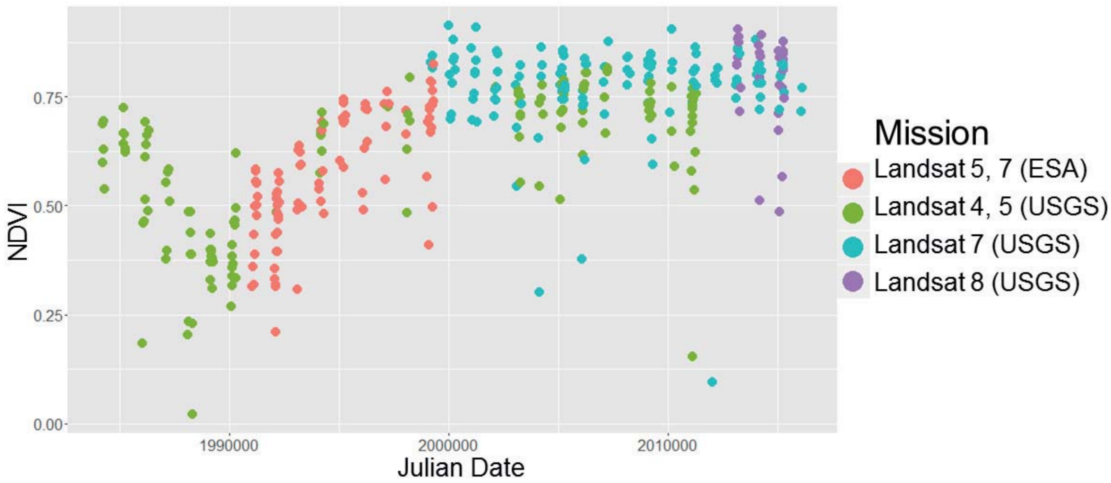

Figure 1. Time series of Landsat 4, 5, 7 and 8 of the combined USGS and ESA archive of an exemplary site at the Exploratories site Schorfheide-Chorin (SEW 11) within the framework of the DFG project Biodiversity Exploratories.

2.3 Characteristics of the Landsat time series

The Landsat time series can be characterized by their spectral, temporal and spatial resolution as well as the time span of recording. The spectral resolution ranges from the visible, near-infrared to the shortwave-infrared (Table 1) facilitating studies on vegetated areas or covers (Cohen & Goward 2004). It is especially used to create vegetation indices like the Normalized Difference Vegetation Index (NDVI), describing the change in greenness, Enhanced Vegetation Index (EVI) or the Normalized difference moisture index (NDMI), which gain their validity by using the relation of the near-infrared and red, or mid-infrared bands. The vegetation indices are useful to describe the condition of the forest, like the species composition, and its temporal dynamics (Cohen & Goward 2004, Vogelmann et al. 2012, Melaas et al. 2016, DeVries et al. 2016). The temporal resolution of 16 days allows for investigations of the phenological cycle and inter-annual temporal changes in forest ecosystems (Melaas et al. 2016). The remote sensing time series of over 30 years offers to research the dynamics of the ecosystem (Cohen & Goward 2004). This exceptionally long time series is especially valuable for forest ecosystems due to their long turnover times (Attiwill 1994). To investigate forest ecosystems with a high heterogeneity in forest structure or composition, a high spatial resolution, like that of the Landsat images with a resolution of 30 m, is advantageous (Rao et al. 2015).

In comparison to the Moderate Resolution Imaging Spectroradiometer (MODIS) by the NASA, another remote sensing mission widely used in ecological and forestry studies, the Landsat time series have the disadvantage of a lower temporal resolution (Table 2). However, Landsat images have a higher spatial resolution and the series comprises a longer period (Vermote et al. 2011, Rao et al. 2015, USGS 2016 a, b).

Table 2. Comparison of Landsat 5, 7, 8 and MODIS (USGS a, b, c, Vermote et al. 2011)

	Landsat 5, 7, 8	MODIS
Spatial resolution	30 m	250 / 500 m
Temporal resolution of each sensor	16 days	1 - 8 days
Time span	1984 - 2016	1999 - 2016

3 Analysis of temporal dynamics in forest ecosystems with Landsat time series

Forest ecosystems are not stable but underlie temporal dynamics of discrete, periodic or directed character, comprising different temporal scales. The Landsat time series have been used to investigate those trends, seasonal variations and disturbances (Attiwill 1994, Kennedy et al. 2010, Zhu & Woodcock 2014, Vogelmann et al. 2016).

In most studies on Landsat analysis, the time series of a vegetation index is regarded. Amongst others, the indices that have been used are the NDVI (Huang et al. 2010, Vogelmann et al. 2012, Vogelmann et al. 2016, DeVries et al. 2016), EVI (Melaas et al. 2013), the NDMI (DeVries et al. 2016), the Tasseled Cap Wetness, Greenness, Brightness and Angle (Cohen et al. 2010, Kennedy et al. 2010, DeVries et al. 2016), or the normalized burn ratio (Cohen et al. 2010, Kennedy et al. 2010, DeVries et al. 2016). These time series of indices are describing for the dynamics of the forest ecosystem over time.

3.1 Trend analysis

The trend of a time series is the systematic change that has no periodicity (Cowpertwait & Metcalfe 2009). In forest ecosystems, climate change, like long-term shifts in temperature and humidity, or stress induced by pests or invasive species can affect the species composition, the biomass and the structure of forests. Long-term gradual changes cannot be detected by the comparison of the images right before and after an event, but by analyzing a series of images (Vogelmann et al. 2016).

In most studies, yearly data are used for the analysis of gradual changes within Landsat time series. One image per year or of every second year of the same time in the growing season is selected to ensure the comparability of the images (Kennedy et al. 2010, Vogelmann et al. 2012, Vogelmann et al. 2016, DeVries et al. 2016).

The simplest models to investigate a trend are linear regression models and estimations with the help of the slope if there is a significant trend (Vogelmann et al. 2012, DeVries et al. 2016). Vogelmann et al. (2012) implemented these regressions over specific time spans and could identify gradual changes and their direction, time as well as magnitude. The Landsat-based detection of Trends in Disturbance and Recovery algorithm (LandTrendr) of Kennedy et al. (2010) is based on temporal segmentation. The first most complex model contains segments between every time step. This model is iteratively simplified. Therefore, gradual changes as well as major disturbances can be detected. Cohen et al. (2010) use a similar approach by dividing the time series into segments. Their tool, called LandSync, distinguishes between disturbance, recovery and stability, the latter two categories describing gradual changes.

A new method, the Continuous Change Detection and Classification algorithm (CCDC), allows to use all the available observations without cloud contamination of the Landsat time series (Zhu & Woodcock 2014). The CCDC regards each pixel not the whole image and fits harmonic functions to describe the seasonality of the forest ecosystem of each year. Gradual changes can be detected regarding the slope of the trend (Zhu & Woodcock 2014, Vogelmann et al. 2016).

The BFAST algorithm (Breaks For Additive Seasonal and Trend) can be used for yearly data as well as times series containing seasonal changes. For seasonal data the time series is decomposed in a trend, seasonal and remainder component. The trend is modelled in between different breakpoints, which can be disturbances (Verbesselt et al. 2010 a). DeVries et al. (2016) used this method to determine the trend before and after major breakpoints or disturbances in the Landsat time series.

3.2 Disturbance analysis

A disturbance is defined in ecology as a "[…] relatively discrete event that disrupts the structure of an ecosystem, community or population […]" and occurs over a short time period (Pickett & White 1985). Disturbance events "[…] alter system state and the trajectory of an ecosystem […]" and cause spatial and temporal heterogeneities (Turner 2010). In forest ecosystems, disturbances can be of abiotic/physical (e.g. fire, windfall, droughts) and biotic/biogenic (e.g. insect outbreaks, pathogens) character. In managed systems, there are additionally anthropogenic disturbances (e.g. harvesting, deforestation, shifting cultivation, urbanisation) (Attiwill 1994, Turner 2010). In the case of a severe disturbance events, the sudden change in the forest structure leads to an abrupt spectral change. This spectral change can last over a longer time span of several years in forest ecosystems (Huang et al. 2010).

Similar to the trend analysis mostly annual data are used for the disturbance analysis. The LandTrendr algorithm (Kennedy et al. 2010, Pflugmacher et al. 2013) can also detect breaks in the time series with the temporal segmentation approach. These breaks tend to be attributed to greater disturbance events.

Another approach using annual and biannual Landsat time series is the vegetation change tracker (VCT) algorithm introduced by Huang et al. (2010). Therefore, time series of the integrated forest z-score (IFZ) calculated from the bands 3, 5 and 7 of the TM and ETM+ sensors are regarded. The IFZ is an inverse index of forest likelihood. A value close to 0 shows a higher likelihood of being forest area while larger values indicate non-forest areas. Based on the time series of the IFZ each pixel is classified as “Persisting forest”, “Forest disturbance”, “Afforestation” or “Persisting non-forest”, depending on the magnitude of the IFZ and its change over time (Huang et al. 2010, William et al. 2013).

Within BFAST, Verbesselt et al. (2010 a) estimate breakpoints in the trend and seasonality of the time series with the ordinary least squares residuals-based Moving SUM test (Zeileis 2005). The CCDC algorithm considers all available data, identifying disturbances by the comparison of predicted values of the model with a consecutive set of actual observations. This method enables to detect abrupt changes in the time series (Zhu & Woodcock 2014, Vogelmann et al. 2016).

3.3 Seasonality analysis

Seasonal variations are repeating or periodic patterns, reoccurring each year or over a longer timespan (Cowpertwait & Metcalfe 2009). The phenological cycle with green-up and senescence is the prevalent pattern in the temperate forest ecosystems (Vogelmann et al. 2016).

The TIMESAT software consists of different least-squares fits methods to derive seasonality parameters, like the beginning and end of growing season, the length of season as well as the amplitude of the highest spectral value (Jönsson & Eklundh, 2002, 2003, Eklundh & Jönsson, 2015).

Melaas et al. 2013 models the spring greenup and autumn decrease in greenness with the EVI. These two phenological models of each year are then compared to the long-term mean phenology models to find out changes in seasonal variables.

The CCDC algorithm uses Fourier’s harmonic functions to describe the phenological cycle represented in the seasonal change in the spectral signature. Therefore, changes in the beginning and end of the growing season can, for example, be detected (Zhu & Woodcock 2014, Vogelmann et al. 2016). BFAST also models harmonic functions to describe the seasonal component in between detected seasonal breakpoints (Verbesselt et al. 2010 b).

4 Discussion

Landsat provides a quantity of data reaching back in time with a relatively fine spatial resolution that no other remote sensing time series can provide. Its spectral resolution is suitable to study vegetated ecosystems like forests. (Kennedy et al. 2014). However, some challenges remain when analysing Landsat time series:

There are still large gaps in the Landsat time series of the USGS archive for several regions. The reason is the ownership of parts of the Landsat 4, 5 and Landsat 7 data by other agencies. In Europe for example, most of the images in the 1990ies are missing in the USGS archive. The ESA made its Landsat archive available in 2011. Therefore, it is possible to gain a longer time series for study areas in Europe. However, several pre-processing steps need to be implemented to be able to analyse the data from both of the archives. For example, the data need to be georeferenced as different reference points are used by USGS and ESA. Moreover, the surface reflectance needs to be calculated for the ESA data with the LEDAPS software which is provided by the USGS. Thus, comparable reflectance values for USGS and ESA data can be assured. Another step is to mask the cloud, cloud shadow and snow pixels for both data sets. Finally, the sensors might need to be adjusted. The pre-processing takes a long time, discouraging researchers from using the complete time series for these regions. Nonetheless, the efforts of the LGAC are a major step forward (Vogelmann et al. 2016, Wulder et al. 2016).

Moreover, the cloud cover might cause lags in the time series. Consequently, the discontinuous time series exacerbates seasonal analysis and the modelling of the phenological cycle. Until now, MODIS time series are more frequently used for seasonality analysis than Landsat series, as the MODIS 8-day composite avoids the discontinuity by the composition of the data. (Vogelmann et al. 2016). Melaas et al. (2016) developed a method to analyse changes in seasonality with Landsat time series. However, the authors recognized that a low cloud cover is required. The CCDC algorithm, by contrast, can deal with the discontinuous time series and therefore offers new opportunities to analyse seasonality (Zhu & Woodcock 2014). Another approach is the creation of dense time series by the fusion of Landsat and MODIS data. Gao et al. (2006) developed the STARFM algorithm to fuse both data sets and to get the fine spatial resolution from the Landsat images and the fine temporal resolution of the MODIS data. However, further research is needed on the seasonal component in Landsat time series (Vogelmann et al. 2016).

The Landsat time series is an important source for trend analysis. For inter-annual analyses it is more likely to find one Landsat image per growing season which has a low cloud cover. Beside the CCDC algorithm, including all clear pixel values, other algorithms, which demand for continuous time series (e.g. BFAST) can also be used. For trend analysis differences in the spectrum of the sensors, especially TM/ETM+ and OLI need to be considered. Research on the comparison of the reflectance of the single bands and vegetation indices of the sensors came to different results. Studies suggest (1) not to adjust the series, as the sensor differences are rather small (Li et al. 2014) or might be smaller than the atmospheric differences between the compared images of the regarded sensors (Vogelmann et al. 2016). Others propose to (2) adjust the Landsat 8 data with linear models (Flood 2014) or to (3) account for differences in time series models by including a categorical variable describing the sensors (Holden & Woodcock 2016).

The introduced methods for the detection of disturbances in Landsat time series are mostly valuable for detecting severe disturbances like fire or deforestation. Small scale and low magnitude disturbance events, like selective logging or wind throw of single trees, are hard to detect with most of the algorithms (Huang et al. 2010). The identification of outliers, for example very low NDVI values in a NDVI time series indicating cloud, haze or snow, is very important for disturbance analysis. These low values might otherwise be detected as a misidentified disturbance (Kennedy et al. 2010). Moreover, knowledge on the study site is needed to confirm the disturbance event. Historical data of forest managers or on forest inventory monitoring might be helpful (Vogelmann et al. 2016).

5 Conclusion

The Landsat time series analysis in forestry research is one of the most recent research areas. Especially regarding the detection of fine scale, low magnitude disturbances and seasonality analysis, further research is needed. The CCDC algorithm is a promising method, as it can model and detect trend, phenology and disturbances from the Landsat time series. The information on ecosystem dynamics gained by Landsat time series is of high interest for biodiversity research. The temporal dynamics of the forest patches can contribute to understanding the spatial heterogeneity in biodiversity. It is also of interest to investigate the alterations and trends of the forests' condition and quality with regard to global change, including climate, environmental, ecological as well as land-use and land-cover change.

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Landsat archives

Landsat 4-5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) Surface Reflectance data courtesy of the U.S.

Geological Survey. Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+) 1992 – 1999. Data provided by European Space Agency.

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Fire risk model for informed decisions to prevent forest fires in dry forest in Costa Rica

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Abstract

Of the current global challenges, perhaps the most important one is, perhaps climate change, which affects countries differently. This results in a negative impact on forest ecosystems that become highly vulnerable to forest fires, especially in tropical dry forests. Seasonal events in the forests of the province of Guanacaste, Costa Rica, give rise to recurrent fires, however, this situation is aggravated by the effect of droughts that intensify with the El Niño/Southern Oscillation (ENSO) phenomenon. The present work presents a model of fire risk mapping based on the adaptation of the Byram formula and the FireStar model, which are based on the traditional components of the fire triangle, indicated by namely; Weather, fuel, and a source of heat. In general terms, cartography consists of two phases, the first corresponds to the development of a static risk map, which is in turn the basis for the development of dynamic mapping. In dynamic cartography, daily forecasts (at 4 am and 11 am by the National Meterological Institute) of humidity, maximum temperature, precipitation and wind are used to update the daily fire risk. The daily models can be consulted at: http://incendiosforestales.cr/. This work was part of a pilot study which was conceived in triangular form between the countries of Morocco, Costa Rica and Germany and in which several institutions have participated. This mapping is intended to provide a planning tool that allows anticipating the management actions that must be carried out day by day in the season of occurrence of forest fires in the Guanacaste Conservation Area (GCA). Until now, and according to the GCA, the fire management plans do not contain a predictive part that provides technical elements for decision making before the possible appearance of forest fires.

1 Introduction

One of the current global challenges, and perhaps the most important one, is climate change, which affects countries differently. Climate change is manifested primarily by the upward trend in temperature and the frequency of extreme events, such as heat waves, (IPCC, 2014). This results in a negative impact on forest ecosystems that become highly vulnerable to forest fires, especially in tropical dry forests (TDF). Costa Rica is not immune to this scourge, with about 537,431.07 ha affected in the period 1998 to 2014 (CONIFOR, 2015).

Guanacaste Conservation Area (GCA), protects one of the most threatened habitat today, the tropical dry forest (TDF). At the arrival of the Spaniards in 1492 there were about 550,000 km² of dry forest in Mesoamerica (Jansen, 1988), today, just 42% of all TDFs remain in the Americas (Portillo-Quintero, 2010). Tropical Dry Forest are defined as seasonal ecosystems with close to 100% deciduous species, an average temperature of 25ºC, precipitation from 900 to 2000 mm, and a dry season between 5 to 6 months.

Seasonal events in the forests of the province of Guanacaste, Costa Rica, give rise to recurrent fires, however, this situation is aggravated by the effect of droughts that intensify with the "ENSO " phenomenon, however, the statistical relationship between forest fires in Costa Rica and ENSO is not demonstrated (Villalobos et al. n.d).

Seasonality, the "ENSO[1]" effect and climatic variations generate consequences that may aggravate the intensity and recurrence of forest fires, which in turn affect the resilience of dry forest ecosystems. This means that the usual forest fire prevention and control practices and strategies must be adapted to new needs and changes.

In many parts of the world different models describing fire behavior have been applied, however, most of these models have the disadvantage of not working well if they are simply extrapolated (Faour et al., 2006). The use of physical models such as FIRETEC and FIRESTAR have shown goodness and are recommended in the absence of specific local models (Larini et al., 1998; Morvan and Dupuy, 2001).

The present model of fire risk mapping is based on the adaptation of the formula of Byram (Byram, 1959) and the model FireStar[2]. We study the mechanisms of propagation and the intensity of a fire, which, being a fundamentally physical phenomenon, is mainly related to the traditional components of the fire triangle, as indicated by Countryman (1972); weather, fuel, and a source of heat. In general terms, cartography consists of two phases, the first corresponds to the development of a static risk map, which is in turn the basis for the development of dynamic mapping. In dynamic cartography, daily forecasts (at 4 am and 11 am by the National Meterological Institute) of humidity, maximum temperature, precipitation and wind (zonal and southern) are used to update the daily fire risk. The daily models can be consulted at http://incendiosforestales.cr/. This work was part of a pilot study which was conceived in triangular form between the countries of Morocco, Costa Rica and Germany, in which several institutions have participated.

Fire propagation models are tools for predicting the rate of fire front progression when propagation conditions are met, mainly wind speed, wind direction, slope and fuel state. Generally, according to the classification of propagation models, there are 3 families of fire prop-

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[1] El Niño-Southern Oscillation phenomenon (ENSO)
[2] available at: http://www.eufirestar.org/en_projet.php

agation models (Catchpole and de Mestre, 1986; Weber, 1991; Burrows, 1994; Pastor et al., 2003; Fernandes, 2009):

Empirical models: mainly aimed at statistically correlating the fire propagation rate as a function of environmental conditions. They are based on observations and measurements on real or experimental fires. The best known models are the Canadian model FWI (Forestry Canadian Fire Danger Group, 1992) or the Australian model (Sneeuwjagt and Peet, 1985). These models have the disadvantage of not being extrapolable in regions other than those in which they were developed.

Semi-empirical: based on the principle of conservation of energy, it is based on the idea that the energy transferred to the unburned vegetation is proportional to that released by the burned vegetation, these models requires several laboratory experiments for the Determination of the factors of propagation. They have the advantage of being flexible and universal. The best known ones are the model of Rethermel (Rothermel, 1972) and Behave. The latter one is however inconvenient for the struggle of firefighters since it was developed under non real laboratories conditions.

Physical models: These to explain the propagation of fire through complex mathematical formulas translating the fundamental principles of heat transfer and the physicochemical characteristics of combustion. The most important benefit of these models is understanding the mechanisms of fire propagation, experimental design, and interpretation of field trials (Burrows, 1994). The best known are the Firetec and FireStar models Larini et al. (1998); Depuy and Morvan (2005).

This mapping is intended to provide a planning tool that allows anticipating the management actions that must be carried out day by day in the season of occurrence of forest fires in the ACG. Until now, and according to the ACG, the fire management plans do not contain a predictive part that allows having technical elements for decision making before the possible appearance of forest fires.

2 Study area

The GCA is located in the province of Guanacaste, Costa Rica, which is a part of the Guanacaste Conservation Area in Costa Rica (10º 48” N, 85º36” W). This site covers an area of 50,000 ha, receives 1720 mm of annual rainfall, has a mean annual temperature of 25°C and a 6-month dry season (Dec-May) (Kalácska et al., 2004).

Specifically, the study area, for this pilot study, corresponds to the protected areas of the Santa Rosa (SNP)and Guanacaste National (GNP) Parks, the Forestry Experimental Station (FES) and Wildlife Refuge of Junquillal (RVSJ), of the GCA which are susceptible to damage by forest fires. The area of an average elevation above sea level between 650 and 900 meters was taken as a non-fire line. A buffer area of 1 km was included outside the protected areas. It is important to mention that in Costa Rica, forest fires are controlled only within protected areas.

3 Methods

The fire risk is composed by two main concepts, one is the danger and the second one is vulnerability. Due to the seasonality of the GCA the fuels are available to be burned in the dry season. That makes the vulnerability an intrinsic factor. The second part, danger is composed by two main factors, one is the fire intensity, and the second one is the ignition probability. At this point we combined the intensity and the ignition probability to get the final output of "Static Risk" as can be seen in figure 1. The part of the dynamic risk map is explained in section3.3.

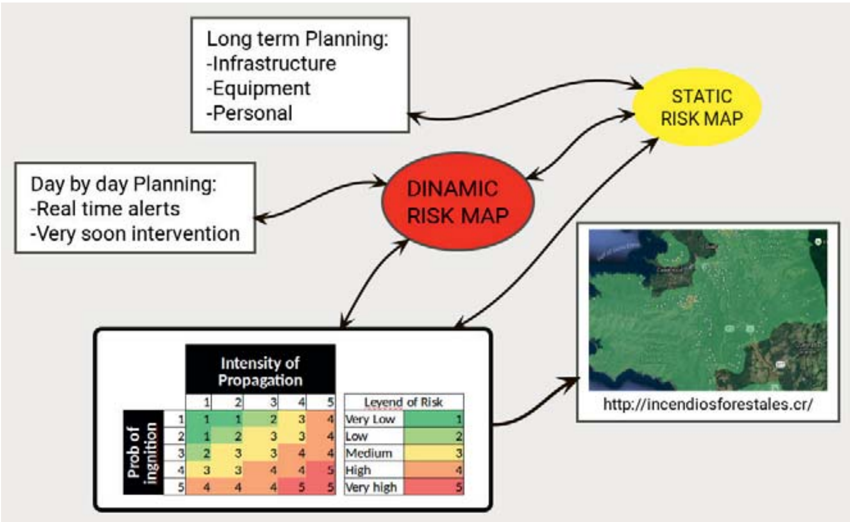

Figure 1. General scheme of the construction of fire risk for the study area

3.1 Fire intensity

The fire intensity is calculated as a function of plant biomass (BioT), speed of spread and a constant commonly bound to 18,000 J for the mean heating value of wood and plants (Byram, 1959), as follows:

$$I=C*BioT*Vp \quad [\text{kWm-1}] \qquad (1)$$

Where:

C is the constant of calorific power in, *Bio* is the consumable biomass (Kg/m^2) and *Vp* is the speed of propagation in m/sec. *I* is closely related to the development of the vegetation (succesional stage), and thus it is very variable in time and space, depending on the availability of fuel, past fires and fuel management.

3.1.1 Biomass of fuels

For the elaboration of the fuel map, first the successional states were identified, later they were grouped into classes that present a similar behavior in terms of forest fires. In view of the fact that post-mortem surveys of fires show that only thin fuel (leaves, branches) less than 6 mm thick participates actively in the fire propagation, the biomass have to be reduced to the thin fuel.

Once field surveys are mapped, the following formula has been used to convert stand types into biomass fuel types (Alexandrian et al., 1999).

$$|BioT = \sum_{i=1}^{n}(PV_i * D_i * PC_i) + BL + BN[\mathrm{kg/m^2}] \qquad (2)$$

Where:

BioT: total biomass in fuel in (kg/m2)

PVi: Phytovolume the type of fuel i is the product of height by percentage recovery.

D_i : Density of the grouping of the case i in kg per metre3, is the density of the species. This is a coefficient that transforms the phytovolume biomass.

PC_i: Phytomass consumable i (in %), the percentage of biomass fuel actively involved in the fire spread (thin elements smaller than 6 mm in diameter). This coefficient is given by expert estimates according of the similarity of species in a given stratum.

B_L: The biomass of litter.

B_N: The biomass of necromass.

The form of evaluation proposed originally by the Moroccan model, is the collection of information a single time for each polygon, this is done because of homogenous conditions within each polygon. For the case of the GCA, several repetitions were made in the polygons, this to better capture the variability between polygons. Only the values were reported for each polygon. For each polygon a randomly assigned points were assigned which is where the information is captured, using the QGIS (Quantum GIS Development Team, 2012) random point generation tool. From that point, the possibility of collecting data in two other sites within the same polygon was evaluated, if it presented changes in its structure that can affect the behavior of a forest fire. The final sample size was of 128 points. Once the point in the field corresponding to the polygon is located, the forest fuel coverage is evaluated in a 10 meter radius (approximately 12 steps). The field variables taken in the field are presented in Table 1 and the schematic diagram of the process is shown in figure 2.

Table 1. Example of the variables acquired in the field.

Variable	Value
Stratum	
Inflamability	
Consumable Biomass	
Density of grouping (kg/m)	
High (m)	
Representativeness (%)	
R (%) Necromass	
R (%) litter	
Dept of litter layer (cm)	
High of the first branch (m)	

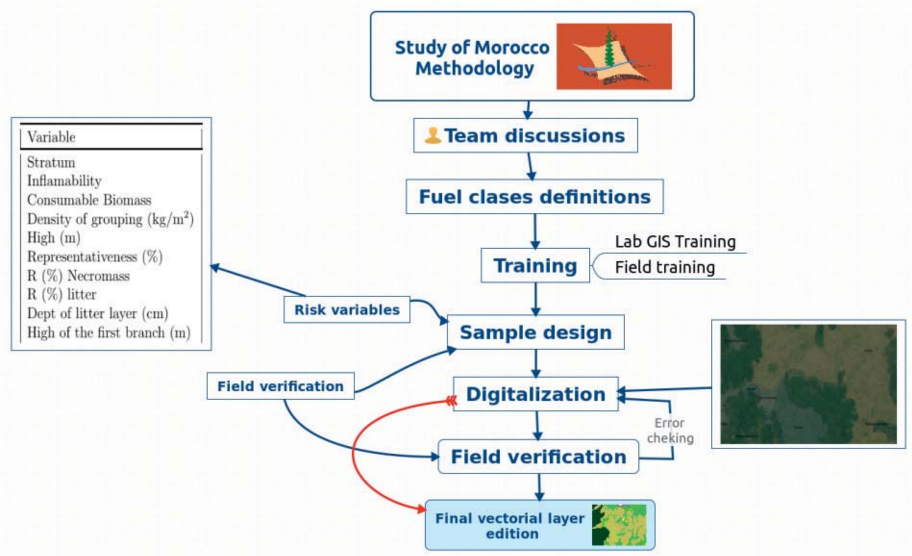

Figure 2: Diagram of the process for the fuel map.

3.1.2 Speed of spread

The propagation speed is influenced by the wind conditions and the water content of the plants. These parameters must be determined by the reference conditions.

3.1.3 Reference conditions

Reference conditions are used for mapping the propagation velocity, these conditions ware modified from Alexandrian and Rouchdi (2006) as follows:

- The largest fires recorded in the area and their starting coordinates.
- The predominant direction of the wind
- wind speed
- humidity

For largest fires we use the GCA fires data base from 1998-2016 and the historical records of wind (zonal and meridional) an humidity form the National Meteorological Institute of Costa Rica (NMI). With this two data bases, we extract the meteorological conditions of each largest fire (>100ha).

For the spatial distribution of winds, we use the software "WindNinja[3]" (Butler et al., 2014) which is a software especially developed for the spatial simulation of the winds, for example, for prediction of the wind behavior. We modeled the wind at 10 m from the ground. We use the spatial resolution of 30 meters which is similar to the digital elevation model (DEM) from the NASA (2000).

3.1.4 Velocity of propagation

For the velocity of propagation, the parametric equations obtained by interpolation from a set of numerical simulations based on FireStar physical model seems the well adapted to such applications in the absence of local model (Alexandrian, 2007).

$$Vp = 0.0025 * Vo(-0.02 * H + 10.5) * \ln(VV - 0.3) * \exp\left[0.07 * P * cos(Ex - DV)\right] \quad [\mathrm{m\,s^{-1}}] \quad (3)$$

Where:

BioT: total biomass in fuel in (kg), : Initial propagation speed without slope or wind in , *H*: Relative humidity in %. *VV*: Wind speed in m per second , *DV*: Wind direction in degress, Ex: Aspect in degress, *P*: Slope in degress.

Alexandrian and Rouchdi (2006) make the following weighted function of the flammability of fuel type:

$$Vo = I * (1 + (100 - \sum(H_i * R_i)/\sum(R_i)/100))[\mathrm{m\,s^{-1}}] \quad (4)$$

Where: *I* is the average fuel type flammability which is relative to the moisture content, *H* is the Hight of species in m, *R* is the recouvrement of species as fuels in m².

The relative humidity map was obtained after interpolating the grid points provided by the NMI using the interplator weighted distance inverse (IDW).

We use the approximation of Albini's (Albini, 1981) model presented by Nelson and Adkins (1986) as follows:

$$H = \frac{aI_B}{U}[\mathrm{m}, a = 1/360] \quad (5)$$

Where: *H* is the Flame height in , *U* is the ambient wind speed in .

The height of the flame combined with the data on the height of the first branch of each type of fuel will allow the detection of areas where the risk of crown fire is high. However given

[3] Available in: http://www.fs.fed.us/rmrs/tools/windninja

the types of fuels that are present in Guanacaste Conservation Area, we assign fixed values for the each type of fuels, as we know that the risk of crown fires is too low.

3.2 Probability of ignition

The three elements that are needed to start a forest fire are the climatic factor, humain pressure and fuel. Those three elements are part of the fire triangle. Thus, the probability of ignition is defined by three main elements. The first is the combination of the topographic and clima conditions, which is the aspect of slopes and the wind. In our case we use the same model of wind from the section 3.1.3. We derived this aspect from the DEM (NASA, 2000).

