The Papua New Guinea Forest Authority was established on October 16th 1991 by the Forestry Act of 1991 (as amended). Its mandate as a responsible state agency is to sustainably manage PNG forest resources as a renewable resource for the collective socio-economic benefits of the present and future generations.

Papua New Guinea's first multi-purpose National Forest Inventory Project Proceedings

This publication includes the full proceedings on the preliminary findings of the NFI supported research topics funded under the European Union multi-purpose National Forest Inventory Project

Editors: M.P. Poesi, M.T. Piafu, Dr. H. Abe and Dr. R. Turia

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Foreword

The European Union (EU) and the Food and Agriculture Organization of the United Nations (FAO) are funding PNG's first multi-purpose National Forest Inventory Project (NFI) to gather information on the forest and land use change, upper plants, non-timber plant diversity, soil carbon and nutrients and biodiversity species in PNG. The NFI has been planned to assess 1000 clusters, covering 4,000 plots in 12 forest types across PNG.

PNG has taken a global lead in its efforts to combat climate change, particularly by proposing measures to reduce carbon by preserving and sustainably managing tropical forests. PNG has been part of the global action through adopting the concept of Reducing Emissions from Deforestation (RED) in international negotiations such as COP11 in Montreal in 2005. This concept was later expanded to include forest degradation and other management objectives and is referred to as REDD+.

The implementation of REDD+ requires accurate national scale forest monitoring, and emphasis is now on significantly improving key areas such as boosting the national capacity on remote sensing based forest assessment in PNG, advancing the national scale information on carbon stock subject to different disturbances, and transforming management practices to sustainably manage the forest resources. With the completion of the NFI, PNG anticipates to gather credible information on carbon stock and accurately estimate Green House Gas emission from deforestation and forest degradation.

The NFI is implemented by PNG Forest Authority and other key partners, namely New Guinea Binatang Research Centre, the PNG University of Technology and the University of Papua New Guinea. International partners such as the European Union (EU), the UN Food and Agriculture Organisation (FAO) and UN-REDD as well as the Italian Development Agency under the auspices of Mountain Partnership Program and the Crawford Fund are supporting the NFI through the provision of funds and technical support expertise. Others also providing similar support, are organizations such as the Sapienza University in Rome, Italy and the University of Queensland, Australia through the Mountain Partnership Program and the Forest Practices Authority in Tasmania, Australia via the Crawford Fund.

The research conference was designed to provide an avenue for the exchange and sharing of research methods, and preliminary results among project scientists and the project stakeholders. It also provided an opportunity for discussing and formulating future research directions, as well as strategize NFI implementation plan for 2018.
Key speakers that officiated at the opening of the Research conference included, The EU Delegation to PNG representative, Ms. Mateja Peternelj who gave the official statement, Deputy Director of FAO Forestry Department in Rome, Dr.Andrey Kushlin, and the Director of Forest Planning and Policy Division, Dr. Ruth Turia.

The preliminary results from the various research topics reaffirmed our research methods and represent the type of information expected to be generated at the end of the project timeframe.

The contributions by Dr. Hitofumi Abe and Dr. Ruth Turia for their editorial directions and those from Mr. Michael Poesi for coordinating the preparation of these proceedings are greatly appreciated.

Tunou. A. Sabuin
Managing Director
PNG Forest Authority

An outline of the multipurpose NFI Project and its first Research Conference

New Guinea is the largest tropical island in the world and contains the third largest tropical rainforest after Amazon Basin and Congo Basin. The country of Papua New Guinea (PNG) comprises the eastern portion of the New Guinea Island as well as numerous islands and archipelagos. PNG is a well-known centre for biological endemism and diversification. Currently PNG's tropical rainforest is relatively well conserved. The PNG Forest Authority (PNGFA) recently produced a national forest base map with assistance from Japan International Cooperation Agency, and conducted remote sensing based national forest assessment with the assistance of the UN-REDD. Both studies showed that PNG's forest covers 80% of country's land area and 60% of the forest are undisturbed. Nevertheless, the forest is coming under increasing pressure, due to resource extraction, especially through logging, and also from land clearing for mining and agriculture. Despite their extent, size and rich diversity, PNG forests are poorly known scientifically. PNG's first NFI will make a significant scientific contribution towards understanding PNG's tropical rainforest and the biodiversity within.

Since the UN-REDD PNG National Programme commenced in 2011, the methodologies of the multipurpose National Forest Inventory (NFI) for all NFI components including tree inventory, non-tree plant biodiversity, ornithology, and entomology and soil survey were established and documented through extensive review studies and discussions at a number of workshops and meetings. Forest in PNG was stratified and all plot clusters were mapped. All the required capacities for the NFI implementation were built within the PNG Forest Authority (PNGFA) by other implementing partner agencies through numerous in-country and overseas trainings for all the NFI components. The NFI was launched by the Prime Minister in March 2016, and the roll out of the field assessment commenced in May 2017.

A total of thirteen students have been conducting Master of Philosophy researches using the multipurpose NFI related data under the project scholarship program. A large amount of data is being accumulated daily, weekly and monthly as the NFI field assessment progresses. It is very important that these data are analysed and the results published in a timely manner. A NFI research workshop supported by Mountain Partnership was held in February 2017 at the PNG Forest Research Institute. The NFI Project sponsored students presented their research ideas and proposals at this workshop, which was then followed by a field assessment where the field data was collected for analysis and reporting. It was at this recent research conference in February 2018 that the preliminary findings of the first PNG multipurpose NFI were presented and discussed.

Conference Objectives and Outcomes

The main objectives of the conference were to:

- Present and publish the preliminary findings of PNG multipurpose NFI;
- Review the protocols and outcomes of PNG multipurpose NFI;
- Build capacity of the PNG researchers and foresters on data analysis, presentation and scientific paper writing;
- Review the progress and research quality of NFI scholarship students, and
- Publish the conference proceedings as the annual research report of PNG multipurpose NFI.

Opening Remarks and launch of PNGNFI Field Manual and Mountain Partnership Project 2nd Phase

Dr. Ruth Turia, Director – Forest Planning & Policy Division, PNGFA

I want to acknowledge everyone here today, in particular the presence of European Union. We are grateful that EU is represented today by Ms. Mateja Peternelj. As you know EU is the main agency that is funding the work of the National Forest Inventory Project in Papua New Guinea, and we are grateful that the EU has sent us their Head of Co-operation.

We also would like to acknowledge the presence of several donor agencies here with us today. We have with us Dr. Andrey Kushlin, Deputy Director, Forestry Department, FAO who arrived this morning; Dr. Mauro Ghirotti of Italian Development Agency who got stuck in Singapore due to his passport and entry visa but he will be joining us soon. I want to also acknowledge other partners in the National Forest Inventory - Dr. Abe and his team in supporting PNGFA. At this juncture we want to acknowledge other partners that have been supporting us through the Mountain Partnership Program - Professor Fabio Attorre and his colleagues from Sapienza University, Rome and Professor Paul Dagush and Nicholas Leseberg of the University of Queensland, Australia; Dr. Peter McIntosh of Forest Practices Authority of Tasmania who has been assisting us with the soil analyses and the Crawford Fund.

Locally, we would like to acknowledge the presence of Professor Osia Gideon from the PNG University of Technology; Professor Simon Saulei and Dr. Balun Lawong from UPNG, Professor Vojtech Novotny and Dr. Francesca Dem from New Guinea Binatang Research Centre and our colleagues from NARI.

I want to say thank you again for coming, and as you all know this is a research conference and the main purpose of this conference is to know what we have in the forests of PNG.

The NFI project itself will be ending next year about this time, with funding and support coming from EU and FAO. We can finish some work by December this year and we need to take on the challenge to move on with it. We are doing research but not publishing what we are doing, and the onus is on researchers to publish their research work.

At the end of the day we want to have some accurate data on our forest and its biodiversity. We have conducted inventories and so far have done about 15 clusters. Researchers are acquiring knowledge and skills but not publishing their research work. I urge researchers to publish research and I challenge researchers to work on what you are doing, analyses and publish.

Technically we should have done 60 plots, however we have measured 56 plots so far. There are 15 clusters and 4 plots within a cluster. The second phase training of researchers will start next week.

I also officially announce the publication of the Field Manual, and hard copies can be obtained outside the conference venue.

Official statement by EU Head of Cooperation, Delegation to PNG

Mateja Peternelj

Thank you Dr. Golman, our host and the staff. I am truly delighted to be here with you - three ladies and gentlemen. So there seemed to be a bit of good gender representation in the room, which is good to know because gender is indeed one of the critical areas that EU is trying to promote and support around the world.

But I think I need to start my statement with an apology for my delay in the commencement of the session due to confusion with getting the wrong directions. As a strict European, close to dramatic culture I'm mindful of time-your time, I do sincerely apologize.

I am indeed very pleased to be here. I might not be sharing your scientific endeavors or aspirations. I am an economist by background (I see the disappointment in your faces), but I do share the love of forest with you. I come from a small EU member state, Slovenia which is very well deep in forests. I come from a Highlands village in Slovenia and I have learnt to grow up and live in the forest.

When I was reading a bit about the project, I got really excited that I am immensely proud that as the EU, well before my time, we have decided to contribute towards the implementation of the project.

Let me tell you just a little bit about the EU but I don't know if that is your main pre-occupation. We entertain strong partnership with PNG; we celebrated just last year, 40 years of cooperation between EU and PNG. Our cooperation is based on international legally binding agreement that is actually coming to an end in a couple of years' time.

It's been 40 years since we started off and we've seen some great successes. This is indeed the way that we have engaged with the Government of PNG and the people of the country. Our primary instrument for engagement is the European development fund which is a multi-annual framework and it's currently in its 11th cycle. We have intended to support two traditional areas over the 40 years – one was rural development and the second was the development of human resources.

As we continue our support and we have chosen three focal areas:

- Rural Entrepreneurship investment and trade;
- Water and sanitation, and;
- General good governance.

Our support continues throughout the period. But you didn't hear me mention forestry as the main area of cooperation in PNG. No, because this is indeed something that comes outside of our bilateral cooperation. It's based on the instruments that we have on hand to support very precise distinct areas that we, as EU uphold people in dear and valued as a public group. And one of such areas is obviously in mind is climate change, and we have established 10 years ago, an instrument, in particular in support of the climate change mitigation actions now that you have probably come across as Climate Change Alliance. So Global Climate Change Alliance is our big EU supported initiative. It's one of the biggest initiatives supports of environment and climate change mitigation actions in the world. It has a budget of 300 million Euros. If my mathematics serves me right nowadays it's well over a billion kina.

So the EU has been committed to promoting climate change actions over the years and we have found PNG as a great partner in all of these. And PNG has in particular taken the lead in mitigating climate change through reducing emissions due to forest degradation and deforestation. So PNG is truly a unique country, a key partner in all of these, not just because of the sheer size of your forests but because of the challenges that you have been faced with over the past years. It has not come as a surprise to me obviously when I mention as one of the biggest challenges to me is the deforestation due to resource exploitation - all that exploitation of your woods. On the other hand, something that we are particularly contributing to by main cooperation supporting the people in the country, which is; support given to the agricultural development, to the shifting of the diversification of the economic activity in the country. So the shifting of the economic activity is also clearly contributing to the deforestation of your country.

Now we are trying obviously our best to mitigate our actions in coming forth to promoting climate change with other instruments.

So when I was back in school, I remember we learnt about the Amazon forest being the lungs of the earth, but now that I've read that basically the PNG tropical rainforest is the very largest in the world. You are the lung of the world as well.

So not only, obviously we'll need to work for the protection of your forest to provide something to all of us which we cannot live for more than two minutes – obviously the oxygen, but the forest clearly is important in your culture and in your society as something that provides food, something that provides material, something that also protects from environmental degradation and provides the mainstay of the majority of the population.

So, indeed the good forestry management has been, and has become the pre-single or important feature in the management of resources in PNG. Unfortunately though and scientifically speaking, the forests in PNG are clearly not very well known.

The European Union contribution towards the establishment of the NFI was to bring us closer to better understanding of what is out there – the PNG forest is unique, rich, but we need to know a lot more about it to be able to protect it and to make good sustainable utilization. So the Project has already reached a few milestones.

We've heard Dr. Ruth speaking a bit about the life cycle of the Project, how to do it, start with.

In 2014, it didn't come to full operation until later in 2015, but then by August last year, we have already reached a big achievement by the opening of the national NFI building in Port Moresby. So I think that already has hosted a few regional workshops – which is already promoting and encouraging scientists like you in understanding better, the forests.

Indeed, I think these are key results that we need to be mindful of. The key results are obviously, the continuous and the multi-purpose National Forest Inventory. You as scientists, you have this notable task ahead of you to set up the data sharing system, and to put it to good use, and to keep on adding to it, to upgrade constantly the research, and to make it available to all interested parties out there.

This is important for the good governance, values and principles in the country. There needs to be transparency, not only in the public, and not only in the political spheres. There needs to be transparency in the finer areas of our societies and political establishments.

So I would really like to express my sincere gratitude and deepest respect actually to the officers and managers of PNGFA for their steadfast and really strong commitments to achieving the results of this project. You have overcome so many challenges already and I think actually this event is a moment to celebrate because it has brought us to the first preliminary sort of tangible outcomes of what the project was designed for.

As part of the project, the EU was happy to provide scholarships to 13 students of you. You have undertaken the Masters of Philosophy in the University of Technology, and you have been, over the past months if not years, conducting research work in all relevant areas of the NFI. I quickly scanned through all the papers that have been proposed for this workshop, and I've seen basically that the research papers cover all components of the NFI; forest structures, soil, biodiversity, ornithology and entomology - great and amazing achievements.

You will be presenting your research today, and it is a great pleasure to see that not only you are building your own personal capacity as researchers, but you are building capacity for the nation to understand better what the national forest of Papua New Guinea has to offer and what is out there in fact to protect and to utilize better in a sustainable way. This is only a part of the puzzle though.

The Mountain Partnership Project was mentioned previously as well. This comes or is a separate initiative from another of the EU member states, which I don't think the representative managed to come today, but I would really like to express my sincere gratitude to the Italian government to have chosen PNG as a model country, as a case study for combined research in forestry and combined research in biodiversity.

I think this is indeed a true spirit of how partnerships should look like. But let me just announce with great pride a new partnership that is coming up that has been confirmed at the end of last year. It is the issue of sustainable wildlife management. It is another of the project that is going to be conducted together with the EU and the FAO around the globe.

There are 12 countries currently posing for the implementation, and PNG is the only country in the Pacific that is going to be part of the implementation. I think this again is a great recognition to you as scientists, to you as officials of the government agencies, and to the nation, that you are on the right way; you are paving the way to be in the frontline of the scientific and professional endeavors in this area.

And I do believe that with the project that we have the pleasure of commemorating today, and two other projects that I have mentioned, that significant contribution will be made to the improvement of forest governance in PNG.

There are future challenges ahead. There are a number of issues that we may still need to resolve like the land tenure, the certification systems etc. There are motions that have been put in place, but this a bit of work for months to come.

In finishing off, I wish to express my deepest gratitude for all your work and your keen participation at the conference today. I wish you good deliberations today and tomorrow. Unfortunately I won't be able to spend much time with you, but I'm hoping that in reading the manual that we're launching today and getting the conclusions from the inventory.

I've been as long as always, but with this I hope that you do understand now the appreciations that the EU has towards this in pushing the boundaries further in this area.

Thank you very much.

Key Note Speech - Forests in a New Landscape and How the PNG NFI Can Play Its Role

Andrey Kushlin, Deputy Director FAO Forestry Department

Good morning everyone, as I have already been introduced, I am Andrey Kushlin and I am from Russia – another deep forest country, and a little smaller than PNG. I work at the FAO headquarters in Rome. I am the Deputy Director of the Forestry Department.

You obviously know FAO is a main United Nation specialized agency focusing on food security and agriculture sectors. Agriculture sector includes forestry and fisheries, so all of them are relevant to your country.

I am really privileged and happy to be here. This is my first ever visit to Papua New Guinea. I look forward to learning more and of course it's a very short first visit and I hope to come here again. I'm starting to learn the land, the culture and the very important work that you are doing here, which is as I will say the importance of this work, obviously not just for your country, but the very unique and hopefully reputable example that you are setting for the rest of the world. So no pressure yet but there is really some important work to achieve here. With all of your great efforts, and those who can get support and encouragement and facilitation from international community, particularly the EU, the UN and many other partners.

I am represented here by those who are overseeing the work of the Mountain Partnership program which is a voluntary UN partnership founded 15 years ago. It has over 300 members, including 59 governments and hundreds of field site organizations all across the world. It's not by chance that I mentioned 59 governments because yesterday, we had some meetings with the Department of Foreign Affairs in Port Moresby about making sure there are no remaining obstacles for PNG to becoming the 60th government member. In any case PNG has already been defector benefitting from participation in these so far, but is yet to formalize the Mountain Partnership program agreement.

This event today as already announced by folks here signify the start of the second phase of Mountain Partnership support to PNG multi-purpose NFI. I want to acknowledge the presence here of our Mountain Partners; the technical partners of the Sapienza University in Rome and the University of Queensland from Australia as well as our colleague, Dr. Mauro Ghirotti from the Italian Development Cooperation. Dr. Ghirotti got stuck in Singapore but he will be here with us hopefully tomorrow. Together with me, we will be launching the 2nd phase of Mountain Partnership support.

Anyway, my colleagues have prepared some talking points or slides for me. As I was coming here from Italy, Rome, I stopped over for a couple of days in Bangkok Regional Office for Asia Pacific. In the FAO's RAP, they are working closely with all Asian countries including of course, PNG. They reminded me of the very important aspect of what we are now all facing in the forest theme or agenda globally, regionally and nationally - that's what they put in as the title of my observations, and its "*Forests in a New Landscape"*. About 4 months ago FAO had an Asia Pacific forest regional meeting in Sri Lanka in October, the theme *Forest in a New Landscape* was a big theme of the overall discussions; that's very strongly resonating with everything we are now facing both internally in power where forests are no longer seen as the silo of the sector. They are a major player, a major contributor and major factor to the overall global sustainable development agenda.

So this topic of the landscape has a powerful meanings of course, not only as a picture on the wall but also a landscape which is the matrix of multiple pieces of land that interact together and plays an equality based on the flow of natural energy and information. But it is also used in a broader figurative meaning that so many changes that are happening.

There's economic landscape globally that has a lot to do with declining growth rates and the pressure to look at the renewable sources of growth as supposed to kind of mechanical expansions to growth.

There's new technological landscape where new technologies are now taking over many areas of traditional practices. At the same how the technology works, there are lots of processing and development here now where new technologies including forestry, forest harvesting, and forest industry. There's a lot of replacement of human labor with mechanization and that creates significant issues in many forest dependent communities. There is a kind of shrinkage in demand of labor for forest operations obviously you know what I am talking about. It makes the technologies so easier on the flow of information and knowledge is going to be shared and be directly accessible to everybody without monopoly by the governments on the information that they hold.

The societal landscape has to do a lot both with the growing generational gap with often the youth which particularly in Asia and in the developing world. Half the population is younger than 30 and this continues to grow and is very relevant to the younger people here - youths who are part of this. The future of the forests globally and nationally is in your hands, not the wise people sitting in the important offices and the capital or the conventional cities.

The new environmental landscape, higher pressure for organization or provider of environmental services and increased appreciation, understanding of the environment use, emergencies and disasters, they are shaping the overall landscape in which forests are being used.

The new political landscape, again we can talk about multiple things. There was a globalization wave, now it seems to be like the department of health's mobilization or immunization and trading device. Those have impacts on forests and how forests are being eroded.

And obviously the institutional landscapes are changing – that sounds like what I have already mentioned. Generally the latest evolutionary, the climate change report and the SDGs, they are now major and important platform for forestry agenda not only to be promoted, but to be fully integrated into decision making at the highest level.

In that sense, forests are affected by these multiple changing landscapes as I described, but they are also part of the solution. It is important to understand that there was no more miscue or right opportunity or right reason for foresters to be detached or paving way for us to embark on. In the current agenda for sustainable development or the SDGs that the FAO has endorsed, these can only be achieved with equal contribution with the use of forests. So when we are sitting on the national forest institutes or research institutes, we may think about narrow technical matters which you think on about forestry. But in the matter of fact the overall sustainable development at nationally, sub nationally and globally can only be achieved with very active contributions from forests in a number of ways. We are not only talking about the commercial forestry or operational timber production. So Forestry needs to go beyond the forest sector, and that's the ultimate point to highlight or convey in the relevant regional workshops.

FAO is a major tactical agency within the United Nations system that governs forestry. As you know FAO is the custodian and it has been undertaking global forest resource assessment for multiple decades now. FAO shifted from ten year cycle to five year cycle. The new cycle of FRA 2008 will be officially launched in Mexico. This will be for all countries and PNG is in as one of them. Everything that the country reports has to define on solid data and of course, the NFI Project is a major key foundation to having the solid data to report in the proper processes. Also, another important aspect I want to highlight is that, there are generally new national processes and also there is increasing requirements in various reporting requirements where international agencies associated with the projects were asked to report. One of the important features to describe is that it is now has joint forces with several reporting mechanism to decrease reporting burdens internationally, and to make sure that all data device, satisfies the multiple reporting requirements. So FRA is one major character or flagship process that FAO is a custodian and the order of global architecture of forests, and the institutional arrangements.

Then you must also been reading that every two years FAO releases the status of world forests report. The report that will be released this year (2018) is *titled Forest path way to sustainable development in a changing landscapes and livelihoods*. This is really important because there is mentioned that systematically all 17 SDGs, determined that forest figured essentially to all of them. But there is particular focus on the 17 SDGs. The report that will be released in July, at the UN Forum in New York, which will specifically focus on the 10 SDGs that forests directly contribute to, but also looking at some of the challenges on how to strengthen that contribution and make forests politically attractive and powerful objects that politicians want to sustain.

In that sense the multipurpose NFI inventory that all of you are undertaking and delivering, I hope and my aspiration is that once the report comes out in a few months, you will make use of the data where your program is providing and generating will help the line agencies, government and politicians to see and amplify the amount of the value of the forests. So that report will also be a major agenda item in the forestry at FAO, and in documenting the multiple values of forest and meeting the various SDGs.

Your project again, in addition to this being a very central instrument in addressing the national goals, your government development goals and the PNG development plan 2050, it is directly relating to PNG's commitment on two major international conventions – the SDGs and the biodiversity and the climate change partnership.

Climate change - as the EU colleague has already mentioned and as you know the REDD+ is the major instrument that she talked about. I wanted to highlight a little more on Convention on Biological Diversity. Because what you are doing, with the richness or presence of very diverse expertise in inventory, biology and social science are really key to producing the very comprehensive assessment reports on your forests, not only the basic physical resource standpoint but also from the standpoint of the forest eco-system services and other aspects.

Our colleague from EU just mentioned the state of wildlife management project which FAO has started. Last week there was the inception phase workshop in Nairobi, Kenya where it detailed the full description of the state of wildlife management project in PNG and Uganda. We have actually made sure that the team will also join us but due to short notice, they could not manage to work it out. This is the team based in Goroka, in the central Highlands. It's a very important part of what we do and what they will do is to make sure the wildlife resources that you guys are assessing or taking stock of, are managed in a sustainable way and working towards some constitutional matters to increase the use of wildlife products as well as achieving the sustainable development goals.

There are other important projects that are being done by Papua New Guinea with government supports from the international partners including FAO which also have direct relevance with what you do. There is cooperation for new update of data and information that you will be producing. There is an ongoing work on timber legality system and standards in PNG. This program is enforcing the government on the trade of timber from sustainable management sources. EU is the major donor for that program including United Kingdom, Sweden and FAO is the implementing agency of the program in PNG.

Papua New Guinea is likely to be considered as one of the piloting countries to test the credibility of the new forestry guidelines for forests assessments. That's also very important announcement on the dissemination of information that the project will be generating. There is very important work on going in PNG on the new program on climate change, and it also has a huge credibility, major potential user and beneficiary of information that you will be generating. So there's lot of credibility on the work that you are doing in PNG – don't look at it from the technical work point of view but it has huge future uptake.

The points that are listed here, I just want to highlight, I know for a fact, as I am new here to PNG, and learning about your project.

Within the REDD+ framework PNG is the first country ever to be doing full integration of biodiversity aspects into systematic statistically robust national forest inventory. Nobody else has done that yet and you are the first one. That is important so that it becomes a reference model for REDD+ framework.

I just realized that what we are talking here is very important. It's essentially everything we all do in our professional lives. It's the efficacy, the results of what we do. It's our technical inputs, our technical competencies, experts, specialist, time and our communications. We can be 100% in our technical side, like the world gurus like Einstein noble prize winners on technical subject matter but if there is zero communications then the results are zero. Myself I come originally from the academic community, we are all focused so much on technical but without communication on what we do, we don't hear about them. But that's a major mistake. We now recently connected to all the communications in the world; we really need to put the formula open in our minds. Of course, the opposite side of the formula is also true. If you are brilliant in communications but your substance is zero, then of course you will have a problem. But in any case it's what we do that we must always do it right - who is the end user of what we do;

how they are going to use that, how you communicate with other people and make sure that they understand what we intend to do and they become your champion or supporter. Otherwise, you reinvent the wheels on what you do.

In this regard, I shamelessly borrowed from a report distributed by EU- results oriented monitoring report the EU-ROM. They had six recommendations. Out of the six these were first three in read. I highlighted the aspects which are correctly applicable to what I just said about the formula to technical strengths and communication aspects. One of the recommendations of the initial report is that there is still some improvements to be made in terms of actually connecting what the source is doing for example in curriculum lobbying, so that there is regeneration of knowledge.

The other three recommendations are all about communications. Urge the NFI field teams to return and meet with landowners to discuss in easily understandable language the findings of the assessments of their sites.

The other one is ensure public access to raw NFI data. You cannot underestimate the worth of that. Of course knowledge is power. Another way of saying it for example people controlling information. Now the old fear of information… that is gone, now in this age, with open data, if you are thinking you are hiding something, there are other people who can and have the ability to monitor data from satellites and also from other networks or platforms, increasingly have direct access to information. Your ability to release to the public is essential may not only to communicate or promote to the public but to engage also with your allies. Out of the six recommendations, four are directly related to what I talked about on how to communicate the information to others.

The previous slides already highlight the importance of what we do in the rest of the world, and nearby Pacific Islands. There’s an obvious first step where you can share your experience in growing that momentum of what you are doing.

In Dec 2016, there was CBD COP 13 in Mexico, an initiative was announced. FAO initiative was to set up a platform for mainstreaming biodiversity into agriculture, forestry and fisheries. That initiative was from FAO delegates. Now this year, the FAO platform will be reviewed at the CBD COP 14 in Egypt. Thus, we will be showcasing what we are doing. We are discussing both with CBD Secretariat with FAO, also the PNGFA, Department of Foreign Affairs to see that the multipurpose NFI to be actually showcased using the global context of REDD+.

At the end it is about communicating, and also to use it to address a linear relationship with how much we talk but how much money we get, but there is a relationship. By promoting what we do in a global context, it increases the interest what we do with development partners and so the challenges that you are referring to about funding in terms of money to finish the work so that interest is actually and resource organization, for expansion. That’s all about FAO, but the last thing to remember is to communicate what you do and I am really looking forward to all the presentations that you all will be presenting.

Measuring forest land-use change between 2000-2015

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Abstract

Systematic point sampling approach using GIS and RS imageries has been proven to be useful in estimating forest land use change in PNG. Spatial analyses of forest land use change using this approach are comparable to wall to wall mapping approach with the use of commercial GIS and RS imageries.

SPS utilizes free open source GIS software called Collect Earth and freely available satellite images. It was applied to measure forest land use change in PNG between 2000– 2015. With the sampling intensity of 4.4 44 km x 4.44 km and 2.22 km x 2.22 km for provinces having less than 500,000 hectares of landmass, a total of 25,279 sample points were assessed. With PNG's total land area of about 46.1 million hectares, about 78% forest land was still intact by 2015. Cropland accounts for 11.2%, grassland 5.2%, settlement 0.9%, wetland 4.6% and other land covering only 0.1%.

Low altitude forest on uplands, low altitude forest on plains and fans and lower montane forest are three forest types that make up high proportion of PNG's forest. More than 70% of forest is still intact or not been disturbed by anthropogenic activities. Most of the forest degradation is caused by commercial logging (10.7%).Gardening (8.3%), fire (3.1%) and others 1.2% accounts for remaining percent. Commercial logging is common in low attitude forest on plans and fans and low altitude forest on uplands. About 80% of commercial loggings occur in Western, Gulf, WNB, ENB and West Sepik. While Gardening occurs throughout they are dominant in the three major forest types. The occurrences of fire are also common in all forest types however they are prevalent in Savana, Woodland and Scrub forests.

PNG's cropland comprise of both subsistence and commercial agriculture. A combined permanent and shifting subsistence agriculture cover about 88% of the total cropland area. The commercial agriculture includes tea, cocoa, oil palm, cocoa, coconut, sugarcane and rubber. Monoculture plantations are not so common in PNG except oil palm. Between 2000 and 2015, a total of about 240,100 hectares or 0.66% of the total forest area was deforested and subsistence agriculture (0.42%) was the main driver behind deforestation followed by palm oil (0.21%). During the same period a total of 2.3 million hectares or 6.2% of the total forest area was disturbed or degraded and commercial logging caused most of them (5.7%).

PNG's forest land use and forest land use change has been determined using the PNG's national forest definition and the IPCC broad land use categories with detailed sub categories based on the country circumstances. This not only produced the broad overview and the perspective of the country's land use at the national scale but also the PNG's land use at the altitudinal range perspective. Thus demonstrating clearly the influence of altitude on the land use change, the vegetation (forest) and the population density.

When applying the national forest definition, the systematic point sampling methodology demonstrates that it can be adopted for land monitoring and estimating of GHG from deforestation forest degradation. More so, it is consistent with the government endorsed forest definition and the IPCC guidelines.

Key words: *Wall-wall, remote sensing, satellite imageries, open source software, and systematic point based sampling, collect earth, forest definition, land use change, IPCC, deforestation, forest degradation.*

1.0 Introduction

Past GIS and remote sensing studies on PNG's forest land use/land cover by highly specialized experts were based on wall-wall mapping approach using commercial GIS and RS imageries. These studies delivered significant results indicating common drivers of forest change but with varying rates of forest extent and decline. The conflicting information in most cases was influenced by the application of different forest definitions.

PNG's land use is complex and is undergoing transitional changes. These transitional changes are caused by human activities such as logging, agriculture, infrastructure expansions, fire and mining. Natural phenomena such as cyclones and landslides also are the causes of transitional change however these are not covered under this study.

Some of these transitional changes especially the changes caused by humans are apparently becoming permanent. Consequently the forests in PNG are declining but the declining rates are subject to some uncertainty and much debate (Filer, Keenan, Allen, & Mcalpine, 2009); (Shearman P. J., Bryan, Mackey, & Lokes, 2010). These changes nevertheless are challenging to detect due to the vastness of the land including the technology and the capacity of the country to measure and monitor these changes.

Remote sensing technology has been proven to be successful and useful where number of studies (list of references) had provided useful information on PNG's forest land use. With the continued improvement in Remote Sensing (RS) technologies and advanced methodologies, it is now possible to measure forest land use at a finer scale as demonstrated in this study. This study used the point sampling approach to collect land use data using the Collect Earth Software and medium to high resolution satellite imageries. The assessment of the forest and land use was based on the PNG national forest definition and the IPCC land use guidelines.

The information on PNG's forest and land use from previous studies indicated that forest is decreasing and needs updating. Furthermore, the application of different methodologies and forest definitions make it challenging for consistent national and international reporting. Moreover, unlike the approaches and methods used in the previous studies where highly skilled GIS and remote sensing experts including the use of commercial GIS software and satellite imageries, this approach used minimum GIS and remote sensing experts including the use of open source software and freely available satellite imageries.

Measuring Forest Land Use Change using the Collect Earth software demonstrates a methodology to producing detailed information on the forest land use in PNG. The results are found to be relatively comparable to the previous studies by Sherman, *et.al* (2010) and Filer, *et.al* (2009). This study provides an alternative approach and option for assessing forest land use in PNG now and into the future. It also estimates the greenhouse gas (GHG) coming from Land Use, Land Use Change and Forestry (LULUCF). This approach is consistent with the PNG government forest definition and IPCC guidelines.

2.0 Materials and Method

The materials used are Collet Earth (CE), satellite imageries and ancillary spatial data. CE is a user-friendly Free Open Source Software (FOSS) and innovative Global Information System (GIS) tool developed by the FAO. It uses a Google Earth interface and facilitates a point-based data collection and visual interpretation of freely available high and medium spatial resolution satellite imagery in Landsat Google Earth, Bing Maps, Here Maps and Google Earth Engine Playground (Landsat 7 and 8). Ancillary data such as Hansen data, Forest Information System (FIMS), Forest Base Map 2012 and 2011 population census data were also integrated with CE to enhance visual interpretation.

A point sampling was used to assess a total of 25,279 plots over PNG land mass. The assessment was conducted systematically at every 0.04 X 0.04 degree grid (4.44 x 4.44 km) and 2.22 x 2.22 km for smaller provinces (Jiwaka, Western Highlands, and Manus).

The land class was evaluated and visually interpreted by recognizing the land key elements. The assessment of their socio-economic functions and the adoption of the 'predominant land use' criteria in the classification scheme are settled by rules. The notion is that the land use function of land can be expressed through hierarchical relationships among key land elements, and that these functional relationships are based on thresholds reflecting the relevance and predominance of key land elements in the observed area. In this situation hierarchical sequence of settlement > cropland > forestland > grassland > wetland > other land will be applied with the thresholds being: settlement 10%; cropland 20%; forestland 30%; grassland 30%; wetland 30%; other land 30% to express their pre-dominance. This means that if there is 6% of settlement, 15% of cropland, 56% of forest land, 16% grassland, and 7% of wetland, then the predominant land use of the observed area would be forest land (Fig 1). However if the settlement area is more than 10%, the predominant land use of the observed area will be considered settlement because settlement is the first preference in the hierarchical sequence. The objective was to provide a systematic approach for the representation of land use that is consistent with the concepts and methodologies developed by the IPCC.

Specifically, the first step was to detect the ‘key land elements’ using medium to very high resolution images. The key land elements are defined as a physical component of the land that characterizes one or more land cover classes and/or land use categories. The second step was to determine the land use function of the land based on the spatial distribution of the key land elements. The third step was to determine/classify the land class by using the hierarchical threshold criteria. The final step was to determine if there is a land use change in the observed area. The land use change was detected using landsat 7 and 8 using Google Engine.

Although the national forest definition for PNG is ‘land spanning more than 1 hectare with trees higher than 3 meters and the canopy cover of more than 10% (The Government of Papua New Guinea, 2014), it is made explicit under this study that this did not include land that were ‘predominantly under agriculture or urban land use’.

3.0 Results

3.1 Land use composition in 2015

PNG has a total land area of about 46.1 million hectares of which 78% is forested, 11.2% as cropland, 5.2% as grassland and 4.6% as wetlands. Settlement and other land accounts for the remaining 1 percent (Fig. 1).

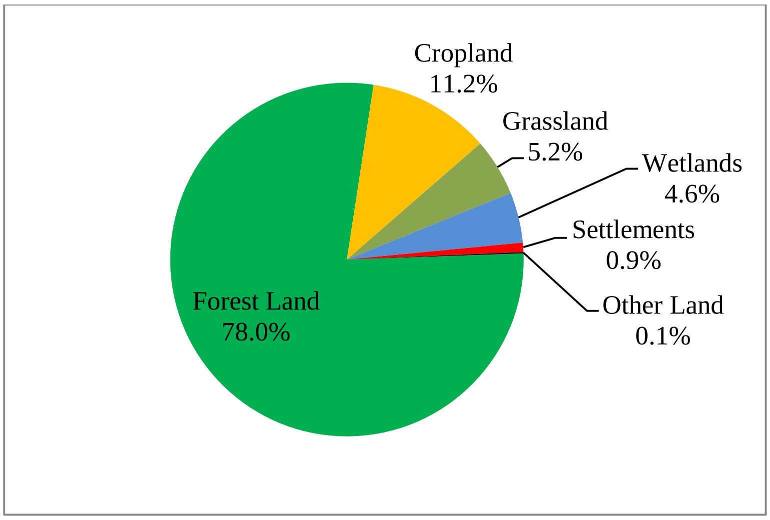

Figure 1 PNG land use composition

3.1.2 Land Use and Altitude

Fig. 2 shows the relationship between land use and altitude in PNG. Forest land occurs from the sea level up to 3,800 m above sea level. Above 3,200 m grassland is dominant and forest starts to decrease its dominancy. Agricultural activities are densest at the elevation range between 1,500 m and 1,900 m. Capital towns of major Highlands’s provinces are located at this elevation range. Almost all wetlands are found at elevation below 100 m.

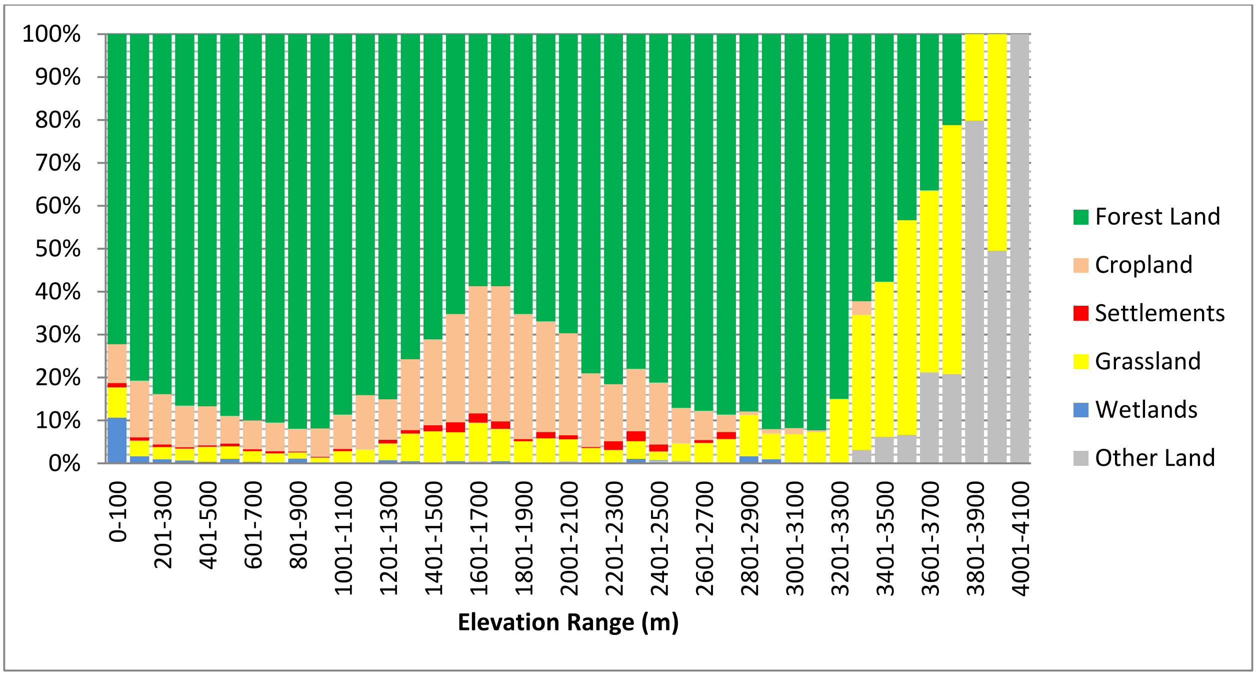

Figure 2 Land use at Elevation Range

3.1.3 Land Use and Population

Figure 3 illustrates a correlation between the proportions of land use and population density. With increase of population density, it directly increases of the cropland and the settlement and the proportion of forest decreases. There are a few settlement plots with zero population density. This is due to the 4 km (or 2 km) grid polygons having no village census units. The village census units are just points in the NSO dataset.

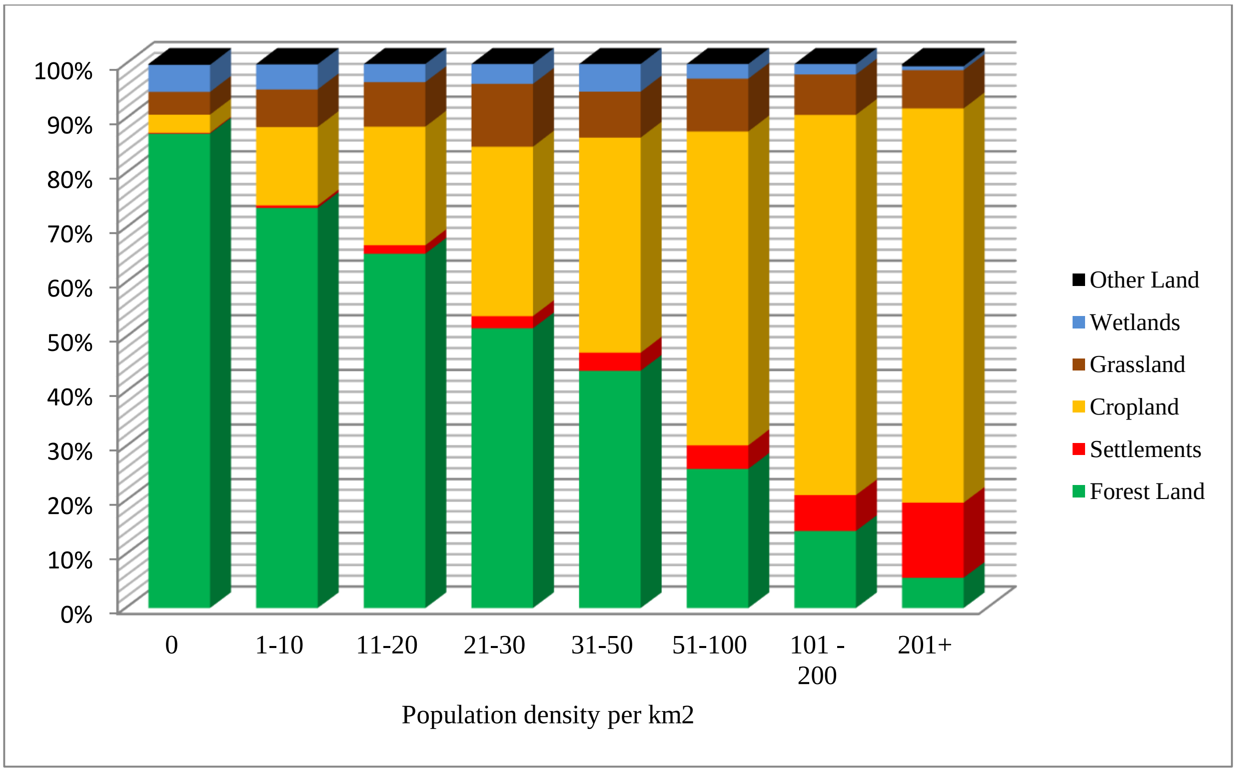

Figure 3 Land use composition in different population density range. Population density of each sampling points was calculated from Census 2011 data of National Statistical Office

3.1.4 Forest land

PNG has a total of about 35.9 million hectares of forest with 12 forest types covering approximately 78% of the PNG land mass and more (Fig. 4). Six provinces with high proportion of forest areas are Gulf (91.2%), West Sepik (90.7%), West New Britain (85.3%), Western (84.4%), Central (82.6%) and East New Britain (81.5%).

Western Highlands Province (43.6%), Autonomous Region of Bougainville (40.7%), Jiwaka (30.5%) and Eastern Highland Province (28.6%) have more cropland compared to other provinces (Fig. 5).