The second side of the triangle is the human pressure. We quantified this issue by mapping all ignition points of the historical fires. These points were supplied by the Fire Protection Program of GCA. This data base containes records of every single fire from 1998 to 2015. To create a surface from the points, we use the kernel interpolation method, which is a variant of a first-order local polynomial interpolation (Hoerl and Kennard, 1970).

The third side of the triangle is the fuel flammability, which represent the plant ability to burn in the presence of heat source. this part is estimated by the average of flammability index of each stratum.

3.3 Dynamic risk map

The dynamic risk map update the intensity of propagation and the probability of ignition maps with the climatic information provided every day by the National Meteorological Institute (NMI). The NMI use the Weather Research and Forecasting System to update a systematic grid of every two kilometers of 539 points for GCA. The variables of rain, relative humidity, wind and temperature are updated with prognoses made at 4 am and 11 am every day. The system goes to the NMI's servers and take the prognoses and updates the intensity of propagation and the probability of ignition maps twice per day. The final outputs can be access online in: http://incendiosforestales.cr/. The final cartography on the Web was developed by the ADDAX company based on the support of the Moroccan counterpart. This platform presents a very interactive way for the end user. However, it should be mentioned that the current Web system presents the organization and systematization of much information that can be used for accountability.

4 Results and discussion

The results of the process of mapping and collecting the parameters for the determination of the static risk are presented in figure 3, where the maps of probability of ignition and the map of intensity are evaluated. These maps cover 75.3 % of the protected wilderness areas of the GCA, since GCA is comprised of 349025.01 ha, which integrate agroforestry and wild protected areas.

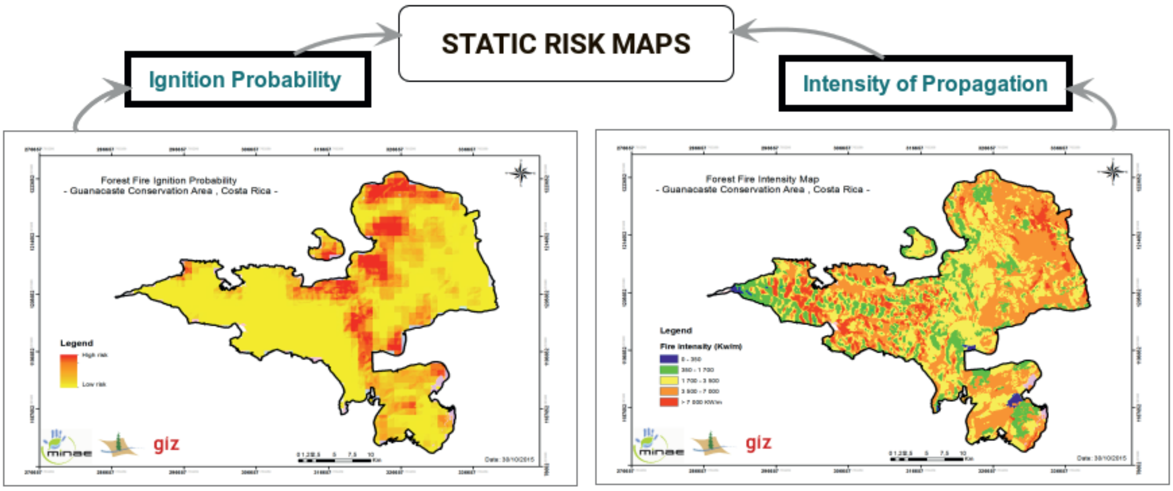

Figure 3. Static risk maps: Ignition probability (left) and Intensity of propagation (right)map

We use the quantiles to calculate the areas in each Risk classes, as it is shown in table 2. On the one hand, the intensity output shows a more homogeneous risk distribution within the classes. On the other hand, the ignition probability shows that just the 10,4% of the area is in high or very high risk. This explains why human pressure is not homogeneous in space. Similar results were found in the north region of Morocco by Assali et al. (2016).

In the GCA the fires are, to 99%, caused by the human being (CONIFOR, 2014). The previous fact means that there is a concentration or zones where the historical recurrence of fires is very high. That is why integrating wind to the risk of probability of ignition, complements very well the making of decisions to avoid fires of high magnitude. The model uses the concept presented by Mangiavillano (2008) where the fire is the product of social and environmental forces.

From a management perspective, the overlapping of the two risk maps then generates an overall risk index that provides tools to both identify areas that are subject to a high risk of ignition and also to identify areas where fires would be generated with high ecological impact by burning large areas (Syphard et al., 2007).

Table 2: Main results of the Ignition and Intensity risk maps

Risk class	Ignition		Intensity	
	Ha	%	Ha	%
Very low	30 812	37,6	15 755	18,6
Low	30 374	37,0	17 681	20,8
Medium	12 208	14,9	18 504	21,8
High	8 398	10,2	16 397	19,3
Very high	198	0,2	16 481	19,4

In terms of prevention and as indicated in the figure 1, the static risk model allows, on the one hand, for long-term planning of the activities related to equipment, infrastructure and personnel recruitment, as well as fuel management, lowering the fuel load in areas of high danger.

On the other hand, the static risk update, that is, the dynamic risk, allows the day to day monitoring, with early alerts and personnel mobilization according to the alerts.

Web-based mapping offers an easy solution to the accessibility issues of up-to-date information. The effort of many people and institutions can be reflected in the web application that can be accessed from any standard internet browser, such as a smartphone. This ensures that civil society, forest firefighters and decision-makers have timely access to information improve performance in reducing the incidence of forest fires.

5 Conclusion

In the sense of the ecological management of fire, the risk model allows to have a planning tool, in the medium term (static risk map) and in daily operational planning (dynamic risk map) through the automatization of the whole process, in order to update the fire risk predictions twice a day.

6 Acknowledgments

This work was carried out with the aid of a grant from the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Germany, Haut Commissariat aux Eaux et Forêts et à la Lutte Contre la Désertification of Morocco, Fundecooperación, Costa Rica. Logistical support by the National System Conservation Areas (SINAC) and Guanacaste Conservation Area (GCA) is acknowledged. We thank all the staff of the Fires Protection Program of GCA for the help during the process of field work.

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Evaluating the quality of satellite based forest/non-forest masks for three test-sites in Germany

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Abstract

128.8 m *km²* of the land area is covered by forests. Global forest/non-forest maps based on multispectral optical data, L-band synthetic aperture radar or proposed for TanDEM-X quick-look satellite data, have only recently been created with high resolution. Due to the diverse nature of these products in terms of underlying data, methods for processing and analysis, the forest maps show certain inhomogeneities and comprise different uncertainties. Further to the existing forest masks, in this study, a new forest map is proposed that is based on Sentinel-1A SLC (Single Look Complex) C-band and TanDEM-X Coregistered Single look Slant range Complex (CoSSC) X-band imagery. All maps are compared and validated against field survey data for three test sites in Germany. Results show that the forest maps are in a range of 85.37 % to 96.80 % of overall accuracy. The test-site Schwäbische Alb shows the lowest accuracies in all maps, caused by its hilly terrain and small-scale landscape features. The forest/non-forest map created by Sentiel-1A and TanDEM-X satellite data has comparable overall accuracies (89.55 % to 93.35 %) to the forest maps based on optical satellite data and to the one based on L-band ALOS-PALSAR. No clear trend in favour of one forest map could be shown for all three test-sites, except for the Copernicus HRL, which has the highest accuracy in both the Schorfheide and the Hainich site.

1 Introduction

Detecting and monitoring forests by means of remote sensing is important in different fields. For implementing REDD+ (Reducing Emissions from Deforestation and Degradation) in tropical forests, the potential carbon storage needs to be estimated based on forest maps to assess the impact on climate (Schlund et al. 2014, after Gibbs et al. 2007). Another field is evaluating the condition of the forests' ecological (e.g. pollution, biodiversity) and economic value (e.g. logging, quantification of renewable resources) in connection with anthropogenic influences, fires or changes due to climate change (Perko et al. 2011, Wegmüller & Werner 1995).

Since decades now, satellite imagery provides a means to objectively map and monitor forest extent, condition and change. However, it is only in the last years that global high-resolution forest/non-forest maps have been created (Martone et al. 2016, after Sexton et al.

2013, Shimada et al. 2014). This is due to recent progress in sensor systems, spatial and temporal coverage as well as techniques for big data assimilation, processing and analysis that have been made available to the public.

Those maps are based on multispectral satellite imagery or SAR (Synthetic Aperture Radar) data. The forest/non-forest maps created on the basis of optical satellite images are the Copernicus High Resolution Layer (HRL) (Copernicus 2012) and the forest map based on Landsat (Hansen et al. 2013). The Landsat forest map has a resolution of 30 *m*. The resolution of the Copernicus HRL forest map is 20 *m*, but it is only available for 39 European states (European Environment Agency (EEA) 2016). The forest map from Shimada et al. 2014 was created with L-band SAR images at 25 *m* resolution. Further, a multitemporal approach with Sentinel-1A SLC C-band and TanDEM-X CoSSC data was used for the creation of forest/non-forest maps with 15 *m* resolution.

The high spectral and spatial resolution of present optical satellite systems with a global coverage (e.g. Landsat-8, Sentinel-2) allows for a reliable differentiation of land-cover type and an accurate mapping of smaller forest stands (Stoffels et al. 2015). However, optical sensors have the drawback that cloud-free images are needed, thus, the generated forest maps mostly represent a single year or a certain observation period (Shimada et al. 2014). SAR imagery in contrast is not hampered by cloud coverage. In addition, the radar wave is able to penetrate the vegetation layer and thus provides information about the vertical structure of natural objects on the ground. This ability is a function of wavelength and polarization of the SAR signal where shorter wavelengths like X- or C-band are generally more limited compared to longer wavelength (e.g. L-Band). Shorter wavelengths provide more information about the tree canopy however (Cloude & Papathanassiou 2003, Wollersheim et al. 2011). X- and C-band are also less sensitive to higher biomass, resulting in a saturation of the signal at low biomass. The ability to separate forest from non-forest is thus decreased (Mitchell et al. 2014). In general, C- and X-band are more limited in forest/non-forest mapping (Shimada et al. 2014), but there have been several studies, which have shown the suitability of SAR C- and X-band data for land cover classification (e.g. Cable et al. 2014, McNairn et al. 2014, Schlund et al. 2014, Martone et al. 2016).

In this paper, we will compare and validate the existing high resolution global forest mask products against field data and two other forest masks that were created recently by the authors. The methods section will explain the characteristics of the products in more detail. The main part of the work is the statistical analysis of the similarities and accuracy of the available forest masks.

2 Study area

The three test-sites are situated along a gradient from Northeast to Southwest Germany comprising different landscape heterogeneity and forest types/dominant tree species and are part of the Biodiversity Exploratories (Biodiversity Exploratories 2016a). Figure 1 gives an overview of the study areas. These three long-term research sites have been set up to evaluate the impacts of biodiversity changes for ecosystem processes. In each Exploratory 50 experimental plots in forest and 50 in grassland have been selected and several features are being recorded, including tree types, diameter at breast height, tree height and crown base (Biodiversity Exploratories 2016a). In the Schorfheide-Chorin area, pine-beech forests with loose pine canopy and a dense middle tree layer in beech stands and beech-forests are the dominant trees. The Hainch-Dün area is the largest closed forest area of broad-leaved trees in Germany with dominating mixed beech-forests (Fagus sylvatica, with Fraxinus exselsior, Acer pseudoplatanus and others). Submontane to montane plateaus characterise the mountain range of the Schwäbische Alb with beech forests, mixed forests and intensely managed spruce monocultures (Biodiversity Exploratories 2016b).

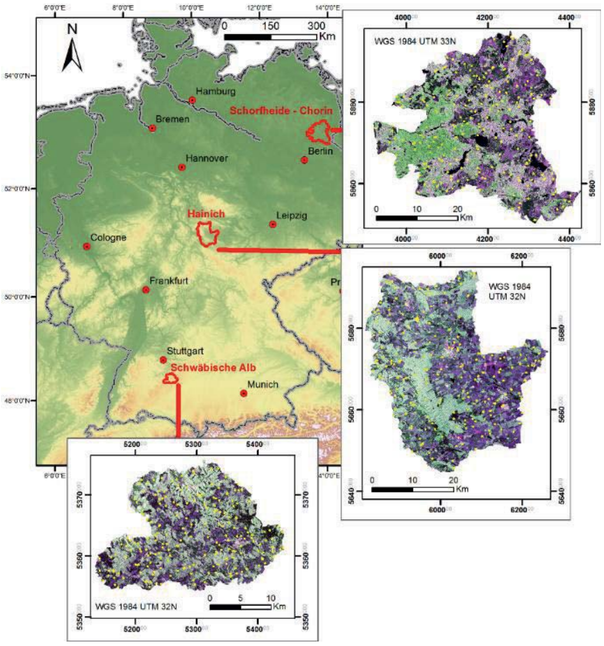

Figure 1. Overview of the three test sites with detailed maps showing the locations of the reference points used for validation (yellow dots). RGB-composites of detail maps: R=VV-polarisation, G=VH-polarisation, B=VV-VH mean of Sentinel-1 images from March to November 2015

3 Data and Methods

The Copernicus HRL Tree Cover Density map is based on a semi-automatic classification of satellite images from IRS-ResourceSat-2, SPOT 4/5 and RapidEye for the years 2011/2012, enhanced with CORINE Land Cover data. It has a resolution of 20 *m* covering 39 European countries. The tree cover ranges from 0 % to 100 %. Excluded are shrub land, vegetation in mountainous areas and open areas within forests (European Environment Agency (EEA) 2016). The cover map was reclassified for this paper. All pixels over 10 % tree cover were defined as belonging to forest and from 0 % to less than 10% analogously to non-forest.

Hansen et al. 2013 used Landsat scenes for a global coverage of forest extent, loss and gain of all landmasses, except Antarctica and a number of Arctic islands, for their forest mask at 30 *m* resolution. Here trees are defined as vegetation taller than 5 *m*. For the analysis of the Landsat data Google Earth Engine was used with a bagged decision tree methodology on Landsat 7 Enhanced Thematic Mapper Plus (ETM+) growing season scenes (Hansen et al. 2013 Supplementary Materials). In the further study, this map will be referred to as Hansen map. The tree cover extent was mapped for the year 2000. Loss and gain were allocated for the subsequent years (Hansen et al. 2013). To get an up-to-date forest map, the loss from 2014 was subtracted from the 2000 cover map and the gain added to it.

Based on L-band SAR data from Advanced Land Observing Satellite (ALOS) Phased Arrayed L-band Synthetic Aperture Radar (ALOS-PALSAR), a forest/non-forest map at 25 *m* resolution was created by applying a rule-based threshold to the *gamma naught* (γ^0) backscatter of the HV polarisation. Forests are defined according to the FAO definition as more than 10 % cover of woody vegetation on an area larger than 0.5 *ha* (Shimada et al. 2014, after FAO 2012).

In addition, we created a forest map (Sentinel-1/TanDEM-X) that combines data from the present national (DLR: TerraSAR-X, TanDEM-X) and European missions (ESA: Sentinel-1) of the space agencies. We developed a workflow for the detection of forest/non-forest areas that relies on X-band coherence and C-band backscatter values and extracted textural features of a time series from March to November 2015. For a comparison of the performance of only C-band data in forest mapping, we further created a forest map based only on Sentinel-1 backscatter and textural features. A more detailed description of the processing scheme and validation of results will be given in a full paper that is currently in preparation for publication.

3.1 Classification

An unsupervised classification approach based on the random forest classifier in combination with k-means clustering was used. The random forest classifier, first suggested by Breiman 2001, has been applied successfully for supervised classification (e.g. Rodriguez et al. 2012). Unsupervised random forest was employed by e.g. Peerbhay et al. 2015 by clustering the proximity matrix calculated by random forest (Peerbhay et al. 2015, after Zhang & Zulkernie 2006). In this study, two clusters were computed. The assignment to the forest or non-forest class after the unsupervised classification was done visually.

Random forest consists of an ensemble of tree-structured classifiers, where each one contributes to the assignment of the most frequent class. A tree is grown by randomly selecting features with replacement from the original data set (Breiman 2001). Another advantage is that the importance of each feature used as classification input is assessed (Rodriguez et al. 2012).

For accuracy assessment, 200 points were randomly created in each study area with a buffer of 20 *m*. Each point was then assigned to the forest or non-forest class based on the DLM-ATKIS digital landscape product (Digitales Landschaftsmodell Amtliche Topographisch-Kartographische Informationssystem) and on visual inspection of Sentinel-2A data of the area.

4 Results and Discussion

The Copernicus HRL Tree Cover Density map has so far not been evaluated. The forest maps based on Landsat and ALOS-PALSAR have been evaluated by the authors of these studies in their articles. Hansen et al. 2013 used training data from Quickbird images, existing percent tree cover layers derived from Landsat and MODIS percent tree cover to assess the accuracy of the loss and gain of tree cover within 120 *m* sample blocks per biome (in total 1500) and a second evaluation with LiDAR data. They received a global loss accuracy of 99.6 % and gain of 99.7 %. The overall accuracy of the forest mask is unknown (Hansen et al. 2013 Supplementary Material). Shimada et al. 2014 utilised Google Earth imagery, data from the Degree Confluence Project, and global Forest Resources Assessment data as references. The reported accuracies range from 84.86 % to 94.81 % (Shimada et al. 2014).

For our study, we assessed the performance of all forest maps based on confusion matrices (Table 2). The results of the forest mapping are plotted in Figure 2 and 3. It is visible that the overall accuracies of the maps vary between the sites. The Copernicus HRL forest map shows, with the exception of the Schwäbische Alb (89.45 %), the highest accuracies with 96.80 % for the Schorfheide and with 94.03 % for the Hainich. Small scale patterns of forest and the hilly terrain in the Schwäbische Alb result in a generally lower overall accuracy of all forest maps in this region. With 91.24 % the Hansen map reaches the highest accuracy, here, followed by our own map with 89.55 %. The range of the values is however similar for all sites. The accuracy of the ALOS-PALSAR forest map is in accordance with the accuracies obtained by Shimada et al. 2014 for different reference points.

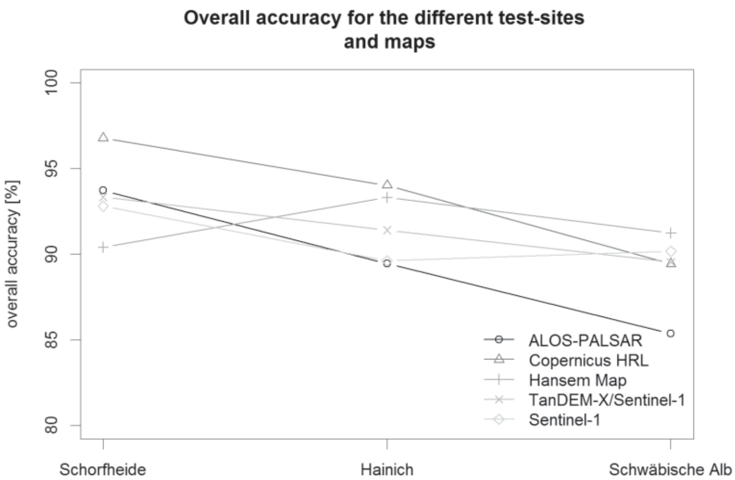

Figure 2. Overall accuracies for forest/non-forest maps in the three test-sites.

It is visible that the amount and spatial distribution of forest differs between the maps. The ALOS-PALSAR map shows a more homogenous appearance with only larger forest areas being mapped, whereas the Copernicus, Hansen map and particularly our map present an increase in forests. A high error of commission for the forest class in the Hainich and Schwäbische Alb (17.79 % and 14.60 %, respectively) can be seen in Table 2. The Sentinel-1 data without the coherence has the highest error of commission with 21.31 % in the Hainich site. Non-forest areas were also mapped as belonging to forest areas in the Schwäbische Alb. The error of commission is higher than 10.7 % for this class in each map, except in the Sentinel-1/TanDEM-X and Sentinel-1 map. In the Schorfheide this error is not as distinct as only small villages are present in this area.

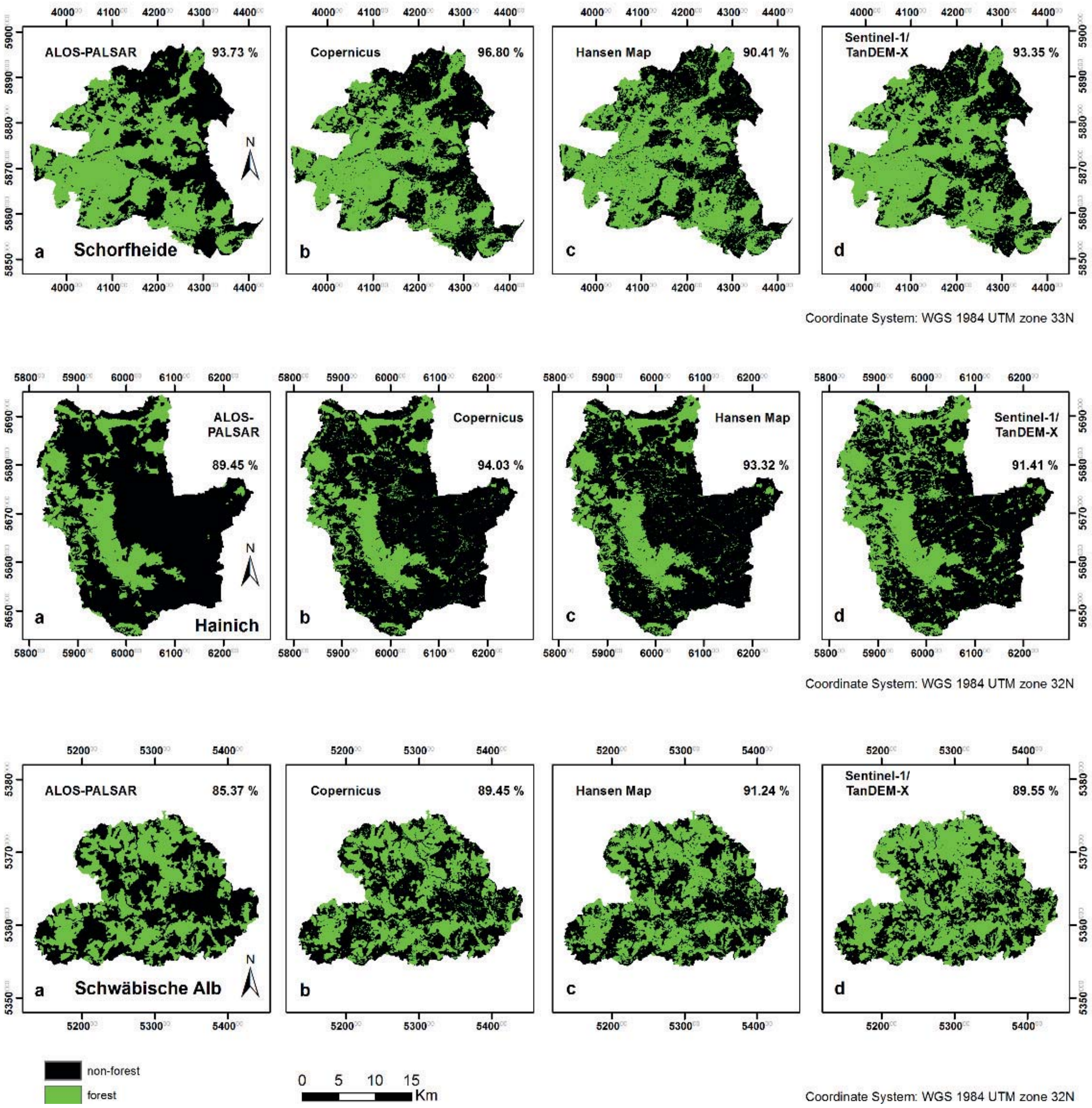

Figure 3. Comparison of the forest/non-forest maps for the three test-sites.

Forests were considerably omitted in the Hainich and Schwäbische Alb by all maps but the Sentinel-1/TanDEM-X and Sentinel-1 map. ALOS-PALSAR has the highest error of omission with 23 %. Due to their definition of forest with a minimum of 10 % tree cover on more than 0.5 *ha*, trees along streets and rivers are not considered in this product. The varying landscapes and related forest types and patterns in the test-sites are certainly responsible for the different results of the products. Using only the Sentinel-1 backscatter and textural features gives little lower results than combining the TanDEM-X coherence and Sentinel-1 (0.53 % lower for the Schorfheide and 1.79 % lower for Hainich), but even 0.63 % higher accuracy for the Schwäbische Alb. In this case, the TanDEM-X coherence seems to act as noise introduced into the classification.

Table 2. Confusion matrix of the three test-sites and the forest maps presented.

Explo	Sensor / Product	class	prod. acc. (%)	user acc. (%)	omission (%)	commis-sion (%)	overall acc. (%)
Schorfheide	ALOS-PALSAR	forest	94.04	94.29	5.96	5.71	93.73
		non-forest	93.38	93.08	6.62	6.92	
	Copernicus HRL	forest	96.77	97.35	3.23	2.65	96.80
		non-forest	96.83	96.15	3.17	3.85	
	Hansen map	forest	93.38	89.12	6.62	10.88	90.41
		non-forest	87.03	92.04	12.97	7.96	
	Sentinel-1/ TanDEM-X	forest	96.85	91.25	3.15	8.75	93.35
		non-forest	89.33	96.11	10.67	3.89	
	Sentinel-1	forest	97.01	90.28	2.99	9.72	92.82
		non-forest	88.00	96.25	12.00	3.75	
Hainich	ALOS-PALSAR	forest	76.42	89.50	23.58	10.50	89.45
		non-forest	95.70	89.43	4.30	10.57	
	Copernicus HRL	forest	88.32	92.06	11.68	7.94	94.03
		non-forest	96.58	94.85	3.42	5.15	
	Hansen map	forest	83.64	94.52	16.36	5.48	93.32
		non-forest	97.77	92.86	2.23	7.14	
	Sentinel-1/ TanDEM-X	forest	92.92	82.21	7.08	17.79	91.41
		non-forest	90.71	96.52	9.29	3.48	
	Sentinel-1	forest	92.07	78.69	7.93	21.31	89.62
		non-forest	88.48	96.02	11.52	3.93	
Schwäbische Alb	ALOS-PALSAR	forest	76.34	91.42	23.66	8.58	85.37
		non-forest	93.53	81.41	6.47	18.59	
	Copernicus HRL	forest	81.82	94.54	18.18	5.46	89.45
		non-forest	95.96	86.07	4.04	13.93	
	Hansen map	forest	86.84	93.84	13.16	6.16	91.24
		non-forest	95.06	89.29	4.94	10.71	
	Sentinel-1/ TanDEM-X	forest	94.61	85.40	5.39	14.60	89.55
		non-forest	84.79	94.36	15.21	5.64	
	Sentinel-1	forest	94.24	86.67	5.76	13.33	90.18
		non-forest	86.39	94.10	13.64	5.90	

5 Conclusions

The evaluated forest maps show overall good, but varying results for the different test-sites in Germany. The ability of C- and X-band SAR data for forest/non-forest classification with an unsupervised random forest approach was demonstrated. The overall accuracies were comparable to the forest maps solely derived by optical satellite images and to the L-band SAR data. There is an added value in using TanDEM-X data for forest detection, but only using Sentinel-1 backscatter and texture features also gives satisfying results. With the freely available raw data of Sentinel-1, the cloud-free acquisitions and the reproducibility of the presented forest map, a unique data set can be used with up-to-date Sentinel-1 SAR images for monitoring changes in forest areas on a yearly basis. Further investigation is needed to simplify the multitemporal approach for the whole growing season. With that, the presented method for forest mapping based on Sentinel-1 images would have an advantage over the ALOS-PALSAR forest map, which is restricted in its availability for the public, and the Hansen map, which needs multiple acquisitions of an area to ensure cloud-free images, especially over the tropics.

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Monitoring of Fire Induced Land Cover Changes in Jambi Province, Sumatra using Sentinel-1 and Google Earth Engine

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Abstract

The province of Jambi in Sumatra has been affected by rapid and massive changes in land use/cover over the last 15 years, caused by land conversion and fires. Detailed mapping of land use/cover changes from optical remote sensing data is difficult because of constant cloud cover, smoke or haze. Due to the high spatial and temporal resolution of Sentinel-1 data, frequent land use/cover change analyses become possible irrespective of the atmospheric conditions. With the use of the Google Earth Engine, a huge computing power and direct data access is provided that allows time series analyses of Sentinel-1 radar data. By comparing the differences in backscatter between two months, using a dual temporal composite, we analyzed the potential of Sentinel-1 data for a near-real-time detection of burned areas. The results show that Sentinel-1 is a useful data source for monitoring changes in land cover caused by fire. Restrictions of change detection are caused by surface structures, which have to correspond to specific characteristics defined by the limits of radar remote sensing.

1 Introduction

The province of Jambi in Sumatra is affected by rapid and massive changes in land cover/use through large-scale land conversion over the last decades (Allen, 2015). Different factors have been identified as main drivers for deforestation and forest degradation, whereby agricultural expansion, land preparation for plantations and encroachment are the most relevant (Albar et al., 2016). The clearing of secondary forest and conversion into monoculture oil palm and/or rubber plantations in the province of Jambi usually starts with repeated burning of secondary forest (Tomich et al., 1998). The frequency of fires as well as size of burned areas have massively increased, which has made Indonesia the largest emitter of greenhouse gases from land use change in the past years (Albar et al., 2016). A reliable estimation of burned areas and related forest cover loss is required as important input to recent forest policies and to understand the spatio-temporal pattern of forest loss by fires.

The detection of burned areas in Indonesia is currently estimated from the active fire locations which are provided by the Fire Information for Resource Management System (FIRMS). This data is extracted from the mid and longwave-infrared bands of the moderate-resolution imaging spectroradiometer (MODIS) sensor mounted on the Aqua and Terra satellites. The MODIS algorithm detects fire hotspots, which exceed a certain temperature and size with a 24 h interval in the moment of the image acquisition (Tansey, 2008). The main advantage of the FIRMS MODIS dataset is the daily update of active fires and the analyses of the spread of the hot forefront of fires over time. However, due to the coarse spatial resolution, information about the presence of a fire can only be given within an area of 1x1 km, irrespective of the number of fires and their spatial pattern. Therefore, this product is only restrictedly useful for determining burned areas and might lead to a strong underestimation of burned area and, as a consequence, the total extent of burned area remains unknown.

Monitoring active fires or land cover change using passive remote sensing systems like MODIS is challenging because of constant cloud cover, smoke or haze. Contrary to that, radar sensors are an active remote sensing technique acquiring images irrespective of the atmospheric conditions in the microwave spectrum (Henderson and Lewis, 1998). The radar backscatter recorded by the sensor is influenced by varying factors such as the structural components of the land surface but also by the varying water content of vegetation and soil (Henderson and Lewis, 1998). Therefore, specific characteristics have to be fulfilled to monitor changes in land cover from radar imagery.