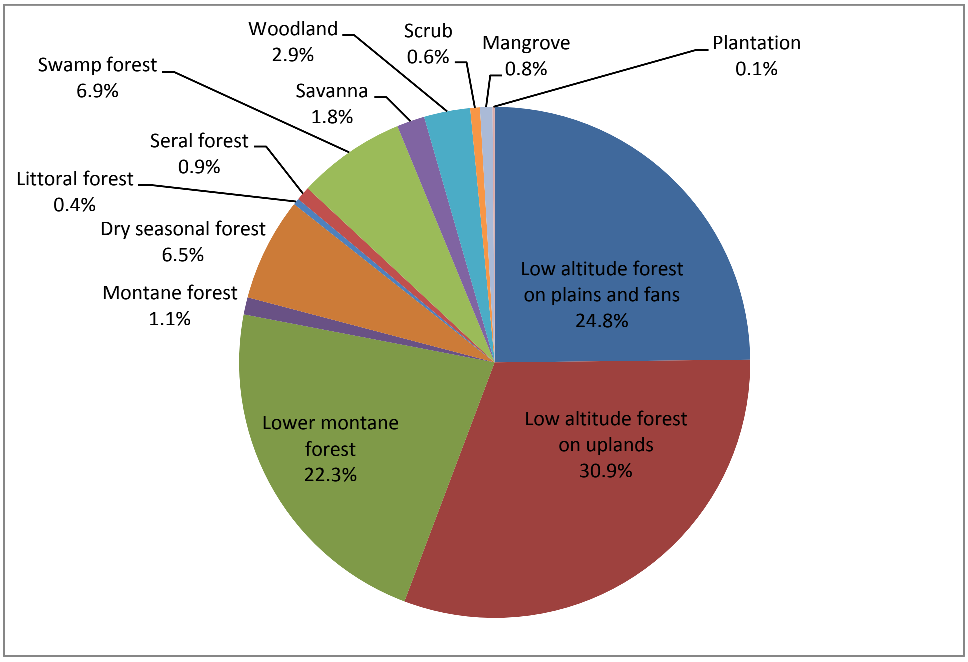

Figure 4 Forest types

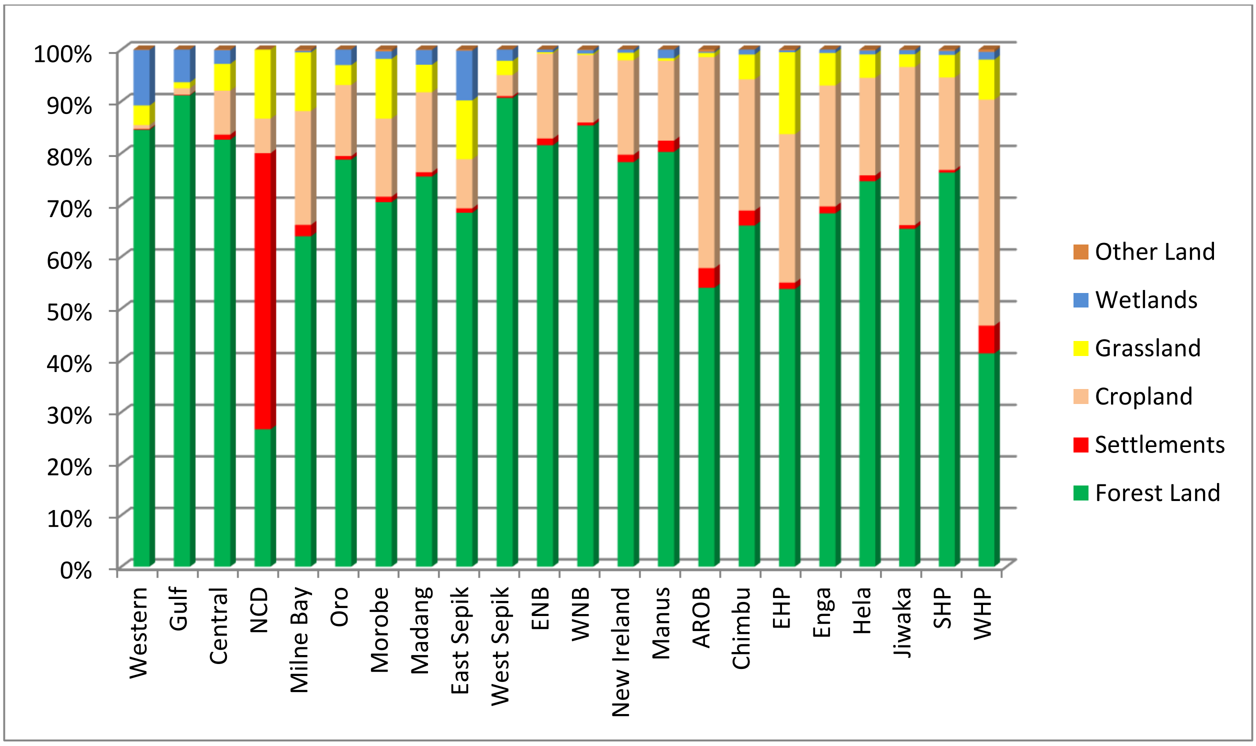

Figure 5 Proportion of forest types in Provinces

3.1.5 Forest Degradation

Forest degradation or disturbance is 23% in 2015 and is caused mostly by commercial logging, gardening fire, walkabout sawmill and others. Commercial logging accounted for about 10.7% of the total forest area in 2015 (Fig. 6).

Elevation has a distinct relationship with anthropogenic activities on the forest land (Fig. 6). Logging occurs from the seashore up to 1100m above sea level (ASL) but is more concentrated between 0 – 500m. Gardening activities occurs throughout but becoming denser between 1000m and 2800m. There is also more cropland in the high altitude areas (Fig.5). Fire also occurs throughout but prevalent between the elevation 2700m and 3400m. The dominancy of Grassland starts at elevation 2700m (Fig.5) and the occurrence of fire seems to follow this pattern (Fig. 7).

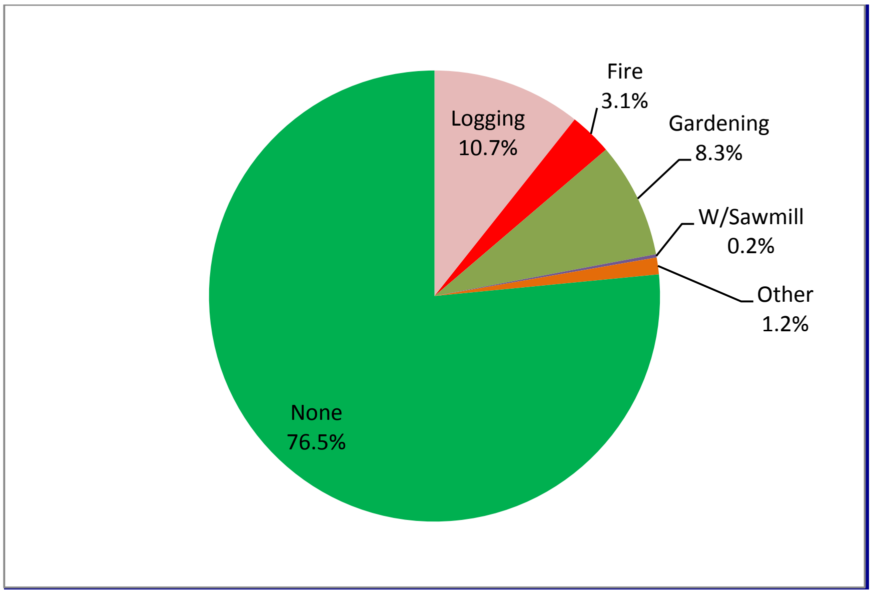

Figure 6 Human impacts on forest land

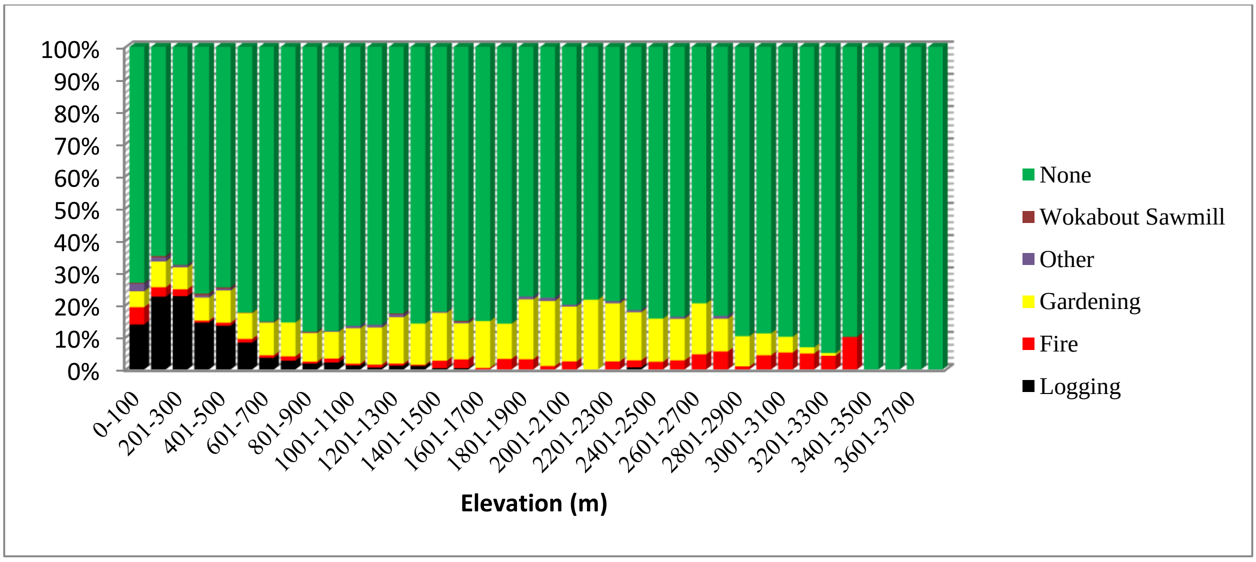

Figure 7 Forest Disturbances at Elevation Range in 2015

3.1.6 Cropland

Table 1 details the different cropland types and their coverage (hectares/percent) in PNG. As revealed in this study, the total area of cropland in PNG is about 5.1 million ha which occupies 11% of PNG land mass. The subsistence agriculture comprised of both permanent and shifting. It accounts for more than 88% of the total cropland area followed by oil palm plantation (6%), coconut plantation (3%), coconut intercropped with cocoa (1%) and Coffee plantation (1%) (Table 1). Large scale monoculture commercial plantations are minor land use in PNG except palm oil plantations.

The proportion of cropland is high in Western Highlands Province (43.6%) followed by Autonomous Region of Bougainville (40.7%), Jiwaka (30.5%), Eastern Highlands (28.6%), Chimbu (25.3%) and Enga (23.3%). There is more cropland between elevations 1000 m- 2500 m (Fig. 8). Most of the cropland comes from subsistence agriculture and this is common in all the provinces except NCD. Oil palm plantations are specific to West New Britain, West Sepik, Oro, Milne Bay, Morobe, Madang and East New Britain (Fig. 9).

Table 1 Cropland types

Cropland		Area (ha)	%
Subsistence Agriculture	Permanent	1,111,675	22
	Shifting	3,427,393	66
Commercial Agriculture	Tea	2,955	0
	Coffee	29,472	1
	Palm Oil	321,975	6
	Cocoa	13,796	0
	Coconut	143,789	3
	Cocoa/Coconut	43,267	1
	Rubber	13,639	0
	Sugar	7,881	0
Not identified	Other	17,606	0
	Not Sure	29,419	1
		5,162,868	

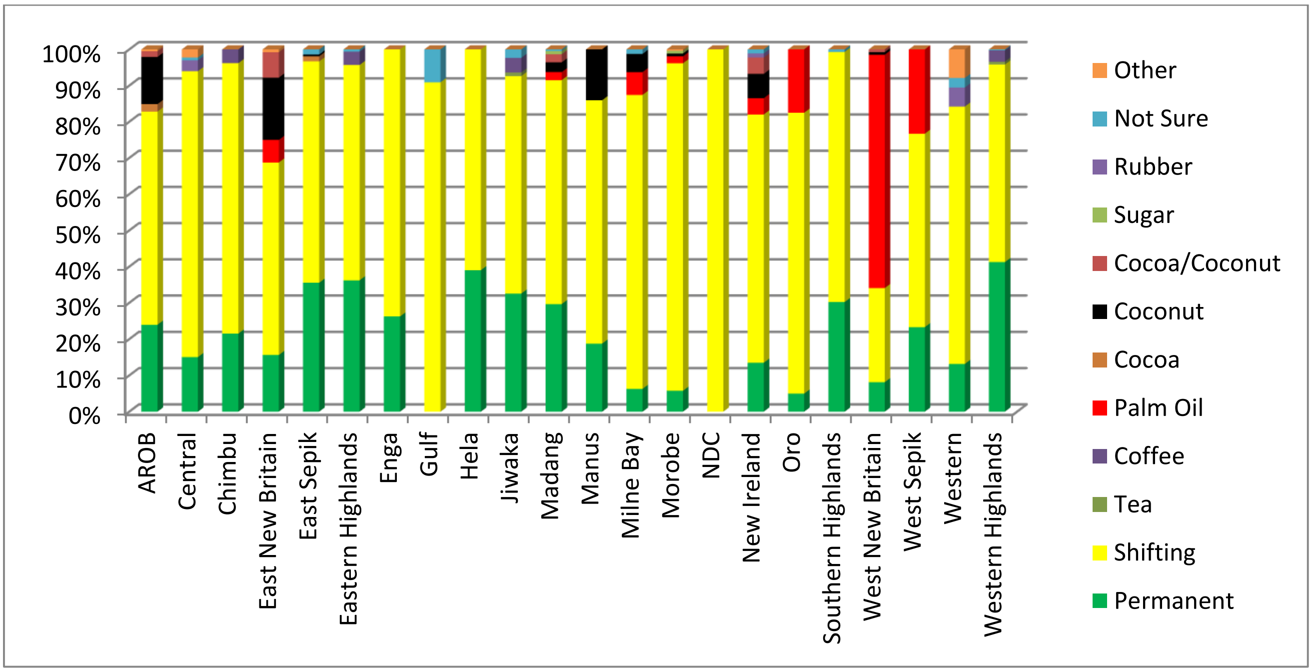

Figure 8 Proportion of Cropland types in Provinces

3.1.7 Land use other than Forest and Cropland

The land use other than Forest and Cropland comprised of Settlement, Grassland, Wetland and Other land (Table 3). They comprised about 10.8% of the total PNG land mass. Settlement covers about 0.9% of the total land area and villages are most dominant followed by large settlements and infrastructure. Grassland covers about 5.2% of the total land area. Herb land is most dominant in PNG and comprised nearly 80% of the total grassland area. Wetland covers about 4.6% of the total land area. Other swamps include low laying seasonal inundated areas comprising of shrubby or vegetated areas and they are most dominant wetland areas in PNG followed by rivers. Other land is not very significant in PNG and they comprised 0.1% of the total land area of PNG. The most dominant subcategory of other land is rocks followed by bare land then sand.

Table 2 Other Land Use

Land Use		Area (ha)	%
Settlement	Village	235,448	60
	hamlet	48,018	12
	Large Settlement	54,013	14
	Infrastructure	56,867	14
		394,346	
Grassland	Herbland	1,886,402	78
	Rangeland	105,316	4
	Others	429,305	18
		2,421,022	
Wetland	River	444,102	21
	Lake	253,541	12
	Dam	3,901	0
	Nipa Swamp	190,817	9
	Other Swamp	1,236,060	58
		2,128,421	
Other land	Bare	16,634	30
	Sand	7,882	14
	Rock	30,836	56
		55,352	
		4,999,141	

3.2 Forest and Land Use Change between 2000 – 2015

3.2.1 Deforestation

A total forest area in 2000 was 36,216,954 hectares. Between 2000 and 2015 a total of 240,100 hectares or 0.66% was deforested and most came from agricultural activities (Table 3). Subsistence agriculture (shifting and permanent) was the major driver and deforested about 0.42% while the oil palm activities deforested 0.21% of forest in 15 years. Furthermore subsistence agriculture (shifting and permanent) accounts for more than 60% of the total area of deforestation followed by oil palm plantations (31.5%).Figure 10 shows more details in support of this argument.
More forest was cleared for subsistence agriculture in West Sepik Province while clearing of forest for oil palm development were concentrated in West Sepik, WNB, ENB and Madang provinces and West Sepik. WNB experienced high deforestation due to oil palm development (Fig.10).

Table 3 Forest types converted to other land use between 2000-2015

Previous Land use (Forest types)	Current land use (ha)								Total
	Cropland							Settlement	
	Permanent	Shifting	Not Sure	Palm Oil	Cocoa	Coconut	Other	Large Settlement	
Dry seasonal forest		1,963							1,963
Low altitude forest on plains and fans	5,887	59,093	-	65,374	1,978	1,957	1,963	-	136,251
Low altitude forest on uplands	-	39,570	-	9,946	-	-	1,963	-	51,478
Lower montane forest	1,479	39,729	1,959	-	-	-	-	-	43,167
Savanna								1,315	1,315
Swamp forest		2,007							2,007
Woodland		3,919							3,919
	7,366	146,281	1,959	75,319	1,978	1,957	3,925	1,315	**240,100**

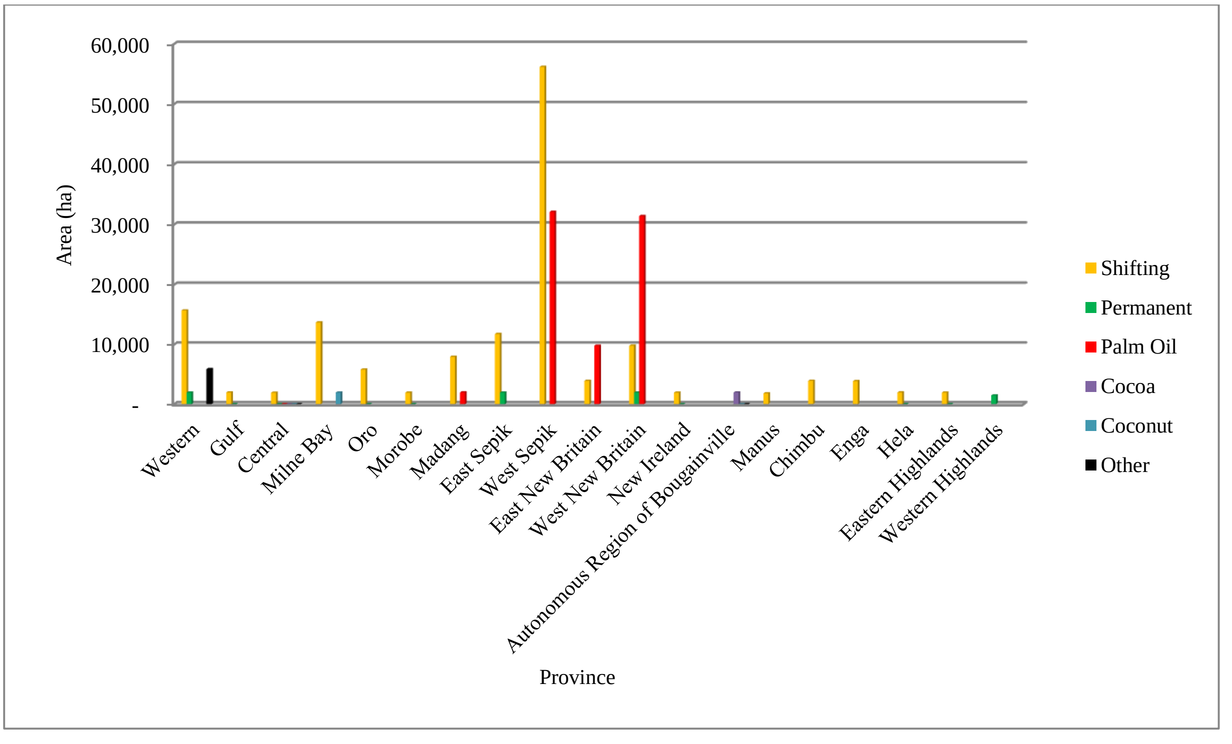

Figure 9 Forest converted to cropland types in Provinces between 2000-2015

4.3.2 Forest Degradation

About 6.2% or 2.3 million hectares of forest in 2000 was disturbed or degraded in 15 years. Commercial logging was the major driver degrading or disturbing and about 5.7% of the forest or 91.2% of the total degraded forest (Fig. 10). The top five provinces with high rates of logging during the 15 year period are Western, Gulf, West Sepik, West and East New Britain (Fig.11).

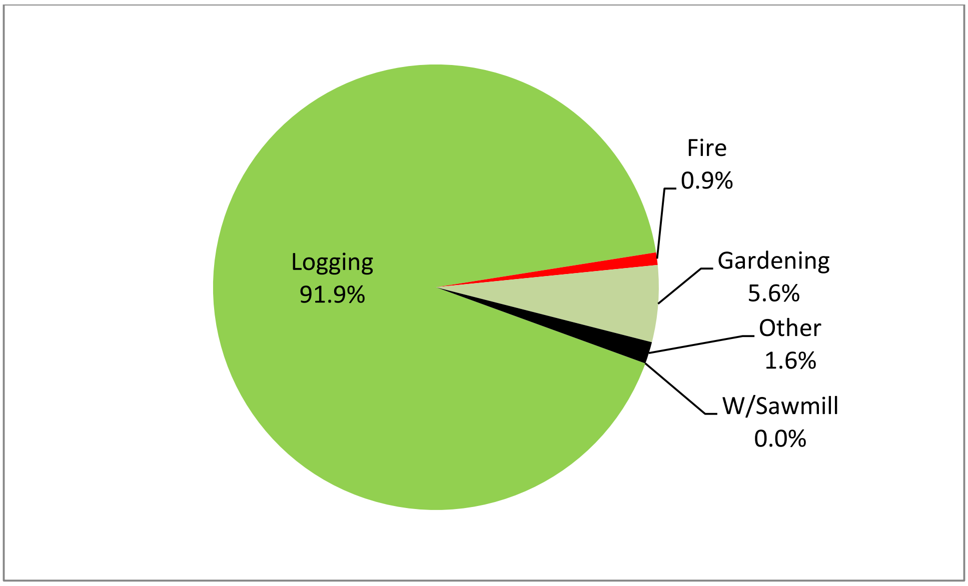

Figure 10 Forest disturbance/degradation by human activities in 2015

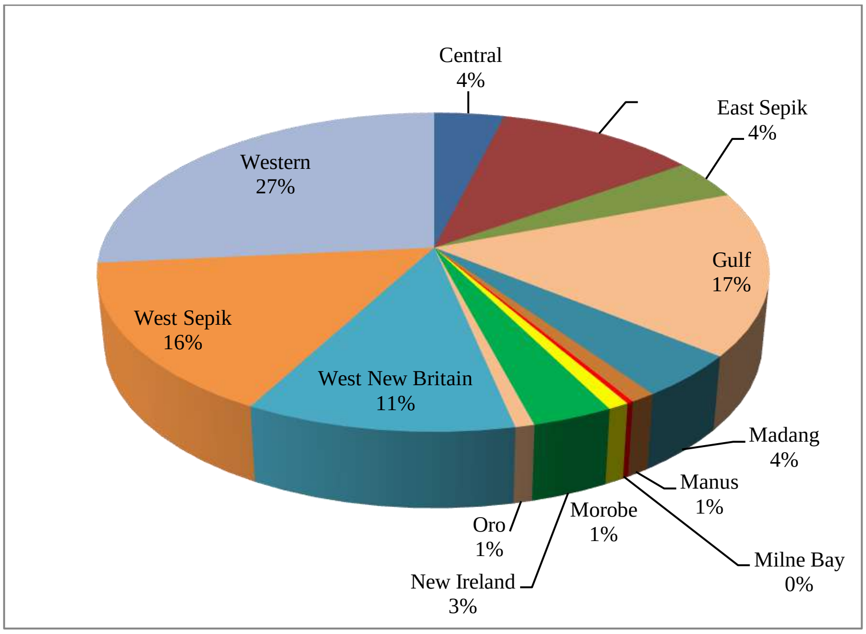

Figure 11 Logging intensity in provinces between 2000-2015

4.3.3 Comparison with Previous studies

PNG' forest extent and rate of both deforestation and forest degradation reported in various studies conducted including this are not consistent (Table 4).

Table 4 Comparison of forest cover, deforestation and forest degradation

Studies in PNG	Forest Cover (%)	Deforestation (%)	Degradation (%)	Total (%)	Period
PNGRIS	69.5			0	1975
FIMS	56.3	0.2	0.3	0.5	1975 - 1996
State of the Forest of PNG	71.0	0.77	0.64	1.41	1972 - 2002
Forest Base Map 2012	80.6	0	0	0	2012
Forest and Land Use in PNG 2013	80.4	*	*	*	2001-2013
The State of Forest of PNG 2014	60.4	0.11	0.23	0.34	2002-2014
Global Dataset	93.0			0.15	2001-2014
FRA 2015	72.5	0.01	1.9	1.91	2010-2015
This Study	78.0	0.04	0.41	0.45	2000-2015

*Not reported

5.0 Discussions

5.1 Comparisons with previous studies

It is challenging to make comparisons considering the differences in the assessment periods, the forest and land classification including the remote sensing methods (Keenan *et al*, 2015) with various datasets; creating different base maps at different scales from different data sources. In essence no single data source can tell a complete story (MacDicken K.G, 2015).

5.1.1 Methodologies

Most previous studies in PNG used the wall-wall mapping approach. This study in contrast used the sampling approach. While both methodologies can be used for land monitoring they are not perfect and have advantages and disadvantages over each other. While wall-wall approach produce both maps and statistics it involves the application of common RS techniques such as modelling or extrapolation including the need to use commercial software and RS imageries (Bey *et al*, 2016) thus requiring both GIS and remote sensing specialists. This study only produces statistics but engaged minimum GIS and remote sensing experts including the use of open source software and freely available satellite imageries.

The previous studies extensively mapped the forest and other land use. It was however not possible to further classify other land use except forest. Saunders, 1993 attempted to classified land use by degrees of intensity while other studies were based on land cover and did not further classify other land use (especially cropland) but grouped them as non-forest (Hammermaster & Saunders, 1995); Shearman *et al*, 2008; PNGFA/JICA, 2012; Bryan *et al*, 2015; FRA 2015). This limitation is attributed to the methodology used and the types of satellite imagery used. It is difficult to identify the type of cropland using Landsat images or settlements from Skaipiksa photographs (Filer *et al.*, 2010).

Point sampling also has its own limitations. Matinez *et al.* 2012 indicated the data suitability in the recognition of the land elements while Bey *et al*, 2016 pointed out a number of them and they include the application of an '*appropriate sampling design and intensity to adequately capture the variability of the land characteristics being assessed*'; the spatial cover is point based therefore the full variability of the land that can be classified and measured is limited; Visual interpretation is based on optical data and cloud cover remains a challenge despite the use of Landsat Greenest pixel products which usually provides cloud-free information, occasional (partial or full) cloud cover over a sampling plot; the imagery and satellite-derived data require internet access and finally for consistencies in the land use assessment, clear methodological framework for augmented visual interpretation is required.

The integration of other data sources in the methodology used in my study including the development of the methodological framework for augmented visual interpretation (hierarchical rules) overcome many of these methodological challenges. These data sources include the Landsat images from Google Engine, high resolution images from Google, Bing high resolution maps from Microsoft, Global data source from the University of Maryland, the 2012 forest base map and the timber concession boundaries.

5.1.2 Forest status

Previous studies on PNG's forest cover found conflicting information on the forest extent resulting in varying rate of forest change (PNGRIS, McAlpine and Quiqley., 1998), Shearman *et al.*, 2008, PNGFA and JICA., 2012; PNGFA., 2013; FRA 2015; Bryan *et al*, 2015). This has generated much debate among the academics *(*Filer *et al.*, 2009; Shearman *et al*, 2010*)* and has created uncertainty amongst the stakeholders on the forest extent and change. However the differences are expected due to technical differences in measuring forest cover and forest cover change (Shearman *et al.*, 2010) and also different forest definitions and forest classifications used. Table 15 show variations in the forest cover and the rates of forest change.

(i) Papua New Guinea Resource Information System (PNGRIS)

The forest cover reported in the Forest Inventory Management System was 63.2% in 1996. In 2002 the forest cover was 72% (Shearman *et al.*, 2008). Bryan *et al.*, 2015 reported 60.4% in 2014 and FRA 2015 showed 72.5%. In contrast the forest cover is much higher in the Forest Base Map 2012 (80.6%), Forest and Land Use in PNG 2013 (80.4%) by PNGFA, 2013, Global Datasets (93%) and this study (78%). This does not mean that the forest cover in PNG is increasing. This study was not able to establish why the forest cover is low in PNGRIS.

(ii) FIMS Forest Inventory Mapping System (FIMS)

In FIMS areas of significant disturbance (significant land use intensity) were excluded from the gross forest area in 1975 because they were misclassified as forest (Filer *et al.*, 2009) resulting in the lower forest cover compared to other studies.

The total area estimated in FIMS is about 46.4 million hectares. Total forest area in FIMS is 33 and 31.7 million hectares in 1975 and 1996, respectively. McAlpine and Quiqley, 1998 reclassified the forest as 'gross forest' thus reducing the gross forest to 29.3 million hectares in 1975 and the remaining gross forest area was 26.1 million hectares or 56.% forest cover in 1996. The reclassification of the forest was based on the forest definition which is the area of trees with "touching or overlapping crowns" (Hammermaster and Saunders, 1995) and the FIMS which was designed to determine potential forest areas for timber harvesting in undisturbed and well stock forest only. This resulted in the exclusion of about 5.8 million hectares of vegetated land classified under my study as forest. These vegetated lands include 3.9 million hectares of woodlands, mangroves, savanna, some areas of swamp forest, dry seasonal, alpine, littoral and seral forests and 1.9 million ha of logged but regenerating forest (Filer *et al*, 2009).

The annual deforestation rate was reported as 0.5%. This includes the 'logged but regenerating forests'. This is considered disturbed forest under my study therefore if the logged forest was excluded than the annual deforestation rate would be about 0.2%. The annual deforestation rate of 0.5% would therefore be considered as annual combined deforestation and forest degradation rate (Shearman *et al*, 2008). The 0.2% however is still high compared to my study because woodlands, mangroves, savanna and some areas of swamp forest, dry seasonal, alpine and littoral forests are included as non-forest. The forest degradation rates are similar in both FIMS (0.3%) and my study (0.4%).

(iii) State of the Forest of Papua New Guinea 2002

Shearman *et al.,* 2008 reported very high deforestation and forest degradation rates between 1972 – 2002 compared with the previous studies including this study. This generated much debated much debate among the academics (Filer et al, 2009; Shearman et al, 2010).

The report indicated the total forest cover declining from 38 million hectares in 1972 to 33 million hectares in 2002 with the annual combined deforestation and forest degradation rate of 1.41% (deforestation – 0.77% and forest degradation 0.64%). The high rate of forest change was due to the forest definition. The forest was defined as trees with canopy density of more than 70%) and tree height (5m) thereby excluding 2.9 million hectares degraded or secondary rainforest that fell below the forest definition threshold including 9.2 million hectares of scrub, Dry evergreen and swamp forests. Furthermore forest plantations, woodland and savanna are not included as forest. If these were included the forest cover would have increase to more than 80% in 2002. This is confirmed in the 2002 data that major broad category of rainforest was about 86% in PNG (Shearman P. , Bryan, Hunnam, Mackey, & Lokes, The state of the Forest of Papua New Guinea. Mapping the extent and condition of forest cover and measuring the driver of forest change in period 1972-2002, 2008).

(iv) Forest Base Map 2012

The forest base map only updated or improved the national level forest base map (FIMS) that was developed in 1996 using high resolution satellite images such as RapidEye, Radar satellite data (ALOS-PALSAR) including the MASP dataset (PNGFA &JICA, 2012). The forest cover found was 37 million hectares or 80.6%. The national forest definition[2] and the PNG vegetation classification (Hammermaster and Saunders 1995) was used to develop the 2012 forest base map. The forest cover is comparable to my study because same forest definition and vegetation classifications used. There was no change analysis done.

(v) Forest and Land Use in Papua New Guinea 2013

A total of 37.6 million hectares or 80.4% of forest was reported in 2013 (PNGFA, 2013). The study used the national forest definition and the vegetation classification of PNG. PNG has six "structural formation of the vegetation" under PNG Resource Information System and these are forest, woodland, savannah, scrub grassland and mangrove (Hammermaster and Saunders, 1995). The woodland, savannah, scrub and mangrove forest are classified as forest by PNGFA, 2013 and my study resulting in similar forest cover. There was no change analysis found in this report.

(vi) The State of Forest of PNG 2014

Bryan *et al.*, 2015 applied the same forest definition in Shearman *et al.*, 2008 and reported 60.4% (27.8 million ha) of 'closed canopy forest' in 2014. This resulted in the excluding of about 8.4 million hectares of dry evergreen forest, swamp forest and mangrove forest and secondary forest. The woodland and savannah were also excluded. These vegetation types are classed as forest in study and therefore if these vegetation types were included as forest then the forest cover would be more than 78% or similar to my study.
The rate of forest change therefore is based on the closed canopy forest which is referred to as rainforest in Bryan *et al.*, 2015 report. In 2014 about 4.1% forest was changed over the 12 year period or 0.34% annually. The change was due to forest land been converted to other land use (0.11%) or the forest land been degraded to secondary forest (0.23%). In contrast these rates are much lower than that of Shearman *et al.*, 2008 despite the same forest definition and classifications used. Bryan *et al.*, 2015 deforestation and forest degradation rates although lower are slightly closed to my study. The slightly lower rates are due to forest changes that occurred in dry evergreen forest, swamp forest, woodland and savanna between 2000 and 2014 not accounted for. My study found both deforestation and forest degradation or disturbance occurring in these forest types (Table 13 and Table 14).

(vii) Global Dataset

The forest cover estimates in PNG is 93% in the Global dataset (Hansen *et al.*, 2014). This is much higher compared to the previous studies. Hansen Global dataset refers forest as standing trees with height more than 5 meters and the canopy density of more than 50% regardless of land use. Consequently vegetated areas in cropland such as oil palm and coconuts plantations and other vegetated areas in grassland falling above the 50% threshold are considered forest by the Global dataset hence the high forest cover.
Furthermore, the vegetation loss or 'tree cover loss' in land use other than forest land can be miss-interpreted as forest change. This is clearly demonstrated in the REDD+ and Forest Monitoring Web-portal (Office of Climate and Development and PNG Forest Authority, 2017).Global Forest Watch, 2015 argues that the annual tree cover loss has been increasing since 2001 and reached its peak in 2015. The forest cover loss is 2.11% in 14 years or 0.15% per annum. Since the forest cover loss refers stand-replacement disturbance' or forest changing to non-forest state, the

[2] *Land spanning > 1 hectare with tree height > 3 meters and the canopy cover of > 10%*

loss occurring is considered to be coming from both forest disturbance and forest clearance of land use other than forest. Despite the high forest cover and increasing forest cover loss, the Global Dataset is reporting less tree cover loss rates compared to other studies and my study. This is because Hansen records only actual loss/change while other studies record both actual loss/change and intact forest areas. Some points in a forest area experience no change but considered change in the previous studies because of the application of different forest definitions and various rules to determine the land use or land cover. For instance McAlpine and Quiqley, (1998), Shearman *at el., 2008* and Bryan *et al.*, 2015 considering logged or secondary forest as non-forest does not mean that all the points in these areas were disturbed. Practically some of the areas within these logged over areas remained undisturbed. In this instance Hansen records only the actual forest change while in the previous studies both forest change and intact forest areas are recorded as change. This is similar to my study where the area showing a network of logging roads are recorded as disturbed forest despite some intact forest still remaining. These intact forest areas include steep areas, buffer zones and other areas constraints to logging. Most timber concessions in PNG apply the PNG logging Code of Practice and the 24 Key Standards.

(viii) PNG Forest Resource Assessment (FRA) 2015

FRA 2015 was put together before year 2015 by PNGFA. The forest areas were projected using simple linear regression based on the Base Map 2012 and the FIMS data set. The country's forest definition was used instead of the FAO's where some areas of vegetation types such as savanna and woodland felled into forest definition threshold were considered forest otherwise they were classed 'other wooded land'.

The forest cover reported in FRA 2015 is 72.5%. This is similar to that of Shearman *et al.,* 2008 in 2001 (71%) but much higher in more recent reports (JICA/PNGFA, 2102, PNGFA, 2013, Hansen *et al.,* 2014) and my study.

FRA 2015 reported the lowest deforestation and highest forest degradation rates compared with the previous studies. The forest area was estimated at 33,627,000 hectares in 1990 and reduced to 33,559,000 hectares in 2015 resulting in the forest loss of 0.2% in 25 years or 0.01% per annum.

There was an exponential increase in the 'other naturally regenerated forest' in 2015. These are naturally regenerating forests disturbed by anthropogenic activities (FRA 2015, Papua New Guinea). In 2015 a total of 15,960,000 ha or 47.6% (1.9% per annum) was reported as 'other naturally regenerated forest'. The exponential increase is attributed to the application of simple linear regression using four data points or years (1990, 2000, 2005, and 2010) to predict the year 2015 hence not realistic.

5.1.3 Land use other than forest

(i) Cropland

Agriculture in PNG has a long history dating back to 10,000 years (Bourke 2009). Despite its long history, its overall coverage of PNG's landmass is barely minimal. This study shows the cropland sharing only 11.2% of PNG's land mass. PNGFA-JICA (2012) Forest Base Map study showed a similar result (10.5%).Shearman *et al*. (2008) indicated a similar area of forest cleared (11%) for subsistence agriculture between 1972 and 2002. In contrast PNGRIS and MASP estimated about 25.6% of areas under some form of land use. This estimate is twice as high compared to Sherman *et.al* (2008), PNGFA-JICA (2012) and this study. This study is not able to establish why PNGRIS and MASP estimate is quite high. In general estimates of land use activities in the previous studies are comparable to this study.

5.2. Drivers of Forest Change between 2000 and 2015

Forest degradation is quite significant in PNG compared to deforestation between 2000 and 2015. The rate of both deforestation and forest degradation is 0.04% and 0.4% respectively. The main driver behind forest degradation is commercial logging while both subsistence and commercial agriculture activities are responsible for deforestation.

(i) Agriculture

About 6.6% of the forest was cleared or deforested during the period 2000-2015. Subsistence agriculture is the main driver of deforestation and was responsible for removing about 0.42% of the forest while 0.21% was cleared for palm oil plantations (Table 13). Shearman *et al*, 2008 also reported that the subsistence agriculture was the main driver of deforestation between 1972 and 2002. More than 80% of PNG's rural population depends on subsistence agriculture. Both agriculture and gardening activities are found to be densest between 1,500 m and 1,900 m ASL. The capital towns of major Highlands provinces including Goroka (Eastern Highlands), Kundiawa (Chimbu), Banz (Jiwaka), Mt. Hagen (Western Highlands) and Mendi (Southern Highlands) are all located at this elevation range and they are known as most densely populated and the busiest. Hence, the population density and land use also have distinct relationships where the proportion of forest decreases with increase in both cropland and settlement. Both settlement and cropland are associated with population. Based on the national census, the population of PNG increased from 5.1 million in 2000 to 7.2 million in 2011. It is about 40% increase in 11 years (National Statistics Office, 2011). The growing population has been projected to double in the next 25 years (Cuthbert et al, 2015). This will most likely affect the land use proportion in the country.
Despite the public perception that oil palm in the country is the main driver behind deforestation, only 0.2% of the total forest area between 2000 – 2015 was accounted for in this period. Unlike subsistence agriculture, oil palm expansions are only in specific locations of the country. Expansion of oil palm plantations into new forest areas may increase slowly due to slow expansion of the oil palm industry (*Nelson et al.,* 2014) and imposition of strict trade regulations (ISO) while on the other end subsistence agriculture expansion will continue to increase due to the continued increasing of the population. Oil palm now is shifted to grassland areas.

(ii) Forest degraded or disturbed by commercial Logging

Commercial logging was responsible in degrading or disturbing about 10.7% of the total forest in 2015, similar to Shearman *et al*, 2008 (11%) and Bryan *et al*, 2015 (13%). Most of the logs harvested through commercial logging in the country are exported as round logs (ITTO (2015) with an average of 2.6 million cubic meters per year (SGS 2000-2015 Annual Reports) fetching more than US$250 million per year in foreign exchange earnings (Forest and Development Website) .
Between 2000 and 2015, commercial logging was responsible for degrading about 6.1% or 2.1 million ha of the total forest. The logging activities mostly occurred in Low altitude forest on plains fans and Low altitude forest on uplands. These forest areas in general are in easily accessible areas (Shearman *et al*, 2008). During the same period a total of 50.3 million cubic meters of logs were harvested (PNGFA internal 2000-2005 reports). This is equivalent to about 2.1 million hectares of forest area logged based on the average merchantable timber stand density of 23m³/ha (National Forest Plan, 1996) similar to this study's findings. Most of the commercial logging activities occurred in Western, Gulf, WNB, ENB and West Sepik. Societe Generale de Surveillance (SGS) 2000-2015 data show a total of 4.2 million cubic meters of round log exports and 80% were exported from these provinces.

(iii) Gardening

It was found that forest disturbance by gardening activities is about 8% as at 2015. Gardening areas are isolated patches of temporary forest clearings usually at the edge of fallow land (cropland). More gardening activities have been detected in high populated forest areas. This indicate that fallow periods are now becoming shorter (McAlpine, 1970) thereby putting much pressure on the natural forest.
However forest disturbance through gardening activities between 2000 and 2015 was not very significant compared to commercial logging during the same period where only 0.4% of the total forest was disturbed in 15 years.

(iv) Fire

Fire is been used for hunting and shifting cultivation and has a long history in PNG (Bourke, 2009). Occurrences of fire are evident in rainforest soils (Haberle *et al*. 2001). Forest fire contributed about 1.2% of the total forest change in 2002 and is linked to population (Shearman *et al* 2008). This study found about 3.1% of the total disturbed forest area was burned in 2015 but was not significant between 2000 and 2015 compared to logging where only 0.1% of the forest was disturbed.

While all forest types were burned at minimum, the occurrences of fire were prevalent in Savannah, Woodland and Scrub forests. In all, Savanah forest was most affected. NASA 2015 Satellite photo show widespread of fires in PNG. More fire was detected in the southern part of the country where the Savana forest is dominant (Mongabay Website).

5.3 Summary

Three studies excluded huge areas of vegetation which are classified in my study as forest. McAlpine and Quiqley, 1998 excluded about 5.8 million ha in 1996. Shearman *et al.,* 2008 removed 9.2 million ha from their forest classification in 2002 and Bryan *et al.,* 2015 considered 8.4 million ha as non-forest in 2014. These exclusions means that both deforestation and forest degradation were not accounted for in these important forest types. The primary forest degraded to secondary forest was considered deforestation. These vegetated areas include woodlands, mangroves, savanna, swamp forest, dry seasonal (dry evergreen), alpine, littoral and seral forests, forest plantations and secondary forest caused by logging and gardening or agricultural activities.

Conclusions

Forest land use change status

We now have information on PNG's forest land use status based on the broad IPCC land use categories and the national forest definition with detail sub categories based on the country circumstances. It provides a broad overview and the perspective of the country's land use at the national scale.

My results support the previous studies that the forest is decreasing. The rate of both deforestation and forest degradation however is not as alarming as what Shearman *et al.* 2008 reported. PNG still has high forest cover and most of these forest areas still not been degraded or disturbed by human activities. Disturbances caused by natural phenomena were not assessed. Commercial logging has had a significant impact on the forest cover and is the major cause of forest degradation or disturbance followed by gardening, fire, portable sawmills and others in order of intensity. Logging activities mostly occur in Low attitude forest on plans and fans and Low altitude forest on uplands while fire is prevalent in Savana, Woodland and Scrub forests. Gardening activities are common in Lower montane, Low attitude forest on uplands and Low altitude forest on plains and fans.

Cropland comprised of both subsistence (permanent and shifting), and commercial (oil palm, coconut, cocoa and Coffee) agriculture. Subsistence agriculture is the major cropland type occupying most of the cropland area. Large scale monoculture commercial plantations are minor land use except palm oil plantations.

Deforestation is not significant in PNG. The major driver of deforestation is subsistence agriculture followed by palm oil. Forest degradation or disturbance is however substantial between 2000 and 2015. Commercial logging is the major driver. Other disturbances are not significant.

Systematic Sampling Approach

My results are comparable with the previous studies that applied wall-wall approach. This demonstrates that the methodology applied in my study is another option for land monitoring in PNG.

Recommendations

(a) Commercial logging is making a significant impact on the forest cover. The current forest legislation needs to be reviewed to reduce the rate of forest degradation.

(b) The result of this study is not recommended for provincial or local level use. If provincial or local level land use information is desired, sampling intensities will need to be increased.

(c) Natural events/phenomena were outside the scope of this study. Further studies on the occurrences of the natural events/phenomena such as landslides, frosts, cyclone needs to be conducted to provide a complete picture of forest and land use status in PNG.

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Developing a model approach for assessing levels of deforestation and forest degradation for addressing REDD plus in PNG

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Abstract

As part of the REDD+ readiness development process Papua New Guinea (PNG) must consider a number of approaches to addressing the drivers of deforestation and forest degradation and strengthening land use management. Previous analyses of deforestation and forest degradation have highlighted the role of both agriculture and logging as key drivers. Deforestation has occurred through the conversion of primary and degraded forest-land into cropland by commercial companies or smallholders (many also containing cash crops). In combating deforestation the concern about the destruction of world's forest has increased considerably in the last two decades and has led to several initiatives to reverse this trend and develop strategies and measures for sustainable forest management (ITTO, 2002).

The study focuses on developing a model for assessing levels of deforestation and degradation within PNG, based on historical trends and key variables that can be used to help guide policy decisions with regard to land-use (agricultural) development and forest management. The study identifies data needs and contributes to strengthening information (GIS/RS database) systems for collection and analysis of data within PNGFA and relevant government agencies to improve its capacity for assessing past and current change in vegetation cover specifically in relation to forest cover and land-use. Undertake analysis of historic rates of deforestation and degradation related to logging and other land-use. The study is initiated by the Dept. of Surveying & Lands Studies of the PNG University of Technology and supported by the PNG Forest Authority (PNGFA) within the Government of PNG as well as programs providing support to PNGFA such as the Japan International Cooperation of Japan (JICA) and the Food & Agriculture Organisation (FAO) through the UN-REDD National Programme. The study outcomes also support the work of NGOs and other government agencies working on similar projects specifically in relation to managing commercial agriculture.

Introduction

Undisturbed forest/vegetation cover and cleared forest/vegetation (deforestation) for land-use or logging requires less effort in applying interpretation elements for their detection compared to assessing secondary forest or regrowth vegetation in terms of detecting and measuring their levels of growth or maturity. Degraded forest/vegetation, regrowth or secondary forest (logging/non-logging related) have been perceived as being not sensitive to source or means of detection in order to quantify their rate of recovery.

Mapping forest degradation with remote sensing data is more challenging than mapping deforestation because the degraded forest is a complex mix of different land cover types (vegetation, dead trees, soil, shade) and the spectral signature of the degradation changes quickly (i.e., < 2 years) (Herold et al. (2009)). High spatial resolution sensors such as Landsat, ASTER and SPOT have been mostly used so far to address forest degradation. Methods for mapping forest degradation range from simple image interpretation to highly sophisticated automated algorithms. Higher spatial resolution imagery is more suitable for detection of specific forest degradation impacts (GOFC-GOLD, 2008).