Since 2014, the European Space Agency (ESA) offers free SAR imagery, gathered by Sentinel-1 radar satellites, for a global monitoring of land use/cover change at high spatial and temporal resolution. Integrated into the Google Earth Engine, a near-real-time analysis of land cover change is possible. The Google Earth Engine is a platform for the scientific analysis of high-resolution imagery. It allows cloud-based processing using large computation power.

This study aims to evaluate the suitability of Sentinel-1 data for near-real-time detection of burned areas in the province of Jambi in Sumatra, Indonesia by visual interpretation of monthly mean backscatter based on a dual temporal composite. We expect the combination of Sentinel-1 and Google Earth Engine to be of high potential for monitoring land cover changes caused by fire.

2 Methods

2.1 Study Area

The Province of Jambi is located in central Sumatra, Indonesia (Fig. 1). The landscape is shaped by the production of palm oil, pulp and rubber. The study area is located at 103°E-105°E and 1.25°S-1.45°S, east of Jambi city in the regency of Muaro Jambi. This area is dominated by peat forests and oil palm plantations containing remnant patches of secondary forest. The extension of oil palm plantations is moving from concessions in the western part towards former wood production concessions close to the border of the National Park Berbak.

The main fire season in Sumatra extends from February to March and later from June to October (Albar et al., 2016). Typically, the fires are extinguished by heavy rain falls that start to occur in the rainy season from October onwards (Albar et al., 2016). The timeframe for our investigation was therefore adapted to the fire season and we concentrated on the months July to October.

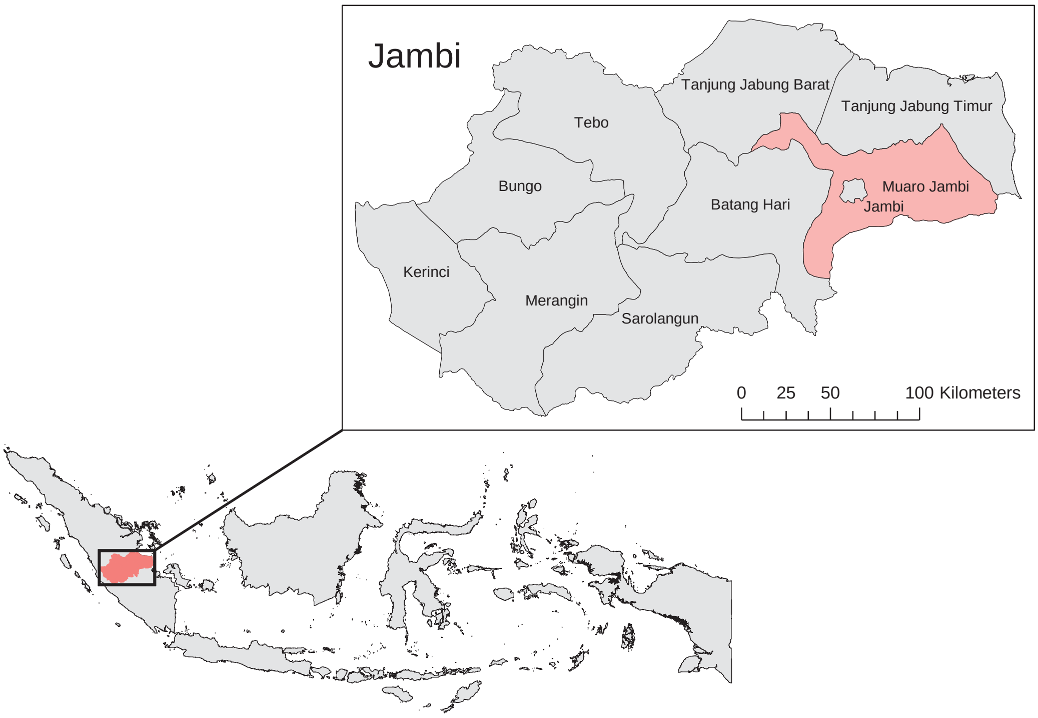

Figure 1. Location of Muaro regency in Jambi province, Indonesia.

2.2 Remote sensing data

Satellite data inputs included Sentinel-1 imagery by the European Space Agency (ESA) and FIRMS MODIS data by the National Aeronautics and Space Administration (NASA). Both datasets are directly accessible via the Google Earth Engine.

The Sentinel-1 instrument operates at a wavelength of ~5.547 cm (C-SAR) and supports image acquisition either in single or dual polarization (ESA, 2016). The two-satellite constellation of Sentinel-1 offers a temporal resolution of six days and a spatial resolution of 5x5 to 20x40 m depending on the acquisition mode and level of processing (ESA, 2016).

The FIRMS MODIS data was originally extracted from the three different MODIS bands and includes, besides the location of the fire, further useful attributes (NASA, 2015). The MODIS sensor onboard of the Terra and Aqua satellites has 36 spectral bands (0.405 and 14.385 μm) (NASA, 2015). In combination, both satellites provide a temporal resolution of up to one day, with a spatial resolution of 250 – 1000 m (NASA, 2015). In this study, we filtered the fire hotspots with a confidence value greater than 90 %, which indicates a high-confidence fire.

2.3 Implementation in the Google Earth Engine

First, we created an image collection of all available ground range detected (GRD) imageries from the 1st until the 28th day of each month in the year 2015. After filtering for dual polarization (VH) and interferometric wide swath mode (IW), a monthly mean SAR imagery was processed. Subsequently, we created a layer stack where each monthly mean image was placed into a separated band. For analysis, change detection results were visualized as a dual temporal composite, where the earlier month was assigned to red and the later month to green and blue.

Afterwards, mean backscatter values per month within a burned area were used to identify a threshold, which can be used as an indication for changes. In addition, FIRMS MODIS data was gathered for August until November 2015 and was used for visual validation by pooling the hotspots per month. To monitor changes in land cover from Sentinel-1 a clear cut or burned area of a minimum size is required.

3 Results

MODIS data (Fig. 2) shows the highest frequency of fire hotspots in the study area for September. Early fires occurred at the edges of oil palm plantations and along infrastructure, like roads or channels and progress deeper into the forest over time.

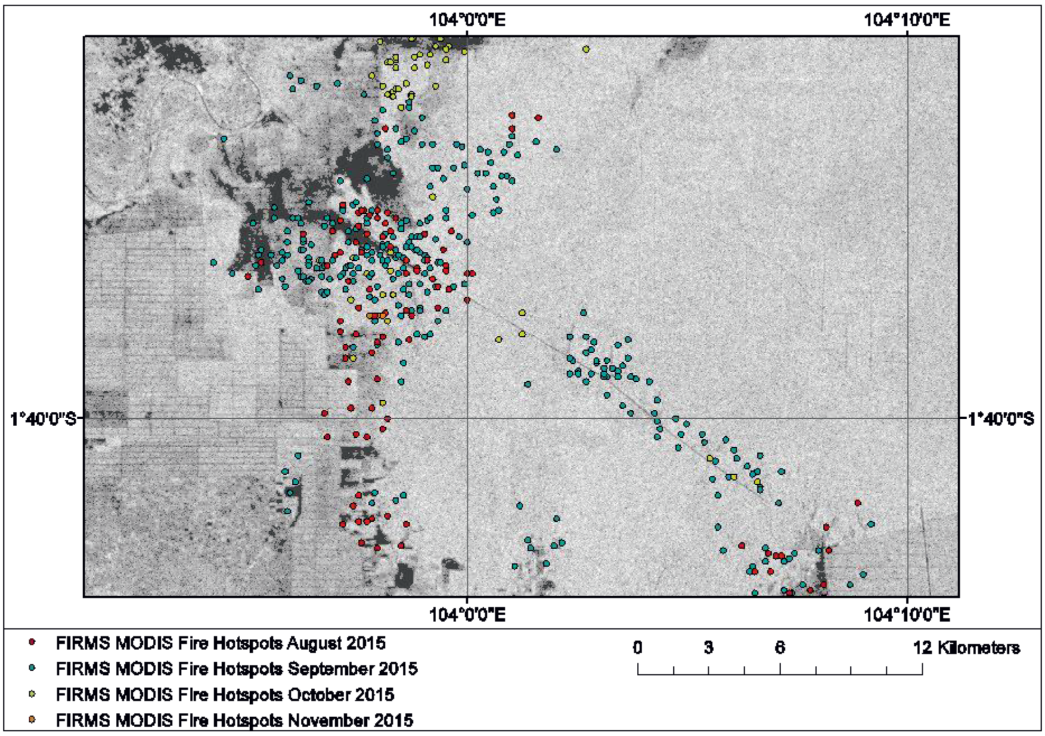

Figure 2. MODIS fire hotspots August – November 2015 and Sentinel-1 backscatter from July 2015.

The pattern of MODIS fire hotspots is reflected in the distribution of land cover change detected with Sentinel-1 (Fig. 3 - 5). Red colored areas are characterized by a lower mean backscatter compared to the previous month. This reduction in backscatter (~ 3 dB) can be caused by a reduction in vegetative structure or by the influence of water. Yellow polygons visualize the extent of a burned area detected over the timeframe of July to October.

However, comparing the location of the active fires and the corresponding differences in backscatter, we see that not all detected changes are matching the fire occurrences. The dual temporal composite of August and September indicates a land cover change west of the indicated burned area (yellow polygon, Fig.4). According to MODIS data only a few hot fires occurred in this area in August. Indeed, in September MODIS data shows a high fire activity in this area, whereas no differences in backscatter were measured between September and October (Fig. 5).

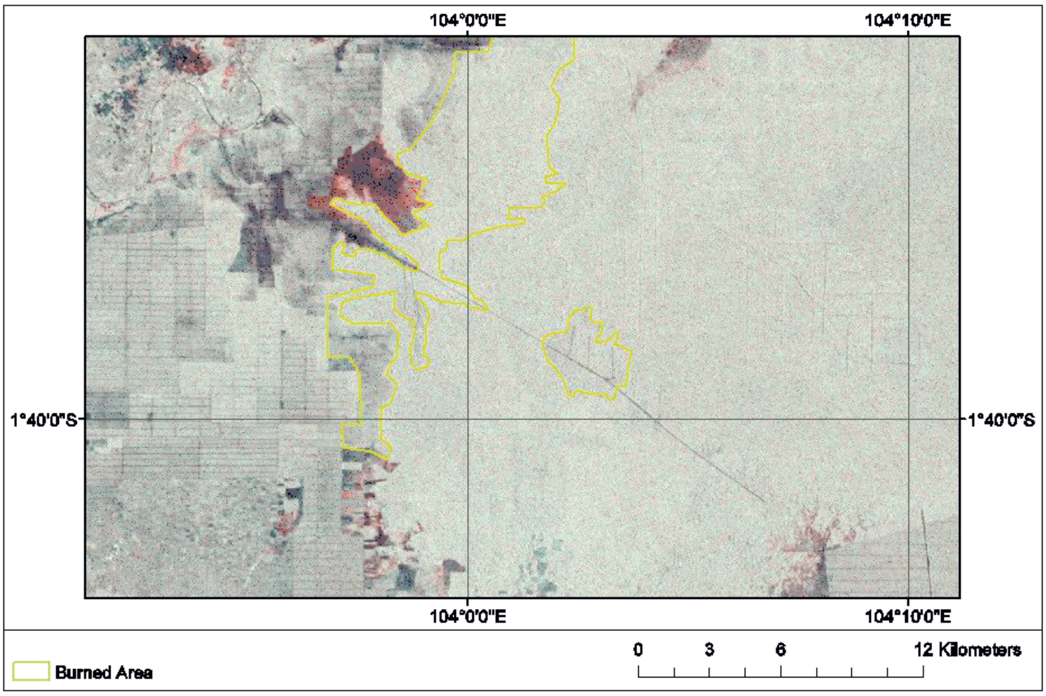

Figure 3. Dual temporal composite of mean backscatter of July and August 2015.

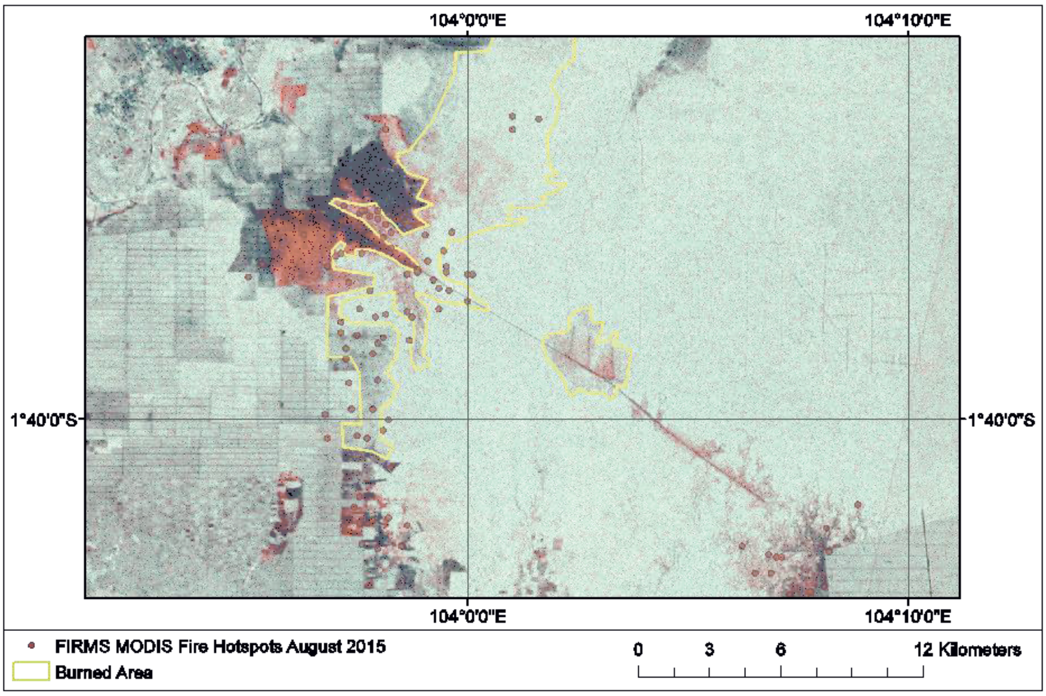

Figure 4. Dual temporal composite of mean backscatter of August and September 2015.

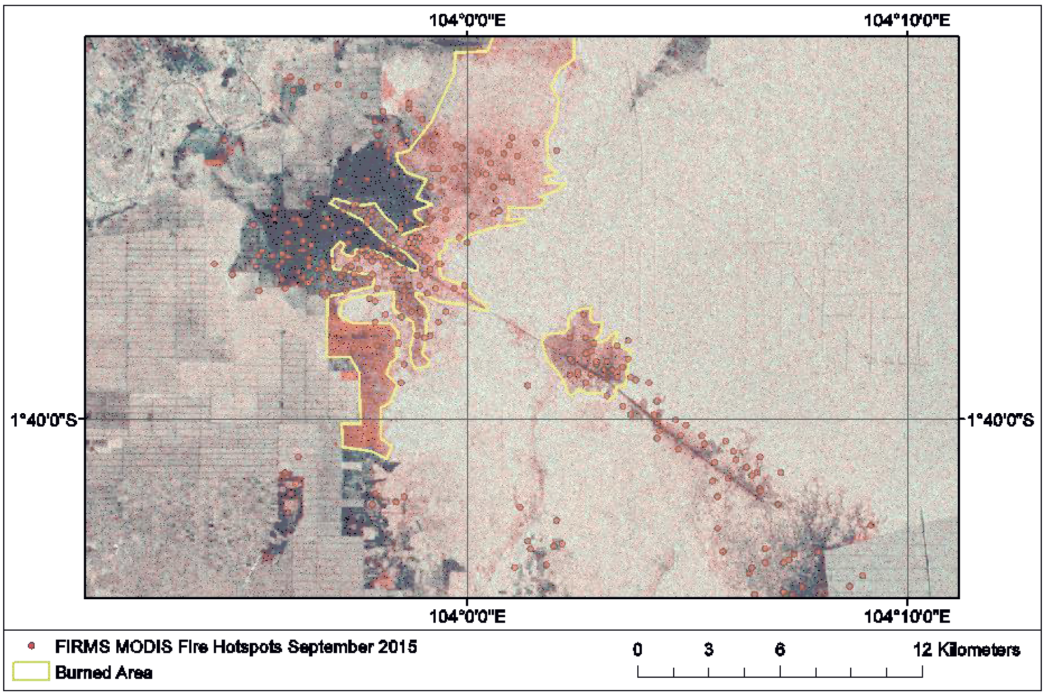

Figure 5. Dual temporal composite of mean backscatter of September and October 2015.

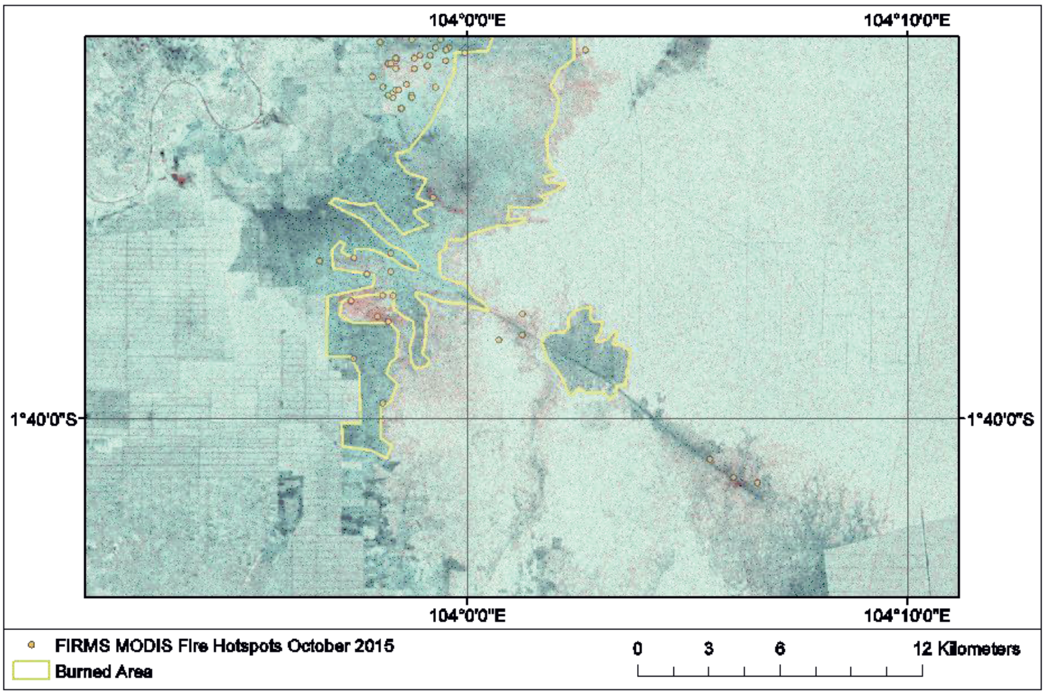

Figure 6. Dual temporal composite of mean backscatter of October and November 2015.

4 Discussion

The Earth Engine provides preprocessed data (Level 1 GRD) gathered by Sentinel-1A and B and gives the opportunity for fast processing. With this combination it is a very powerful tool for change detection with a high spatial and temporal resolution.

The interpretation of change in land cover caused by fire or other anthropogenic disturbances is still complicated. Changes in backscatter are caused by many different aspects. Acquisition mode, local topographic aspects like slope or surface roughness, changes in structural complexity due to remaining standing trees or even variation of the water content have an influence on the backscatter response. In our study area multiple of these influencing factors are present, as seen in Fig. 4 and 5. The FIRMS MODIS fire hotspot data partly confirms that there is a relationship between fire occurred and reduction in backscatter in the respective time frame.

However, parts of the study area are characterized by peat forest that are crossed by channels and small rivers (especially in the eastern part). Especially in Jambi where heavy rain events and partial flooding of these riparian sites occur regularly, a misinterpretation of the backscatter due to changes in the water table is possible. Unfortunately, the latter can lead to similar reductions in the radar backscatter as known from the burned area pixels. Therefore, a clear cause of the change cannot be determined and the interpretation of images of land cover change from radar backscatter alone is therefore critical.

Furthermore, ground observations of large burned areas in the study area, where vertical structure is still given by remaining trees, were not detectable by Sentinel-1 imageries. As the backscatter is dependent on surface structure and, therefore, on the magnitude of changes in structural complexity, standing trees still influence the signal and can cause a different pattern compared to a completely cleared surface

For further research we recommend to include additional data, like MODIS fire hotspots and/or land surface temperature, or on-site assessed validation data to overcome the challenges of radar imagery interpretation.

5 Conclusions

The objective of this study was to evaluate the suitability of Sentinel-1 data for land cover change detection using the Google Earth Engine. This study showed the general potential and suitability of Sentinel-1 data for monitoring burned areas over time on a high temporal resolution. In general, radar remote sensing is a beneficial tool for observing land cover changes where optical images are rarely available due to cloud cover. However, radar data alone might lead to misinterpretations in temporarily flooded areas and should therefore be used together with other data (e.g. MODIS fire hotspots) to confirm whether changes in backscatter are a result of fires or other loss of forest cover.

Further, when using the Google Earth Engine it needs to be considered that only GRD level 1 data, an already processed product with less information than the initial data, is provided. Therefore, depending on the purpose, the possibilities of analysis are limited.

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Exploring normalized vegetation index as a remote sensing tool for monitoring tropical forests

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Abstract

Global interventions in sustainable forest management and conservation requires adequate monitoring as measurement of the progress of initiatives. Often, concerns for money, time and labor are major considerations in forest inventory and monitoring activities. However, since the advancement of technology towards optical observations from satellites, remote sensing provides a means to monitor vegetation with a considerably less effort and time. Sensors aboard satellites are calibrated to detect specific wavelengths and the use of NDVI, which emphasizes reflectance from red and near infrared wavelengths, proves to be an important indicator for vegetation monitoring. This work gives a general overview on the application of NDVI as a forest monitoring tool with examples from different scenarios and at the same time it makes some criticisms about the use that is given to the NDVI results, about how errors are generated calculating the anomalies and how this leads to erroneous ways of analyzing trends.

1 Introduction

Tropical forests are one of the most important ecosystems across the globe. They contain the most incredible species of plants and animals, thanks to the variability in the microclimates found within them. While covering only 10% of the total land area, they represent approximately 50% of the area covered by the world's forests and contain well over 80% of all terrestrial and freshwater biodiversity. At the present time 10 million people worldwide are engaged in forest management and conservation (Hussin et al.1996; FMAM 2010).

Tropical forests, most of which are in developing countries, are especially essential for the management of global environmental goods and services. However, despite the importance of these forests, they are at risks from deforestation and degradation. This is especially worrisome due to the fact that the conversion and degradation of tropical forests accounts for approximately 90% of total GHG (Green House Gases) emissions (FMAM 2010).

It is recognized that climate change will have a severe global impact, and is one of the major issues currently discussed throughout the world. For that reason, initiatives have been created, such as the Reduction of Emissions from Deforestation Forest Degradation REDD project, whose goals are to implement processes and practices of sustainable management and conservation for these tropical forests (Vega et al. 2008).

In order for these initiatives to reach their goals to conserve tropical forests, they must be monitored over time. This makes monitoring of the dynamic changes occurring within the tropical forests a priority, as is the collection of necessary and reliable data that can provide insight into the changes that have and are occurring within the managed areas.

The vegetation cover is a natural indicator of environmental health and an environment's response to changing climate. The photosynthetic activity that occurs within the vegetation is a useful tool to detect these changes. Structural features of forests can serve as useful indicators of a forest's condition, and can be assessed with remotely sensed imagery, which provides quantitative information on forest ecosystems at high temporal and spatial resolutions (Alcaraz-Segura et al. 2008; Carter Ingram et al. 2005). This is why the time series of satellite images are an excellent tool to analyze changes in different aspects of the functioning of vegetation and why over time these tools are being used increasingly worldwide (Tiedemann et al. 2010).

In this paper, we review the use of one of these tools: *the Normalized Difference Vegetation Index* (NDVI); NDVI is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum found within satellite imagery, to determine whether the target location being observed contains live green vegetation or not (Karnieli et al. 2009).

This index is produced by the NASA sensor MODIS (Moderate Resolution Imaging Spectroradiometer), it was launched in 1999 and is a key instrument aboard the Terra and Aqua satellites. MODIS "plays a vital role in the development of validated, global, interactive Earth system models which are capable of predicting global change accurately enough to assist policy makers in making sound decisions concerning the protection of our environment"(Lindsay n.d).

This review aims to expose the reader to the fields in which this index can be applied, the fundamental principles of remote sensing on which it is based and also discuss the analysis used to interpret the data results.

2 NDVI concept and definition

The use of remote sensing techniques to classify surface vegetation has received considerable interest over the past decades owing to its advantages of large spatial coverage and objective mapping characteristics. This widespread application has come about through the conclusion that the combination of two or more spectral bands gives a descriptive signature that can be used to develop a vegetation index (Chebouni et. al, 1994). Recently, several vegetation indices have been developed (Zhou et al., 2009; Mroz and Sobeiraj, 2004; Qi et al, 1994). These vegetation indices can be classified into three main groups; slope based, distance based, and orthogonal transformations (Silleous et al 2006; Jackson and Huete, 1991; Qi et al, 1994). The most widely used slope based vegetation index is NDVI.

NDVI is one of the vegetation indices developed to describe the net productivity of plants in a given area from earth observation systems (Tucker, 1979). It utilizes spectral reflectance from chlorophyll and other internal structures of plants. This is possible because green plants absorb energy from solar irradiance. This energy absorption peaks between the blue and visible red (VR) regions (0.45 um – 0.67um) of the light spectrum while the electromagnetic radiation in the green region is reflected, thus giving the distinct color of green leaves (Jensen, 2007). But in the near infra-red (NIR) region (0.7um – 0.1um), energy is strongly reflected by the internal structures of leaves. This reflectance characteristic is very specific to green plants and has been the basis for developing several vegetation indices (Yengoh et al, 2014). Combining the relationship between these spectral bands, the contrast between the absorption and reflectance in the VR and NIR regions of the spectrum is used to describe the photosynthetic capacities of plants upon which NDVI values are estimated (Silleos et.al, 2006; Jackson and Heute, 1991).

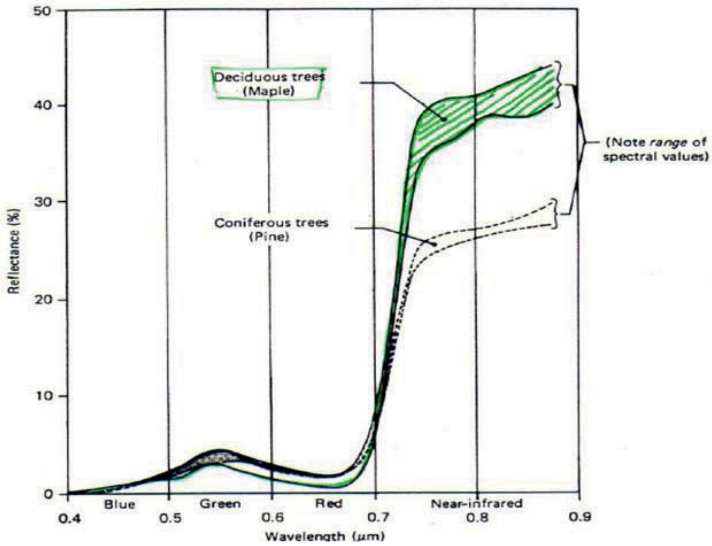

Figure 1: Spectral characteristics of coniferous and deciduous plants showing higher electromagnetic reflections in NIR region. (UOF, 2008)

Since 1981, NDVI data sets have been estimated from Advanced High Resolution Radiometer sensors (AVHRR) aboard the National Oceanic and Atmospheric Administration (NOAA) satellite (Le Jiang et al., 2008). Currently, NDVI data can be obtained from several satellites at a much higher spatial resolution. These satellite sensors record the spectral reflectances from the VR and NIR separately. NDVI is then estimated as the ratio of the difference between the bands (NIR and VR) and the sum of the bands (Equation 1) (Rouse Jr. et al., 1974; Le Jiang et. al, 2008; Alcaraz-Segura et. al., 2009).

$$NDVI = \frac{NIR-VR}{NIR+VR} \quad (1)$$

Where; *NIR* is the estimate for near the infra-red band; and *VR* is the estimate for the red band.

As a ratio, NDVI values are normalized in the range of -1 to 1, with only the positive values representing vegetative surfaces (Yengoh, et al., 2014). This is used as a proxy for surface vegetation greenness from leaves.

The spectral behavior of the leaves changes during senescence (Basso et al, 2004). This characteristic is used to monitor the phenological life cycle of trees (Figure 2). During the early developmental stages of plant growth, their NDVI values are low and gradually increase with the increasing above ground vegetation. The relationship is established from the strong correlation between chlorophyll content and NDVI values. Higher NDVI values correspond to more chlorophyll content in the target area.

Spectral properties of soil have different characteristics therefore, it is possible to differentiate between vegetation and soil reflectance (Figure 2). Soil reflectance depends on the soil constituents, soil particle size and soil moisture (Rondeaux et al, 1996). Dry soils with smooth soil particulate surfaces show higher reflectance than wet soils.

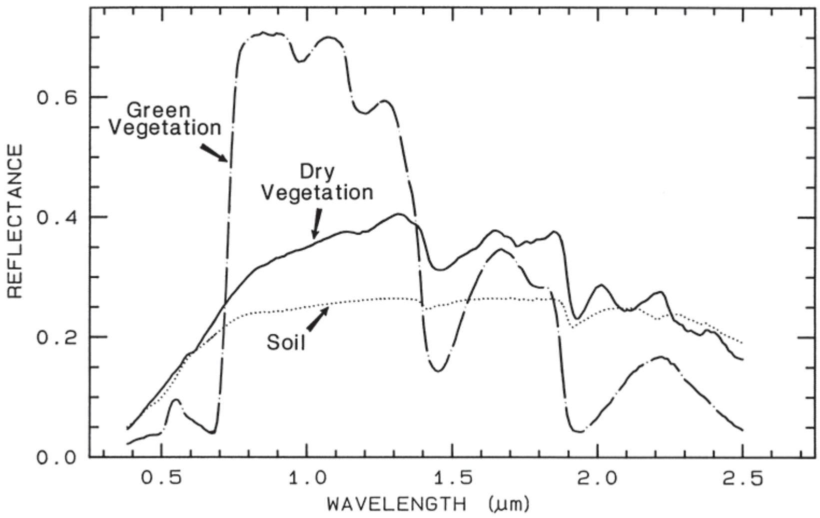

Figure 2: Spectral characteristics of green vegetation, senescing vegetation and soils. Low NDVI values for soils show higher reflectance in the NIR region. Intermediate reflectances from dry vegetation indicate the low amount of chlorophyll in the vegetation as compared to green vegetation with high chlorophyll content. (Source: Geoinformatics, 2008)

2.1 Data Sources and processing

Since 1981, NDVI data sets have been acquired from the NOAA/AVHRR sensors at a spatial resolution of 8 km (Le Jiang et al., 2008). This means that a single pixel represents 8 sq.km on the earth surface and that there is a high probability of not detecting small scale variations of ground information. Currently, sensors with high spatial resolution such as LANDSAT 8, Système Pour l'Observation de la Terre (SPOT), Moderate Resolution Imaging Spectroradiometer (MODIS), etc. have been developed. The development has taken place in the quest for an improved understanding of terrestrial processes and changes.

Applications of satellite remote sensing are diverse, but the underlining principle is universal (Shen et al., 2014; Yengoh et al. 2015). Thus, we assume that the underlying principles of the different types of satellites and sensors currently in use for NDVI estimation, are the same and hence we focus this section of the paper on one of them, the MODIS sensor, due to two reasons: MODIS training data is freely available and also have high temporal resolution which helps in generating time series (Justice et al, 2002).

MODIS data is acquired from the NASA Earth Observing Systems (EOS), Terra and Aqua. Its land imaging characteristics are a combination of AVHRR and Landsat sensors to provide improved monitoring of the Earth's surface at global scales (n.d, 2006). Spatial resolutions for MODIS are fixed at 250m, 500m and 1km with a revisit time between 1 to 2 days. It is designed to cross the equator at a time when cloud cover is at a minimum with a 16-day composite interval (n.d, 2006). Jenkerson and colleagues (2010), argue that the frequent repeat cycle and the high resolution component makes MODIS suitable for vegetation studies. Additionally, the field view angle of MODIS is $\pm 55^{o}$ off-nadir which enables it to have a swath width of 2330 km.

The MODIS satellite gathers data by detecting surface reflectance in 36 different bands (Annex 1) from 0.4 μm to 14.4 μm. Bands 1-7 are most beneficial for landscape mapping (Justice et al., 2002). Although it is the aim to detect these spectral reflectances without distortions, it is hardly achieved in practice. Spectral data are often interfered with by aerosols, clouds, and also the viewing angle of satellites (Jiang et al., 2008; Chen et al., 2004). These data have to be corrected to give meaningful interpretations. Data compositing is one of the methods for smoothening the data. In MODIS, compositing is done by examining pixel by pixel of each observation with the maximum NDVI. The maximum NDVI value for a pixel is then retained to reduce the cloud contamination and to keep the pixels to near nadir pixels (Swets et al., 1999; Holben 1986). To circumvent residual contamination, among other problems, an improved version of the NDVI – the Enhanced Vegetation Index (EVI) was introduced. This is to reduce interferences from soil background, reduce vegetation saturation and ensure atmospheric correction (Justice et al. 2002). Because both NDVI and EVI data are similar, there are emerging studies on the comparability between the two data sets. Yengoh et al. (2014) showed high correlation between the two data sets in their study, while still arguing that the intended purpose of EVI is slightly under achieved. However, the introduction of the EVI is a major milestone in an attempt to develop a universal, suitable and highly sensitive vegetation index that would be at the same time insensitive to spectral interferences. This present an advantage for the MODIS program since it provides two different vegetation indices which are aimed to explain similar processes. While the purpose of the EVI has already been outlined above, the continuous estimation of NDVI on MODIS could be to ensure the continuity of the already accumulated NDVI data set from NOAA/AVHRR since 1982.

3 Applications of NDVI

3.1 Detection of changes in the forest landscape

According to Angnes & Sendra (2008), the cartographic expression of land cover is one of the basic applications for space remote sensing equipment. It was developed, among other purposes, for inventory and spatial diagnostics, spatial planning and monitoring, forming an important source of geographical data on the formal aspects of land use on Earth. Attached to this are phenology studies, which observe the periodic events in the life cycle of plants, such as flowering, fruiting bud and leaf senescence (Tiedemann 2011). This vegetation index can be utilized as a tool to monitor these premises over a longer time span, in order to record and observe changes to vegetation.

Loss of vegetation due to deforestation is the most significant trace of the destruction and degradation of terrestrial ecosystems in the last 50 years according to Galicia et al. (2014). According to the NDVI results, the vegetation type can be classified as forest or not. Through the time series we can observe changes in forest cover and relate these data to phenomena that may have affected or created patches of deforestation or otherwise. Particularly in the tropical regions of America, Asia and Africa; the use of medium resolution images (MODIS, LANSAT and SPOT) has allowed the quantification of changes in forest ecosystem coverage.

Figure 3 shows a series of images corresponding to the NDVI for the country of Costa Rica for the year (FAO 2016). We can clearly notice when the greening phase starte; in May until December and the dry season comes from December to April. When we tie together the areas of greatest greening in the figure, these correspond to areas in which large extents of forest are known to exist. On a smaller scale, NDVI could be used in combination with other field data (annual measurements or permanent plots) in order to acquire a more comprehensive description about changes taking place in terms of reforestation and deforestation in the region.

One of the conclusions of Vega et al. (2012) in a similar article made for the zone of Costa Rica, is that many studies show the seasonal relationship between NDVI results and rainfall and that it is also crucial that we have a look at precipitation and potential evapotranspiration (seasonally) in order to have a better understanding of the interactions and relationships of climate and vegetation in a specific region.

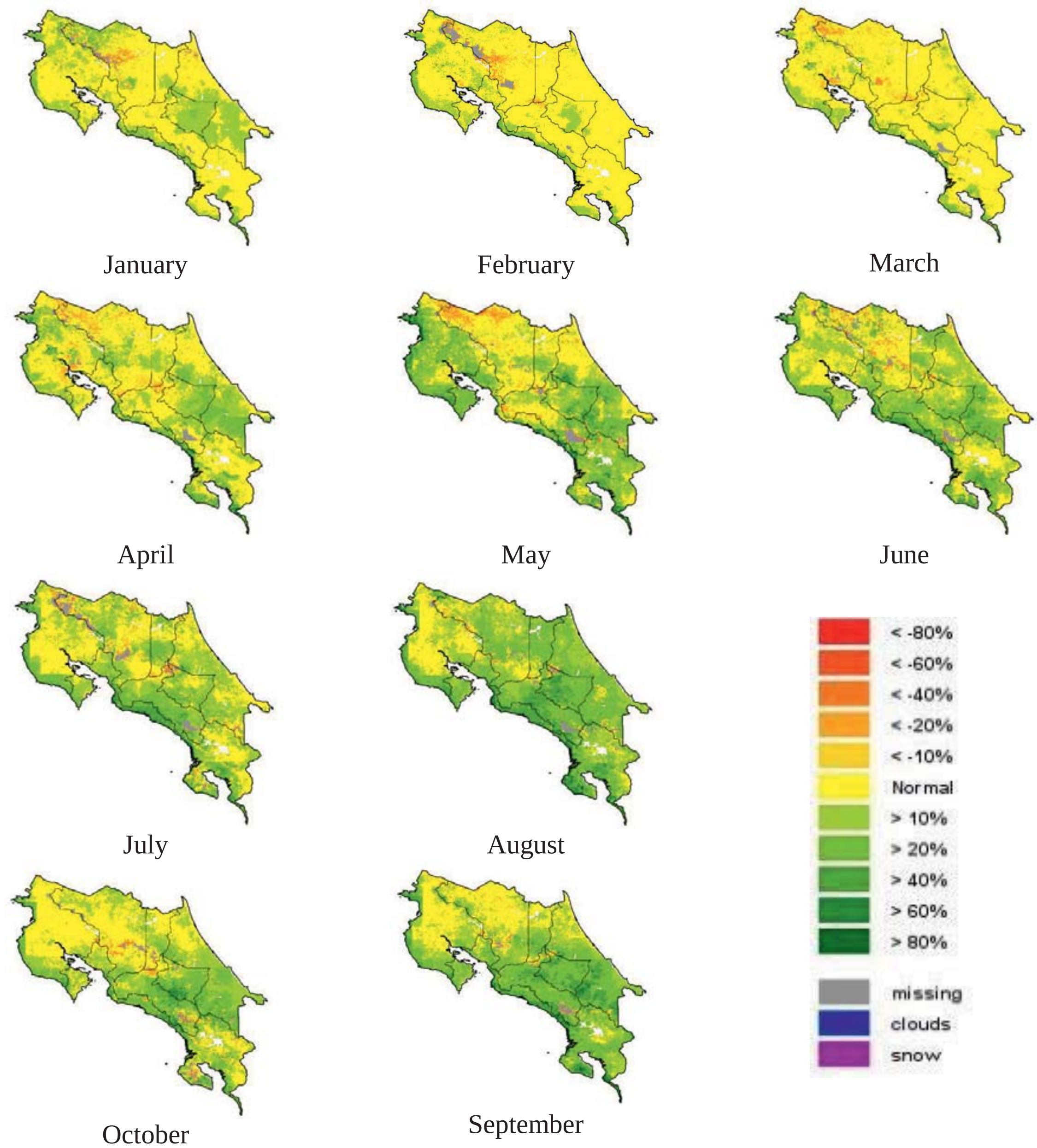

Figure 3. Series of images NDVI mean from January to October 2016 (FAO 2016).

3.2 CO^2 emission monitoring

It is often forgotten that every day of our lives depends on the existence of plants, due to the oxygen we breathe, the food we eat, wood, medicines and even the clothes we wear. Through the process of photosynthesis, plants use energy from the sun to draw down carbon dioxide from the atmosphere and then use it to create the carbohydrates they need to grow, capturing carbon in the biomass of each plant. To meet their needs for industry, agriculture, and transportation, humans annually release more than 7 billion tons of carbon into the atmosphere through the burning of fossil fuel. Yet, scientists cannot account for where all this carbon ends up. Between 1 and 2 billion metric tons of carbon per year are “missing” from the global carbon budget (EOS, 2016).

Carbon sequestration describes processes that remove carbon dioxide from the atmosphere and sequester it to long term storage in the terrestrial biosphere, underground or in the oceans to help mitigate the effects of CO2 on global warming.

"Today Terra is providing the most important clues to help them solve the mystery of the missing carbon. Every eight days the mission's MODIS instrument produces a global map of where and how much carbon dioxide is drawn out of the air and fixed by vegetation during photosynthesis" (EOS, 2016). Both quantitative and qualitative information derived from NVDI results in different studies helps in evolving key strategies for detecting new carbon stockpile, maintaining existing carbon pools and also improving the carbon sequestration in different forest types. Remote sensing is a very powerful tool in the provision of such information (Kumar et al. 2014).

The next false-color map represents the Earth's carbon "metabolism" (Figure 4), the rate at which plants absorbed carbon out of the atmosphere. The yellow and red areas show the highest rates, ranging from 2 to 3 kilograms of carbon taken in per square meter per year. The green, blue, and purple shades show progressively lower productivity.

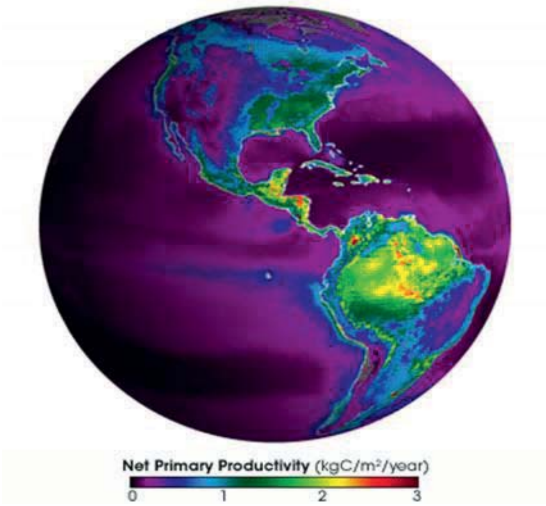

Figure 4. Global, annual average of the net productivity of vegetation on land and in the ocean during 2002. (EOS, NASA 2016).

3.3 Drought monitoring

Drought is a recurring natural weather phenomenon that occurs in all climatic zones (Thenkabil et al., 2004). It is often characterized by the precipitation deficit. Since there is an uneven distribution and demand for global water and precipitation, there are subjective definitions or meanings for droughts (Wilhite, 2004). In this paper, we limit our definition of drought to: an extreme persistence of precipitation deficit over a specific region for a specific period of time (Zargar et al., 2011). Specifically, the definition of drought can be considered from two perspectives: conceptual and operational drought definitions. The former helps us to understand the general concept of droughts and its impact while the latter considers drought's beginning, end and degree of severity for a given period in a specific region. Undoubtedly, the use of remote sensing focuses on the operational definition to develop specific indicators in characterizing and monitoring drought conditions (Zargar et al. 2011). There are more than 150 drought indicators developed over the past few decades to characterize drought conditions (Niameyer, 2008). Among them is the use of NDVI for the detection of vegetation water stress which is translated into environmental drought conditions. From observational studies, we know that long periods of drought in ecological systems lead to changes in the physiological and biochemical characters of plants (Chakraborthy and Sehgal, 2010). NDVI which measures leaf variables, utilizes the biophysical changes and their associated reflectance to detect and monitor water stress in plants (here referred to as vegetation drought). In monitoring vegetation drought using NDVI, large amounts of temporal (time series) data of the regions of interest are required at regular intervals for longer periods of time to establish baseline deviations. Vegetation drought is then estimated as the deviation of the current NDVI values from the temporal mean NDVI values within a specific time frame (equation 2) (Anyamba and Tucker, 2005). When the resulting NDVI values are negative, they indicate below normal vegetation conditions and therefore suggest drought conditions. Very high negative values indicate severe drought conditions.

$$DV = Y(st) - [NDVI] \qquad (2)$$

Where, *DV* is vegetation drought; *Y(s,t)* is the NDVI value for site “*s*” at time “*t*”; and [*NDVI*] is the mean NDVI value over the time frame.

Using times series data from 1981 – 2003, Anyamba and Tucker (2005) established a close relationship between the rainfall pattern and drought conditions of NDVI data from the NOAA/AVHRR sensor of 8km resolution and temporal rainfall data of the Sahel desert. They observed that the high mean monthly rainfall patterns corresponded to high NDVI values between July and October at which time there was high vegetation cover (Figure 5b). It is important to note that, NDVI cannot predict drought but can only detect its effect through its anomalous trend from surface vegetation’s spectral behaviour. To observe the yearly variations of the drought conditions of the Sahel in the same study, the long term mean NDVI values from July to October from 1981 -2003 were deducted from the annual mean NDVI values of the same months (Figure 5c). They observed that there were general reductions in NDVI values from south to North implying intensive drought conditions along the same altitude.

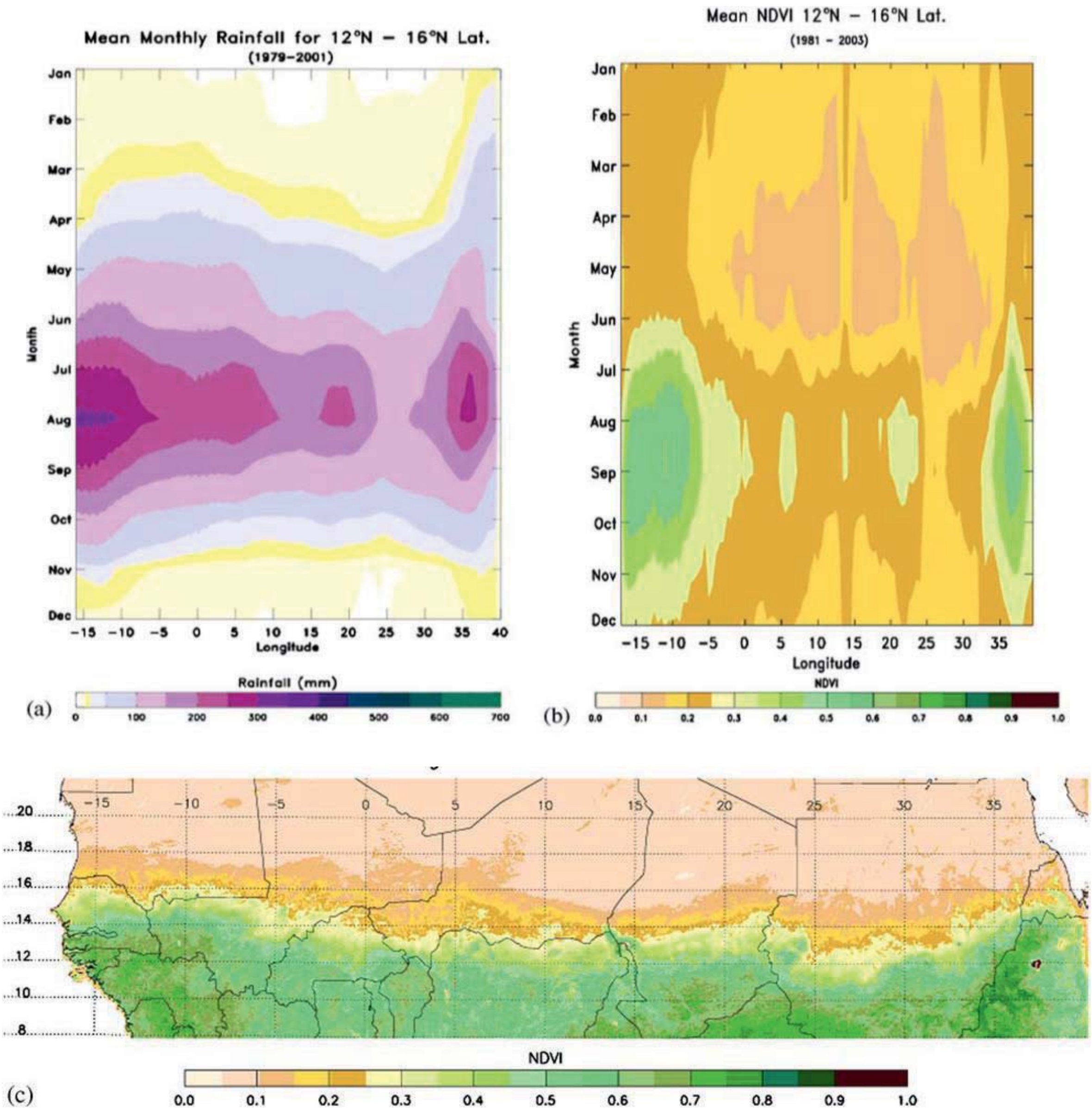

Figure 5(a) (b) (c). Average annual rainfall for the Sahel region (1979–2001) derived from a blend of satellite measurements and rain gauge network (a—top). Long-term mean NDVI for the Sahel region (1982–2003) showing the transition from wet savannah with values of 0.5 to dry savannah with values 0.2 close to the Sahara desert (b—bottom). The numbered locations indicate sites where NDVI data were extracted to examine the temporal variations and trends in NDVI from 1981 to 2003 (Anyamba and Tucker, 2005).

3.4 Detecting forest fires

Throughout history, remote sensing has been used to analyze impacts of fire on regional and global scales. The most common studies have been based on sensors of average spatial resolution, whose objective has been mainly to map burned areas, which can be determined quite accurately (Galicia et al. 2014). More recently, studies have been published to determine post-fire severity conditions from images. This task is particularly interesting in order to more accurately assess damages and establish potential regeneration conditions.

MODIS is operatively used to transmit active fires in real time, being of special utility in those countries that do not have a system for collect or detect terrestrial information. Various efforts have been made to validate this product, especially from by using data taken simultaneously by a sensor with much higher spatial resolution, which has confirmed the good quality of this sensor, provided there are no clouds or dense smoke (Chuvieco, 2009).

In the detection of fires through the NDVI there are three main stages at which the index can perform. (Cruz Lopez 2007; Días Delgado 1999). The alert (pre-fire) stage consists of the dead fuel moisture model (areas with dehydrated vegetation) and the vegetation anomaly index. That together with the heat points can define the possible path of propagation of the fire. A second stage (during the fire) is the detection of hot spots in real life by means of the MODIS application. And in a third stage, the NDVI is used as a product for the identification of burned area that corresponds to the evaluation phase (after the fire) and the regeneration monitoring (Cruz López 2013).

3.5 Challenges of analyzing NDVI anomalies and trends: browning or greening?

In this section we will be discussing how researchers use the data obtained from NDVI in time series and how they determine the trends through the detection of anomalies. For this we review the methodologies used in three different cases: 1) *NDVI trend in the period 2000-2014 as an indicator of land degradation in Argentina: advantages and limitations* (Gaitán et. al 2015), 2) *Spatial and Temporal Patterns of Global NDVI Trends: Correlations with Climate and Human Factors* (Liu et. al 2015) and 3) *Trend changes in global greening and browning: contribution of short-term trends to longer-term change.* (Jong et. al 2012). For the purposes of this article, the trend is taken as the statistical or mathematical form in which the data obtained from the NDVI are evaluated in the time series, this may be using the central tendencies such as: the mean, the mode or the median, or another algorithms or ways of analyzing the information in the time series. However, some of these trends may be creating misinterpretations, showing anomalies that may not be true.

The main discussion here is that the NDVI yields values between 1 (-) and 1 (+) and in a series of NDVI images there may be data at both extremes of the line. What happens if we had, for example, for a data series: 0.012; 0.7; 0.2, 0.002, 0.8 the average would be 0.34, which is not representative of the extreme values, on the other hand this would indicate that in average these five pixels are a space that has been greening. But we can notice that 3 of 5 pixels are not telling us that.

For case 1, NDVI in the region of Argentina, whose surface area is 2 780 400 km2 and which has about nine distinct biomes (IGN, 2016), the authors used the mean trend analysis for the temporal trend. Thus, the temporal trend of the average NDVI at the level of each pixel was calculated over 14 years. For this, the linear regression between time (variable x) and average NDVI (variable y) in each pixel was analyzed. From the sign of the slope and the statistical significance of the regression analysis, a map of areas with significant negative and positive trends was created.

The authors concluded that their study showed a pattern with a marked spatial heterogeneity, suggesting the existence of different processes that act on a regional scale and that the NDVI allows to observe general patterns of positive or negative trends in vegetation activity (as an indicator of ecosystem functioning) and the rate at which these processes occur. However, they mention that the information should be more stratified (at the regional or local level), in short, the interpretation of results must be based on two sources of data, meteorological data (climatic phenomena) and verification of the results of using NDVI data, getting field data in the study area.

In the second case, they use NDVI trends from 1982 to 2012, estimated by *the Theil–Sen median slope method* (which is another measure of central tendency that leaves extreme values aside) to explore their spatial and temporal patterns. Then, their results show that on average, NDVI increased by 0.46×10^{-3} per year from 1982 to 2012 globally with decadal variations. For most regions of the world, a greening (increasing)–browning (decreasing)–greening (G-B-G) trend is observed over the periods 1982–2004, 1995–2004, and 2005–2012.

Are the results of the NDVI a reliable estimator to say that the world turns greener over a period of time? Without taking into account that each region has different seasons and that these same regions could have been affected by atmospheric phenomena that generate droughts or excessive rain, such a conclusion is too general. Then the way to measure and calculate the anomalies is really what is creating errors at the time of interpreting the results (trends), at least for those two particular cases.

For the last case, we have the authors using a trend break analysis *Breaks For Additive Season and Trend (BFAST)* for R language, it integrates the decomposition of time series into trend, seasonal, and remainder components with methods for detecting and characterizing abrupt changes within the trend and seasonal components. They are working with 27 year time series (1982–2008). Each pixel consists of 648 NDVI measurements with a frequency of 24 scenes per year. In this article the authors found that there are positive abrupt changes on 15% of the global territory (greening of the world).

In their discussion they mention that there are events, including climatic and oceanic oscillations, such as El Niño/La Niña, Southern Oscillation (ENSO), volcanic eruptions and anomalously warm and dry years (e.g. the European drought of 2003) that may influence measurement. Aside from biophysical drivers, the observation record might be contaminated with measurement errors originating from sensor changes, orbital drift of satellites or atmospheric effects. Most measurement errors can be well corrected for, but other drivers are likely to cause actual changes in vegetation response in some biomes or regions (e.g. volcanic eruptions and oceanic oscillations). In the analysis they masked pixel values below 0.1 with the yearly mean (some of the pixels are too blurred and it is not possible to get information from it).The resulting dataset is 86% unmasked. However, they are very insistent in that those results for these regions were interpreted with caution. In general, they concluded, that greening prevails in all land cover classes and as a result the global figure indicates greening between 1982 and 2008. But the strongest indication for this was found in croplands and the weakest in forests, which is a conclusion that we should not discard.

4 Conclusions

The tool NDVI proves to be an important vegetation index for monitoring and characterizing surface vegetation distribution and conditions. The relationship between vegetation and NDVI primarily allows for long term studies of changing land use systems of an area. Similarly, long time series analysis of NDVI values of a vegetated area provides information on the phenological stages of plants. This may be used for policy makers as an indicator for planned activities or interventions in forested areas. In water deficit areas, time series analysis of NDVI correlates with the rainfall pattern in situ and thus can also be used to determine the productive seasons of the year.

In conclusion the diverse applications of NDVI show its useful versatility in the ecological environment. Although it does not replace direct field measurement, it compensates for time, labor and areal coverage. It also provides a useful basis for predictive modeling through its long spatial and temporal trends of vegetation monitoring. NDVI is a good vegetation indicator if it is for study a climatic region in specific, but should be combined with field measurements and other indicators to give a holistic overview of forest conditions.

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Chapter six

Climate change & Case studies

Biomass of a fragment of the Atlantic Forest in the state of Espirito Santo, Brazil

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Abstract

The paper analyzes the biomass of a segment site of the Atlantic forest, located in the biological Reserve Sítio dos Palmares in the state of Espirito Santo, Brazil. On six plots of 400 m^2 each all the trees with *DBH* $\geq$ 5 cm were measured. In the area 341 trees distributed in 70 species and 32 families were found. The tree population presented an average of 14.82 cm *DBH* and a basal area of 43.60 m^2/ha, corresponding to 518 m^3/ha (stem and branches) equivalent to 397,674 kg/ha of standing biomass.

Key words: Floristic survey; timber volume; wood density; forest biometrics.

Resumen

El trabajo analiza la biomassa de un segmento del bosque Atlántico. El área está localizada en la Reserva Biológica Sítio dos Palmares del estado de Espírito Santo, Brasil. Foram instaladas seis parcelas de 400 m^2, donde fueron medidos todos los árbores con *DAP* igual o superior a 5 cm. Se encontró 341 árboles distribuidos en 70 especies y 32 famílias. El *DAP* médio aritmético fue igual a 14,82 cm y el área basimétrica igual a 43,60 m^2/ha, contabilizando 518 m^3/ha de troncos y ramas, lo que correspondió a 397.674 kg/ha de biomasa en pie.

Palabras llave: Levantamiento florístico; volumen de madera; densidad de la madera; biometria florestal.

1 Introduction

Different phytofisionomies of the Atlantic forest are typically related to natural factors and human uses that until little more than five centuries ago were spreading over the whole Brazilian Atlantic coast. At present the Atlantic forest is fragmented into areas by the coastal mountainous range of the south and southeast regions of Brazil (Delduque, 2008). According to SOS Mata Atlântica (2008), the southeast region the Atlantic forest was covering 11,8 % of its original surface in 2008, at present it has come down to 111 million hectares (Servico Florestal Brasileiro, 2011).

The bibliographical review about the Atlantic forest stated the existence of little released works relative to the wood volume and the determination of the arboreal biomass, demonstrating the importance of analyzing related studies on this forest formation. The literature registers the work of Souza and Jesus (1991), Chichorro (2003) and Rolim et al. (2006) that has defined volume equations; studies by Burger and Delitti (2008), Rolim et al. (2005), Silveira et al. (2008); Scallop et al. (2008) and Cunha et al. (2009) approach the determination of the biomass by means of allometric models.

Regarding ecological studies, pedology, floristics and phytosociology on the Atlantic forest, several works were published. In relation to the dynamics and structures of growth of the natural succession of the arboreal communities' studies were carried out by Drumond and Meira Neto (1999), Marangon et al. (2008) and Aparício et al. (2011).

The present study is justified, considering that the Atlantic forest is one of the ecosystems with the most anthropic uses. The study's object is the arboreal floristic growth in a fragment of the Atlantic forest for determining the wood volume and the corresponding biomass.

2 Material and methods

The study area is in the Biological Reserve Sítio dos Palmares, District of Santa Maria Jetibá, in the state do Espírito Santo (Figure 1), in 692-m altitude.

Figure 1. Localization of the Palmares Biological Reserve.

The climate of the region is classified as Cwb, subtropical highland climate, in accordance with the Köppen classification, with quite definite rainy and dry periods. During the cold season the temperature remains between 7 and 9 °C, and in the warmest months it is between 25 and 27 °C. The annual average temperature is 18 °C. The annual average precipitation is 1800 mm (Instituto Capixaba de Pesquisa, Asistencia Técnica e Extensao Rural, 2011). The soil is of the type Cambissolo Háplico (Panoso, 1978).

The Biological Reserve Sítio dos Palmares possesses preserved and antropic areas of the Atlantic forest. For the present study, a preserved area was selected randomly. Six plots of 400 m^2 (20x20 m) were installed totalizing 2.400 m^2. In these plots, all trees were identified and measured, including the palms, since they had a *DBH* ≥ 5 cm. The botanical nomenclature was based on the classification w^3 Trópicos of the Botanical garden of the University of Missouri (Tropicos, 2015).

Of every arboreal individual, the *DBH* was measured in cm and when trees were taken down the diameter at 0,30 m was measured that was named low diameter *(Dinf*), the diameter in the base of the first thick branch (*Dsup*), and between these two diameters the corresponding height of the stem (*Hf*) in meters. In the branches the same methodology was used, measuring the diameters in the base of the branch (*Dinf*) and in the base of the following fork (*Dsup*) and the correspondent distance (*H*), only in the branches that had diameters bigger than 5 cm (Figure 2).

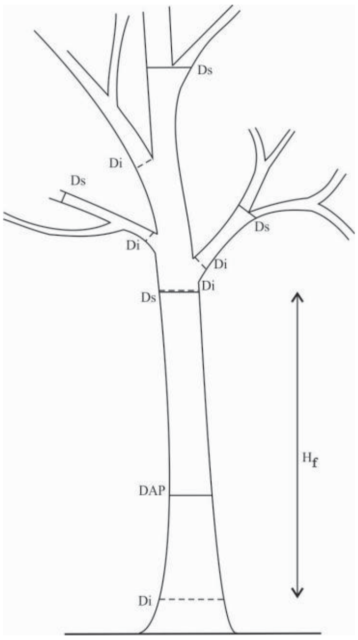

Figure 2. Diameter measure points on the stem and branches, until an D_{min} = 5 cm.