Aims/Objectives

Methods with high degree of accuracy are needed for monitoring recovery levels of regrowth in vegetation or secondary forest after logging and for planning sustainable use of resources.
The aim is to:

(a) investigate the changing status of vegetation and forest cover after logging has occurred or by other anthropogenic means of disturbance through certain period, and;
(b) Test if high resolution satellite data, with high degree of accuracy, can be used for detection, and for quantifying and mapping of secondary forest and vegetation regrowth to determine levels of degradation and deforestation.

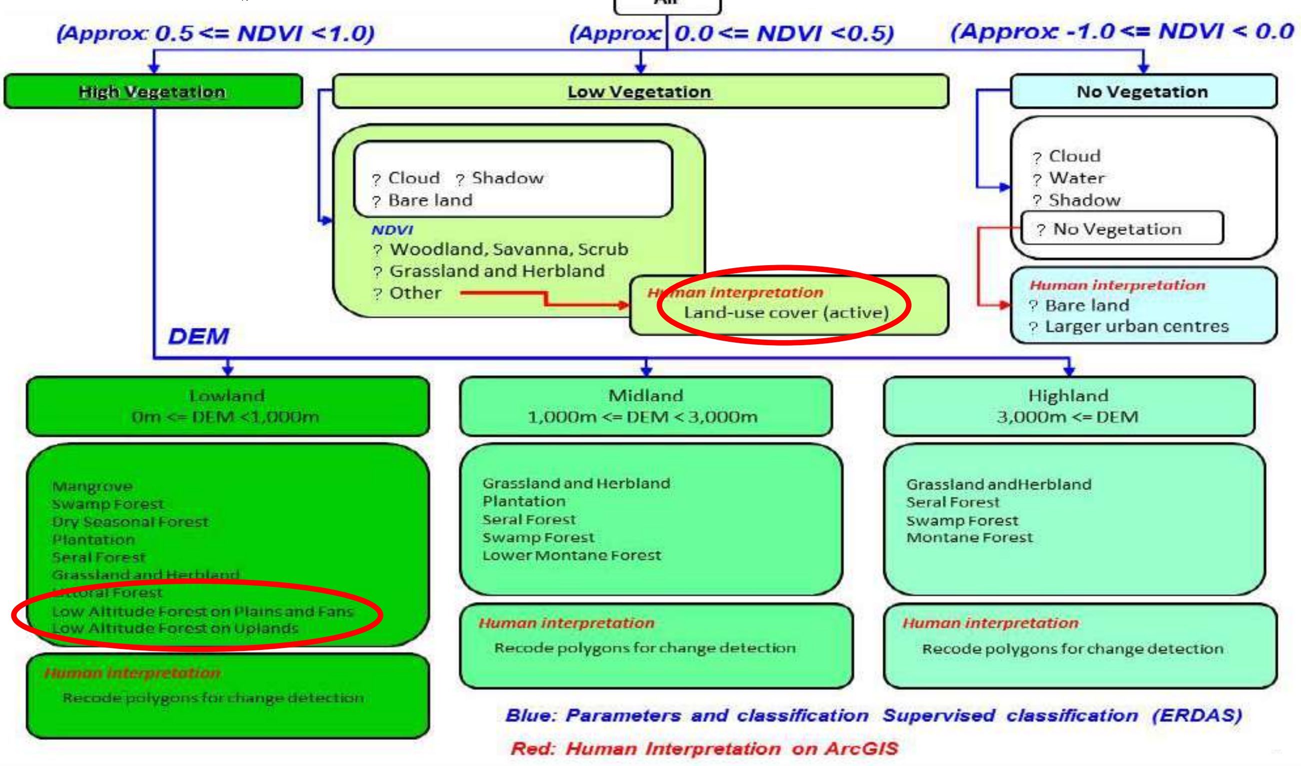
Materials: Data and Software Specifications (Software: MapInfo 10.5 / ERDAS 8.5 / ArcGIS 10.1)

Primary Data	**Band, Resolution, Scale**	**Layer**	**Data source/Year**
Land SAT ETM+	7 band, 30m, 1:25,000	Raster	USGS/2000-2015
Rapid Eye	5 band, 5m, 1: 25,000	Raster	Planet Labs/2011
SRTM	90m	DEM	NASA/2008

Secondary Data	**Scale**	**Layer**	**Data source/Year** *(collateral):*
PNG Forest Base-map	1:50,000	Forest Classes/Concessions	PNGFA / 2012
FIMS	1:100,000	Vegetation types	PNGFA / 1996
PNGRIS	1:100,000	Soil types	Dept. of Agriculture
Census	1:100,000	Population distribution	National Statistical Office
Hansen	variable	Forest loss/gain	Maryland/2000-2015.

Methods: Forest Change Detection Analysis

Class Tree Hierarchy



Methods: ***Definitions of drivers of Deforestation and Degradation (DD)***

A list of possible drivers of deforestation and degradation are set as illustrated in tables 1 and 2. Definitions of them are provided in a set of land use (IPCC land-use categories) and strata combinations. The set of typology and definitions takes into consideration technical limitations associated to Remote Sensing analysis. Some of definitions are deliberately simplified to facilitate analyses.

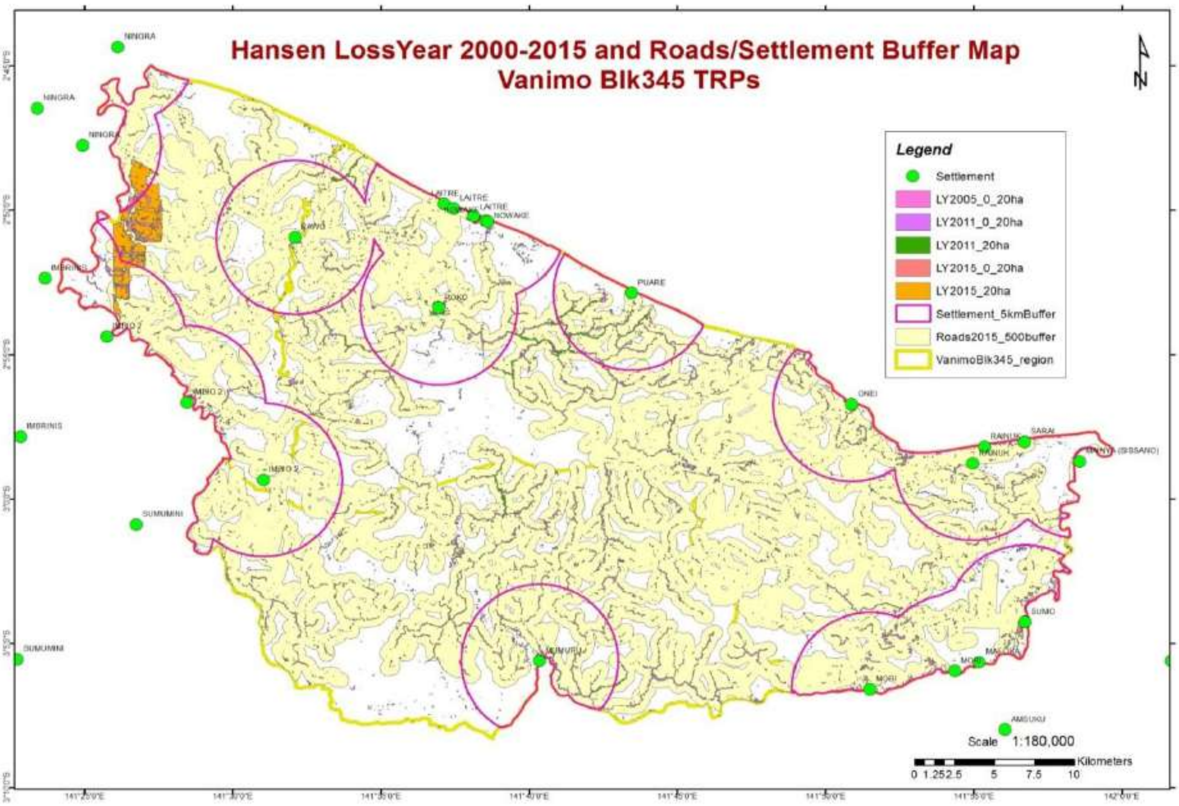
Table 1 Deforestation drivers

Driver	Initial LU class/ strata	Final LU class/ strata
Subsistence agriculture	Forest land/ strata	Cropland/ annual crops Grassland/ shrub Grassland/ grassland
Commercial agriculture		Cropland/ perennial plantations
Large fire		Grassland/ grassland
Mineral extraction		Settlements/ infrastructure
Road construction		Settlements/ road
Urban expansion and settlements		Settlements/ infrastructure

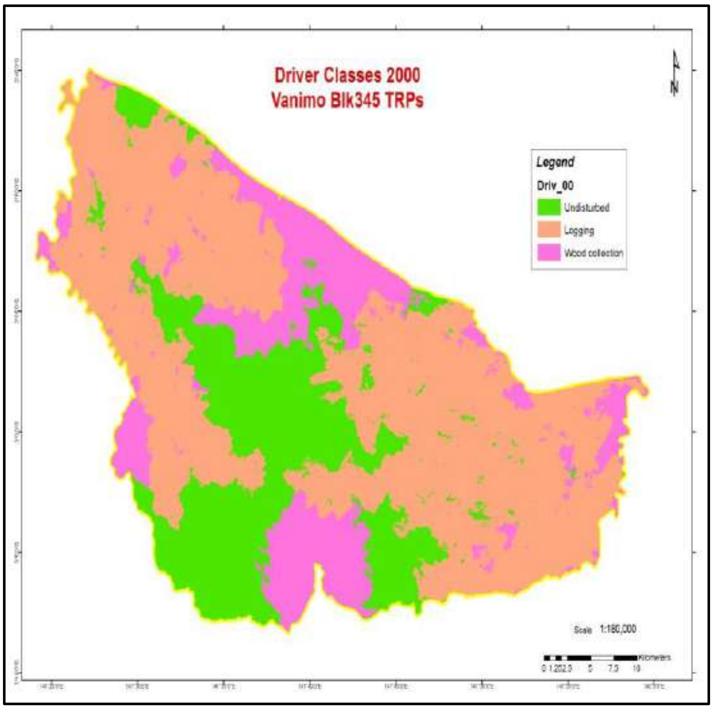
Table 2 Degradation drivers

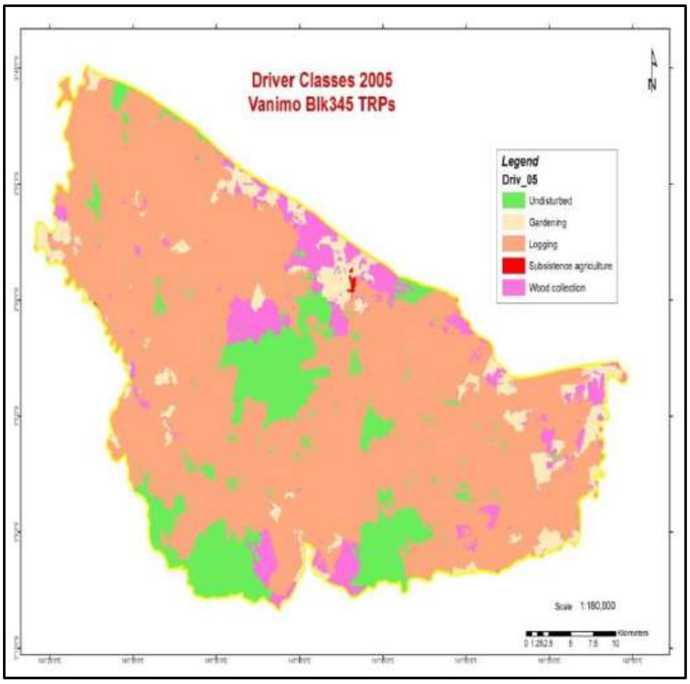
Driver	Initial Forestland strata	Final Forestland strata
Authorized selective logging	Primary forest	Logged over forest
Wood collection (non-authorized logging + fuel wood collection)	Primary forest	Non-logged degraded forest
Gardening through slash and/or burn (so small fires are included here)	Primary forest	Non-logged degraded forest
Logging in forest plantations	Forest plantation/ Close - canopy plantation	Forest plantation/ open-canopy plantation
Grazing	Usually happens in Grassland though may have a potential of forest degradation	Grassland/ shrub Grassland/ grassland

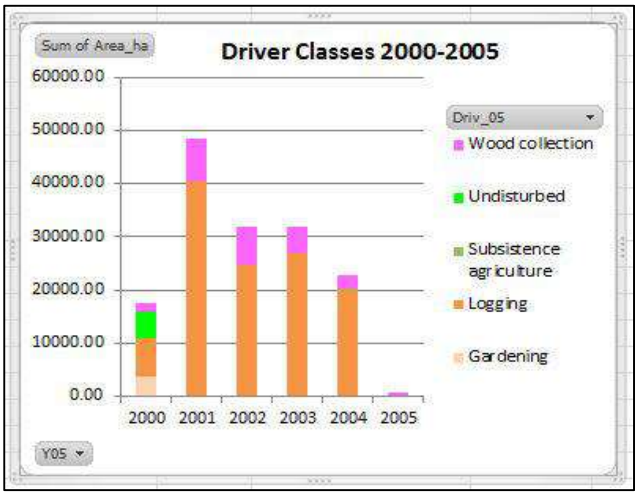
Results

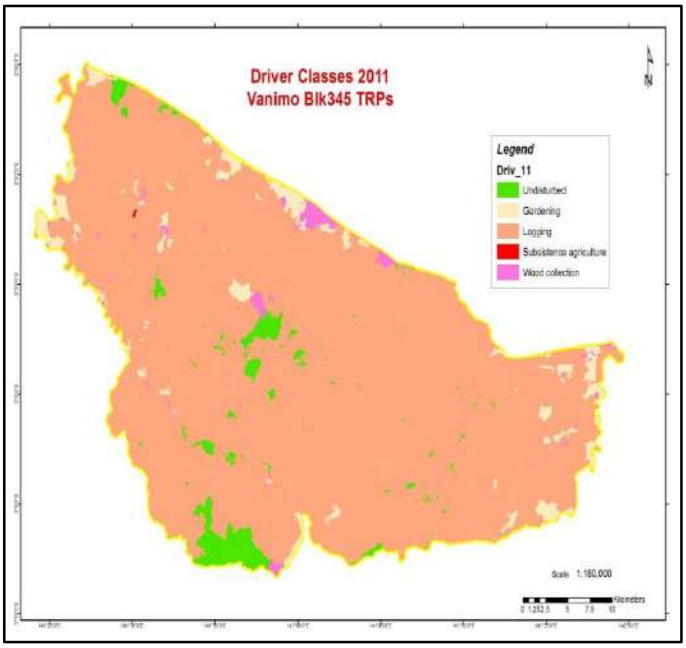


Analysis Results - Thematic Maps: Driver Classes Yr2000 and Yr2005 Total Values




Driver Classes 2005
Vanimo Blk345 TRPs
Legend
Driv_05
Undisturbed
Gardening
Logging
Subsistence agriculture
Wood collection


Sum of Area_ha
Driver Classes 2000-2005
Driv_05
Wood collection
Undisturbed
Subsistence agriculture
Logging
Gardening
Y05


Driver Classes 2011
Vanimo Blk345 TRPs
Legend
Driv_11
Undisturbed
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Logging
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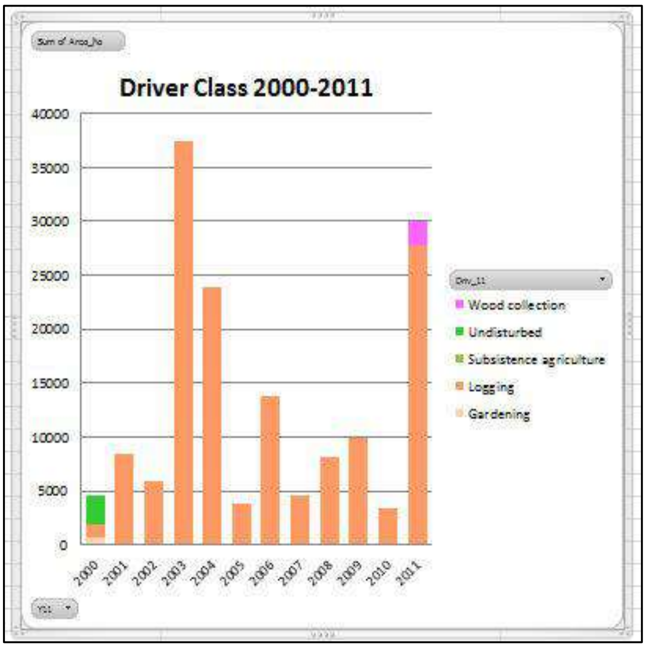
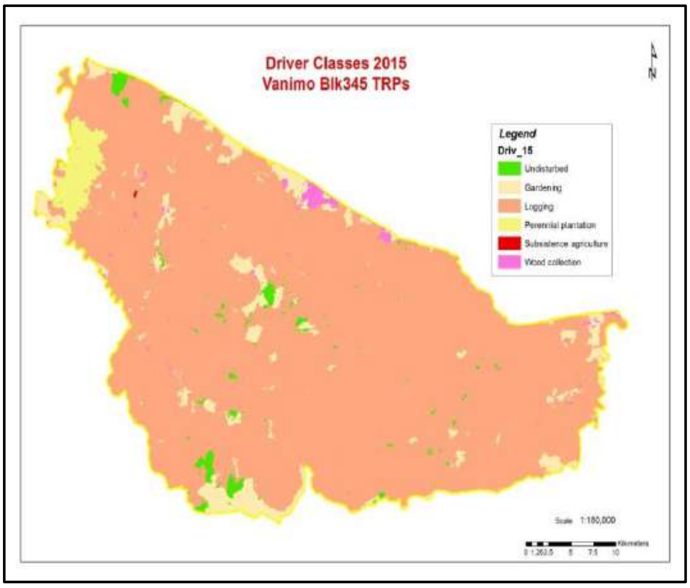
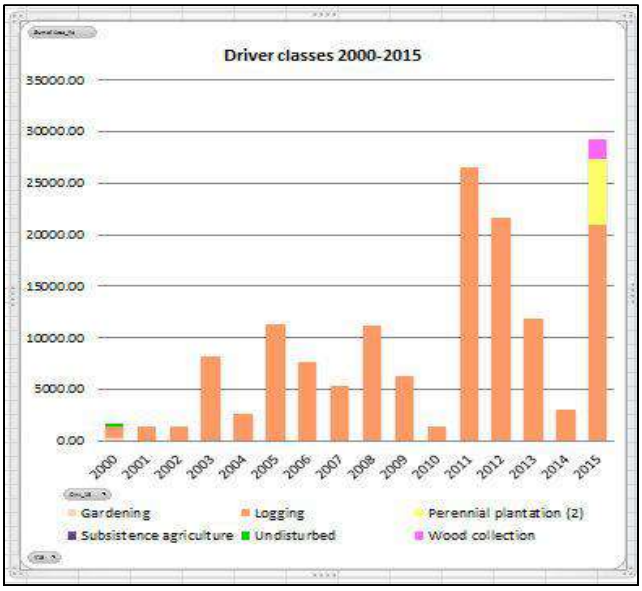
Wood collection


Driver Class 2000-2011
Wood collection
Undisturbed
Subsistence agriculture
Logging
Gardening





Discussion

Initially the maps of periods 2000 to 2005, 2005 to 2011, and 2011 to 2015 were compared to elucidate what types of land cover increased or decreased between the temporal periods. The comparison revealed the main changes in land cover were degradation of hill forest (H) and plain forest (P) and conversion of P into perennial plantation (Qa) and subsistence agriculture (O). The following parameters: *concession (Expired), 500m buffer from logging road (2000-2015), 5km buffer from settlements, Hansen Loss year (2000- 2015), threshold value of 20 ha to ascertain level of impact by drivers of Deforestation and Degradation (DD) including elevation (SRTM, 90m) and slope* were applied to develop model for assessing levels of DD. Analysis results are tabulated below to enhance the model for assessing levels of DD.

Ranking	FC2000	FC2005	FC2011	FC2015	Area (ha)	Change Decrease (less degraded)	Change Increase (more degraded)	Change in Biomass * (average) t/ha
1	H				75,966			
2	P				69,898			
3	O				2,833			
4		H degraded			75,873	93		13,485
5		P degraded			69,570	328		47,460
6		O degraded			3,372		539	
7			H degraded		75,673	200		29,000
8			P degraded		69,429	141		20,445
9			O degraded		3,857		485	
10				H degraded	29,384	46,289		6,711,905
11				P degraded	108,223		38,794	5,625,130
12				O degraded	8,362		4,505	

* Multiply by factor of 145 t/ha for average above ground biomass of logged over lowland tropical rainforest in PNG, Fox *et al.* (2010)

The ranking (table above) is decided by the three major LULC classes of focus in this study including magnitude of their area impacted by drivers. According to the table, ranking increases with degradation during the temporal period (2000-2015). However, if the difference in area size between two time series (e.g. 2011 and 2015 for H class) is positive (75,673ha-29,384ha=46,289ha) the area is identified as less degraded due to the decrease in H class being degraded. The residual area of 46,289ha could be possibly determined as regrowth area. Hence, the average biomass for above ground could be estimated by multiplying the area (ha) of each land cover class by 146.0 t/ha as determined by Fox et al. (2010)

The constraint to determine the regrowth area is identifying *spatially* the location of the **less degraded** (above table) or **regrowth** areas within degraded forest cover (secondary forest) by remote sensing which the study could not yield among the positive results. In the absence of ground truth data such as forest inventory data the simple ranking method attracted positive results though it could be improved to verify condition of secondary (recovery) forest. However, the study traced a pathway forward in further investigating how to assess levels of forest deforestation and degradation with applications of GIS and Remote Sensing.

Conclusion

In determining degradation and deforestation the study was able to figure out where and how much forest resources are available for a sustainable forest management. To get handle on the dynamics of forest resources is highly significant for a better forestry planning, monitoring and management. The study involved creating past forest cover maps for the subject area which was able to ascertain forest conditions focussing on;

(a) Where intact or undisturbed forest is;
(b) How degraded forest has recovered (<u>recovery rate of forest);</u>
(c) How deforestation or forest degradation has expanded, (<u>rate of forest degradation</u>), and;
(d) If land-use activity is cyclic over temporal period or not. Those data are useful information not only as outcome of the study but also for addressing REDD+ issues in PNG.

Challenges and Way Forward

With available forest inventory data such as species composition of forest types, the results of the simple ranking method could be improved to verify conditions of forest. However, the results of the research provide positive approach by methods of GIS/RS in assessing levels of Deforestation and Degradation in addressing some issues of concern as discussed in recent report on PNG's REDD Plus FREL (submission for UNFCCC 2017) by OCCD. The issues include;

- A distinction between degradation drivers. There is currently no information available for emission factors which would allow for a distinction between forest degradation due to logging and other kinds of forest degradation. It is anticipated that this data will become available as part of the ongoing NFI.

- There is no country specific data for above ground biomass for land use other than forest is available in PNG. Carbon stock after deforestation is considered zero in PNG's FRL as the concept of gross deforestation due to lack of reliable data for estimating carbon accumulation in regrowth.