For the measurement of the diameters a tree calliper was used and for the distance (height) of the stem and branches a 20-m tape. For achieving the corresponding volume of wood of the stem and branches, the measured diameters were transformed into sectional areas (Ai), that together with the height of the stem or distance on the branch in meters, were calculated by the Smalian formula.

$$A_i = D_i^2 \cdot 0{,}7854$$

where: *Ai* = cross sectional area in m^2

*D*i = low or top diameter of the considered section

0,7854 = π/4

$$V = \frac{A_1 + A_2}{2} \cdot H$$

where: A_1 = cross sectional area of the low diameter

A_2 = cross sectional area of the top diameter

H = height of the stem or length of the section.

Every section of the contemplated branch had its volume calculated by the formula of Smalian. The sum of the corresponding volumes of the obtained sections presented the entire volume of the branches for a tree that was later classified by species. The green woody biomass was also calculated for every species. This parameter was obtained by the multiplication of the volume with the corresponding value of the basic density of the wood. The calculation was carried out by tree and its corresponding sum was extrapolated for the hectare.

$$BM_L = V(m^3/ha) \cdot DB(kg/m^3)$$

where: BM_L = woody biomass (kg/ha)

V = volume (m^3/ha)

DB = basic density of the wood (kg/m^3)

For the determination of the basic density of the wood of the species, discs were cut at breast-height and in the base of the fork of the first branches. The samples went through the standard process of drying, and determining the corresponding value through the expression:

DB = Ms (g) / Vv (cm^3)

where: Ms = dry mass and Vv = green volume.

The basic density was determined for the weight of the dry sample, obtained in a heater of 105 ± 2 degrees centigrade on the volume of the saturated sample (constant weight).

The floristic diversity was identified by the index of Shannon-Weaver (H') based on the proportional diversity of the species (Magurran, 1988) using the expressions:

$$p_i = \frac{n_i}{N}$$

where: p_i = proportion of individuals (i) found, of every species

n_i = number of individuals of the species "i"

N = entire number of individuals of the sample

$$H' = (-\sum p_i \cdot \ln p_i)$$

where: ln = logarithm in the base n

Σ = sum of all "i" species of the sample.

3 Results and discussion

In the studied fragment 341 individuals were found which originated from 70 species, distributed in 32 families.

The species that had major presence by number of individuals were *Euterpe edulis* (62), *Maprounea guianensis* (28) and *Salacia amygdalina* (20) that group constituted 32,26 % of the observed community. The number of individuals that can been extrapolated for the hectare would be of 1420 trees, a value that can be accepted when compared with Alves Junior et al. (2007) who registered between 549 to 1657 individuals per hectare for fragmets of the Atlantic forest of Recife, with a *DBH* of more than 5 cm, distributed in 54 species and 25 families. Oliveira (2002) found a population of 2784 n/ha of the age of 25 years, and 2273 n/ha of the age of 50 years in a fragment of the Ilha Grande (Rio de Janeiro). Kurtz and Araújo (2000) inform the existence of 1370 n/ha in the forest of the Ecological Station of Paradise which is also in the state of Rio de Janeiro. Observing the population density and the corresponding floristic richness found by Kurtz and Araújo (2000) and Oliveira (2002), it is possible to infer that the tree structure of the studied fragment belongs to the clímax development stage. Drumond and Meira Neto (1999), in a site of the Atlantic forest in the middle region of the Rio Doce in the state of Minas Gerais, found 1247 n/ha, distributed in 43 species. Rolim et al. (2006b) in an area of 20.000 ha in the region of Linhares (state of Espirito Santo) registered 408 species distributed in 59 families.

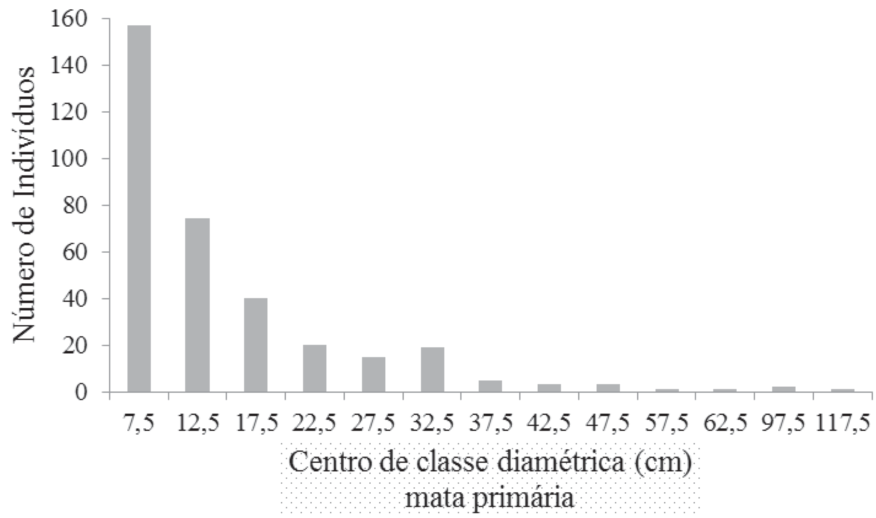

Figure 1. Diametric distribution of the forest population at the Reserva Biológica Sítio dos Palmares.

The index of Shannon-Weaver showed low species diversity, corresponding to the value of 2.68 nats/ind, which stayed inside the interval (H' between 1.69 and 4.4). Borém and Oliveira-Filho (2002) found pertinent indexes between 3.6 and 4.1 for a 30-year-old fragment, located in the state of Rio de Janeiro.

In the analysis regarding the *DBH,* a 14.82 cm average was found. It is possible to infer that the forest community structure is of a small sylvicultural size (Figure 1). According to Beek and Sáenz (1992), Hawley and Smith (1982), this average is placed in the fustal class in dense tropical forests.

The diametric distribution shows the typical curv of the inverted J. Regarding the basal area of 43.60 m^2/ha, Panties et al. (2009) found in a fragment of the Atlantic forest in the Forest Reserve of Paradise (Minas Gerais) values between 21.17 and 60.35 m^2/ha. Kurtz and Araújo (2000) registered 57.28 m^2/ha and Oliveira (2002) between 26.3 and 32.4 m^2/ha in sites of 25 and 50 of age respectively; in fragments in the state of Rio de Janeiro. Borém and Oliveira-Filho (2002) indicated between 23.15 and 33-34 m^2/ha for fragments also located in the state of Rio de Janeiro.

In Table 1 the relative parameters for the calculation of the wood volume and biomass are presented, specified for 70 species found in the field of study. The entire volume was 124.60 m^3, being 84.34 % of the volume of the stems and 15.65 % of the branches corresponding to 518.34 m^3/ha.

The species that presented the major volume were *Manilkara longifolia* (11.27 m^3), *Aspidosperma australe* (8.36 m^3), *Maprounea guianensis* (7.82 m^3), *Tapira guianensis* (7.63 m^3) and *Basiloxilon brasiliensis* (7 m^3). These five species with 63 arboreal individuals (18 % of the whole), accumulated 42.08 m^3 corresponding to 33.77 % of the entire volume. It was observed that 37 species (53 %) presented volume of wood lower than 1 m^3.

A whole of 95,594.76 kg of biomass was registered, consisting to 84.5 % of the stems and 15.5 % of the branches, which represented 397,674.20 kg/ ha. Rolim et al. (2005) and Vieira et al. (2008) registered for a fragment of the Atlantic forest between 241,000 and 437,000 kg/ha. In this sense the opposing result is framed by the information registered by Rolim et al. (2005). The species that presented the biggest values in biomass were *Manilkara longifolia* with 11,303.23 kg, *Aspidosperma australe* with 7,690.01 kg, *Manilkara rufula* with 6,259.83 kg, *Maprounea guianensis* with 5,630.33 kg and *Tapira guianensis* with 4,957.95 kg. These five-species accumulated 35,841.35 kg corresponding to 9 % of the whole of the studied biomass. The obtained results of the structure and the state of development of the fragment of the studied site forest, supported the information of the literature.

Table 1. Volume and biomass parameters of the species on the fragment of the Atlantic forest at the boplogical Reserva Sitio dos Palmares

Species	basic density kg/m³	n	DBH medio cm	volume stem m³	volume branch m³	volume total m³	volume m³/ha	biomass stem kg	biomass Branch kg	biomass total kg	biomass kg/ha
Aegip sellow	512	2	11,5	0,1061		0,1061	0,4417	54,37		54,37	226,18
Agona brasil	880	1	13,0	0,1837	0,0085	0,1923	0,8000	161,73	7,52	169,25	704,08
Alcho triplin	503	1	7,5	0,0353		0,0353	0,1470	17,78		17,78	73,96
Anade macro	860	1	22,5	0,5725	0,1005	0,6730	2,7999	492,4	86,44	578,84	2407,97
Andir fraxii	782	2	15,25	0,9886	0,1207	1,1093	4,6149	773,13	94,39	867,52	3608,88
Apeib tibour	320	1	30,0	1,0602	0,1106	1,1709	4,8712	339,29	35,42	374,71	1558,79
Apule leiocar	989	2	23,25	1,5197	0,2587	1,7784	7,3984	1.503,03	255,87	1.758,90	7317,02
Aspid austra	920	7	24,43	6,7267	1,6319	8,3587	34,7722	6.188,58	1.501,43	7.690,01	31990,44
Aspid cylindr	660	1	30,0	1,1781	0,1791	1,3572	5,6462	777,55	118,25	895,8	3726,53
Aspid polyne	898	5	11,2	0,6630	0,0208	0,6839	2,8451	595,41	18,76	614,17	2554,95
Aspid popul	894	1	17,0	0,3204	0,0430	0,3635	1,5122	286,48	38,51	324,99	1351,96
Aspid subin	880	2	9,5	0,0651		0,0651	0,2711	57,37		57,37	238,66
Basil brasi	374	12	20,04	5,9201	1,0835	7,0037	29,1354	2.214,15	405,24	2.619,39	10896,66
Cabr canjer	670	1	10,0	0,0117		0,0117	0,0490	7,89		7,89	32,82
Carin estrel	628	3	26,0	2,2515	0,3466	2,5982	10,8086	1.414,00	217,7	1.631,70	6787,87
Cassi ferrug	806	1	13,0	0,0980	0,027	0,1256	0,5228	79	22,31	101,31	421,45
Cecro catari	403	1	19,0	0,3805	0,0094	0,3899	1,6223	153,35	3,81	157,16	653,79
Cenos angus	910	3	18,67	0,9731	0,0991	1,0722	4,4607	885,53	90,25	975,78	4059,24
Carai densif	820	1	20,5	0,4830	0,0480	0,5310	2,2091	396,08	39,38	435,46	1811,51
Cordi sellow	793	3	19,5	0,9940	0,1779	1,1719	4,8754	788,31	141,07	929,38	3866,22
Cordi tricho	684	2	22,25	0,9681	0,1652	1,1334	4,7150	662,22	113,05	775,27	3225,12
Couep rufa	982	1	66,0	3,2345	0,9046	4,1392	17,2190	3.176,37	888,4	4.064,77	16909,44
Couss fribur	804	3	10,5	0,0816	0,014	0,0962	0,4002	65,67	11,68	77,35	321,78
Cupan vernal	700	2	20,5	1,1356	0,1776	1,3133	5,4636	794.98	124,39	919,37	3824,58
Dalbe decipu	899	1	47,0	2,3255	0,2561	2,5817	10,7399	2.090,69	230,28	2.320,97	9655,24
Dalbe nigra	920	4	12,87	0,6783	0,1179	0,7963	3,3129	624,12	108,55	732,67	3047,91
Enter contor	598	1	31,0	1,217	0,1955	1,4128	5,8776	727,99	116,92	844,91	3514,83
Eugen invol	808	9	13,72	1,3466	0,2597	1,6064	6,6828	1.088,12	209,89	1.298,01	5399,72
Euterp eduli	798	62	8,52	1,8167		1,8167	7,5575	1.449,73		1.449,73	6030,88
Fícus enorme	558	1	18,5	0,3835	0,0405	0,4241	1,7645	214,04	22,64	236,68	984,59

Species	basic density kg/m^3	n	DBH medio cm	volume stem m^3	volume branch m^3	volume total m^3	volume m^3/ha	biomass stem kg	biomass Branch kg	biomass total kg	biomass kg/ha
Galles goraz	612	1	13,5	0,1696	0,0112	0,1808	0,7524	103,82	6,88	110,7	460,51
Guare guido	798	5	16,3	1,7913	0,2264	2,0177	8,3937	1.429,46	180,69	1.610,15	6698,22
Huber glazio	818	1	5,5	0,0086		0,0086	0,0359	7,07		7,07	29,41
Hymen courb	850	3	27,67	3,1685	0,3819	3,5504	14,7700	2.693,22	324,7	3.017,92	12554,55
Laciste pubes	709	3	8,0	0,1429	0,0107	0,1536	0,6393	101,35	7,62	108,97	453,32
Manilk elata	1018	3	22,5	2,7602	0,4794	3,2397	13,4772	2.809,97	488,08	3.298,05	13719,89
Manilk longi	1003	8	31,19	9,6149	1,6544	11,2694	46,8807	9.643,79	1.659,44	11.303,23	47021,44
Manilk ruful	1053	4	33,87	4,4073	1,5374	5,9447	24,7301	4.640,94	1.618,89	6.259,83	26040,89
Maprou guia	720	28	12,52	6,9892	0,8306	7,8199	32,5307	5.032,29	598,04	5.630,33	23422,17
Mezilau nava	843	3	12,83	0,5811	0,0138	0,5950	2,4753	489,95	11,67	501,62	2086,74
Miconi cinna	910	4	10,25	0,4766	0,0727	0,5494	2,2857	433,8	66,21	500	2080,00
Miconi minui	800	7	9,0	0,7193	0,0410	0,7604	3,1634	575,51	32,85	608,36	2530,78
Mollin gilgia	608	1	15,5	0,0365	0,0202	0,0567	0,2360	22,2	12,29	34,49	143,48
Myrci pubipe	812	7	7,93	0,1611		0,1611	0,6702	130,83		130,83	544,25
Nectan myria	782	3	9,67	0,1909		0,1909	0,7942	149,31		149,31	621,13
Nectan reticu	792	2	9,5	0,0702		0,0702	0,2924	55,67		55,67	231,59
Nectan rigida	797	1	26,0	0,7759	0,1209	0,8969	3,7311	618,45	96,38	714,83	2973,69
Ocote catari	833	13	10	1,1218	0,1838	1,3056	5,4315	934,48	153,13	1.087,61	4524,46
Ocote elegan	780	17	12,85	4,4551	0,5346	4,9898	20,7577	3.475,04	417,03	3.892,07	16191,01
Ocote glome	600	8	21,12	4,9905	0,7136	5,7042	23,7294	2.994,35	428,17	3.422,52	14237,68
Ocote pretio	534	15	14,13	3,759	0,4573	4,2170	17,5428	2.041,52	248,33	2.289,85	9525,78
Ocote pulche	638	6	15,33	2,294	0,2689	2,5632	10,6632	1.463,80	171,57	1.635,37	6803,14
Ormos arbor	812	1	8,0	0,018		0,018	0,0784	15,31		15,31	63,69
Ormos fastig	790	2	18,25	0,7245	0,1286	0,8531	3,5492	572,38	101,64	674,02	2803,92
Parki pendul	530	1	95,0	2,7979	2,9090	5,7070	23,7412	2.076,11	1.541,79	3.024,73	12582,88
Piptad comm	790	1	14,5	0,1639	0,0313	0,1953	0,8127	129,55	24,78	154,34	642,05
Platyc regnel	910	1	27,0	0,8482	0,1283	0,9765	4,0625	771,89	116,79	888,68	3696,91
Protiu brasil	600	1	31,5	0,8906	0,1281	1,0188	4,2382	534,39	76,9	611,29	2542,97
Psychot vello	611	2	7,0	0,0289	0,0071	0,0360	0,1499	17,66	4,36	22,02	91,60
Rheedi brasil	803	1	7,0	0,0164		0,0164	0,0686	13,24		13,24	55,08
Salac amygd	600	20	9,27	1,4165	0,1861	1,6027	6,6672	849,95	111,68	961,63	4000,38
Sclerol densi	804	1	13,0	0,1010		0,1010	0,4204	81,27		81,27	338,08

Species	basic density kg/m^3	n	DBH medio cm	volume stem m^3	volume branch m^3	volume total m^3	volume m^3/ha	biomass stem kg	biomass Branch kg	biomass total kg	biomass kg/ha
Sweet frutico	993	2	37,0	2,3483	0,2073	2,5557	10,6318	2.331,91	205,92	2.537,83	10557,37
Syagr botryo	883	3	13,67	0,3595		0,3595	1,4957	317,49		317,49	1320,76
Sympho globu	620	1	26,5	0,7492	0,1002	0,8495	3,5340	464,55	62,16	526,71	2191,11
Tabeb cassin	502	1	21,0	0,8131	0,0621	0,8752	3,6410	408,19	31,18	439,37	1827,78
Tapiri guian	650	8	24,81	6,1393	1,4883	7,6276	31,7308	3.990,55	418,62	4.957,95	20625,07
Vataire araro	600	1	16,0	0,310	0,0614	0,3717	1,5466	186,23	36,85	223,08	928,01
Vochys bifal	588	1	14,0	0,2634	0,0184	0,2823	1,1747	155,17	10,88	166,05	690,77
Xylopi serice	800	13	8,81	0,6989	0,0879	0,7868	3,2732	559,13	70,33	629,46	2618,55
Total		341		105,09	19,50	124,60	518,33	80.807	14.786	95.594	397.674

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Error propagation in AGB estimation - Comparison of uncertainty estimation of AGB obtained with different devices

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Abstract

Obtaining more accurate estimation of aboveground biomass (AGB) in forest, has become a requirement for transparency in the management of forest resources and also economic resources. Because of this, it is important to consider that there are multiple sources of error that contribute to the uncertainty in the estimation of AGB. This work focused on studying the uncertainty due to the field measurements using diameter at breast height (DBH) and total height (TH) as explanatory variables derived from allometric equations to estimate AGB. Repeated measurements were performed with two instruments for each explanatory variable: diametric tape and caliper for DBH, and hypsometer and Vertex for TH. With the estimation of the statistics of these variables, the uncertainty was calculated from the field measurement using the error propagation. The error in TH, due to the accuracy of the measurement made with Vertex contributed 0.5% of the measurement, while in the measurement with hypsometer it was 5.9% of the contribution in average. The errors due to the accuracy of the instrument in DBH measurements were similar for the devices used (3.4%: caliper and 1.9% tape). The uncertainty in AGB estimation per tree range from 1 to 19% in the measurements made with diameter tape and Vertex compared with 3 to 41% of the measurements made with of Caliper and Blume Leiss.

1 Introduction

Estimation of Biomass in forest ecosystems is important especially as part of the quantification of Greenhouse Gas emissions (GHG). In developing countries, it is important to relate the forest above ground biomass (AGB) estimates to deforestation, forest degradation and land use change. There are already mechanisms in place such as REDD, that offer incentives to conserve or enhance forest carbon stocks by reducing deforestation and forest degradation. However, fair allocation of incentives will require transparency in the estimation process. Consequently, it is necessary to incorporate uncertainty analysis into the Measurement, Reporting Verification (MRV) procedures.

The capacity of the worldwide forest as a carbon sink has been estimated by Hall et al (1994), in their work it is stated that 2.7 PgC yr-1 is the average absorption rate, with 1 PgC yr-1 (almost 30%) of uncertainty. DeFries (1994) emphasizes the importance of continuous and systematic estimation for all the components of the global forest carbon stock. Therefore, if one important part of this carbon sink is forest biomass carbon, then it is necessary to know how the forest biomass contributes to the overall uncertainty.

In this context, error propagation in the estimation of AGB has been previously studied at different scales (Chave et al 2004; Ahmed et al 2013; Holdaway et al 2014). At tree-level, uncertainty has been reported to stem from tree measurement (diameter at breast height, total height, wood density, and species identification) and the choice of the allometric model (AGB/tree). At plot level, the errors propagate from variability in plot size and type (AGB/plot) whereas for larger areas the precision of estimates may also be influenced by the sampling design (AGB/forest). To propagate the errors, it is necessary to know how the errors are distributed and how much variability these errors contribute to the biomass.

Measurement errors in tree variables have been studied with the main aim of finding out the accuracy of the devices to measure forest variables. Regarding measurements of DBH, there have been studies which aimed to explain the differences of results between diametric tape and caliper measurements (Kraunch 1924 and Behre (1926), considered the impact of this measurement error on the basal area growth (McRoberts 1994) or described the difference of the measurement using these two devices in a geometric way (Matérn 1956).

Total tree height (TH) measurement errors have been also studied with different purposes and methods: For the comparison of indirect height estimation with direct measurement of felled trees (Hyppönen and Roiko-Jokella 1978), using distance methods compared with clinometer mensuration (Omule 1980), using a distance method and clinometer to compare the measurement of trees' TH (Howe and Adams 1988, Päivinen et al 1992), and recently, using laser measurements compared with dendrometer measurements (Williams et al 1999). As we can notice, there exists a worry about how to obtain better mensuration.

Scientific works usually report estimations using devices with proved accuracy or at least assuming high accuracy in the mensuration. In the case of the National Forest Inventories (NFI) conducted in developing countries, the devices used are generally less accurate than in scientific research, mainly due to the cost of the required devices. This study describes the errors (discrepancies) for DBH and TH measurements considering the use of two devices for every measurement. This information will be used to propagate the error and determine how different the AGB estimation could be using different devices and the uncertainty associated with the measurement.

2 Methods

2.1 Study area

The data acquisition for this study, took place in a state forest in the north of Göttingen, Lower Saxony, Germany (Figure 1). This forest is located in 54°34’ North latitude – 9°57’40’’ East longitude. According to the Botanical Garden of the University of Göttingen (GAUG 2016), annual rainfall (628 mm) is uniformly distributed in the year and temperature ranges from 1 to 17.4 °C (mean information from 1971-2000).

The forest belongs to the Highland of southern Lower Saxony and specifically to the Vegetation Sector “Forest of Göttingen”, according to the classification of Germany (GAUG 2016). The principal forest species in the site of study are beech (Fagus sylvatica) as a dominant species, accompanied by european ash (Fraxinus excelsior), field maple (Acer campestre), Norway spruce (Picea abies), and wild cherry (Prunus avium), among others species. This forest is typically used to conduct practices related to the training of students of the University of Göttingen.

Figure 1. Study area location. Göttingen, Germany. (Source of images: Wikipedia https://en.wikipedia.org/wiki/G%C3%B6ttingen, Google maps https://www.google.de/maps/place/Gotinga/)

2.2 Sampling design

In the forest 47 plots were established in summer 2015. The arrangement of these plots was a systematic grid of 75 by 75 m. Eleven plots were selected to describe and to analyze the measurement discrepancies of above ground biomass (AGB) in diameter at breast height (DBH) and total height (TH).

2.3 DBH-Height

The aim of the study is the use of the “best measurement”, or control data, of the two variables (DBH and TH) in every tree. To obtain this control data, two devices to measure the DBH and two devices to measure the TH were used.

A protocol of measurement was developed for the field work. This protocol was used to establish the measurement criteria for the use of the devices in the measurement procedure. By applying these protocol rules, it is assumed that systematic errors will be avoided and these were therefore not considered. This document was based on the protocol established by FAO (FAO 2004), which explains in detail how to manage the different situations in the forest to obtain correct measurements for DBH and TH, among other variables.

In the following lines, the characteristic of the devices used in this study will be described briefly, considering the accuracy (if available) provided by the manufacturer. The devices used for the measurement of the explanatory variables were:

- DBH, 1) Caliper 65 cm (Haglöf), measurement unit centimeter (cm), measurement resolution 0.1 cm, accuracy not provided; 2) Diametric metallic tape for 96 cm (Richter), measurement unit cm, measurement resolution 0.1 cm, accuracy not provided.
- TH, 1) Hypsometer - Blume-Leiss (Carl Leiss Berlin GmbH), trigonometric principle, measurement unit meter (m), measurement resolution 1 m, accuracy not provided; 2) Hypsometer-VERTEX IV (Haglöf), trigonometric principle measurement unit m, measurement resolution 0.1 m accuracy 1% provided only for distance (Haglof 2007).

The general procedure of data acquisition consisted in conducting repetitions of "blind measurements" (Condit 1998). This method consists in the following steps: 1) Measure one variable of all the trees of the plots considered in the study, this was the first repetition of the control data, 2) Re - measure the same variable for all the trees without access to the data of the first measurement made (considering at least 2 re-measurements) 3) Performing the steps 1 and 2 using the four devices evaluated, one at a time.

The measurements made with tape (DBH) and vertex (TH) were made 5 times (n=5) with one observer, and the measurements for caliper (DBH) and Blume-Leiss (TH) were made 3 times (n=3) with a second observer. The minimum value for DBH considered in this data collection was 7 cm and the plot size was 500 m2. The devices used for this study were always the same during the data acquisition to avoid bias due to the device.

3 Error propagation

3.1 Model definition

The error propagation methodology is described in the Guidelines for national greenhouse gas inventors (IPCC 2006). Following this guideline it is feasible to estimate the uncertainty that is due to the measurement. The first step was defining how to estimate the target variable.

This estimation was defined with a formula or model which represents how our target variable is related to our response variable.

The models used in this study, to estimate the AGB, were developed for broadleaf trees and coniferous trees (Fehrmann 2006). To derive the models Fehrmann (2006) used n=528 data for the general broadleaf tree model and n=963 data for the conifers general model. The models generated in that study were:

for broadleaf trees model, using DBH and TH as explanatory variables

$$AGB_{BL} = 0.04390 * DBH^{2.0476} * H^{0.7589} \quad (1)$$

With R2: 0.9848; DBH range (cm): 0.8 – 77.1; TH range (m): 1.9 - 39.1.

For conifers model, using DBH and TH as explanatory variables

$$AGB_{C} = 0.08175 * DBH^{2.1704} * H^{0.3492} \quad (2)$$

With R2: 0.9703; DBH range (cm):1.2 - 73.8; TH range (m): 1.9 – 38.4.

3.2 Sources of uncertainties

Two sources of uncertainty were identified for every measurement: device resolution (DR) and repeatability (REP). In the first source, the uncertainty due to the resolution of the device was calculated as a standard deviation of a uniform distribution:

$$u_{DR} = \frac{DR}{\sqrt{12}} \quad (3)$$

The uncertainty due to REP was calculated with the standard deviation of the repeated measurement divided by the number of repetitions made in every tree. This ratio of the standard deviation and the number of observations is also called standard error, and is a common term related with the accuracy of the measurement

$$u_{REP} = \frac{sd}{\sqrt{REP}} \quad (4)$$

3.3 Sensitivity coefficients

The coefficient of sensitivity is the partial contribution of each response variable in the estimation of our target variable. This proportion is obtained when a partial derivation to the formulas (1) and (2) is applied.

$$DBH = \frac{\partial AGB}{\partial DBH} \quad (5)$$

$$TH = \frac{\partial AGB}{\partial TH} \quad (6)$$

3.4 Combined uncertainty

The combined uncertainty is the addition of all the partial effects of the response variables. It is important to consider that the partial contribution for one response variable is obtained adding the sources of uncertainty obtained for resolution and repeatability (3) and (4).

$$u_{DBH} = u_{DR} + u_{REP} \quad \text{and} \quad u_{TH} = u_{DR} + u_{REP} \qquad (7 \text{ and } 8)$$

$$u_{COM} = \sqrt{\left(\left(\frac{\partial AGB}{\partial DBH}\right)^2 * u_{DBH}\right) + \left(\left(\frac{\partial AGB}{\partial TH}\right)^2 * u_{TH}\right)} \qquad (9)$$

3.5 Expanded uncertainty

Finally, is very important to report the result of the uncertainty. For this, it is necessary to select the k coefficient. This coefficient is associated with the significance and is mainly the number of standard deviations considered for the final result.

$$u_{EXP} = k * u_{COM} \qquad (10)$$

$$CI_{95\%=} \left((\overline{AGB}) - u_{EXP}\right) \leq AGB \leq ((\overline{AGB}) + u_{EXP}) \qquad (11)$$

3.6 Data analysis

Descriptive statistics were performed to explain the characteristics of the tree measurement of DBH and TH using the different devices. Considering that the aim of this study is the propagation of the error, it was important to describe the variation obtained with the measured repetitions. For every tree the mean, variance, standard deviation, relative standard deviation and standard error were calculated. These statistics were obtained for every pool of measurement for each device.

A normality test was performed to the resulting statistics. Once that we obtained the result of non-normality, the pairs of measurements were compared with a non-parametrical Wilcoxon signed-rank test.

4 Results

The total number of trees measured for this study were 250. The DBH ranges from small trees with 7 cm until 64 cm. The TH measurement ranges from 5 to 37 m. The number of species found were 8 and the dominant specie was Beech (Fagus sylvatica).

4.1 Standard deviation

In the figure 2, we can observe the standard deviation of the measurement obtained for every tree sorted in ascending order. On the left-side, DBH measurements appear to be similar and only the highest values of Caliper measurement increased more in comparison with Tape measurements. On the right-side the difference between the results of the devices used is clear, Blume-Leiss values were above the values of Vertex. In the standard deviation comparison, the TH analysis was statistically different ($p<0.01$).

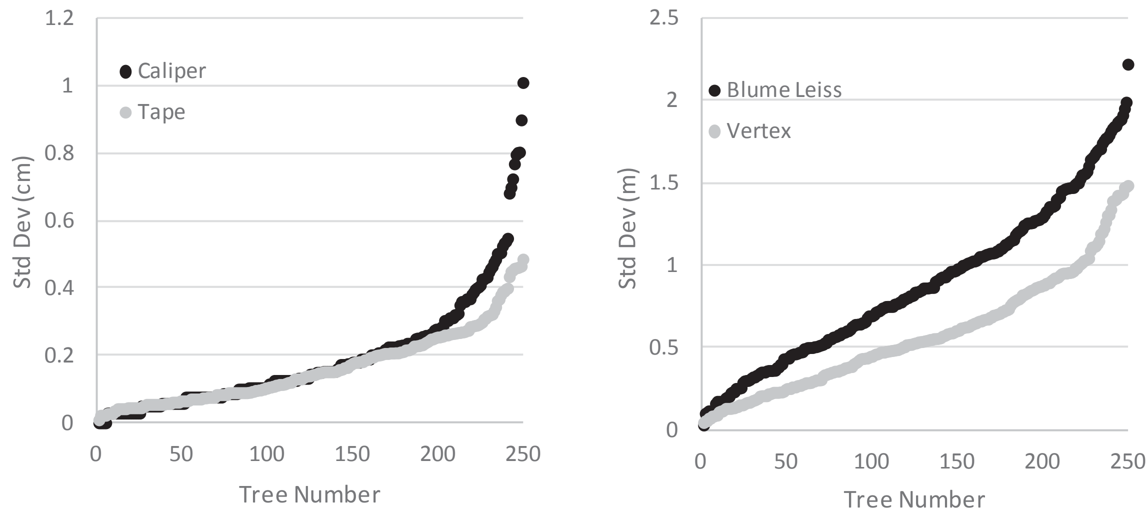

Figure 2. Standard deviation. X axis values are the number of trees measured, Y axis in the left- side are in cm and in the right-side are in m.