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Acknowledgements

Using GIS and remote sensing for land-use/ cover classification and change detection: A case study of Oomsis Concession Area, Morobe Province, Papua New Guinea

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Abstract

Spatial and temporal changes in land-use and land cover pattern are essential information to aid decision making in resource planning, management and monitoring. Land-use changes have impacts on forest cover, biomass, biodiversity, greenhouse gas emissions and climate change. This case study was done in a logged-over forest concession area. The aim of this study is to classify the current land-use and land cover in the logged-over forests and to detect changes that had taken place over a 16-year period (2001 - 2017) using remote sensing (RS), Geographical Information System (GIS) techniques and ground truth information.

This study looks at particularly the application of optical remote sensing and GIS to analyse the spatial and temporal distribution of various land cover categories, hence facilitating change detection analysis. Landsat ETM^+ and Landsat OLI images were used in this study. The satellite images were pre-processed and georeferenced as a prerequisite prior to further processing and analysis. Pixel-based supervised classification, using maximum likelihood algorithm was used in this study followed by change detection analysis using selected algorithms viz. post-classification comparison and image differencing techniques. Overall classification accuracy attained was 96% and 98% with overall kappa stats of 0.9274 and 0.9575 for 2001 and 2017 respectively. Results indicated undisturbed forest increased by 6.45% - an indication of forest recovery following human disturbances, whilst disturbed forest decreased by 10.25% over 16-years period following cessation of large-scale logging operations. Moreover, cropland increased by 2.24%, whilst grassland and settlement had slight increases of 0.66% and 0.89% respectively.

Current study demonstrated the importance of remote sensing and GIS for resource management through identification, classification, assessment and interpretation of land-use and land cover categories. Medium resolution satellite data (freely available online) were also demonstrated in this study for assessing the dynamics of land-use and land cover in logged-over forest. GIS analysis in this study has shown its vast potential in solving complex problems and providing information that could aid decision making in resource management.

Key words:

Land-use/ cover, remote sensing, GIS, supervised classification, maximum likelihood algorithm, change detection, resource management

Introduction

The dynamics of land-use and land cover are essential information for effective planning and management of forest resources. Land-use and land cover are different terminologies often used interchangeably (Dimyati *et al*., 1996; Rawat J.S and Kumar M, 2014). Basically, land cover refers to the bio-physical characteristics of the surface of the earth, including both natural and other physical features of the land. Land-use refers to the way in which land has been used by humans or the socio-economic description or functional dimension of areas. Kumar M (2015) stated that land-use and land cover pattern of a region is an outcome of both natural and anthropogenic factors.

Papua New Guinea (PNG) contains approximately half of the third largest tract of tropical rainforest in the world, which is an important national asset. Nonetheless, major disturbances on land cover due to land-use changes to meet socio-economic aspirations are obvious. Burgeoning population also contribute to changing land cover particularly in accessible areas resulting in forest cover either being dwindled or converted to other land uses over time (Samanta *et al.*, 2016). Anthropogenic impacts especially commercial agriculture, logging and shifting cultivation are major drivers of land cover changes in PNG (Shearman *et al*, 2009). Land-use changes have subsequent impacts on forest coverage, biodiversity loss, socio-economic stability (Vitteck. M *et al*., 2014), greenhouse gas emissions and climate change (Fox *et al.,* 2010; IPCC, 2003), increased surface run-off and flooding. Past studies (e.g. Yosi *et al.,* 2011; Fox *et al.,* 2010; Saulei. S, 1999) indicated land-use change such as through timber harvesting also affect forest ecosystems in terms of species composition and structure, biomass, spatial distribution pattern and forest recovery following disturbances.

Monitoring land-use and related changes is important for establishing linkages between policy decisions, regulatory actions and subsequent land use activities (Lunetta, R.L, 2006) to improve management of forest resources. Accurate monitoring (and mapping) of spatial and temporal land-use and land cover is a prerequisite to capture the dynamics in land cover including the magnitude and direction of change over a geographical area. In PNG, ineffective planning and management of logged-over forests (Nir, 1992) coupled with the land tenure system, complicate efforts in resource management following logging operations. It's worth noting that 97% of the land in PNG is customarily owned (Karigawa, Babarinde, & Holis, 2016), hence in most instances following logging operations, customary landowners venture into other cash-generating options for sustenance especially when there are opportunities and accessibility for market supply and demand. Shifting cultivation, farming of cash crops or engagement of portable sawmills to harvest remnants of the standing trees to supply local market demands are most common such activities following logging operations.

Various studies (e.g. Ahmed B, 2001; Fichera *et al*, 2011*;* Lillesand *et al*., 2007) indicate that remote sensing and geographical information system (GIS) is vital for research, monitoring and to support decision-making, for instance, in relation to resource management and planning. Remote sensing is a technique of deriving information about objects on the surface of the earth without physically coming into contact with them (Lillesand *et al*., 2007). GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modelling, representation and display of geo-referenced data to solve complex problems regarding planning, and management of resources. Spatial distribution of resources over a geographical area can be temporally mapped out facilitating change detection analysis. Hence, utilising remote sensing and GIS is important to improve management decisions and to support policy issues, relating to sustainability of forest resources and management of logged-over forests in PNG.

Optical remote sensing, utilising the visible and near infrared (NIR) bands of Landsat 7 and Landsat 8 were explored in this study. These sensors capture images of the earth's surface by detecting the solar radiation reflected from the targets on the ground (Lillesand T.M, Kieffer R.W & Chipman J.W, 2007). Lillesand T.M, *et al.*, 2007, stated that since different materials reflect and absorb differently at different wavelengths, various targets can be differentiated and analysed accordingly based on their spectral reflectance signatures in the remotely sensed images. This is essential for land-use and land cover (or vegetation) classification and change detection analysis.

This research study aimed to identify and quantify the current land-use and land cover categories, including the magnitude and direction of changes that had taken place from 2001 to 2017 and to determine the current status of the logged-over forests using remote sensing, GIS techniques and ground truth information of the area of interest.

The specific objectives of this study are as follow;

1) To classify and quantify the different land-use and land cover categories of the study area.
2) To analyse and quantify the magnitude and direction of change of the various land-use and land cover categories of the different years (2001 and 2017).
3) To map out and quantify land cover categories that had changed from initial categories as a result of land-use changes over the last 16-year period (2001–2017).

Materials and Methods

1. Study site

This study was conducted at Oomsis logged over forest, Morobe Province, Papua New Guinea. The site is located between coordinates 6˚41' to 6˚ 44' south and longitudes 146˚ 49' to 146˚ 51' east. Oomsis is located about 30 km by road south-west of Lae City, the capital of Morobe Province. The site was chosen due to increasing human activities occurring in the area in recent years (Patrick Nimiago, pers. com, 2016) and easy accessibility following timber harvesting.

The dominant vegetation type found at the study area is lowland medium crowned forest (Paijmans 1976, cited in Nimiago and Nir 2000), or low altitude forest on plains and fans (PNGFA 2014). Climate of the area is typically humid. Annual rainfall ranges from 1,500 to 3,000 mm and experiences a high rainfall of 5,000 to 6,000 mm in the peak period between June and September. Average temperature is around 23 to 32 ˚C (McAlphine *et al,* 1983, cited in Nir 1992). Altitude ranges from 300 to 1000 meters above sea level.

2. Materials

Materials used to carry out this case study are; Satellite data (Landsat 7 ETM$^+$ and Landsat 8 OLI; Personal computer; Soft wares: ArcGIS 10.0 and Erdas 8.5; Microsoft Office 2010 (Microsoft Word, Microsoft Excel and Microsoft PowerPoint), Hand-held Garmin GPS and Digital camera.

2.1. Data types

Data types used in this study included Landsat satellite data, ancillary data and ground truth data.

2.2. Soft wares

Soft wares used in pre-processing and processing of the satellite image data were; Erdas Imagine 8.5, and ArcGIS 10.0. Erdas Imagine 8.5 was used to carry out pre-processing and actual processing or classification of land-use and land cover of the satellite image data. ArcGIS was used for composing the final classified maps and change detection analysis. Finally, Microsoft Office 2010 programs particularly Microsoft Word, Microsoft Excel and Microsoft PowerPoint was used for writing the report and presentation.

3. Data acquisition and pre-processing

The primary data sources used in this study are Landsat 7 ETM$^+$ (Enhanced Thematic Mapper) and Landsat 8 OLI (Operational Land Imager). The datasets (Table 1) were acquired from the USGS website.

Table 5 Tabulated are the selected satellite/ sensor and bands used in this study

Satellite/ Sensor	Name of location	Date	Path/ Row	Bands	Wavelength (μm)	Spatial Resolution (m)
Landsat 7/ ETM+	Oomsis, Morobe Province	2001-03-03	Path=96 Row=65	2: Green	0.53-0.59	30
				3: Red	0.64-0.67	30
				4: NIR	0.85-0.88	30
Landsat 8/ OLI	Oomsis, Morobe Province	2017-02-19	Path=96 Row=65	3: Green	0.52-0.60	30
				4: Red	0.63-0.69	30
				5: NIR	0.77-0.90	30

4. *Pre-processing*

Satellite image pre-processing is a prerequisite step undertaken to make satellite imagery data "ready" prior to image analysis to achieve the objectives of the study. Image pre-processing in this study included geometric correction or rectification (geo-referencing) and projection. Rectification of the satellite image data (in this study) was performed using the Universal Transverse Mercator (UTM) projection system and WGS84 (Zone 55S) datum. In essence, to perform change detection, it is essential that image pairs are comparable in terms of their geometric and radiometric qualities (Samanta. S and Pal DK, 2016).

In this study, the selected bands were combined through 'layer stacked' using Erdas Imagine 8.5 to create composite bands. The composite bands were enhanced spatially and the study area was extracted using Erdas Imagine 8.5.

5. *Ground Trothing*

Ground truth in this study involved the following activities;

- Extensive reconnaissance survey of the study area was carried out from the 16th to 20th October, 2017. This was to get a general view of the landscape.
- Locate and identify the dominant land-use/ land cover classes found on the landscape as shown on the satellite imagery (e.g. Google map).
- Collect GPS coordinates and photographs of sample land cover types, as well as interviews with landowners regarding land-use practises in the area of interest

6. *Processing and Data Analysis*

A detailed flowchart of the methodology used is provided below (Fig.1). After the image was rectified/geo-referenced, the study area was extracted using the digitized boundary of the study area. The extracted study area was then subjected to pixel-based supervised classification. From the available techniques of supervised classification, maximum likelihood classification algorithm was used in this study considering its potential and suitability. During the classification process, care was taken when generating the signatures of each cover type. A total of five land-use/land cover catergories were identified. The signatures were then fed into the software (Erdas Imagine 8.5) to run the supervised classification process of the remaining pixels of the satellite image. The classification land cover map was verified using reference data including ground thruth information of the area. Land cover class was corrected using recode technique wherever needed based on ground truth information.

In remote sensing studies relating to land-use/ land cover, classification system applied is important. The classification system adopted in this study was by the IPCC Good Practice (IPCC, 2003). The top level land categories were used, except forest land. Forest land of the study area was dominantly classified as lowland medium crowned forest (Paijmans 1976, cited in Nimiago and Nir 2000), hence was further differentiated as being 'undisturbed forest' or 'disturbed forest'. The revised categories used in this study following field verification are as follow; (1) Undisturbed forest, (2) Disturbed forest, (3) Mixed Cropland (4) Grassland, and (5) Settlements.

7. Change Detection

Change detection analysis was carried out to determine the magnitude and direction of change over a 16-year period (2001-2017). Change detection techniques applied in this study were 'post-classification comparison' and 'image differencing techniques'.

Results

1. Classification of Land-use and Land cover Categories

Land-use and land cover classified maps for years 2001 and 2017 were generated. Classification of land-use and land cover types facilitated the quantification of different land cover categories including change detection analysis.

Figure 2 Detailed flow chart of methodology used in this study

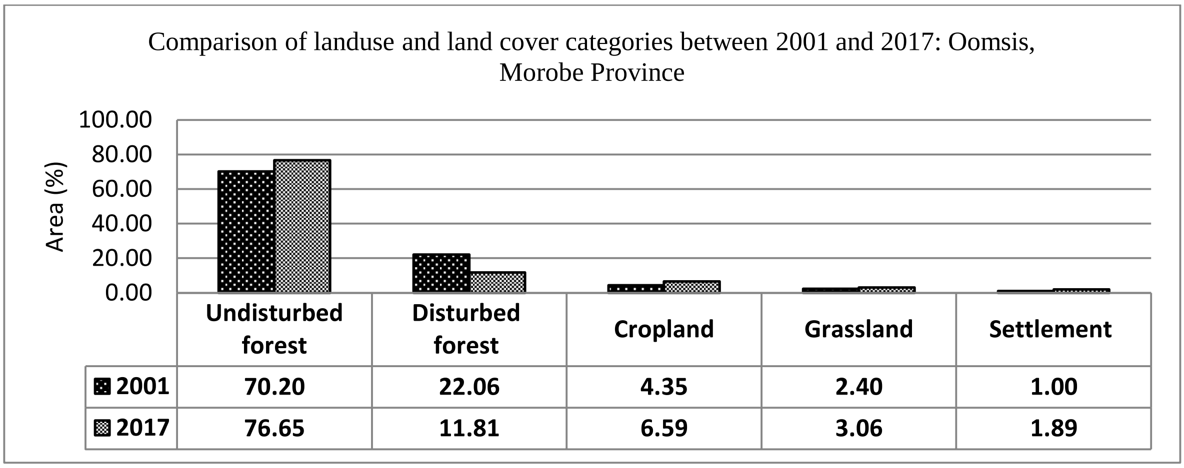

Figure 3 Quantification of the various land cover categories

1.2 Accuracy assessment

Accuracy level attained for the supervised classification using maximum likelihood algorithm is presented below (Table 2).

Table 6 Accuracy assessment of the supervised classification

Reference Year	Classified Image	Overall Classification Accuracy (%)	Overall Kappa Statistics
2001	Landsat ETM$^+$	96	0.9274
2017	Landsat OLI	98	0.9575

2.0 Change Detection Analyses

2.1 Post-classification comparaison technique

Results from post-classification comparison technique for change analysis is presented below (Table 3), indicating the magnitude and direction of change (area in percentage) over the study period.

Table 7 Post-classification comparison technique of change detection analysis: 2001 to 2017 (area in %)

CLASS	1	2	3	4	5	Year-2017
1	61.83	14.78	0.00	0.04	0.00	76.65
2	6.41	5.21	0.09	0.10	0.00	11.81
3	1.61	1.71	2.68	0.43	0.16	6.59
4	0.34	0.23	0.76	1.63	0.10	3.06
5	0.01	0.13	0.81	0.20	0.74	1.89
Year-2001	70.20	22.06	4.35	2.40	1.00	100.00
Key: 1. Undisturbed forest, 2. Disturbed forest, 3. Mix Cropland, 4. Grassland, 5. Settlement						

Note: Cells highlighted diagonally (in orange) represents the land cover categories (areas in %) that did not underwent any changes between 2001 and 2017.

Bi-temporal change analysis of the various categories revealed interesting results relating to the magnitude of area changed between 2001 and 2017. Figure presented below (Figure 4) shows the magnitude of changes in each category over the duration of the study period.

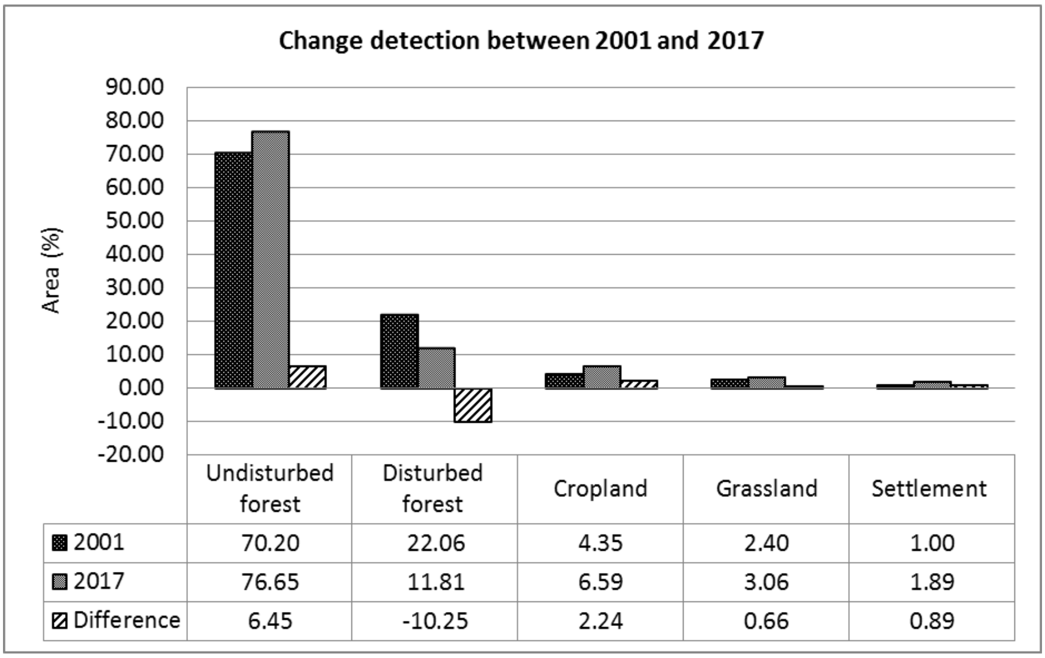

Figure 4 Magnitude of change between 2001 and 2017 for each land cover category

2.2 Image differencing technique

Image differencing algorithm was also used in change detection analysis and the results are presented below. The results presented (Figure 5) indicated the total area (ha) in each land cover category that had experienced human disturbances over the duration of the study period.

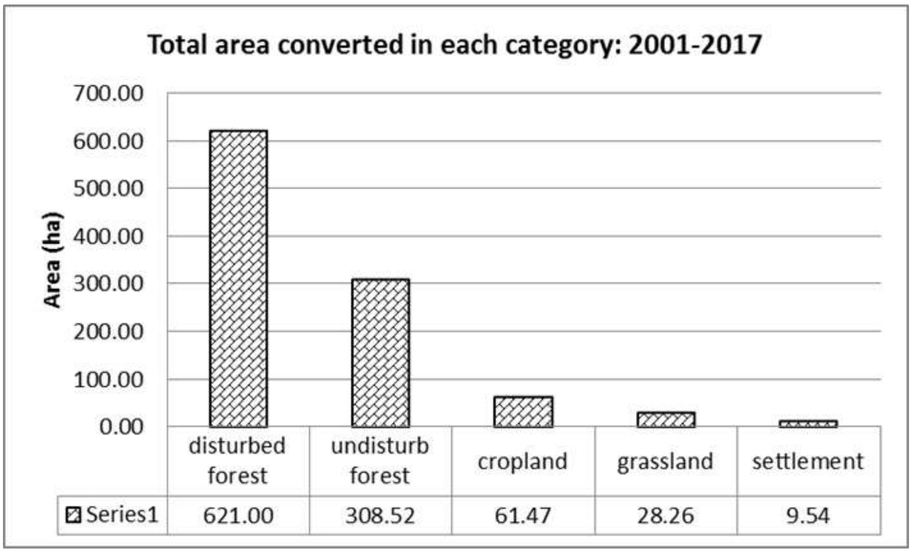

Figure 5 Total area (ha) in each category converted to other categories other than the initial categories

Discussion

1.0 Land-use and land cover classification

The current study provided baseline information on the different land use and land cover categories of the study area, including the spatial extent of those categories over the last 16 years (2001 to 2017). The classification done in this study is quite exceptional, due to the fact that the accuracy assessment done attained the following results; overall accuracy was 96% and 98%, and overall kappa statistics was 0.9274 and 0.9575 respectively for year 2001 and 2017.

Interestingly, key results obtained from the current study (Figure 4, 5 & Table 3) showed that undisturbed forest area increased by 6.45% (from 70.20% in 2001 to 76.65% in 2017) in terms of area coverage. This was not anticipated since the site had undergone logging operations and other human disturbances such as shifting cultivation and cash crop farming. However, after more than a decade following logging, results from the current study indicated that the disturbed forest is recovering after major logging operations ceased (around 2003/04). Consequently, 'disturbed forest' area has reduced by 10.25%. This signified a reduction in anthropogenic disturbances in forested areas over the 16 years period.

Remote sensing methodology employed in this study was principally assessing the status and the canopy cover of the forest - and not so much on the quality of the forest in terms of desirable commercial tree species for 'production forest' purpose. The increased in undisturbed forest (6.45%) and reduction in disturbed forest (10.25%) shows that the disturbed forest is recovering whereby canopy gaps created during logging disturbances are closing up.

Past studies conducted in logged-over forest of PNG (e.g., Fox *et al* 2010, Yosi 2011) using data obtained from Permanent Sample Plots (PSPs) established in logged-over lowland rainforests of PNG indicated similar trends whereby the logged-over forest were recovering both in terms of forest structure and composition. Studies by Saulei, S (1996), and Saulei, S *et al* (1999) using data obtained from plots (100m x 50m) established in logged-over forests in Gogol, Madang also indicated the forest was recovering after more than 10 years following logging operation. However, in terms of ensuring and enhancing production forest and promoting sustainable management of logged over forest resources, regeneration of desirable commercial species is important which could be ensured through actual field inventories and appropriate rehabilitation and silvicultural interventions.

Mix cropland areas showed an increase of 2% between 2001 and 2017. Such result was expected as there was widespread evidence of cropland areas (including shifting cultivation) at the study area. Results from the current study (classified maps) indicated cropland areas were more associated with settlement areas. Areas where there was evidence of settlements had higher occurrence of cropland, and lesser or none where there was no evidence of settlement areas. Similar trend was also indicated by Samanta & Pal (2016) in studies done in Morobe, NCD and Milne Bay Provinces. On the other hand, grassland areas had non-significant changes over the last 16-years. Moreover, settlement increased by 1% over the 16 years period (2001 to 2017). The increase in settlement was expected due to increased accessibility following logging operations.

2.0 Land cover change detection

Post-classification comparison technique of change detection was adopted in this study to quantify the magnitude and direction of land cover changes. A change matrix was obtained from the analysis done (Table 3). The results indicated that despite human disturbances, 61.83% of undisturbed forest still remaining unchanged by 2017. Most of these undisturbed forest areas are located in inaccessible mountainous areas. In fact, in 2001, 70.20% of the total study area was classified as undisturbed forest, with an increase of 6.45% in 2017. The increase in undisturbed forest area was largely attributed to 14.78% recovery of disturbed forest over the 16-years period after cessation of large-scale logging operations.

Moreover, in 2001 disturbed forest covered 22.06% of total study area; however it reduced by half (11.81%) 16 years later, as a direct result of natural forest recovery following logging operations. Despite the dynamics of forest changes, 5.21% of the disturbed forest area remained unchanged till 2017. Likewise, cropland also increased by 2.24% with significant conversions mainly of disturbed forest areas (1.71%) followed by undisturbed forest and grassland areas. Grassland increased by a mere 0.66% by 2017 due mainly to conversions of croplands, whilst settlement areas increased by 0.89%.