4.2 Standard error

The comparison of the standard error in the measurement (Figure 3) shows the effect of the number of repetitions made for every device. For DBH, on the left-side, we can observe that the trend of the standard error for both devices is very close but in the end, similar to the standard error (previously described), the value of the data from caliper measurements increases. On the right-side, the results of the devices show a clear difference between both devices, Blume-Leiss and Vertex. The analysis of comparison found the results of standard error for both DBH and TH to be statistically different ($p<0.01$). This result means that the value of the median is not the same for the variables DBH and TH.

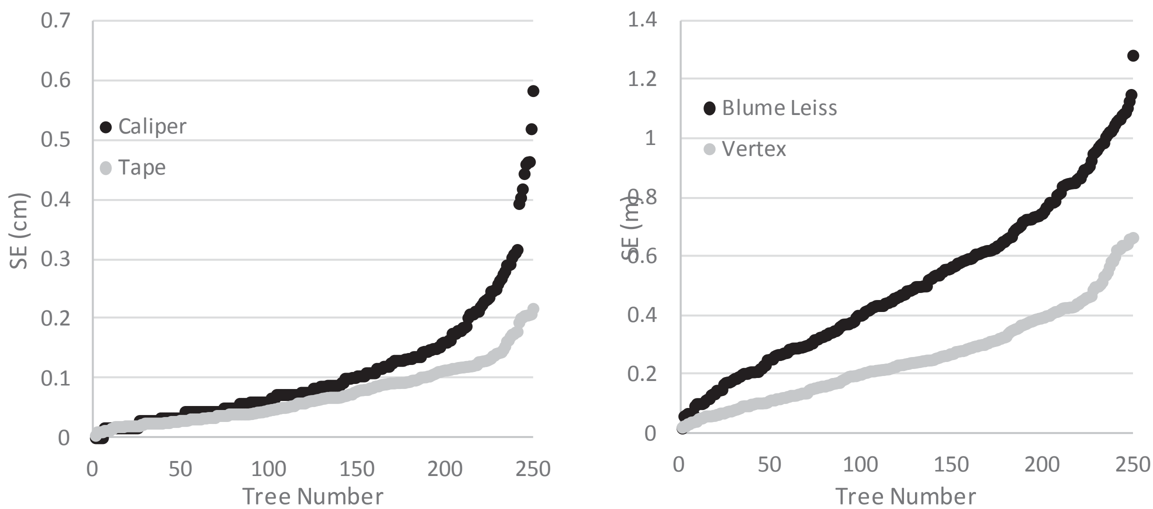

Figure 3. Standard error. X axis values are the number of trees measured, Y axis values in the left- side are in cm and in the right-side are in m.

4.3 Relative Standard Deviation

The relative standard deviation (RSD) is calculated using the value of the standard deviation divided by the mean value of the repetition made for every tree. This lets RSD become dimensionless and, in this case, we can use it to compare all the measurements made in DBH and TH. In the Figure 3, we can see that the measurements made for DBH (Tape and Caliper) are close to each other and, compared with the trends of standard deviation and standard error, there is not a dramatic increase of the values for the bigger RSD values. For TH, the RSD values differ due to the small sized trees. The comparison analysis found statistical difference ($p<0.01$) in the TH measurements.

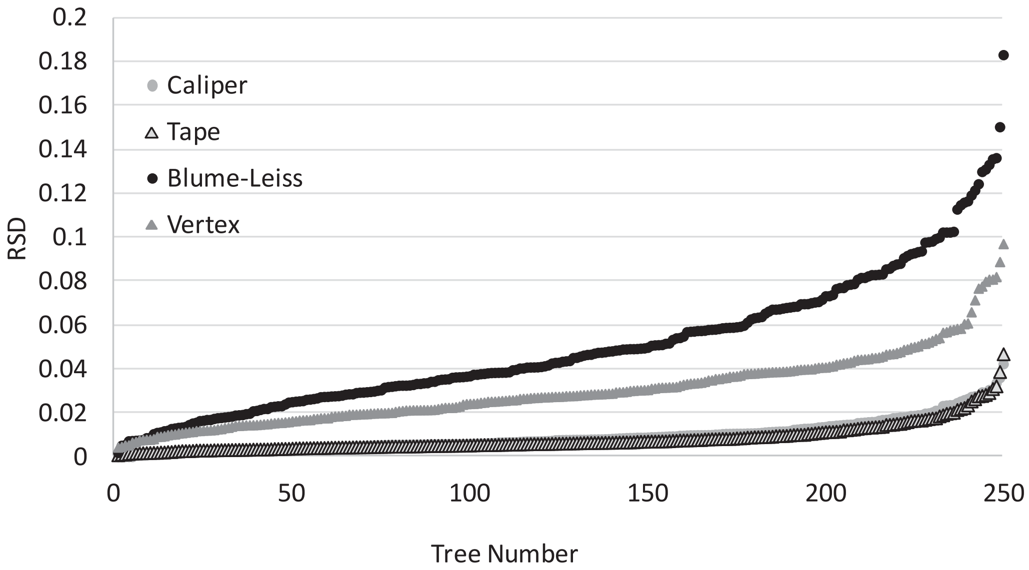

Figure 4. Relative Standard Deviation. X axis values are the number of trees measured, Y axis values in the left- side are in cm and in the right-side are in m.

4.4 Error propagation

Sensitivity coefficients

The sensitivity coefficients for TH and DBH were obtained, applying the equations (5) and (6) to equation (1), i.e. broadleaf model:

$$\frac{\partial AGB}{\partial DBH} = 0.08991 * DBH^{1.0476} * TH^{0.7589} \quad (12)$$

$$\frac{\partial AGB}{\partial TH} = \frac{0.03332 * DBH^{2.0476}}{TH^{0.2411}} \quad (13)$$

Using these coefficients, we calculated the uncertainty for every device. In this calculation, we included the partial contribution of uncertainty due to the different sources. Uncertainties for DBH (Figure 5) have similar trends for both devices. Due to the standard error estimated for tape being less than 0.1 cm, and this being the size of the resolution of this device, we can explain that the contribution to the error by the device's resolution increases in comparison with the Caliper.

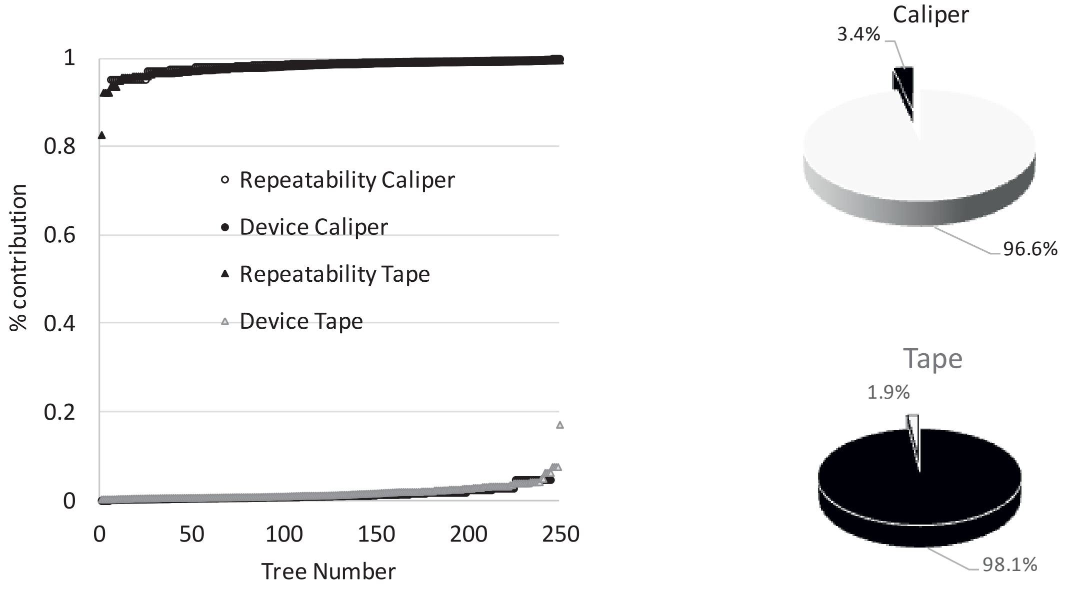

Figure 5. Uncertainty for DBH measurements. Left: X axis values are the number of trees measured, Y axis value is the percentage (%) of contribution in the error for the DBH measurement, "Device Tape" is the uncertainty due to resolution of the device. Right: Average of partial contribution to the error for each device.

In the uncertainty for TH (Figure 6) we can see a different trend than the one observed in DBH. In both devices, the contribution of the repeatability to the error is considerably bigger than that of the resolution of the device. In the Vertex IV results are clear and we can state that the device resolution has a low contribution to the uncertainty.

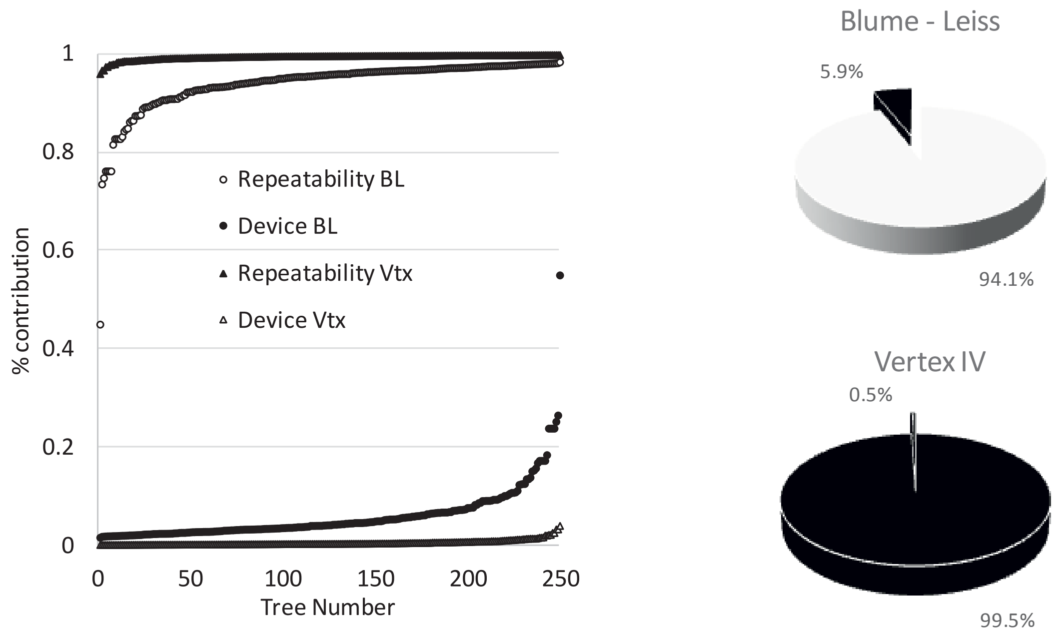

Figure 6. Uncertainty for TH measurements. Left: X axis values are the number of trees measured, Y axis value is the percentage (%) of contribution in the error for the TH measurement, "Device BL" is the uncertainty due to resolution of the device. Right: Average of partial contribution to the error for each device.

4.5 Uncertainty

The expansion of the uncertainty for AGB tree-1 was estimated considering a factor k=2 (assuming normality in the distribution of the uncertainty). The values of the uncertainty of AGB (Fig 7) show the increase of the uncertainty when there is also an increase of the AGB of the tree. The range of values for uncertainty in proportion of the AGB estimations are from 1% to 19% using Diameter Tape and Vertex IV and from 3% to 41% using Caliper and Blume-Leiss.

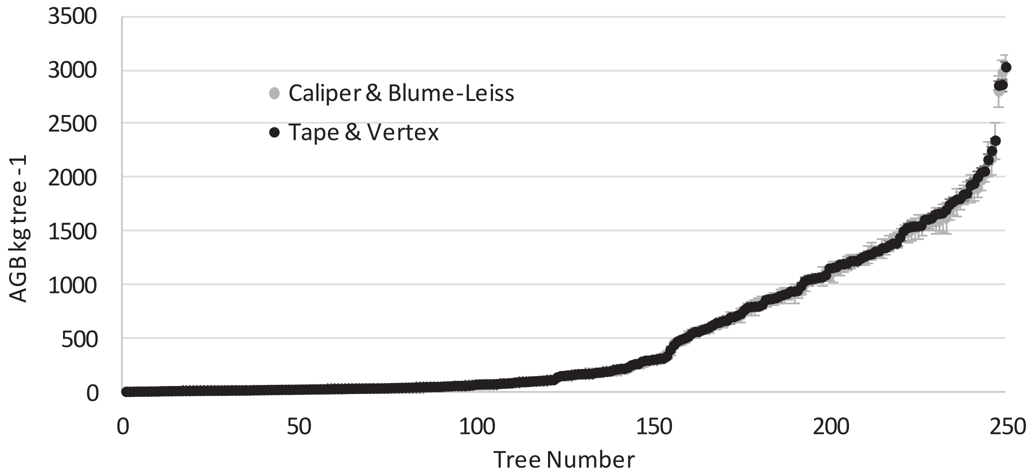

Figure 7. Uncertainty per Tree. Left: X axis values are the number of trees measured, Y axis value is the percentage AGB estimated per tree.

Conclusions

The use of protocols is important when we conduct an experiment in which we need to focus on certain sources of error. In the case of this paper, it was very important to avoid a systematic error and this was achieved with the use of clear rules for the use of the devices and the criteria involved in the mensuration itself.

The difference in measurement of DBH, with caliper and diametric tape, could be consider negligent since no statistical difference was found. This suggest that in the study area we can use indifferently one of these devices and the result will not differ significantly.

It is important to emphasize the differences found in TH measurements. With the data analyzed we can noticed that measurements made with Vertex IV had better accuracy compared with the Blume-Leiss. This could be related to the resolution of the device which is 5 times better for Vertex IV.

The error propagation method used in this study is easy to implement in this scale of work. In further steps, we could implement the Monte Carlo assessment to compare the results and also include de propagation of the error at plot level.

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Climate Change Adaptation Practices of Forest Dependent Poor People: Comparative Study of Nepal and Ghana

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Abstract

Climate change is a globally challenging disturbance that causes upsets in climatic factors and strongly affects the environmental condition, ecosystems and biophysical systems. Evidences from climate change studies shows that impacts are occurring throughout the world. Temperature and precipitation are two main factors which regulate the climate of an area. The level of intensity of suffering from climate change impacts is not the same to all wellbeing groups. The poor segment of society is more vulnerable to climate change due to the dearth of social safety nets, lack of access to basic health services and education. As a common coping strategy, for some urgent livelihoods issues induced by climate change, poor households in the context of Nepal are forced to let their children discontinue going to school and get involved in wage labour, and sell their seed stock, utensils and livestock for subsistence during scarcity. Coping strategies commonly practices in Ghana are planting mixtures of crops and cultivars, starvation reserve crops such as cassava and using landraces resistant to climate stress.

Keywords: Climate change, adaptation, livelihoods, Nepal, Ghana

1 Introduction

It has been proven scientifically that climate change could create serious impacts on the poor segment of the world population in the coming years. (Adger *et al.*, 2003; Agrawal and Perrin, 2009; Hedger *et al*., 2008; IPCC, 2001). The Millennium Ecosystem Assessment (2005) indicates that changes in the climate have been serious contributing factors to the degradation of ecological and ecosystem services and it also claims that deterioration of ecosystem services is triggering harm to the poorest population of the word, thereby increasing poverty. Continued exacerbation of poverty, lack of access to health facilities and education opportunities, and a deficiency of social safety nets increases the degree of vulnerability to climatic change for the poor segment of society (Adger *et al.*, 2003; Smit *et al.*, 2000). IPCC (2007) reported that "temperate and tropical Asian countries are likely to have increased exposure to many extreme events, including the possibility of glacial melts, floods and landslides, rising sea levels, large-scale inundation, recession of flat sandy beaches, increased fire risk, water stress, typhoons and tropical storms, and vector-borne diseases".

Although, there are several literatures published and available on the climate change, they are not equally understandable to all levels of people as the literatures use very scientific language with jargon and shaped by sophisticated mathematical models with the result that a majority of the people understand little about the impacts of climate change and its causes. Besides, most of the information about climate change and its consequences are scattered and is hence, out of the reach of ordinary people (Chaudhary and Aryal, 2009). Chaudhary and Aryal (2009) also explain that the information is even more limited for most of the poor countries including Nepal, although these countries are very susceptible to climate change and its consequences, because they suffer from persistent poverty, illiteracy as well as ignorance of these climatic issues. In this situation, the dearth of such essential information obstructs the formulation of effective policy to address climate adaptation and mitigation approaches, pushing the poor countries towards even more extreme vulnerability. In this context, it is very urgent and important to explore the factors contributing to climate change, to examine how ecosystems and human wellbeing are affected by these changes and lastly to recommend ways forward to increase the local ability to adjust to the changing scenario. Against this background, this paper compares climate change adaptation practices of Nepal and Ghana focusing on poor forest users.

2 Global climate change and its impacts

Global warming is a globally challenging disturbance to the climatic factors through which environmental conditions, ecosystems and biophysical systems are affected. These changes are widespread and alarming and many of them have negative consequences for human well-being (Chaudhary and Aryal, 2009). The changing climate impacts human beings and ecosystems in a different way. As an example, climate change can not only affect human health and cause changes to forests and other ecosystems but also alter rainfall which directly influences yields of agriculture as well as forest crops and even impacts to the energy supply in an ecosystem. All over the world, there have been many evidences that climate change related impacts are being experienced in different ways (some of the evidences are depicted in figure 1). Two important climatic factors affected by climate change are temperature and precipitation. The concentration of Green House Gasses (GHGs) has increased in the atmosphere which results in the rising of the global average temperature that has been noticed constantly since the mid twentieth century and scientists also forecasted that it is expected to rise continuously in the future (Groom *et al.*, 2007). The earth surface temperature rose by 0.74 ± 0.18 °C (1.33 ± 0.32 °F) during the 20th century (IPCC, 2007) and scientists conclude that it could rise as much as 6.4 °C (11.5 °F) on average during the 21st century due to an increasing rate of GHG release (Wigley 1999, IPCC, 2007). Studies show that ecosystem processes and functions are severely affected by changes in rainfall and temperature – snow and ice melting, soil properties changes, and upset in hydrological systems are some examples (IPCC, 2001). It has been noticed that the rising of the sea level has not halted since 1990 and it is predicted to continue to rise for several decades (IPCC, 2001, Pirages and Cousins 2005). Projections by Church *et al.*, (2006) indicate that rising of the sea level will reach 280-340 mm on average between 1990 to 2100, and that the melting of ice would contribute nearly 30% of this sea level changes (IPCC, 2001). Fluctuations of temperature, changes in precipitation and ecosystem processes have great influence on the biological fabric in different ways (Pounds *et al.*, 1999). Some of the examples include shifting of ranges, changing of phenology, extinction, changes in morphology and behavior of flora and fauna which are connected to the warming-led ecosystem change (Table 1).

Table 1: Various Examples of Range Shift in Different Places around the World

Country	Species	Observed range shift	Reference
Costa Rica	Lowland bird	Begun breeding on mountain slopes	Pounds et al., (1999)
Switzerland	Alpine flora	Expanded toward the summits	Grabherr et al. (1994)
Sierra Nevada, CA	Edith's checkerspot butterfly	Shifted upward by 105 meters	Parmesan (1996)
Canadian Rockies	Treeline	Upward movement	Parmesan (1996)
Canada	Arctic fox	Contracted toward Arctic ocean	Hersteinsson and MacDonald (1992)
USA	Sactrem skipper butterfly	Expanded from CA to WA	Crozier (2003)

Adapted from: Groom et al. (2006)

It has been recorded that some species' location changes from lower to higher elevation with the increased warming (Woodward 2002, Klanderud and Birks 2003). As a result, some dependent herbivores and insects also shift with them, just as carnivores are compelled to change their habitat along with their prey populations (Whittaker 1999). Scientific evidence has recorded horizontal and vertical shifting of species at a rate ranging from 7 to 100 km per decade (Thomas and Lennon 1999, Parmesan *et al.*, 1999). As an example, it has also been recorded that trees start growing at altitudes of 40 meters higher than the original places they were found 25 years ago (NGS, 2002). Evidences also includes the fact that phenology and breeding behavior of species has changed (Figure 1), such as courtship calling, birthing, mating, singing in animals and insects, as well as blooming and flowering time changes in plants species-ranging from a few days to as early as a month prior to historical patterns (Hersteinsson and MacDonald 1992, Grabherr *et al.*, 1994, Parmesan 1996, Pounds *et al.*, 1999, Crozier 2003, available in Groom *et al.*, 2007).

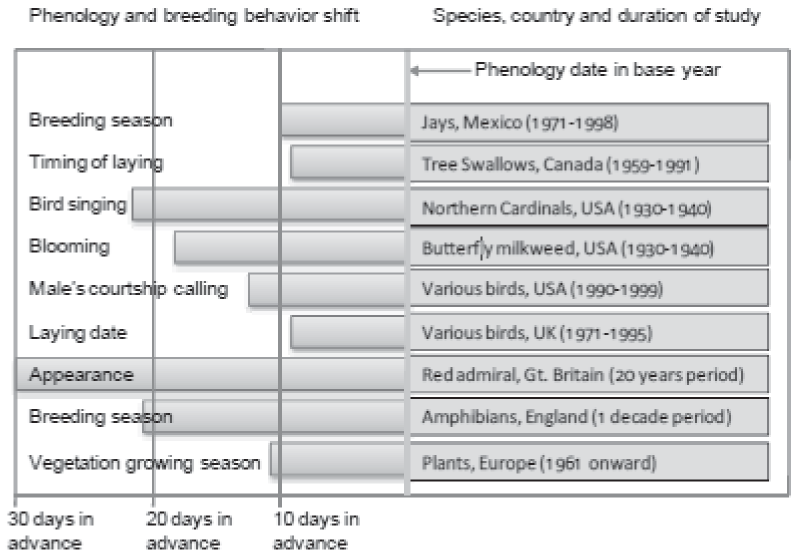

Figure 1. Some examples of early phenology and breeding behaviours of various plants and animals (adapted from Groom et al. 2007)

3 Climate Change in the Context of Nepal

Nepal is very sensitive country to climate change and its impacts. It has a diverse geographical structure as well as a variation in the wellbeing of the people. The economically very poor segment is more affected by climate change issues. Particularly, fluctuation in temperature, changes in precipitation, and implications on agriculture and effects on important resources are the major impacts experienced by the Nepalese people.

3.1 Temperature

Topographically Nepal is diverse in elevation, ranging from the plain areas to the Himalayan high mountains including the highest peak of the world. It therefore has the extreme influence of the many mountain ranges and the South Asian monsoon. Nepal is an extremely climatically complex country (GON, 2010). Over the last four decades, the warming was found to be consistently increasing. Over the past period from 1977 to 2000, the average mean maximum annual temperature was recorded to have increased by 0.06 °C and it was found to be 0.04 °C higher in Terai (Lowland) and 0.08°C higher in the Himalayas. The pronounced warming was thus found in the higher regions of the country (Shrestha *et al.*, 1999). It can be seen in the variation in radiation observed by glacial lakes and meting of snow in the Himalayan region (Malla, 2009).

3.2 Precipitation

In Nepal, the precipitation situation is unclear, and large uncertainties prevail. According to the National Adaptation Programme of Action of Nepal, precipitation data has no general national trend, however, the UNDP country profile reported, the annual precipitation trend to be decreasing (McSweeney *et al.*, 2003). Some other studies (for example, Baidya *et al.*, 2008; Practical Action, 2009) report that a precipitation change over the different seasons is recorded as increasing in some parts of the county, however, it is found to be decreasing in other regions. As an example, the community's responses of Lamra village (Mid-hills) of Nepal, along with the historical timeline showed that a declining and unpredictable trend of pre-monsoon and monsoon rainfall has been experienced in current years which also corroborate to meteorological data acquired from recording stations (Gentle and Maraseni, 2012). The country has also experienced extreme precipitation days, recorded particularly in weather stations below 1500 meters, which have been a serious problem for landslides, flash floods and inundation (Baidya *et al.*, 2007). Consequently, variations in climate with frequent occurrence and extreme incidences of climate events (particularly floods, landslides and droughts) have been found to be key challenges to the infrastructure, the agricultural sector and the rural livelihoods of Nepal (GON, 2009).

3.3 Effect in Agriculture

Topography and corresponding climatic settings are the principal factors that determine the growth of plants and their yields where rainfall, sunlight and temperature are the major limiting factors of plant growth and yields (Gurusamy, 2008 cited in Acharya and Bhatta, 2013). The impact of climate change might have a significant direct impact to the Nepalese national economy because more than one third of the Gross Domestic Product (GDP) is contributed by the agricultural sector of Nepal and this sector is also providing employment opportunities to more than two third of the total labour force (Acharya and Bhatta, 2013). The impact on agriculture is not similar across the country. For example, the eastern part of the lowland faced rain shortage in the year 2005/06 which resulted in a crop production reduced by 12.5%. Similarly, about 10% of agricultural land were forced to remain uncultivated due to rain deficit. The situation was more sever in the western part of the lowland, which faced heavy rainfall including floods that reduced 30% of the crop production in the same year (Regmi, 2007).

3.4 Resource degradation

People are experiencing resource scarcity, and particularly the poor segment of society seems more vulnerable to resource depletion. Because of climate change, the water resource has changed drastically. A study done by Gentle and Maraseni (2012) shows that mountain rural communities have been suffering from depleting water resources for irrigation and drinking use. Local communities also claimed that inadequate winter rain fall, limited snow fall and drought have substantially affected forests and rangeland which in turn impacted livestock grazing (e.g. low productive grazing land due to overuse and less moisture content) and forest products such as Non-timber Forest Products (NTFPs), which are playing an important role for the subsistence of people and are depleting. Consequently, poor people are forced to reduce their livestock number as they cannot afford stall feeding.

3.5 Impacts on major livelihoods options

Mountain people face diverse hazards of climate change. Some of them are irregular rainfall, drought, landslides, and diseases identified by mountain communities of Nepal (Table 2). In this region, agricultural crops, NTFP collection, wage labour, livestock, and seasonal migration to India are the major livelihood options which are intensively affected by climate hazards (Gentle and Maraseni, 2012).

Table 2: Vulnerability matrix of Lamra VDC, Nepal. Significant impact-3; medium impact-2; low impact-1; and no impact-0 (Source: Gentle and Maraseni, 2012).

Major livelihood resources	Major hazards				
	Erratic rainfall	Drought	Landslides	Water/vector borne diseases	Rank
Rice cultivation	3	3	1	0	I
Winter crops	3	2	1	0	II
Wage labor	2	1	0	1	IV
Livestock (forage and grazing)	1	2	1	1	III
Seasonal migration to India	1	0	0	0	V
NTFP collection	2	3	0	0	III
Total score and rank	12 (I)	11(II)	3(III)	2(IV)	

4 Climate Change effects in the Context of Ghana

Climate change has significant impacts in Ghana and Its people are experiencing climate change effects in different sectors. Economically weak and poor people are found to be more vulnerable to climate change. Fluctuation in temperature, changes in precipitation, effects in agriculture and implications on important livelihoods resources are the major impacts faced by people.

4.1 Temperature

Average yearly temperatures in Ghana moved up by 1.0 °C since 1960. The highest and lowest temperatures shot up by 2.5 and 2.2°C respectively in the same time (Dontwi *et al.*, 2008). Changes in temperature in Ghana are mostly dependent on the eco-climatic zone under which the area falls. For instance, upward adjustment in temperature reported by Minia (2008) and McSweeney *et al.*, (2010) has been found to be more rapid in the savanna zones than in the deciduous forest zone. Mean temperatures observed within a period of five years from 1961 to 2000 depicted about 1°C rise in the Sudan and Guinea Savana zones, less than 1°C rise in deciduous forest (0.8°C), rain forest (0.4°C) and coastal savanna (0.6°C) zones.

4.2 Precipitation

Generally, in view of the irregular nature of rainfall patterns in Ghana, monitoring its yearly or decadal occurrence to establish a sequence is strenuous. However, in the 1960s a report from McSweeney *et al.*, (2010) depicted an increase in frequency but a drastic fall in levels between the late 1970s and early 1980s. Similarly, the situation was not different along the coastal area in Ghana within the period of 1961 and 2000 (Dontwi *et al.*, 2008). A consideration of the average yearly rainfall differences between the periods of 1951 to 1970 and 1981 to 2000 at meteorological stations across Ghana also showed minimal rainfall (Owusu and Waylen, 2009). Deciduous forest and rain-forest eco-climatic zones known to usually experience relatively high rains observed an average fall in precipitation ranging from 136.9 to 335.3 mm as did the coastal zone with a decline of 260.5mm. The savana eco-climatic zone experienced a decline in the percentage of total yearly rainfall of 20%, as low as half the amount of rainfall experienced in the rain forest zone (Owusu and Waylen, 2009).

4.3 Effect in Agriculture

The agricultural sector has power and great influence in the Ghanaian economy when we consider the money it contributes, the people it employs and the food it supplies to the citizenry (GSS, 2008). In view of the fact that agricultural production in Ghana is largely rain dependent, high lack of consistency in its spread over larger areas has been a key challenge to the sector. It has been fully established that rainfall as a climatic factor affects Ghana's agriculture during the cropping season by letting it start late and ending relatively earlier than normal. Biazin *et al.,* (2012) report of decreased crop productivity due to high evaporative demand while the situation improves with heavy rainfall. Moreover, as Schlenker and Lubell (2010) indicated, floods and drought make crops susceptible to pest and diseases: there was a similar climatic situation with an average yield reduction of 20% of maize, millet, sorghum and millet within the period of 1961 to 2006 in Ghana.

4.4 Impacts on major livelihoods options

Occupations of coastal and freshwater residents primarily depend on fishery resources. These resources in Ghana are mostly confronted with threats which could partly be attributed to climate change but more so to human factors. Some of the prevalent climate-change related threats include increased ocean temperatures beyond optimum levels, thus killing large numbers of fishes, and massive siltation in lakes and other water resources to reduce water depth which consequently dries up the water bodies thereby depriving residents of their livelihoods. However, persistent human induced threats include: a shifting of fishing practices to more destructive manners as well as prolonging the harvesting season. Both these operations weaken the probability of stock recovery (CRC, 2010; Nelson and Agbey, 2005).

5 Adaptation strategies

Historically, the communities who live in and around the natural resources, manage these resources collectively. This is particularly the case for forest, water, fish stocks and livestock which are highly dependent on weather (Adger *et al.,* 2003; Agrawal, 2001). The adaptation strategies practiced by communities focus on short term shock measures (Ellis, 1999; Nuorteva *et al*., 2010) rather than being based on initiatives planned in policy as long term strategies

(Bates *et al.*, 2008; Smit *et al.*, 2000). It has been noticed that adaptation practices by communities are more responsive towards independent and socio economic aspects which requires lower capital investment (Sohngen and Mendelsohn, 1998).