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Land Use and Land Cover Change Assessment from 1995-2015 in a Forest Management Area

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Abstract

Land use and land cover mapping techniques are applied in most GIS and Remote Sensing applications to understand land use patterns, changes and to assess the quality of the environment. Classification is defined as ordering and arrangement of observed features into bio-physical properties of the earth's surface. Supervised classification is the main technique applied for data extraction in an imagery to get activity data or land use and land cover information. The key activities carried out to fulfill the classification was post-classification and accuracy assessment to get the relevant land use and land cover maps ready for calculating areas in hectares per forest type, which excluded non-forest types. In this current study it is observed that land use and land cover changes mainly due to selective logging activities which can be investigated through the time series remote sensing satellite imagery by evaluating the difference between mapped time X activities and mapped time Y activities. Hence, a forest area that existed in year 1995 is logged in the recent year. The ultimate goal of this study is to understand the changing pattern of aboveground living biomass in terms of vegetation cover from year 1995 to 2015. Highest forest degradation occurred in year 2000 compared to the year 1995, where there was no selective logging on the interpreted satellite imagery. The results of this research indicate the rate of degradation for the period 1995-2015 is 6.45%. Based on the data availability this kind of study can be conducted in entire Papua New Guinea.

Keywords: Land use and land cover, Remote sensing, GIS, Classification, Forest degradation

1. Introduction

The basis of land use and land cover (LULC) is based on the Intergovernmental Panel on Climate Change (IPCC) requirements with application of GIS and remote sensing. IPCC is a scientific arm of the United Nations Framework on Climate Change Convention (UNFCCC, 2009, 2010) initiated through 'Conference of the Parties' or COP meetings between developed and developing countries on climate change agendas. IPCC provides fundamental guidelines for forest inventories and reporting carbon emissions, a process which member countries like PNG through PNG Forest Authority or PNGFA and Climate Change and Development Authority or CCDA provide according to several reporting templates or instruments.

A country is required to develop national monitoring systems based on IPCC Good Practice Guidelines when identifying sources of GHG's under the land use and land use change and forestry (LULUCF) sector (IPCC, 2006). LULUCF is the largest sector earmarked for the non-annex 1 countries (developing countries) like PNG. LULUCF covers forest degradation and deforestation as a result of anthropogenic activities on land. Objectives formulated for the study are aimed to try and achieve direct satellite imagery results and see what needs to be addressed in the near future for integration of satellite imagery and carbon information of the forests. The key objective of the study is to develop actionable data or land use and land cover type maps from Landsat annual greenest pixel imagery of 1995, 2000, 2005, 2010 and 2015 that can be used for future climate, biomass and carbon stock assessment. Many studies have been conducted assessing change in land use and land cover change (Samanta and Pal, 2016) with trends in carbon stock (Yali and Samanta, 2014) and carbon dioxide emissions. An overview of the methods and results that provided the platform for this study is discussed, commencing with a background on PNG's early days of a fully integrated GIS system that stored land cover units or resource units. In the early seventies Papua New Guinea forest was surveyed by the Australian Army who developed 1:100,000 scale topographic maps based on aerial imagery and field patrol data. These maps contained generic level 1 and specific level 2 classifications of the land use and land cover classes. However, in the early 1990's great improvement through assistance from the Australian Government, Papua New Guinea had its digital land cover maps stored electronically in a system called the PNG Resource Information System (PNGRIS, 2008). This gradually led to the development of a fully integrated Forest Inventory

Mapping System dated 1995. This mapping system applied level 2 classification defined by a lowest mapping unit called vegetation mapping unit. However, some vegetation units in remote areas covered several heterogeneous landforms (Shearman et al., 2008). Agriculture database on land use and crops about PNG was also integrated to PNGRIS resource mapping units producing Agricultural Mapping System. This contained refined mapping units reflecting occurrences of crops and more specific land use types.

A most recent land cover and land use change mapping conducted in PNG was from 1972 to 2002 (Shearman et al., 2008) under the institutional arrangements of the University of Papua New Guinea and the European Union. The objective was to map out the land use and land cover and conduct change detection quantifying loss of forest due to deforestation and degradation. The study utilized some of the finest optical satellite imagery from SPOT and Landsat ETM+. These images were pre-processed by applying image enhancement techniques known as Tussle-cap analysis where a set of band readings are converted to composite values or ratio of; Brightness-measure of soil, Greenness-measure of vegetation, and Wetness-measure of moisture (Lillesand et al., 2008). After enhancement the satellite imagery went through object-based classification or segmentation using recognition software. The segments were classified according to nine (9) land cover classes and one (1) land use class. The land use and land cover maps attained an accuracy of 97.7 percent for 2002 map and 96 percent for 1972 map (Shearman et al. 2008).

A site specific study conducted in the Kokada Track in Oro and Central Provinces (Williams et al., 2013) identified specific land cover classes using high resolution airborne radar (GeoSAR and LiDAR) data. Radar backscatter from tree canopy was used to determine tree height information. The difference from first and second return values from the earth's surface were used to create a surface model depicting the height of objects above the ground. In addition, with compliments from optical image, all data were processed through an advance classification method called Support Vector Machine. This produced accurate stratification of the forest into 'primary', 'secondary' and 'eucalypt savanna'. The three strata were further grouped into, Lowland, Lower montane, Mid-montane and Upper-montane. Forest not falling into these divisions was classed into three separate classes i.e. 'Other forest' and 'Forest (Other)' and 'Mangrove'. Mangrove was further classed into three types i.e. 'short', 'tall' and 'other'. In addition, high resolution optical imageries were also used to develop 'training data' to provide better accuracy to classification process. This study is a good example of how radar remote sensing capabilities can be applied to devise high resolution surface models to assist in classification of land cover types and measurements of aboveground living biomass in a high intensity cloud cover country like Papua New Guinea.

A study conducted by Fox et al. analyzed the dynamics of carbon based on previous studies on assessment of aboveground carbon in primary and selectively harvested tropical forest in Papua New Guinea (Fox et al., 2010). Selective logging area was the basis of carbon stock and carbon dioxide emission estimation was done for a time period of 1960-2008. Medium resolution satellite imagery applied for forest regeneration is challenging. Forest regeneration as opposed to failed regeneration is cleared area but, after a period of time recovers with new shoots appearing. This is noticeable with very light pixels seen on the following year or time 2 imageries and in this case would be after 5 to 10 years. The three key activities defining selective logging are collateral damage, deforested areas and failed regeneration areas (Fox et al., 2011; Bryan et al., 2010; Abe, 2007). Deforested areas are those linear patterns or footprints of logging roads constructed for accessibility for trucks to access log sites to load logs for dispatching to mill stations. Collateral damage is killing the trees during the process of cutting a large tree for timber. This accounts for branches and other smaller trees killed. This is termed as collateral damage which decomposes to residue (Fox et al., 2011). Failed regeneration is the areas cleared and assumed to recover naturally over a period of time but does not recover.

2. Methodology

The Vailala Block 3 forest management area located in the Kikori District in Gulf Province was selected to conduct this study (Fig. 1). The area is bounded by two major rivers; Purai River on the western side and the Vailala River on the eastern side. The northern tip, in which the boundary diverts from Purari River, uses the ridge tops to join Maropo Creek that flows towards Vailala River. The boundary then continues following the Vailala River until it reaches the coastline. Overlay of the boundary shape file and the imagery did not align with the image coastline and the rivers described above. Therefore the boundary shape file was re-digitized to match the image coast line and rivers from the northern portion, western side and the eastern side. The area contains vast gentle slopes with lowland forests with high marketable species which makes it conducive for logging. Vailala Block 3 logging concession is approximately 195,414 hectares. This is 6% of the total land mass of Gulf Province (3.45 million ha).

Satellite images from Landsat satellite series 5, 7 and 8 with 5 year intervals from 1995 to 2015 were used to assess LULC characteristics. Enhanced sensor instrumentations like Thematic Mapper (TM) in Landsat 5, Enhance Thematic Mapper plus (ETM+) in Landsat 7 and Operational Land Imager (OLI) in Landsat-8 are designed to monitor medium-scale features on the Earth's surface. Two TM images of the year 1995 and 2000, two ETM+ images of 2005 and 2010 and one OLI image of year 2015 with the spatial resolution of 30m are used to develop LULC database of the study area. All details of the data are summarised in table 1. ERDAS imagine 8.5 are used to perform digital image processing tasks on image data preparation, classification and interpretation.

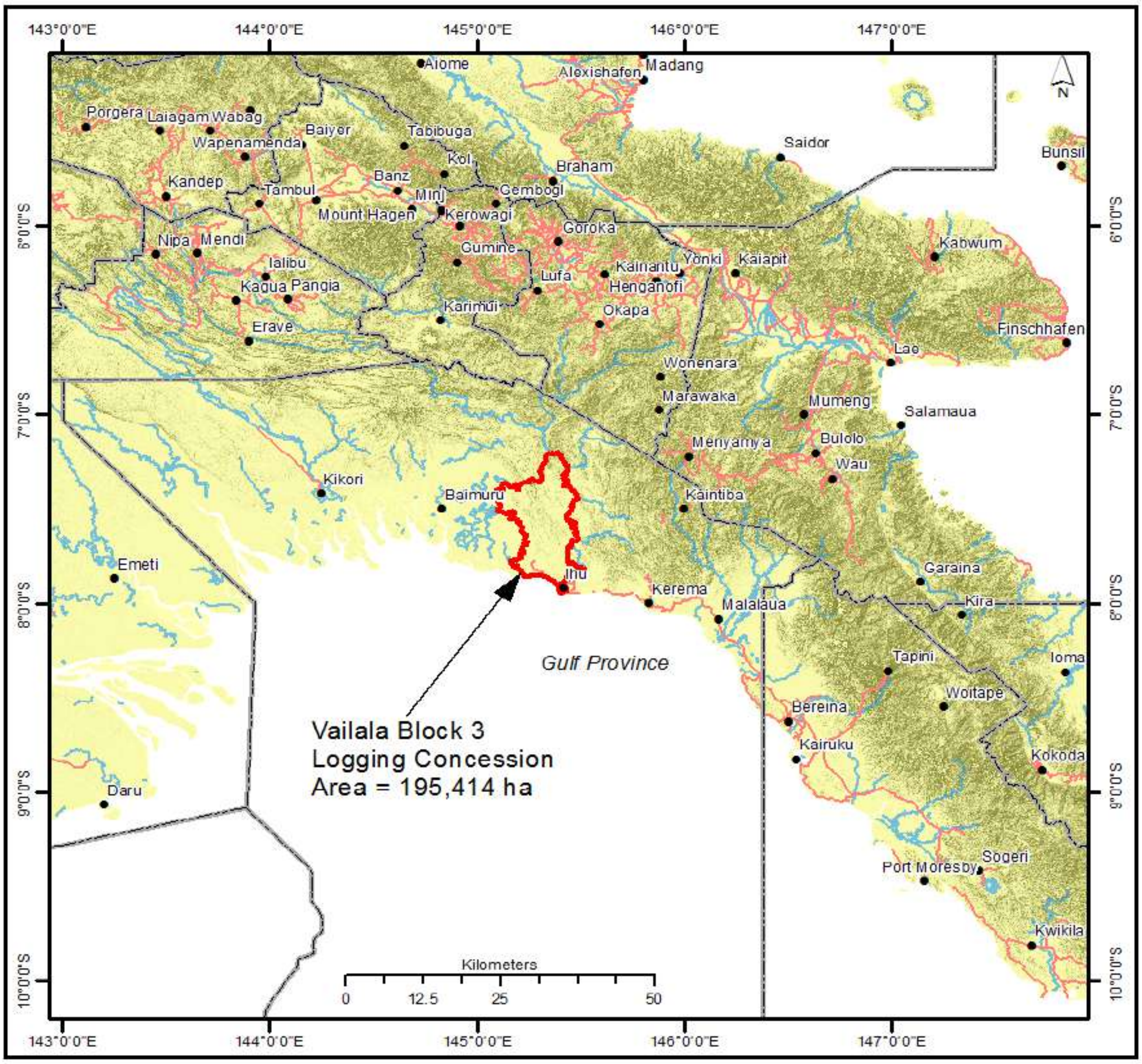

Fig. 1 Location of study area - Vailala Block 3 Logging Concession

Table 1 Landsat satellite specification used for the assessment

Year	Satellite	Standard False Colour Composite Bands	Bands for visual interpretation	Pixel size
1995	Landsat 5 TM*	4,3,2	4,5,3	30m
2000	Landsat 5 TM*	4,3,2	4,5,3	30m
2005	Landsat 7 ETM+**	4,3,2	4,5,3	30m
2010	Landsat 7 ETM+**	4,3,2	4,5,3	30m
2015	Landsat 8 OLI***	5,4,2	5,6,4	30m

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

Different methods of digital image processing were successfully implemented to achieve the objective of this research. Methods are broken into three parts, preparation, interpretation and analysis (Fig. 2).

Landsat AGP data have random noise that still exists after being pre-processed by Google. These are basically traces of cloud and haze edges that were not fully taken out. It was also anticipated that PALSAR and RapidEye were good data to eradicate this cloud and haze edge issue, but unfortunately were not applied due to permission of usage not being requested from PNG Forestry Authority.

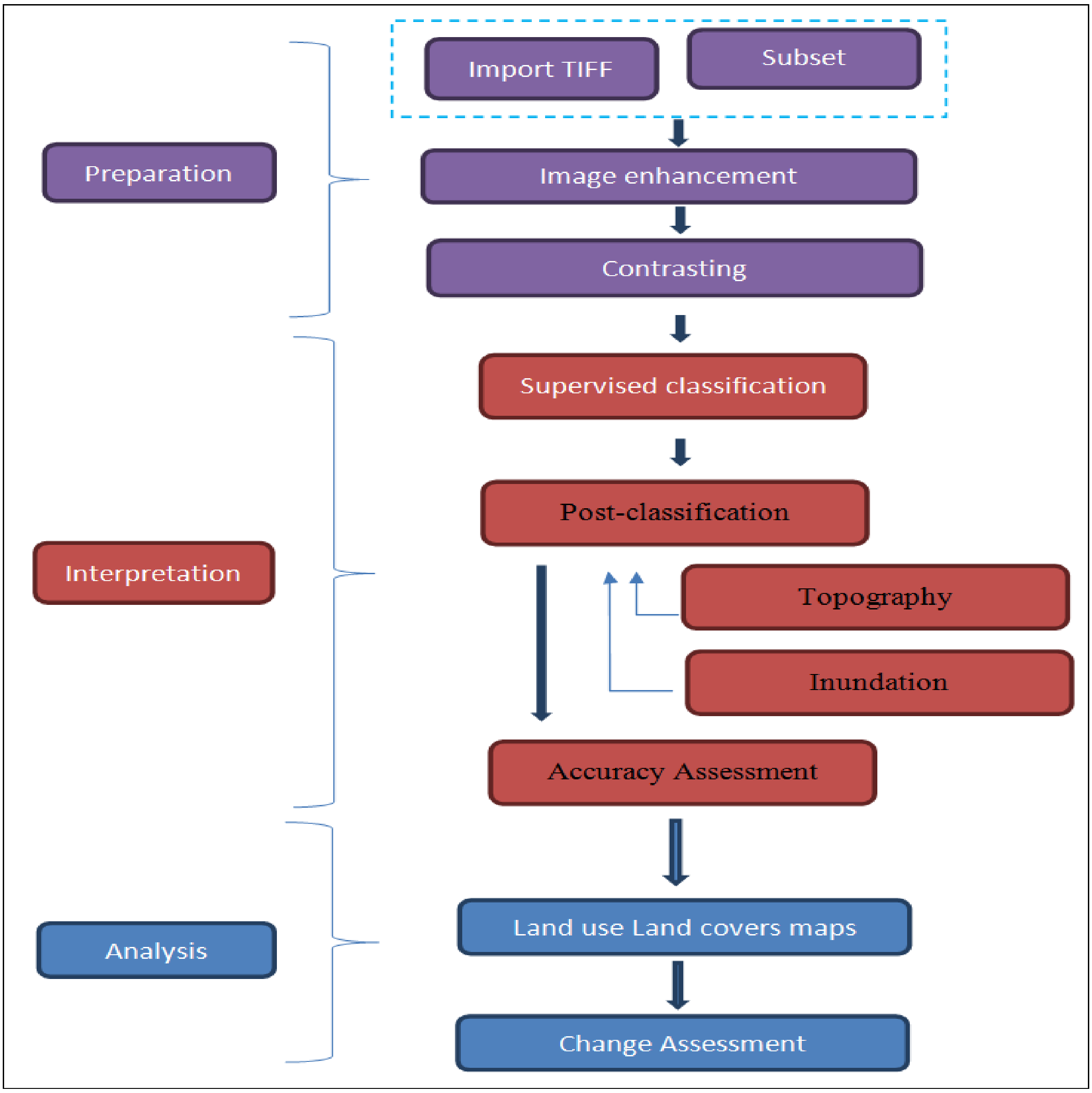

Fig. 2 Workflow chart showing the various stages of processing in an image analysis stage

Below are steps on how the Landsat AGP data were prepared for analysis. Landsat AGP images were properly rectified by the image suppliers. The following section discusses methods of correcting and restoring the image quality before being applied for interpretation and analysis stages (PNGFA, 2004). No atmospheric correction was performed. The Landsat AGP images had gone through a complex process for atmospheric correction called 'top of the atmosphere' or TOA processing by Google Inc. This was aimed at removing atmospheric reflected radiances – cloud and haze. No geometric correction was performed on the main data (Landsat AGP). However, topography and inundation layers from PNGRIS 2008 were re-projected to align with the Landsat imagery projected coordinate system – UTM Zone 55 South. Convolution filtering is a process of averaging small sets of 'noisy' pixels across an image. This process of filtering was a key technique to improve image surface reflectance but was not performed. However, post-classifications methods applied ruled out this technique. All Landsat AGP data were initially acquired from Google Earth Engine as TIFF format. Initial step was importing to Erdas Imagine software. The image was defined or cut to the extent of study site by using the subset tool in Erdas Imagine. All six (6) bands i.e. Bands 1, 2, 3, 4, 5 and 7 were maintained to create the new image. Brightness correction was applied to improve the visual condition of all images before classifying the image into LULC subdivisions. The enhanced images were then saved as new images with new file names. After performing brightness and contrasting the images were allocated bands 4, 5, 3 for Landsat 5 and 7 images while Landsat 8 was allocated band composition of 5, 6, and 4. This band arrangement was set to collect 'training data sets' or creation of signature file through visual interpretation.

NDVI is a spectral transformation method which is the ratio of the difference and the sum between the Near Infra-Red and Red bands. The process discriminates vegetation very well from non-vegetated areas. The Landsat AGP images from 1995 to 2010 ranges from Landsat 5 and Landsat 7. For the year 2015 the imagery is taken from Landsat 8 sensor. Therefore, two separate calculations were performed. Landsat 5 and 7 AGP images NDVI raster was performed in Erdas 8.5 and year 2015 imagery NDVI raster was calculated using the ArcGIS raster calculator.

The NDVI value of more than 0.5 was grouped as forest cover and less than 0.5 as non-forest. Only 1995 NDVI map was a surrogate to assist visual interpretation of forest and non-forest areas with the Vailala Block 3 logging concession (Table 2).

The following formula used for NDVI calculations;

$$\mathbf{NDVI} = \frac{Near\ Infrared - Red}{Near\ Infrared + Red}$$

Table 2 NDVI statistics of the study area from year 1995 to 2015

Year	Max	Mean	Std. dev
1995	0.842	0.739	0.068
2000	0.822	0.383	0.127
2005	0.870	0.709	0.077
2010	0.839	0.724	0.081
2015	0.871	0.787	0.072

Training samples or areas are sets of pixels observed to be known features on the image demarcated to drive the supervise classification (Jenson, 1996). Training samples for this study were developed in ArcGIS using base map as 1995 image. Visual interpretation bands set to 4, 5, and 3 to guide pattern recognition of the known level 2 classes. Demarcated sites were assumed to be completely containing a class.

Signature file is a set of data that defines a training sample, feature space as in Areas of Interest or a cluster. After identifying AOI of a class the information was imported into the signature editor tool which automatically defined the pixel range covered in a sample. All samples in the same class were merged into one class. Bands used to define the signatures were set to False Colour Composite band 4, 3, 2. The only different arrangement of bands was the year 2015, bands set to 5, 4, and 3. Signature creation for year 2000 – 2015 was directly compiled in Erdas using AOI tool.

Forest land, Grassland, Cropland, Wet land, Settlement and Other land classes were extracted through supervised classification method. As the target class was forest, final selection of land use and land cover types was done based on forest inventory mapping system (FIMS) (McAlpine, and Quigley, 1998) and reclassed into IPCC classes (IPCC, 2006) (Table 3).

Table 3 Land use and land cover types based on FIMS and connection to IPCC 2006 classes

IPCC	Veg_ID (FIMS)	Land use and Land cover Class
Forest	H	Lowland forest on uplands – below 1000m
Forest	P	Lowland forest on plains and fans – below 1000m
Forest	Fsw	Swamp forest
Forest	M	Mangrove
Forest	W	Woodland
Grassland	G	Grassland and Herbland
Wet land	E	Lakes and large rivers
Settlement	O	Land use intensity classes 0-4 (inclusive of agriculture)
Other land	Z	Bare land
Forest	D (own code)	Degraded forest
Forest	R (own code)	Regenerated forest

Digital Elevation Model with 90 meter resolution was used to recode top level forest classes, in to (a) lowland forest on uplands (>100m) and (b) lowland forest on plains and fans (<100m). Overlay of landform type 'mangrove swamps' layer (Shearman et al, 2008) provided the separation of ‘mangrove forest' in swamp forest class and in lowland forest on uplands and on plains and fans. A total of fifty (50) random stratified points were used to conduct the Accuracy assessment (Samanta et al., 2012) of the five (5) LULC maps using the Erdas imagine accuracy assessment tool. Two assessment methods applied are accuracy totals and kappa statistics. Accuracy totals to provide omission and commission errors and kappa to see whether the agreement of classes is genuine. Table 4 presents full accuracy assessment tables for each classification map from 1995-2015.