6 Comparison of adaptation practices of Nepal and Ghana

In the context of Nepal, the study conducted by Gentle and Maraseni (2012) shows that poor families are practicing various adaptation measures. Children are getting involved in labour in different places after forcing them to drop out of school. Preserved seed, kitchen utensils, and livestock are also sold during scarcity. In the mountain communities, labour selling in the local market and migrating seasonally to the neighbouring country India have been other common strategies to cope with the situation. Although migration is a traditional strategy for poor communities, in recent times, intensity of seasonal movement to India, accompanied by other family members search for employment has increased. In contrast, comparatively rich families are trying to adjust locally by storing crops against starvation, saving of money, money lending for interests, and purchasing of irrigated land. They are also exploring new technology for diversifying agriculture products as a part of adaptation measures (Table 3).

In Ghana, fluctuation of temperature and rainfall is pushing farmers towards vulnerability. To tackle this unpredictable climate situation, people are practicing some adapting measures. Most commonly practiced strategies by farmers include the planting of mixed crops and cultivars in different moisture conditions to reduce complete crop failure, the practice of mulching to protect moisture, conservation of water resources as well as using landraces resistant to climate stresses (Challinor *et al.*, 2007). Farmers have also started to cultivate starvation reserve crops. Cassava is an example of a starvation reserve crop which comprises 14 local varieties and 3 improved varieties providing flexibility through different maturation period. Cassava has already proven its used during scarcity. For example, it was massively used during crop failure during the drought period in 1983 (Sagoe, 2006). Water collection and storing is also in practice in Ghana. Big water storage barrels and cans for watering are an example. Similarly, a simple treadle pumps is being used by farmers largely in the Volta and Ashanti regions. In the northern parts of the savanna zones, off season vegetable crops are promoted in floodplain. Since the many irrigation options involve infrastructure as well as collaboration among groups, the farmers having a low income are not able to use them. As a result, some farmers choose off-farm activities such as trading or they choose to migrate towards urban areas during stressful seasons leaving agriculture behind (Adeoti *et al.*, 2007) (see some of the options in Table 3).

Table 3: Comparison of Climate Change effects and responses between Nepal and Ghana

Observed changes	Wellbeing status	Effects on livelihoods		Adaptation practices	
		Nepal	Ghana	Nepal	Ghana
Decreasing and unpredictable precipitation, low pre-monsoon and winter rainfall Increasing mean maximum and minimum temperature Prolonged drought drying pasture land and water sources	Well-off	Reduced production of rice and winter crops, reduction in livestock numbers	Decrease fodder Increased soil erosion	Varying cropping pattern, storage of grains, money saving, selling non-irrigated land and purchasing irrigated land, lending out money	Shifted attention on livestock. Plant legumes as cover crops. Brewery of local beer, called “Pito”
	Medium	Limited production of rice and winter crops, decrease in livestock numbers, scarcity of resources	Crop failure	Changing cropping pattern, storage of grains, cash saving, selling properties (livestock/land), increased seasonal migration, shifting towards skilled jobs	Plant varieties of crops and cultivars e.g. sorghum, millet, maize, rice, yams, groundnuts and beans. Women diversify their income by engaging in petty trading and selling of cash crop like Cola
	Poor	No production of rice, limited production of winter crops, food deficit and hunger, debts	Crop wilting	Changing cropping pattern, sale of property (seed, utensils, garments, livestock, land), changing food behaviour, consumption loan from local lenders, selling of labour in the local and Indian market, dropping out of school and sent to do work	Plant more drought-tolerant varieties of red sorghum. Shift towards cultivation in low lying, marshy areas and river valleys where soils retain more moisture. Mulch yam mounds to regulate soil moisture content, Engage in bee-keeping for honey

Source: Gentle and Maraseni, 2012; Sagoe, 2008; Gyasi et al., 2008

7 Conclusion

There are changes in climate with negative effects on livelihoods options for people in both countries. Because of the limited livelihood options, particularly poor people are affected by unseasonal and uncertain whether events, remoteness, and poor services. Agricultural production, which is essential for subsistence livelihoods, seems to be increasingly risky due to unpredictable rain, erratic snowfall and recurrent drought events. Similarly, cattle grazing and collection of NTFPs and their selling are also under threat due to uncertain weather patterns.

The level of intensity of suffering from climate change impacts is not the same for all socio-economic groups. Based on various studies, it can be concluded that there are higher impacts on the livelihoods of the poor who live in very vulnerable regions. This is because they own Little and non-irrigated land and heavily rely on rain fed subsistence agriculture production, they further own little physical assets, have low or limited education, and little knowledge and skills that can be utilised to explore new adaptation strategies and benefit from available livelihood adaptation strategies and resources.

Apparently, climate change and its impacts are a very complex issue. This complexity should be understood by all stakeholders right from the planning stage to implementation. Policy makers particularly political leaders who play a very important role in decision making in policy process are to be informed clearly on how climate change is happening and how people are being affected. As it is a scientific topic, and there is a limited and scattered availability of information about specific regional contexts, more in-depth site-specific studies, including knowledge of affected people should be conducted and scaled up to influence policy process. Lastly, context specific national and local policy must be developed having flexibility and innovativeness with the provision of contingency and a role of institutions to facilitate adaptation at local level.

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Species distribution models as support tool for forestry-related activities in tropical montane forests

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Abstract

Deforestation, environmental change and weak institutional resources, are among the primary challenges in forest management in tropical mountain regions. Species distribution models, also known as environmental niche models, are a relatively easy and cost-effective way to incorporate projections of species distribution as support tools into decision-making processes. In this article, we aim at presenting to forest managers and practitioners, a brief summary of the Maxent methodology, key sources of input data for modeling species in tropical mountain forests and a short discussion before presenting the results. In spite of the assumptions and limitations of using presence-only data, Maxent can provide highly accurate estimates if implemented properly. Furthermore, open source quality data as well as novel platforms for the operation of Maxent could facilitate the inclusion of this methodology into any forest related activity.

1 Introduction

Recent improvements in remote sensing allow for accurate measurement of forest resources in near real time (Rosette et al. 2015; Nölke et al. 2015. Puliti et al. 2015)- However, projections and modeling are still used to deal with uncertainties, particularly when treating questions of suitability and change. In this sense, predictions of the spatial distribution of species have been used since 1972. Their most simple form is the use of Generalized Linear Models (Li and Wang 2013). At present, there are numerous algorithms to project species range that are more complex and accurate, however, most of them are based on presence and absence data. Maxent is one of the few processes, along with GARP modeling, that behave well with presence-only data (Li and Wang 2013).

Since its inception, Maxent (Phillips et al. 2006) has been used in over 1000 published applications (Merow et al. 2013), but the majority of studies are conducted in a purely ecological context, with species presence data, particularly for plants, traditionally derived from herbaria collections. However, in the case of tropical timber species there is a wealth of information in the form of forest inventory datasets, which are probably unrecognized as the most critical source of precise presence records for important tree species.

In tropical regions, mountains are characterized by irregular vegetation patterns, resulting from highly variable environmental conditions present in relatively short distances due to the altitudinal gradient and ecological processes at different levels (Gosz, 1993. In Price, 2013). Nevertheless, trees are always the dominant life forms up to 4000 m of elevation (Wittich et al. 2012; Price, 2013). However, in most cases, these mountain forests are heavily threatened as result of deforestation and increased human pressure on natural resources. Moreover, some changes in natural patterns have already been detected as result of climate change (Feeley et al. 2011). Given these threats, all forestry-related initiatives can benefit from accurate projections of the potential distribution of target tree species.

Species distribution models can be relevant to decision-makers as feasibility studies before reforestation and restoration activities, or before enrichment planting as described by Mosandl and Günter, 2008. This technique can serve to identify suitable areas for certain tree species, or explore potential implications of climate change in large areas (Thuiller, 2004). If properly applied, this tool could also be used to take more informed decisions before the implementation of agroforestry systems, enrichment of pine plantations or any other forestry-related activity from government institutions, civil society organizations, research centers or development agencies.

The objectives of this article are to give forest managers and practitioners a rapid overview of species distribution modeling, as well as to list the most relevant sources of input data specifically applied to tropical montane regions, where environmental variables can be extremely heterogeneous and species richness attains its peak (Kessler and Kluge, 2008). We also provide some important considerations to inform decision-makers about the strengths and limitations of the outputs of these models.

2 The modeling stage

In order to model species distributions for any region, it is of critical importance to be aware of the essential characteristics of the species such as the ecological conditions where the species is usually found or the environmental requirements. Rather than thinking in a purely mechanistic perspective, it is recommended to thinking from an ecological viewpoint i.e. what are the most important requirements for the presence and survival of the species of interest?

In addition, since the Maxent methodology is based on previously identified points of presence, the more numerous the records, the better they are for the representation of the model. Although this is not the only factor influencing accuracy of the model, the good thing about relevant species in forestry activities is that some of their climatic requirements are well studied. Furthermore, it is likely that presence records are well identified in national inventories or other forest surveys. For a complete list of sources of information for input of the model see Table 1.

2.1 The Maxent algorithm

Maxent is a relatively new addition in a long history of models used to predict the geographical distribution of species (Li and Wang 2013). It uses a collection of presence locations and a group of user-defined environmental backgrounds as predictor variables to calculate the probability of species presence in the landscape (Merow et al. 2013). Its strength is that it can rely on presence-only data and has a strong predictive power compared to other approaches (Wisz et al. 2008).

Execution of the models can be done through its Java platform (Phillips et al. 2006) or via an R package such as Dismo (Hijmans et al. 2016). However, for trainees the first option is preferable provided that it is accompanied by a GIS software to examine presence records and manipulate raster files. Nonetheless, the Dismo package builds on the graphic capabilities of R resulting in a robust alternative to handle and analyze spatial data.

2.2 Input data

The minimum recommended number of presence records is 30 per species (Wisz et al. 2008). Consequently, the more confirmed locations for the species there are, the better for the model. Although quantity is not the only restriction for reliable outcomes, assuring quality of the input data guarantees quality of output data (Pearson. 2008; Zuckerberg et al. 2011). This means that one should make sure to correct for potential sources of error such as location accuracy or misnomers.

The most widely used source of environmental data is worldclim.org, with some alternatives such as Climond.org and CIAT consortium datasets. However, for the purpose of tropical montane forests, the data with the highest resolution available is chelsa-climate.org because it incorporates topoclimatic variables e.g. orographic rainfall and wind fields.

2.3 File processing and tutorials

There are plenty of step-by-step guides in the grey literature for different levels of expertise on handling spatial data for Maxent (Uribe-Convers and Aghai. 2010; Young et al. 2011; Brown 2014a; Scheldman and van Zonneveld. 2011; Hijmans et al. 2016). However, the most important considerations for running the models are described in Elith and Leathwick, 2009. Detailed guidance in fine-tuning the Maxent package is offered in Merow et al. 2013. It is worth mentioning that there are current efforts to bring species distribution modeling and niche predictions to a web interface (Kass et al. 2015).

2.4 Validation of models

Sources of uncertainty come mainly from, but are not restricted to missing covariates, small sample size or bias in species occurrences (Elith and Leathwick. 2009). The Area under the receiver-operator curve (AUC) is one of the few methods used to validate and compare models. Although there are strong arguments against the use of AUC metrics, there is no consensus of a better alternative (Lobo et al. 2007; Merow et al. 2013). In order to obtain a diagnostic of the outputs, the recommended choice is to use cross-validation while preparing to model, this allows to obtain a range and standard error of any model fit metrics (Merow et al. 2013).

In the case of forest management, validations of outputs could be possible by referring to the opinion of experts and establishing the product as an approximation. However, if a comparison of performance between two or more models is needed, it can be done through ENMTools (Warren et al. 2010), which also allows for niche overlap assessments.

3 Considerations for decision-makers:

If species distribution models are used to identify most suitable areas for certain tree species of interest, the main limitation for the communication of the results to decision-makers is that models are approximations only, with results being heavily influenced by the quality of data and the environmental variables available for the extent of projection. The methodology is better seen as an exploratory analysis than a forecast. If decisions can be made in spite of this assumption and the model validation, considerations for its application should not be limited to restoration and reforestation activities, they could also be applied to large-scale agroecology and agroforestry initiatives, to explore scenarios of carbon stocks, preliminary studies for REDD+ plans or to help improve sustainable forest management strategies. In the case of forest researchers, Maxent models could be seen as a tool to ask better questions rather than providing final answers (Merow et al. 2013).

4 Discussion

There is a strong argument that indicates that models generated with presence-only data make strongly simplified assumptions and that overall occurrence probability or prevalence of species cannot therefore be deduced (Hastie and Fithian, 2013). Likewise, there is also concern that climatic variables are overemphasized and that other important background variables are omitted, such as biotic interactions and microclimates (Pearson and Dawson, 2003; Kearney and Porter 2009), both of which are particularly relevant in tropical mountain ecosystem. However, in the face of making land management decisions with scarce resources, Maxent can provide highly accurate estimates (West et al. 2016) and robust predictions that can be used in planning, which can prove better for endemic taxa than ubiquitous species (Cobben et al. 2015) and small-scale applications suitable for forest management in tropical mountain settings (Kübler et al. 2016).

Despite the distribution models' battle between accuracy and realism, which in turn can be interpreted as reflecting over simplicity or over complexity (Thuiller et al. 2008), output maps could be useful for forest managers or decision-makers as a support tool to take more informed decision, if implemented correctly. The exploration of species range through Maxent seems cost-effective and easy to implement by local agencies in developing countries.

Furthermore, current developments in Maxent operability (Kass et al. 2015) could allow for democratization of the tool and the involvement of underrepresented groups into the forest management sphere.

Moreover, any prospect of misuse of distribution models, exacerbated by the need for expert understanding of species ecology, is an opportunity for local universities or other research institutes to provide expert knowledge and help bridging the science-policy gap in what concerns forest management in tropical mountains.

Table 1. Summary of relevant sources of information to elaborate Species Distribution Models. Recommended inputs for beginners particularly applied to tropical montane forest regions are marked with an asterisk.

Element	Source where it can be found	Author(s)
Maxent algorithm	• As Java platform: www.cs.princeton.edu/~schapire/maxent/ *	Phillips et al. 2006
	• Along an R package: https://cran.r-project.org/web/packages/dismo/	Hijmans et al. 2016
Modeling tutorials	See author's reference for access to the complete manuals: • For ArcGis	Uribe-Convers and Aghai, 2010; Young et al. 2011; Brown 2014a; Brown 2014b
	• For Qgis *	ESSC, 2013
	• For R	Hijmans et al. 2016
	• For DivaGis	Scheldeman and van Zonneveld, 2011
	• For internet browsers (beta version)	Kass et al. 2015
Species occurrence records	• Global biodiversity information facility: www.gbif.org *	Various. Worldwide
	• SpeciesLink: www.splink.org.br/index	Various. Emphasis in Brazil
	• Forest surveys: Check national forest inventories for the area of interest *	
Environmental variables	• WorldClim –Global climate data: www.worldclim.org	Hijmans et al. 2005.
	• Climond –Global climatologies: www.climond.org	Kriticos et al. 2012.
	• CIAT-CGIAR program : http://ccafs-climate.org	Various
	• Chelsea –Climate at high resolution: http://chelsa-climate.org *	Karger et al. 2016a; Karger et al. 2016b
	• IPCC –Intergovernmental Panel on Climate Change: www.ipcc-data.org/index.html	Various
	• CGIAR-CSI Consortium: www.cgiar-csi.org/data	Various
	• Global land cover facility: www.landcover.org/data	Various
	• Global soil information: https://soilgrids.org	Hengl et al. 2014; Hengl et al. *In press*
Model comparisons	See author's reference: • ENMTools software	Warren et al. 2010 (pp13-15)
	• SDMtoolbox ArcGis package	Brown et al. 2014b (pp64-68)

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The landscape and forestry plantations in Chile

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Abstract

In Chile, plantations were introduced in the early 20th century in the coal area, Lota and Coronel, and today there are extensive plantations that dominate the landscape of several regions of the country. These plantations are associated with an important forestry industry and an economy that fully satisfies the domestic demand for wood and paper and has made our country one of the largest exporters of forest products worldwide, with about US $ 7 billion annually, generating a full employment of about 300 thousand people.

1 Introduction

The forest plantations are part of the national landscape, just as the vineyards of the central zone or the cattle landscape of the South, where exotic species are handled just as in the plantations. However, forest plantations are more extensive and last longer, therefore their effects on the landscape are larger and more visible. For this reason, it is necessary to incorporate landscape criteria into forestry management in order to allow for the plantations to make a contribution to the landscape as well as solving their adverse ecological effects.

The current plantation model tends to homogenize the landscape, generating large areas of a single species and age with the same color and texture. Geometric shapes and straight lines dominate the landscape and clear-felling harvests are very visible, affecting soils, water and biodiversity. In this sense, several authors have argued that there is a close relationship between ecology and aesthetics (Daniel and Boster, 1976). More diverse, harmonious and structured landscapes tend to generate ecologically sounder means. In general, the highest quality of the landscape or scenic beauty goes hand in hand with a greater environmental conservation.

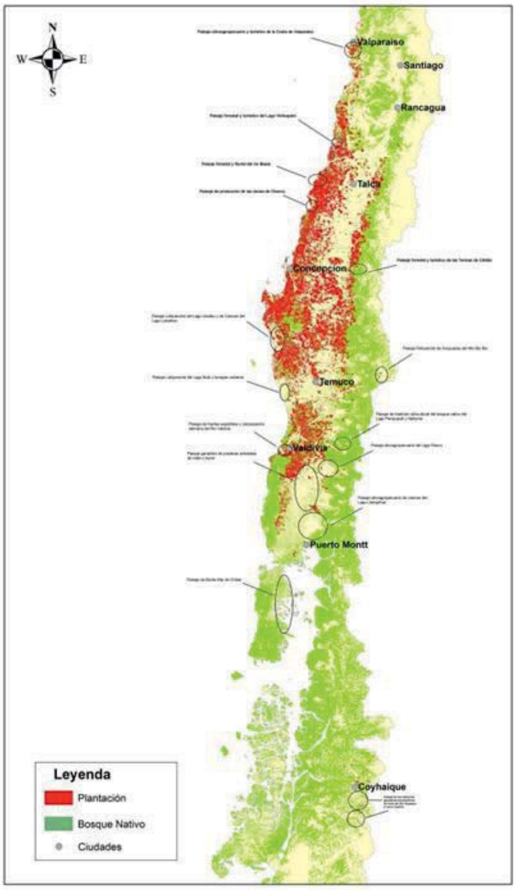

Figure 1. Distribution of forest plantations.

The main objective of the plantations was to stop the disastrous erosion of the soils, caused by the large fires that occurred in the mid-nineteenth century. These fires aimed to provide agricultural lands, which destroyed 78% of the natural forests in the Chilean coastal mountain range between the regions of Maule, Cautín and Aysén (Otero, 2006). Pine plantations were able to grow rapidly and curb the soil erosion and the advancement of desert areas in the south-central zone.

2 Forest policies for plantations

Forest policies in Chile were mainstreamed by all governments from left to right. In the mid-1960s the Christian Democratic government of Eduardo Frei Montalva gave a strong impetus to afforestation to protect the soil. The Socialist government of Allende promoted and finished building large pulp mills in Arauco and Constitución and also created the National Forestry Corporation (CONAF), an institution that until today governs the forest sector. From 1974, during the Military Government, the plantations were strongly fostered by the Decree Law 701, which in its first article stated as main objective to contain the soil erosion. At the beginning of the 1980s, however, the central objective of this law became economic, aiming to supply the wood and pulp industry. The massive pine and eucalyptus plantation began, which included a process of substitution of native forests for plantations of about 260 thousand ha (Prado, 2015). Since 2008, companies stopped replacing native forests and began to incorporate social and environmental objectives into forest management promoted by the FSC-Forest Stewardship Council.

Fifty years ago, forestry plantations with fast-growing exotic species, radiata pine and eucalyptus basically enjoyed cross-acceptance and support at the national level. The contribution of these plantations to the solution of the serious problem of erosion was widely recognized by all sectors of public opinion at the national level and no one questioned the validity of a national reforestation plan aimed at correcting this massive erosion of soils and thus recovering the productive capacity of these soils. At that time, the achievements of the Chilean forestry sector were mainly measured by the number of hectares annually afforested.

On the other hand, forest plantations have played a significant role in supplying an ever-increasing demand for wood and paper to meet the needs of housing, printing of books, energy and toilet paper, among other fundamental needs. Nowadays, more than 80% of the wood cut in the country comes from plantations and more than 98% of the wood for industrial use is pine or eucalyptus. One of the greatest contributions of the plantations is to have avoided the destruction of native forests, by reducing the exploitation pressure. Today we have about 4 million hectares of secondary forests or forests that have been regenerated after the great fires that devastated the country until the decade of the 60's.

Figure 2. Soil exploitation and destruction in the coastal mountain range of Valdivia. Year 1945. Futa river.

At that time, it was hard to imagine that the forestry sector would become one of the cornerstones of the national economy. However, by the year 2015, with 2.7 million hectares, pine and eucalyptus forest plantations in Chile and the companies involved, are not popular, they are, on the contrary, rejected to a large extent by some politicians, NGOs and the civil society.

The reason is that these plantations are often established in extensive and continuous areas, giving rise to a significant area of monoculture; the so-called "green desert" which, in the eyes of the local, regional and also national community, has little or no consideration for environmental services such as biodiversity, water production, soil resource conservation, wildlife, alternative land uses, and scenic beauty, among others. All of this has been mainly caused by the traditional system of harvesting plantations as well as the extensive logging, which sharpens the conflicts that are commonly generated with local communities. The case of the clear-felling, generates homogenization of the landscape, reduction of the hydric yield in the basins that reach 42% and soil losses by erosion of about 20 tons per ha.

Figure 3. Plantations and the homogenization of the landscape.

Figure 4. The clear-felling of large areas and the environmental and aesthetic deterioration of the landscape

3 Current and future challenges

The current and future challenge is "how to continue planting" and avoid this negative public perception that the forestry sector has gained today. What is clear is that sustainability at the forest management unit level, that is to say, the policy that ensures reforestation after harvest, is no longer sufficient and must be replaced by a broader view of the plantations at the landscape level.

In this sense, it is necessary to design a new landscape based on a variable mosaic of forests with different species, different ages, with forests of different sizes and shapes in order to form a mosaic landscape, as various ecologists have proposed (Forman 1986, Fuentes (1994) and the FSC (Forest Stewardship Council, 2014).

Several trials have been carried out in the South of Chile with several forestry companies and with important and positive results from the scenic, ecological and operational point of view.

The effect of these new landscapes will contribute to a greater conservation of the environment and, above all, to a higher quality of life of the rural and urban population of the south of the country, which will undoubtedly change the perception and acceptance towards the forestry activity in Chile.

Figure 5. Landscape management to create a variable mosaic that protects the environment and scenic beauty.

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Evaluating fuel complexes for fire hazard in Mexican forest: a study case

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Abstract

In Mexico, three decades of fire exclusion have led to an unnaturally large accumulation of fuel in some forest communities, particularly at the Experimental Forest Research Station (EFRS) at the Universidad Autonoma de Nuevo Leon. In order to develop fire management plans in the station, the aim of this study was to estimate the forest fuel loads generated by several years of fire exclusion and a non-management plan for the forest. The fuel load estimation was obtained by using the planar intersections technique described by Brown in 1974. The overall mean fuel load for the EFRS was 37.57 Mg/ha. The mean litter and fermentation layer load, together account for a total of 14.55 Mg/ha. The kriging interpolation method was used to predict the behavior of the forest fuel loads. The interpolation of the map shows that in the northwestern part of the study site higher loads are observed, ranging from 64.77 to 79. 30 Mg/ha, while in the northeastern part of the study site the lowest values are shown (3.07 to 10.59 Mg/ha). In addition to the map of fuel behavior in the field, a fuel photo series were taken in order to give general information on the forest structure, species present in the area and a detailed fuel load content of each time lag class. The patterns revealed in the map of fuel loads enable more informed decision making by the EFRS forest managers. For instance, the use of prescribed fires to reduce fuel loads. Forest managers are now aware of the spots to burn under less dangerous fuel conditions and this type of fire could be better managed with the fuel map developed in this study.

1 Introduction

Mexican forest ecosystems are exposed to a variety of natural disasters. These include forest fires, which are one of the primary causes due to which a large portion of the forest in Mexico is lost. In addition, some of the effects of fires are transboundary, for example smoke and water pollution and their impacts on human health and safety, loss of biodiversity, and site degradation at the landscape level, leading to desertification, soil erosion or flooding (FAO, 2006). These actual conditions in the Mexican forests are projected to increase with global warming (Secretaría del Medio Ambiente y Recursos Naturales, 2012). According to Mexican statistics, the number of fires is increasing, during the year 2016 about 280,000 ha were affected (Comisión Nacional Forestal, 2016). In addition, the Northeastern part of Mexico has also experienced an increase in human development in areas surrounding the forest, thereby creating and expanding a wildland urban interface. With these activities comes an increased risk to human life and property as intense forest fires become common. In response, federal agencies such CONAFOR and SEMERNAT have advocated fire control and promote the implementation of fuel management techniques among land managers in order to mitigate risk and hazard of severe wildfires. However, the budgets are limited and the cost of fire exclusion is continually increasing. In addition, there is limited founding available for control and for the estimation of an accurate accounting of fuel complexes to predict potential fire behavior. These practices are neither sustainable nor helpful for fire hazard mitigation planning in Mexican forests. Hence, resource management requires increasingly effective fire management, and fire managers require ways and tools for evaluating the elements affecting ignition potential and probable fire behavior for proper fire control and use. Furthermore, fuel characteristics are increasingly of interest to ecologists, air quality managers and carbon accounting modelers. Techniques for reliable and rapid assessment of fuel characteristics are therefore essential for wildland fire management decisions (Gould, Lachlan McCaw, & Phillip Cheney, 2011).

For this research, the objective was to (1) use inventory data to define current fuel complexes and assess current wildfire hazard by means of a Fuel Classification Maps (FCM).

2 Fuels loads

Fuel loading is the amount of plant material, both living and dead (total fuel) excluding roots and animal matter, present on a site and expressed in weight per unit area (kg/m^2 or Mg/ha). Available fuel is the amount of fuel that will burn under a specific set of fire conditions (Pyne, Andrews, & Laven, 1996). Thus total fuel is the maximum quantity of burnable biomass while available fuel is part of it, depending on the burning conditions during fire (Taylor et al., 2014).

Fuel load and particle size distribution are two main variables that are normally considered together in fire propagation and risk studies (Keane, Drury, Karau, Hessburg, & Reynolds, 2010). Fuel load data arranged by time lag classes, is a significant parameter for the definition of aspects of fire potential and for the calculation of fire risk and propagation characteristics, using mathematical modeling (Thompson, Vertinsky, Schreier, & Blackwell, 2000). This is a common practice in most operationally used models developed in the US. Since it is related with the fire intensity and the rate of spread, the total fuel load in an ecosystem can be used as an indicator of the fire potential, in particular concerning crowning and fire severity(Riccardi et al., 2007).

Fuel load, or down deadwood (DDW) is arranged into 1-, 10-, 100- and 1000-hour fuel classes, and each class is defined by the amount of time, or time lag, that it takes this fuel class to reach a moisture equilibrium with the environment (Brown, Oberheu, & Johnston, 1982). The 1-to 100- hour fuels (<7.6 cm in diameter) are termed fine woody material (FWM). The 1000-hour fuels (> 7.6 cm in diameter) are termed coarse woody material (CWM).

A Fuel Classification maps is created to represent the diversity of fuels found in the ecosystem or stand, and predict their relative fire hazard. It consists of a database of physical parameters that describe the abundance, physical character, and arrangement of forest fuel bed (Ottmar, Sandberg, Riccardi, & Prichard, 2007; Riccardi et al., 2007). The structure and status of the fuel complex regulates the dynamics of a fire (Berg, 2007; Kreye et al., 2014). Hence, describing and quantifying fuel loads is a key factor for understanding fire behavior and also provides information for fire management activities including prescribed burning, suppression, fuel hazard assessment, and fuel treatment.

The FCM are useful at both stand and ecosystem levels, not only for determining the spatial coverage of fuel types but, when connected to other data layers and fire behavior models can be used for fire management planning purposes. An example would be fire preparedness *(e.g.* movement of fire suppression resources based on levels of potential fire behavior). Both strategic (preparedness) and tactical *(e.g.* suppression, natural prescribed fire) aspects of fire management can use site specific fuels information which, when combined with information on topography and weather, allow prediction of potential and real time fire behavior (Andreu, Shea, Parresol, & Ottmar, 2012; Pyne et al., 1996).

3 Methods

3.1 Study area

For this research three experimental plots (P1, P2, and P3) have been selected from a template forest ecosystem, which has been taken out of forest management 30 years ago. Both plots are located in the state of Nuevo Leon, Mexico and are under protection from the Universidad Autónoma de Nuevo León. The experimental plots are located 15 km southeast of Iturbide in the Experimental Forest Research Station (EFRS, 24°42´N and 99°51´W). The EFRS extends over an area of about 1,035 ha (Figure 1). The main vegetation types are mainly mixed pine-oak forest.

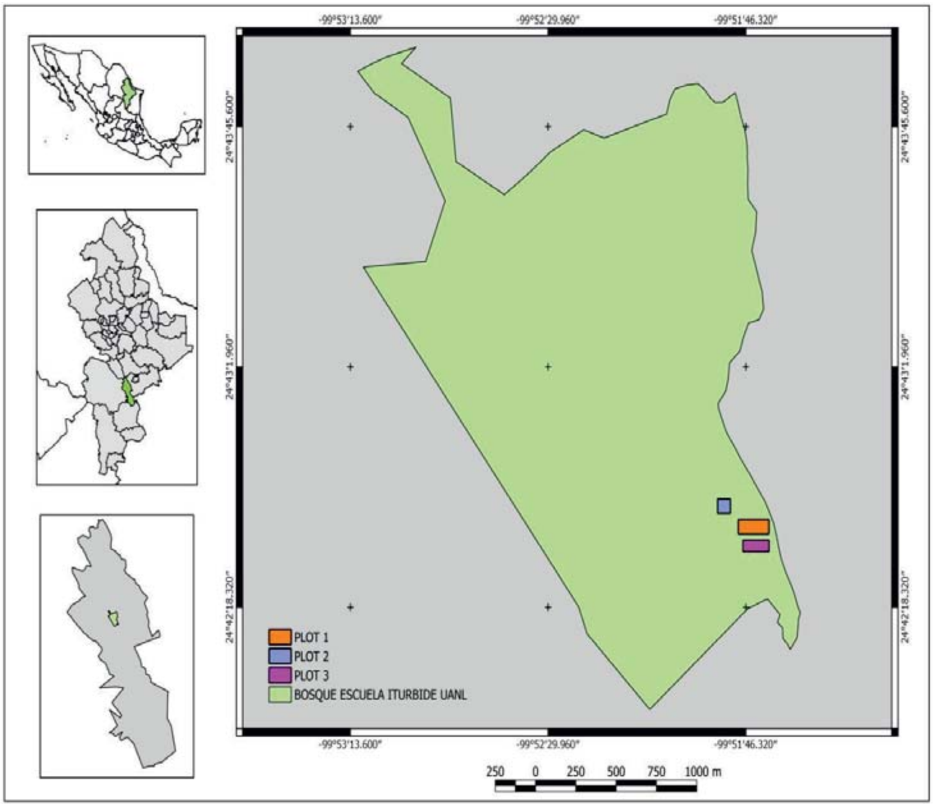

Figure 1. Location of experimental plot at the Experimental Forest Research Station in Iturbide, Nuevo Leon, Mexico

3.2 Fuel sampling

Each monitoring plot has an area of one hectare. Each plot consisted of 25 locations of 400 m^2 (20x20) for sampling of woody fuels, with 3 lines oriented at 0, 120 and 240° azimuth, and two squares of 0.3 x 0.3 m for litter and fermentation layer (Rodríguez Trejo, Tchikoue, Cintóra González, Contretas Aguado, & de la Rosa Vazquez, 2011).

The sampling lines were 15 m long and divided into four segments to measure different types of fuel according to the timelag classes (TL) of woody fuels: 1 m (1 h), 4 m (10 h), 7 m (100 h) and 15 m (1000 h). Samples of litter and fermentation layer were collected, dried in the laboratory and their load was calculated (Figure 2). Samples were collected in 75 locations: 150 sites for litter and fermentation layer and 225 lines for woody fuel inventory. The center of each line was geo-referenced with a geopositioner (GPS).

Figure 2. From left to right: wood fuel sampling, litter and fermentation layer sample, litter sample and final weight of the litter and fermentation samples.

3.3 Spatial analysis and maps

To model the behavior of the fuel load across both plots a spatial statistical analysis was employed using the coordinates of each sampling conglomerate, as well as the total fuel load of each conglomerate. In order to predict the response variable of interest (fuel loads in Mg/ha), in non- sampled points, the geo-statistics technique of kriging was employed (Gelfand, Diggle, Fuentes, & Guttorp, 2010). The reason for using this technique, is that kriging is an optimal prediction method with strong theoretical support (Jansen, Judas, & Saborowski, 2002; Kalkhan, 2011) which allows for predictions of the response in points not observed, as well as to study the possible effect of covariates on such predictions.

3.4 Map generation

In order to support the elaboration of the FCMs this project used only free and open source software: Quantum Gis (QGIS). The input data used are obtained from the fuel-sampling inventory at the three areas.

4 Results

4.1 Forest fuel loads

The total fuel loads per plot are shown in Table 1. The highest loads were observed in plot 2 with a total load of 49,91 Mg/ha, followed by plot 2 with 30,78 Mg/ha and finally plot 3 with the lowest fuel load of 27,56 Mg/ha. Regarding the woody fuels, the highest load was found in the time lag class's 10hr and the lowest was observed at the 1hr time lag class (Table 1).

The overall mean fuel load for the Experimental Forest research station was 37.57 Mg/ha (includes wood fuels, litter and fermentation layer). The highest load category was 10 hr fuels (6.07 Mg/ha) which accounted for 28% of the average load; the lowest category was the 1 hr fuel (1.24 Mg/ha) accounting for 6%. The heavy fuels (1000h time lag class) accounted for 41% of the total loads (Figure 3). Out of the mean total fuel load (37.37 Mg/ha), the woody fuels account for 61.3% (21.02 Mg/ha) and the litter and fermentation layer accounts for 38.7% (14.55 Mg/ha).

Table 1. Total forest fuel loads (Mg/ha) for each plot and time lag classes.

Time lag classes	Plot 1	Plot 2	Plot 3
1 hr	1,35	1,05	1,27
10 hr	7,41	5,05	5,75
100 hr	5,41	5,25	5,28
1000 hr (live)	2,95	3,01	3,90
1000 hr (dead)	6,95	5,50	4,44
Litter layer (Ho)	2,26	8,64	2,79
Fermentation layer (Hu)	4,44	21,4	4,13
Total load	30,78	49,91	27,56

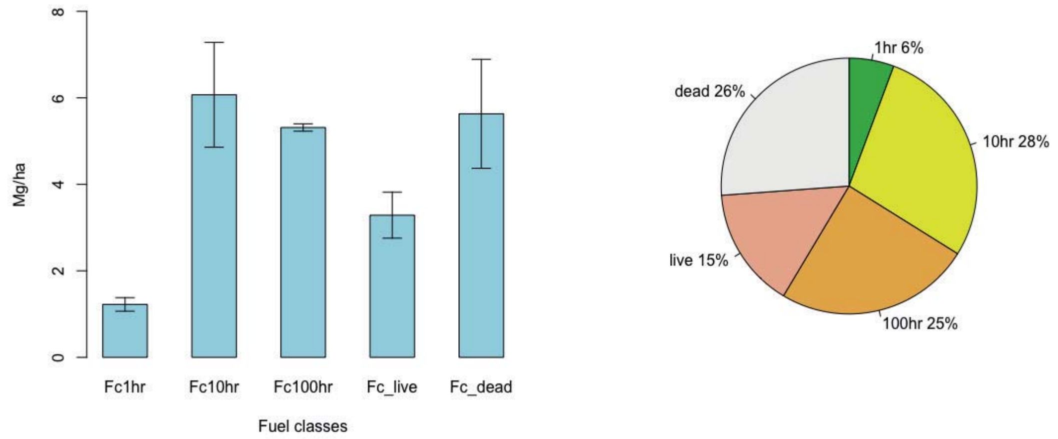

Figure 3. Left: mean forest fuels loads. Right: Contribution of each class to total woody fuel loads at the Experimental Forest Research Station

4.2 Litter and fermentation layer

The mean litter and fermentation layer load account for a total of 14.55 Mg/ha (38.7% of the total fuel load). The fermentation layer (Hu) showed the highest load (9.99 Mg/ha) and the fermentation layer (Ho) load was 4.56 Mg/ha (Figure 4).

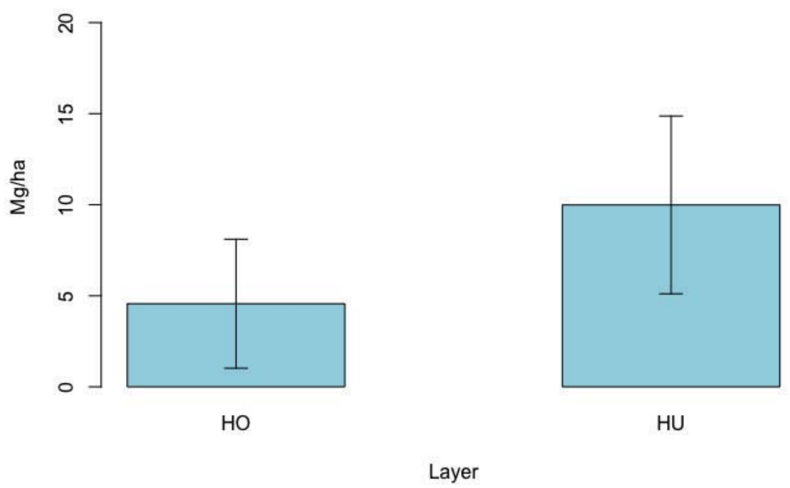

Figure 4. Mean loads of litter and fermentation layer at the Experimental Forest Research Station

4.3 Forest fuel map

The kriging interpolation method was used to predict the behavior of the forest fuel loads in the Experimental Forest Research Station. The following map depicts a surface of 10.2 ha of the study area (Figure 5). The interpolation of the map shows that in the northwestern part of the study site the higher loads are observed ranging from 64.77 to 79. 30 Mg/ha, while in the northeastern part of the study site (green color) the lowest values are shown (3.07 to 10.59

Mg/ha). Fuel loads similar to the overall mean were modeled to be present (orange color) in the northwestern part of the study site, the fuel loads range from 36.22 to 43.74 Mg/ha.

In addition to the map of fuel behavior in the field, a fuel photo series were taken in order to give general information of the forest structure, species present in the area and a detailed fuel load content of each time lag class. The figure 6 depicts an area of the prediction map colored in yellow with a condition of total fuel load of 30.78 Mg/ha

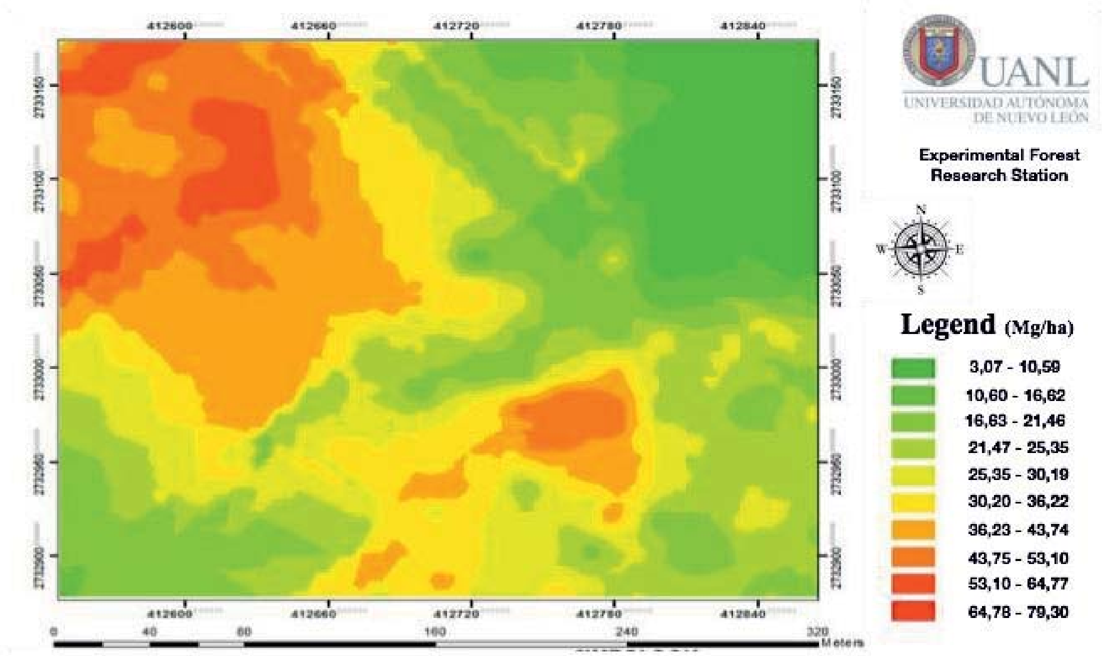

Figure 5. Map of forest fuels loads for the Experimental Research Station UANL

5 Discussion and conclusions

Mapping surface forest fuel loads from inventories is a great tool for forest managers since the produced output has an accuracy of 62%. The results improves previous fuel mapping efforts in the study area in which some plots were mapped with less accuracy and without standardized methodology as well as data collection via different methods. Patterns in the predicted fuel map were consistent with the findings in the field within the study area.

The patterns revealed in the map of fuel loads enable more informed decision making by the EFRS forest managers. For instance, the use of prescribed fires to reduce fuel loads. Forest managers are now aware of the spots to burn under less dangerous fuel conditions and this type of fire could in addition be managed better with the fuels map developed in this study.

Lag classes					Litter and Fermentation			Layer depth	
1 hr	10 hr	100 hr	1000 hr (live)	1000 hr (dead)	HO	HU	Total	Deep HO (cm)	Deep HU (cm)
1.35	7.41	5.41	2.95	6.95	2.26	4.44	30.78	2.96	3.31

Figure 6. Summary sheet representing a general view of the plots and the forest fuels loads for each time lag classes.

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Spatial and temporal patterns of fires at the wildland-rural-urban interface. Case study of Santiago del Estero, in Argentina´s Chaco dry forest region

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Abstract

The spatial and temporal distribution of the fire phenomenon is described in an environment of forests, pasturelands and cattle ranches in the vicinity of the capital city of Santiago del Estero in the semiarid Argentinian region of Chaco. By means of the GIS analysis, using data of thermal anomalies of the MODIS sensor, the zones with greater concentrations of fires for the period 2001-2016 were determined. Two spatial patterns are distinguishable, in the east, where the largest area of provincial irrigation is concentrated, the hot-spots have a uniform distribution; while in the west, in a fragmented landscape of forests, pastures and cattle ranches, the hot-spots are grouped, due to the concentration of fire in the fields where fire is used for the regrowth of the pastures. The phenomenon in the studied area concerns the rest of the province, strongly influenced by deforestation that comes with fire as a complement to eliminate residual biomass.

1 Introduction

The “Gran Chaco Americano“ region is, by extension, the second largest South American forest formation after the Amazon. In Argentina, the largest area of Chaco forests is located in the province of Santiago del Estero (SAYDS 2007). Heavily affected by deforestation, the rural and forest fires associated with this phenomenon determine the spatial patterns of distribution of land use and land cover and define the state of the transformed and residual landscape matrix (Zerda 2013, Zerda 2014).

Due to the progress of deforestation in Argentina, a new law has been elaborated in 2007 to protect the native forests (Argentina 2007). Nevertheless, there have been many inconveniences in their definition and zoning (García Collazo et al. 2013), which shows a great lack of coordination between the provinces. The federal government has controlled the implementation process of the new law, finding great failures in the control of deforestation (AGN 2014) that affected, for example, forest areas of great importance in the province of Santiago del Estero (Zerda 2013, Zerda 2014). Manuals of good practices have been developed which include the use of fire (Brassiolo et al 2007, Moscovich et al) but the forest fires are still one of the main causes of landscape transformation and its forest matrix.

The capital city of Santiago del Estero and its neighboring city of La Banda have 252,192 and 106,441 inhabitants respectively, which represents 41% of the province population (INDEC 2010). This urban center is limited by an area of irrigation established in the 70's and new cattle ranch areas approaching from the west and southwest. In these land uses, fire is a management tool for eliminating agricultural or deforestation waste, or to favor the regrowth of the grasslands. This poses a potential hazard to the population due to the emissions of microparticles. Various investigations have shown that fire smoke produces microparticles that generate diseases and infections in humans (Liu et al 2016, Martin et al 2016). It is therefore important to control the activities that use fire as a management tool as well as their spatial delimitation.

In the province, the activity of using fire concentrates mainly in the winter months until the beginning of the spring (Zerda 2009), a time in which the vegetation has less photosynthetic activity or is in its dormancy season (Zerda y Tiedemann 2010, Tiedemann et al. 2012).

1.1 Objectives

It is intended to determine the spatial and temporal characteristics of the fire activity in an area surrounding the capital city of Santiago del Estero and the city of La Banda, determined for the purpose of this study.

2 Materials and methods

The study area (C50) was defined by a circle of 50 km radius with its center in the main square of the capital city of Santiago del Estero. The largest region under irrigation of the province is located to the east, while in the west the landscape is dominated by large fragments of native forests, pastures and cattle ranches.

Although there are other definitions for "wildland-rural-urban interface"(SILVIS Lab 2016) in this work the area denominated C50 was defined by considering the large spaces in the region and the extensive influence of wildfire smoke in the Chaco region that can be visualized in the MODIS (2014b) images.

For the recognition of patterns of burnt areas in the field and their comparison with MODIS, OLI LANDSAT 8 images , and MODIS hot-spot maps, geotagged photographs were used.

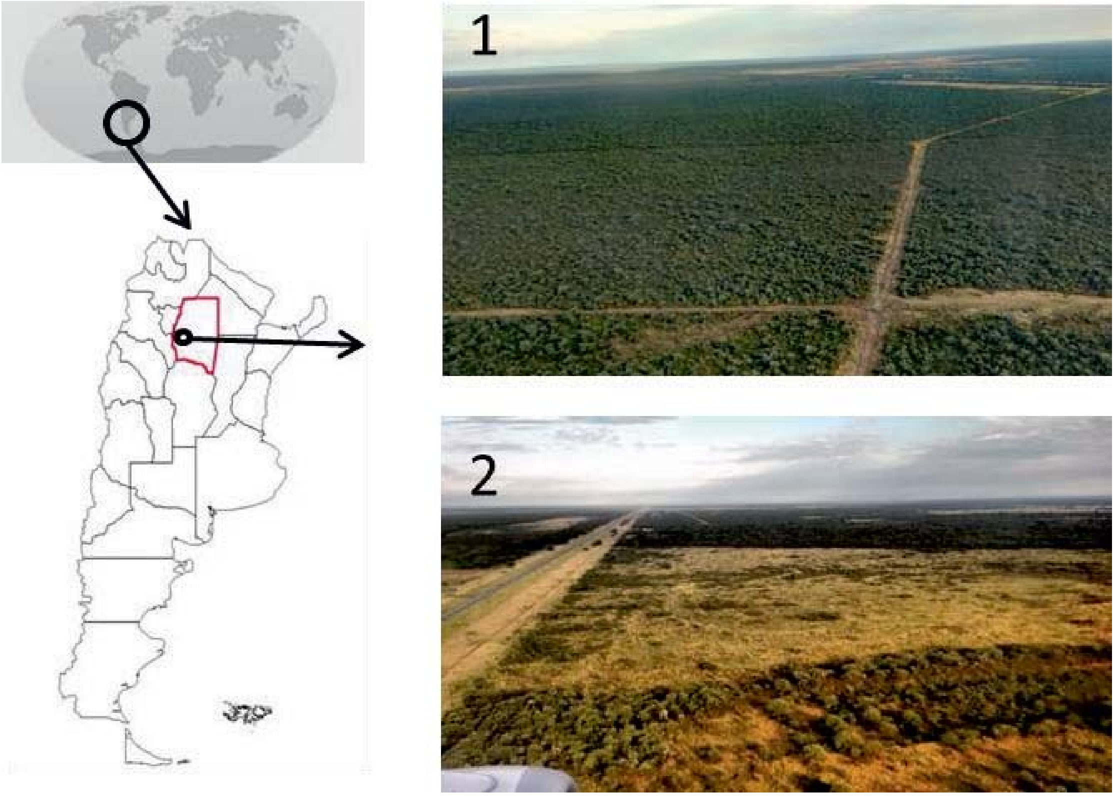

Figure 1. Location of the study area, 1: Extension of Chaco forests, xerophityc thorn formation- 2: Scar of fire in the center.

The thermal anomaly data of MODIS sensors come from the SIG-Queimadas (http://www.dpi.inpe.br/proarco/bdqueimadas/) in the database of National Institute of Spatial Research of Brasil (INPE). "MODIS Thermal Anomalies/Fire products, named hot-spots, are primarily derived from MODIS 4- and 11-micrometer radiances, and the fire detection strategy is based on absolute detection of a fire, and on detection relative to its background" (NASA 2016).

The processing, data analysis and cartographic outputs were made using the software QGIS v. 2.16.2: i) geometric transformations, ii) data clipping to area of study, iii) time classification, iv) density analysis per annual period, and extraction of the basics statistics.

Heat mapping was used as a method of showing the geographic clustering of the fire phenomenon from the hot-spot data, and to create a continuous density surface in raster format. The used interpolation parameter was 5 km searching, this balanced the „density patterns" with the local wildfire pattern.

3 Results

The temporal analysis of the MODIS hot spot showed that in the C50 area two spatial patterns are distinguishable, in the east, where the largest area of provincial irrigation is concentrated, the hot-spots have a uniform distribution; while in the west, in a fragmented landscape of forests, pastures and cattle ranches, the hot-spots are grouped, due to the concentration of the fire in the fields where fire is used for the regrowth of the pastures (Figure 2 and 3).

At the beginning of the studied temporal series, the average of hot-spot in “C50 area“ shows similar values and behaviors as the total area of the province (Table 1) where deforestation and cattle ranching has advanced considerably until the year 2008 when the Law for the Protection of Native Forests (Ley de Protección de Bosques Nativos), was applied and a growth of the hot-spot density can be observed in the C50 area (Figure 4).

Table 1. Frequency and density of hot-spot derive from MODIS instrument of Terra/Aqua satellites.

	N hot-spot		N hot-spot/km2	
Year	Province	City 50 km	Province	City 50 km
2001	2007	70	0,015	0.009
2002	3443	258	0,025	0.033
2003	17409	1217	0,128	0.155
2004	16158	706	0,119	0.090
2005	9872	470	0,072	0.060
2006	11158	544	0,082	0.069
2007	5513	308	0,040	0.039
2008	4939	222	0,036	0.028
2009	6228	259	0,046	0.033
2010	7844	417	0,058	0.053
2011	12421	1125	0,091	0.143
2012	6167	450	0,045	0.057
2013	7587	486	0,056	0.062
2014	4265	246	0,031	0.031
2015	5012	294	0,037	0.037
2016	6055	367	0,044	0.047
	Total = 126078	Total = 7439	Average = 0.058	Average=0.059

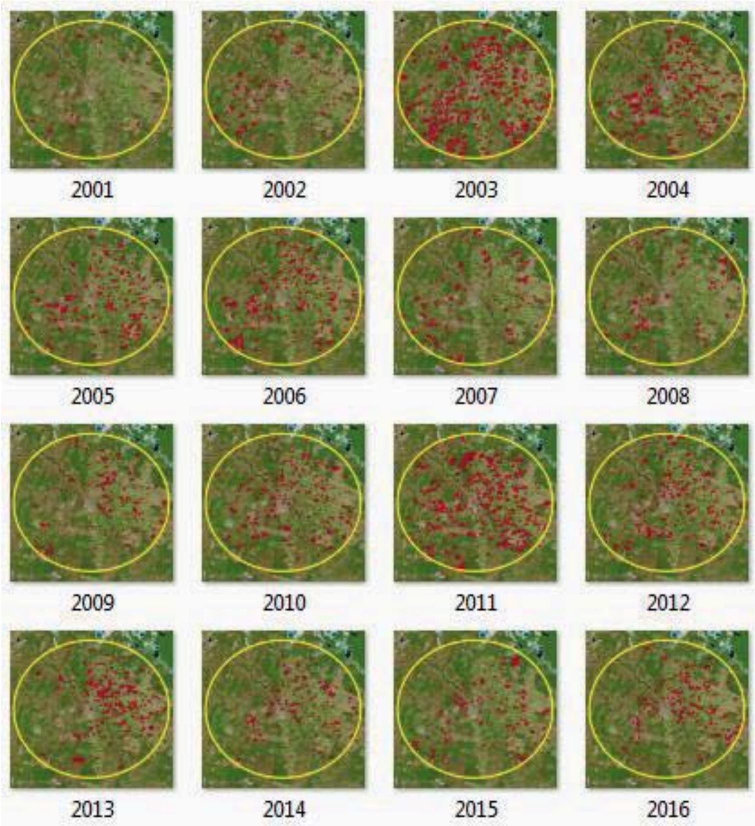

Figure 2. Spatial and temporal distribution of hot-spot MODIS from 2001 to 31.10.2016, 50 km around the city Santiago del Estero. Background: MODIS Terra 721RGB.

Figure 3. Maps from the temporal series of hot-spot MODIS, representing the spatial density of the surface thermal anomalies associated to fires in study area from 2000 to 31.10.2016.

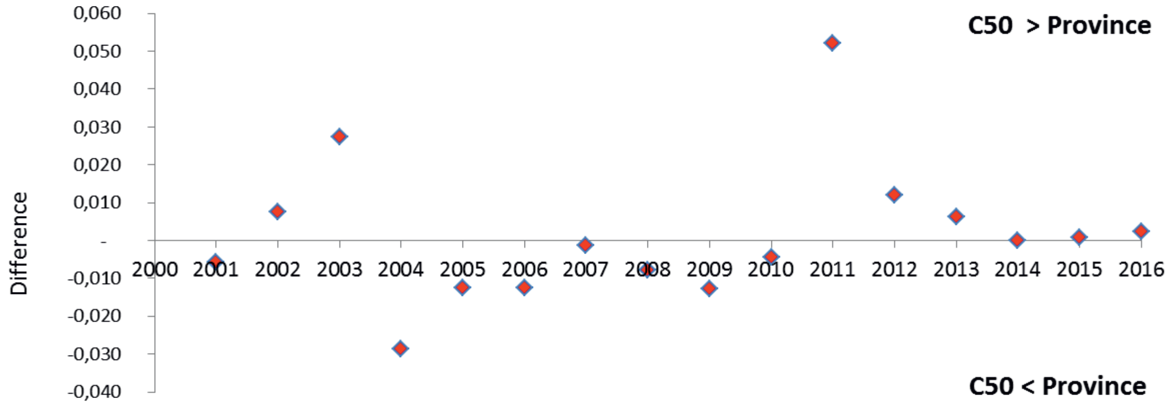

Figure 4. Differences between the density of hot-spots/km2 in the C50 area and the province.

4 Conclusions

The results show that the wildland-rural-urban-interface of the city Santiago del Estero shows a similar behavior to the rest of the province where the deforestation of large areas takes place, which are subsequently burned and intensively used as cattle ranches.

It is also seen that there are years where the density of fires in C50 is greater than in the rest of the province. The maps facilitate not only the location of the phenomenon of fire, but also the evaluation of its magnitude through density maps.

The results would allow the policy makers to better know this important area to plan environmental monitoring actions and the territorial organization of the forest landscape in the wildland-rural-urban interface, as well as to take advantage of this easily exportable information in order to employ it in office tools of free use such as Google Earth or QGIS, as used in this work.

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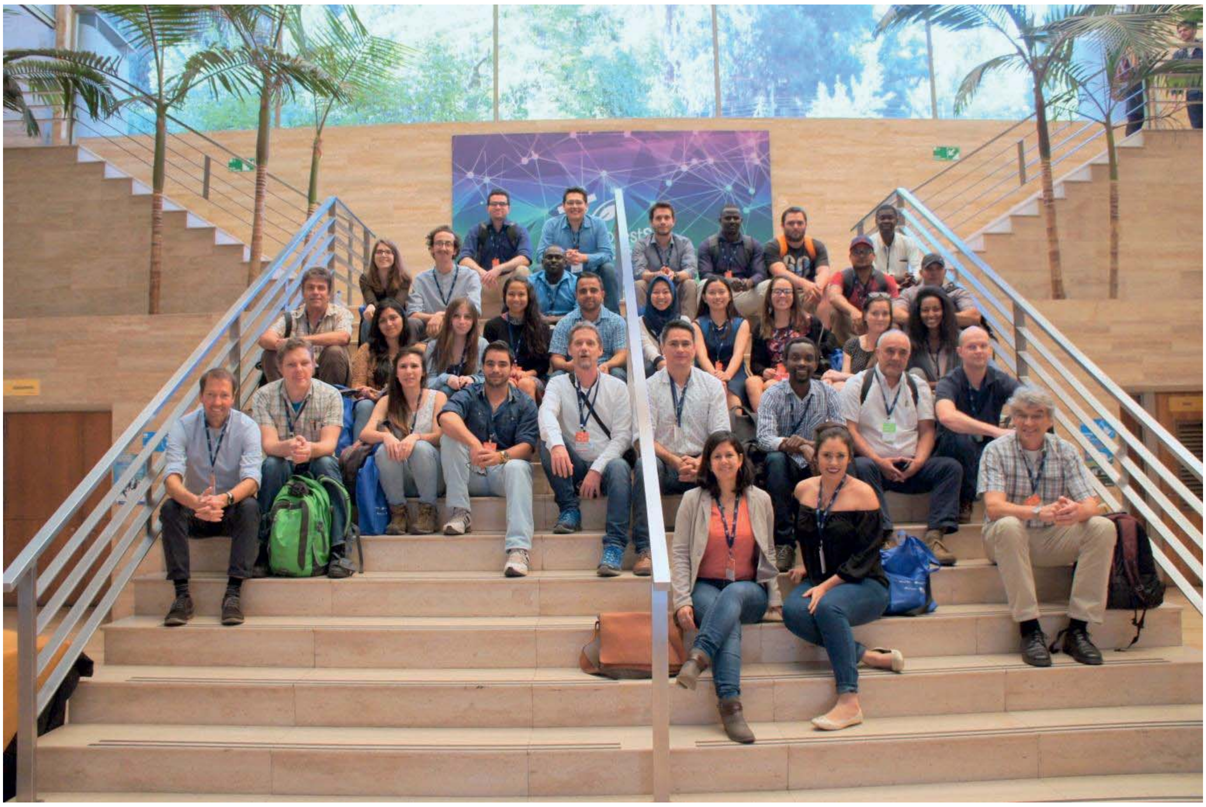
Appendix

Workshop participants at the Ascot Conference Center, Pietermaritzburg.



Front Row from left to right: Dr. Stefan Erasmi (Göttingen), Jhenny Salgado (Colombia/Göttingen), Fatima Acevedo (Mexico), Prof. Dr. Christoph Kleinn (Göttingen)

Second row from left to right: Dr. Paul Magdon (Göttingen), Rebeca Campos Valverde (Costa Rica), Milton Serpa de Meira Junior (Brazil), Dr. Lutz Fehrmann (Göttingen), Gustavo Cardona (Colombia), Collins Kukunda (Uganda/Göttingen), Prof. Dr. Victor Sandoval (Chile), Dr Nils Nölke (Göttingen)

Third row from left to right: Dr. Hans Fuchs (Göttingen), Julia Pintos (Argentina), Nayadeth Damari Muñoz Gómez (Chile), Darlyn Alejandra (Ecuador/Göttingen), Arun Parajuli (Nepal/Göttingen), Sonya Dyah Kusumadewi (Indonesia/Göttingen), Precious Annie Lopez (Philippines/Göttingen), María Ysabel Perdomo (Paraguay/Dresden), Nolwenn Boucher (France), Shibire Bekele Eshetu (Ethiopia/Dresden)

Fourth row from left to right: Wanda Graf (Göttingen), Riccardo Testolin (Italy/Göttingen), Frederick Dadzie (Ghana/Göttingen), Thakur Prasad Magrati (Nepal/Göttingen), Kumar Darjee (Nepal /Dresden)

Last row from left to right: Kevin Jair Hernández Bado (Colombia/Göttingen), Carlos Manchego (Bolivia/Göttingen), Rodrigo Vera Ramírez (Perú/Göttingen), Vianny Ahimbisibwe (Uganda/Dresden), Julio Gerding Vargas (Chile), George Ofori Ankomah (Ghana/Göttingen)

Missing: Prof. Dr. Marco Gonzalez (Mexico), Cori Ham (South Africa), Prof. Dr. José Imaña (Mexico), Ricardo González Jimenez Jerarquía (Chile), Alina Kleinn (Göttingen), Prof. Dr. Luis Otero (Chile), Prof. Dr. Eduardo Treviño (Mexico), Ramòn Trucios (Mexico/Göttingen), Kira Urban (Göttingen), Dr. Mauricio Vega (Costa Rica), Christian Velasco (Ecuador), Prof. Dr. Hugo Zerda (Argentina)