Table 4 Accuracy assessment results for accuracy totals and kappa statistics for 1995-2015

Accuracy Totals						Kappa
Class Name	Reference Totals	Classified Totals	No. Correct	Producers Accuracy	Users Accuracy	
Year 1995						
Lowland forest on uplands	8	8	8	100%	100%	1.0000
Lowland forest on plains fans	11	12	11	100%	92%	0.8932
Swamp forest	7	6	6	86%	100%	1.0000
Mangrove	4	4	4	100%	100%	1.0000
Woodland	4	4	4	100%	100%	1.0000
Grassland	4	4	4	100%	100%	1.0000
Water body	8	4	4	50%	100%	1.0000
Settlement	4	4	4	100%	100%	1.0000
Bare land	0	4	0	0	0	0.0000
Totals	50	50	45			
	90%					0.8846
Year 2000						
Lowland forest on uplands	8	8	8	100.00%	100.00%	1
Lowland forest on plains fans	8	11	8	100.00%	72.73%	0.6753
Swamp forest	12	9	9	75.00%	100.00%	1
Mangrove	4	4	4	100.00%	100.00%	1
Woodland	4	4	4	100.00%	100.00%	1
Grassland	2	3	2	100.00%	66.67%	0.6528
Water body	5	5	5	100.00%	100.00%	1
Settlement	3	3	3	100.00%	100.00%	1
Bare land	2	2	2	100.00%	100.00%	1
Logging-2000	2	1	1	50.00%	100.00%	1
Totals	50	50	46			
	92%					0.9075
Year 2005						
Lowland forest on uplands	7	7	7	100.00%	100.00%	1
Lowland forest on plains fans	10	11	9	90.00%	81.82%	0.7727
Swamp forest	10	9	8	80.00%	88.89%	0.8611
Mangrove	4	4	4	100.00%	100.00%	1
Woodland	4	4	4	100.00%	100.00%	1

Grassland	2	3	2	100.00%	66.67%	0.6528
Water body	5	5	5	100.00%	100.00%	1
Settlement	3	3	3	100.00%	100.00%	1
Bare land	2	2	2	100.00%	100.00%	1
Logging-2000	2	1	1	50.00%	100.00%	1
Logging-2005	1	1	1	100.00%	100.00%	1
Totals	50	50	46			
	92%					0.9079
Year 2010						
Lowland forest on uplands	4	5	4	100.00%	80.00%	0.7826
Lowland forest on plains fans	5	5	5	100.00%	100.00%	1
Swamp forest	4	4	4	100.00%	100.00%	1
Mangrove	4	4	4	100.00%	100.00%	1
Woodland	4	4	4	100.00%	100.00%	1
Grassland	5	4	4	80.00%	100.00%	1
Water body	4	4	4	100.00%	100.00%	1
Settlement	4	4	4	100.00%	100.00%	1
Bare land	2	4	2	100.00%	50.00%	0.4792
Logging-2000	3	4	3	100.00%	75.00%	0.734
Logging-2005	5	4	4	80.00%	100.00%	1
Logging-2010	6	4	4	66.67%	100.00%	1
Totals	50	50	46			
	92%					0.9127
Year 2015						
Lowland forest on uplands	5	6	5	100.00%	83.33%	0.8148
Lowland forest on plains fans	9	8	8	88.89%	100.00%	1
Swamp forest	6	5	5	83.33%	100.00%	1
Mangrove	3	3	3	100.00%	100.00%	1
Woodland	4	4	4	100.00%	100.00%	1
Grassland	4	5	4	100.00%	80.00%	0.7826
Water body	6	5	5	83.33%	100.00%	1
Settlement	3	3	3	100.00%	100.00%	1
Bare land	1	3	1	100.00%	33.33%	0.3197
Logging-2000	3	3	3	100.00%	100.00%	1
Logging-2005	3	3	3	100.00%	100.00%	1
Logging-2010	1	2	1	100.00%	50.00%	0.4898
	50	50	45			
Totals	90%					0.8894

The assessment completes the process of validating the classification, although the classification is not 100% perfect. On the other hand, there are uncertainties associated with the extent of each class in hectares. Addressing uncertainty requires a separate analysis to assess how confident the data is by determining the threshold above and below the actual areas in hectares of the forest types.

3. Results

Accuracy totals and kappa statistics were generated separately for each year and each individual class. Table 4 shows two methods that were applied for accuracy checks of the five (5) years individual maps. Before post-classification was applied the level of accuracy was very low. Upon conducting the accuracy assessment after the post-classification all were above the required accuracy total cut-off mark 85% and Kappa statistics required agreement minimum of 0.4 (Table 5). A total of five classified thematic raster maps were produced for 1995, 2000, 2005, 2010 and 2015 (Fig. 3). In the year 1995 the forest cover was 96%, whereas 94% in 2000, 92% in 2005, 90% in 2010 and 89% in 2015 respectively (Fig. 4). The trend is that the forest stock in Vailala Block 3 is decreasing. It is notable from the charts that other land use types do not have impact on the forest due to the minute size of the activities compared to logging. The rate of degradation for the period 1995-2015 is 6.45% (Fig. 5). In year 1995 there was no selective logging based on the interpreted satellite imagery. Highest forest degradation occurred in year 2000 due to the large footprints of irregularly arranged linear bright pixels representing selective logging. Lowland forest on upland (H) and lowland forest on plains and fans (P) are highly impacted by selective logging. In year 2000 alone around 83.31% (or 3,347.87 ha) of lowland forest on plains and fans was selectively harvested for timber. The trend changes in 2005 and 2010 as loggers presumably tried to access higher ground or the upland forests. According to records with SGS, 543.425 m^3 of logs were exported between 1997 and 2003.

Table 5 Accuracy assessment overall results

Year of Classified Map	Accuracy Totals		Kappa Statistics	
	Before PC	After PC	Before PC	After PC
1995	64%	90%	0.4876	0.8800
2000	82%	92%	0.8000	0.9075
2005	84%	92%	0.8232	0.9079
2010	80%	92%	0.7819	0.9127
2015	86%	90%	0.8465	0.8894

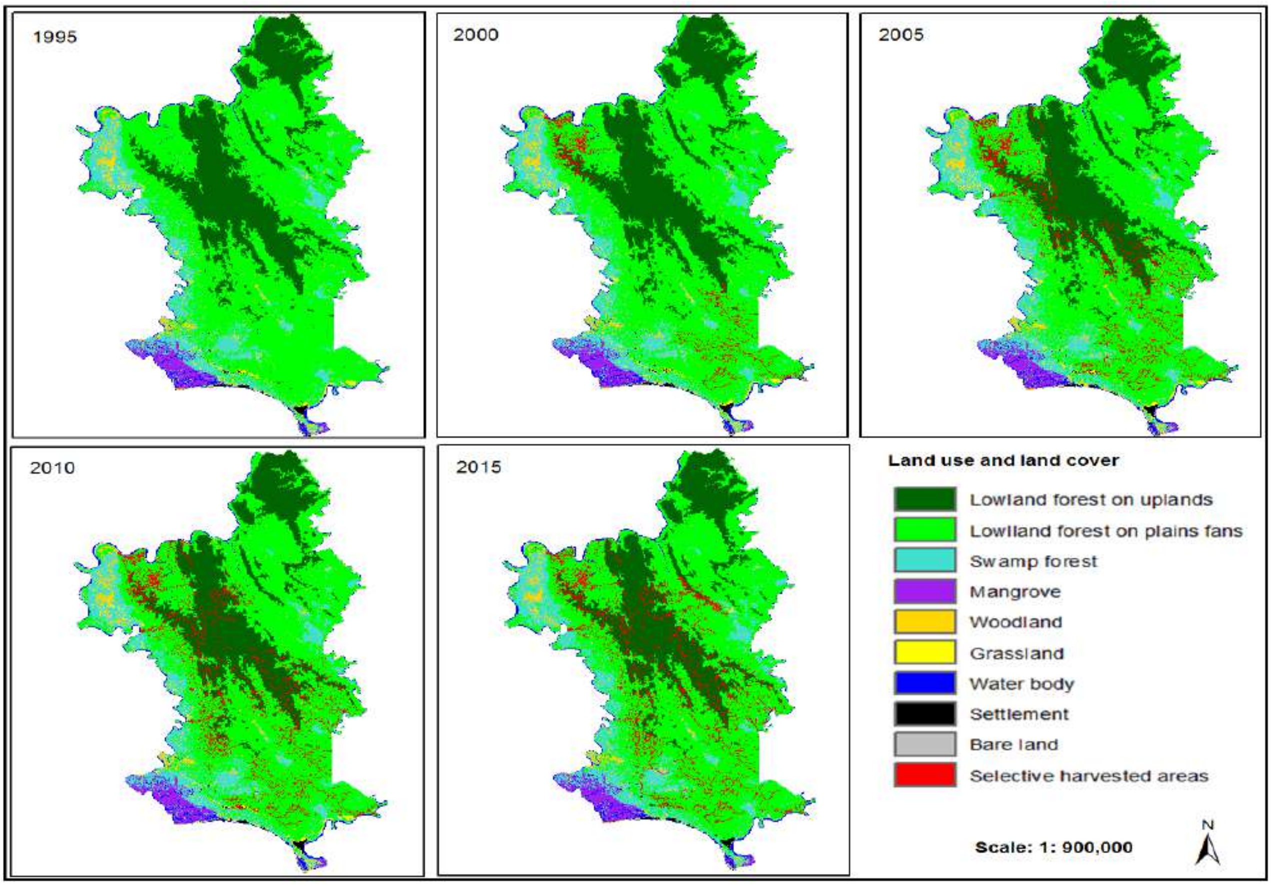

Fig. 3 Final classified maps from 1995-2015

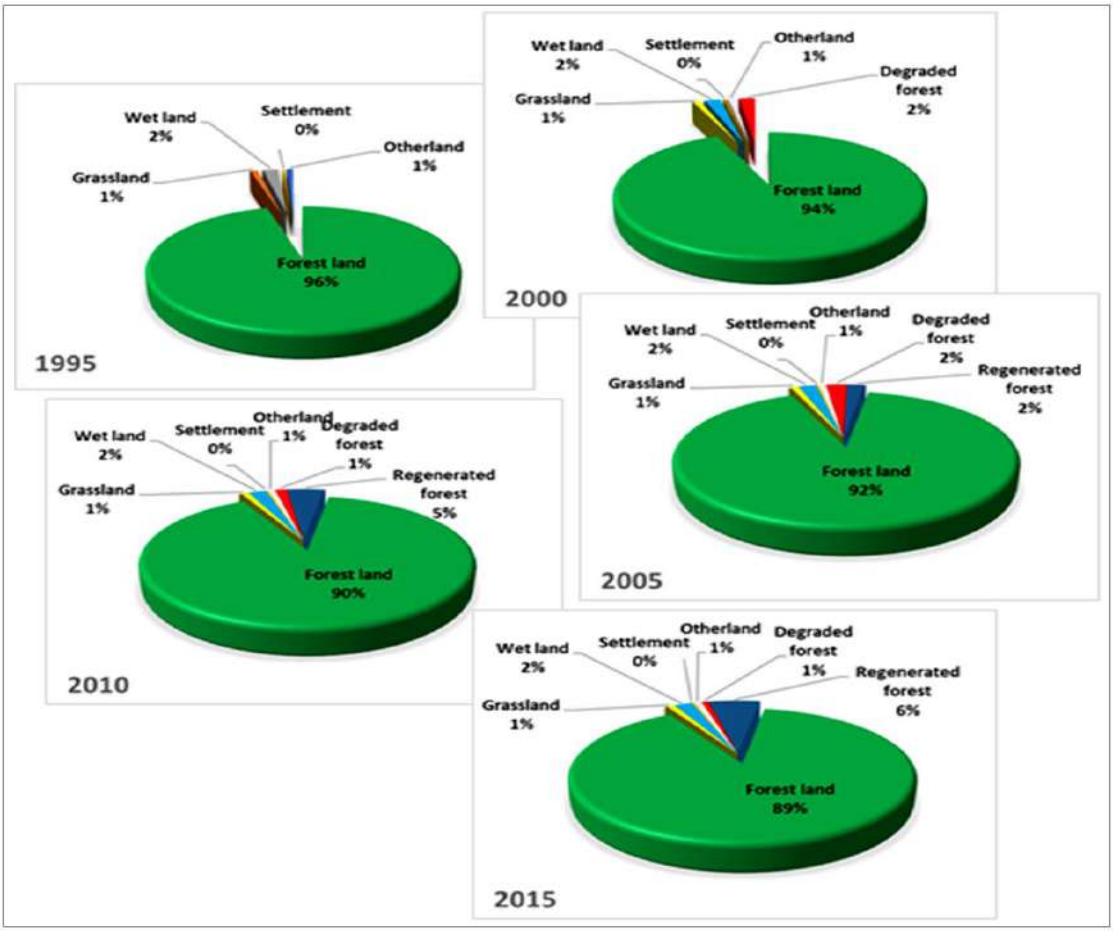

Fig. 4 Characteristics of land use and land cover from 1995-2015

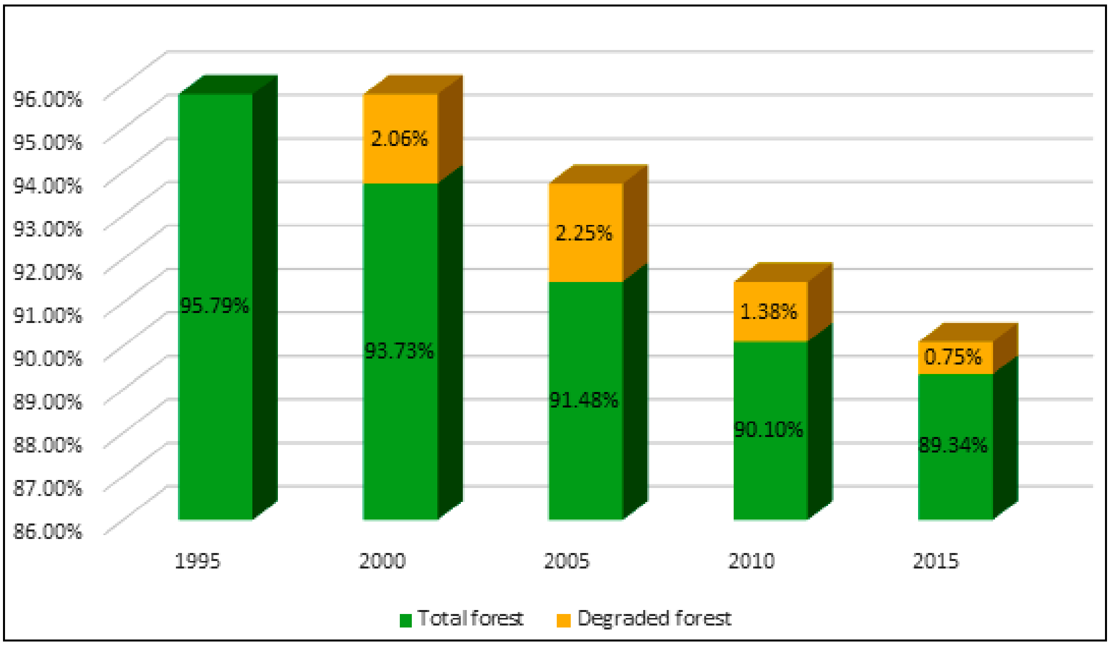

Fig. 5 Amount of remaining forest stock and the amount of degraded forest

4. Discussion

A total of five (5) land use and land cover types were mapped using Landsat annual greenest pixel imagery of 1995, 2000, 2005, 2010 and 2015. These LULC maps were produced using supervised classification. After classification two land use categories were identified, namely forest degradation and forest regeneration. The classified maps went through post-classification in which the accuracy assessment results were improved from accuracy assessments done before the post-classification. Forest degradation rate of 6.45% is greatly contributed through linear clear-cut areas that are used for logging roads. Access routes to chain-saw cut areas are likely sites for regeneration whilst the key linkage road connecting log ponds and other access points is continuously used throughout the operation life-span. Annual Logging Plans and cutting cycles would provide a better correlation to what is actually occurring on the ground. The study has provided a new platform on how to assess forest degradation and regeneration using Landsat medium resolution imagery in a selectively harvested area even in the absence of Annual Logging Plans. In addition, the study has provided a glimpse of how Fox et al. (2010) emission factors can be applied to satellite image assessments. Although the final result of this study requires further validation to reduce the uncertainty from the changes of the areas in hectares and also the carbon stock changes from one point in time to another.

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Forest Policy Now and into the Future

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Abstract

Policy statements are intentions and are implemented whenever circumstances permits and, such is the case with pre and post- independence forest policies. The 1991 Forest Policy was designed to address forest operational issues and issues relevant to equitable benefit to stakeholders as per the findings of the forest enquiry into aspect of forestry and forest industry sector. The administrative set up of the PNG Forest Authority as per the current Forest Policy and the Forestry Act 1991 (as amended) has been implemented adequately but require strengthening. While the administrative set up is complied with, the key sustainable forest management aspects with regards to landowner participation, reforestation and domestic processing have remained stagnant for various reasons. Central to all elements of sustainable forest management is the land tenure issues where the government may not understand that the land and forest resources are customary owned. Land tenure can effectively be addressed if landowners participate meaningfully and hence, government need to take ownership of facilitating their participation which among others training and developing a partway. The insignificant progress in critical aspects of forestry places sustainable benefits from forestry in question. However, there are success stories such as Open Bay Timbers Ltd, Stettin Bay Lumber Company Ltd and PNG Forest Products Ltd, and using the lessons learnt, progress can be made to ensure a sustainable forest industry.

The conclusion of the multi- purpose national forest inventory will provide valuable information that would enable the government to rethink its forest management strategies and towards a new paradigm shift. Climate change mitigation through reduced emission from deforestation and forest degradation (REDD+) is providing a way forward in the management of the forest sustainably as its components are actually addressing sustainable forest management. Development of Timber Legality Standard (TLS) and other relevant standards have the potential of diversifying timber markets thus enabling competitive price for PNG timbers and further strengthens sustainable forest management. Though the emerging issues are not provided for in the 1991 policy, the policy objectives and statements are still relevant to current circumstances and will address the emerging issues if forest policy provisions are adequately implemented.

1. Introduction

Forest policy like any other sectoral policy, plays a significant role in guiding how the forest of a country is to be managed and utilized in view of prevailing socio-economic and environmental circumstances of a country, and Papua New Guinea (PNG) is no exception. In PNG, over 85% of the people live in the rural areas and are dependent on the forest for their livelihood (PNG government, 2017 p3). The country, however, is increasingly moving into the cash economy and the increased cost of goods and services for the landowners and the government's desperation to generate income to support the national budget, is putting pressure on the forest. Responsible forest management remains the cornerstone for ensuring sustainable benefits and hence forest policy need to be designed to achieve this core objective.

The current forest policy of PNG, was developed and approved by the government in 1991 following the Barnet Enquiry into the aspects of forestry and forest industry where the sector was out of control in the 1980's due to loop holes in the forest policy and legislations that existed at that time coupled with the increased demand for timber in the international market. The intention of the 1991 forest policy was therefore to address the short comings of the previous forest policy and addressing new situations in the forestry sector. (Ministry of Forest, 1991).

In this Research the 1991 forest policy was reviewed to dissect the level of its implementation and its relevance to changing trend and development, as it has been in force for the last 26 years and compared to previous pre and post-independence policies, the 1991 forest policy has been in existence much longer period.
Detail research is done on aspects of forest policy that are key to sustainable forest management and these are landowner participation in industry and equitable benefits, domestic processing of timber products and reforestation.
Responding to immerging issues that affect the forestry sector is very significant as they cut across all aspects of forest management. These issues are climate change impacts, international timber regulation and forest certification. Addressing these emerging issues ultimately addresses sustainable forest management.

2. Problem Statement

The 1991 National Forest Policy has been in existence for the last 27 years, a much longer time than the previous forest policies as illustrated in ***Figure 1.*** Forestry issues are fast evolving due largely to increased economic activity, population growth and the immerging issues of climate change.

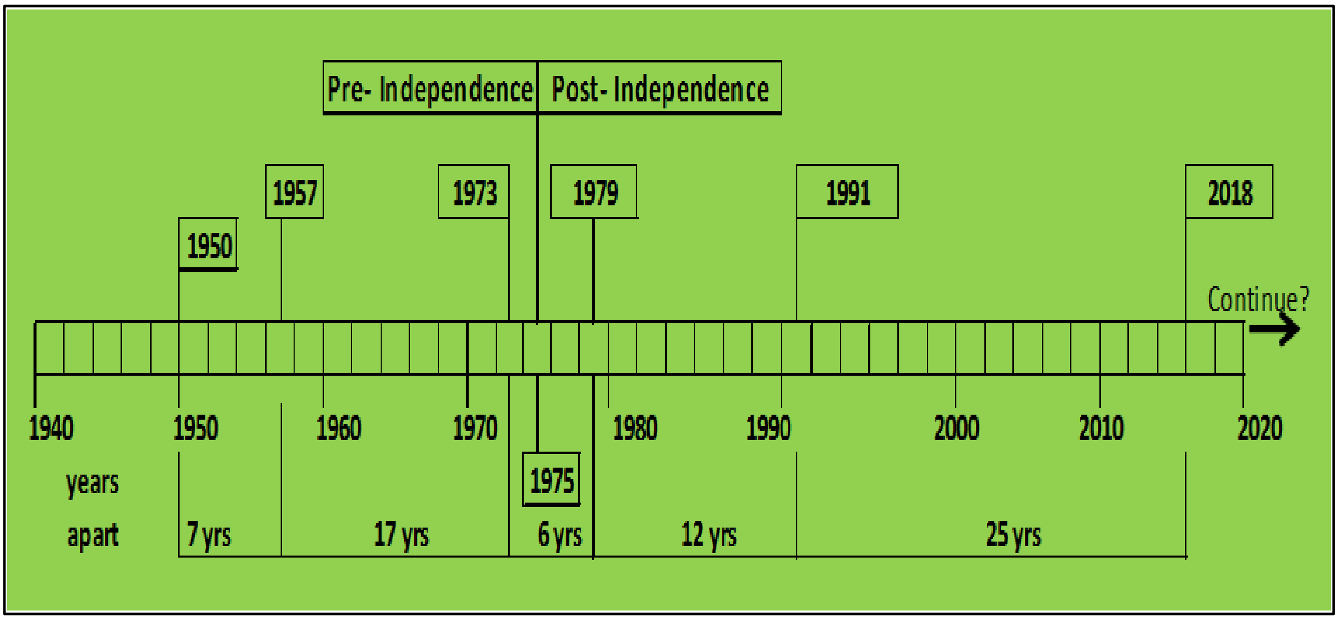

Figure1 Chronology of Forest Policy Development in Papua New Guinea

The key aspects of forest policy that are significant to achieving sustainable forest management, have not been adequately implemented which puts sustainability in question.

These key aspects are:

Landowner participation in industry: The forest and the land in PNG is customary owned through complicated landownership pattern however the forest industry sector is dominated by the foreign investors since precolonial period and even after 42 years of political independence. Forest policies and practices of the colonial administrations and that of after independence assume that land is crown owned with no real understanding that land and the forest in PNG are owned by the people (Turia, 2015). Policy intensions for landowner participation in industry are provided but implementation appears to be minimal. Landowners do participate through the use of wokabout sawmill but these are considered to be minimal and are informal as they do not operate under any form of authority.

Increased domestic processing: Log export has dominated the industry since 1951 and continues to be at its peak consistently as shown in ***Figure 2.*** The 1991 forest policy do provides for maximum processing of forest products however, it has been at a juvenile stage for so long since 1951as shown in ***Figure 3***. Data for 1991-1995 for processing were not available. Processing can contribute towards value adding, technological transfer and employment creation.

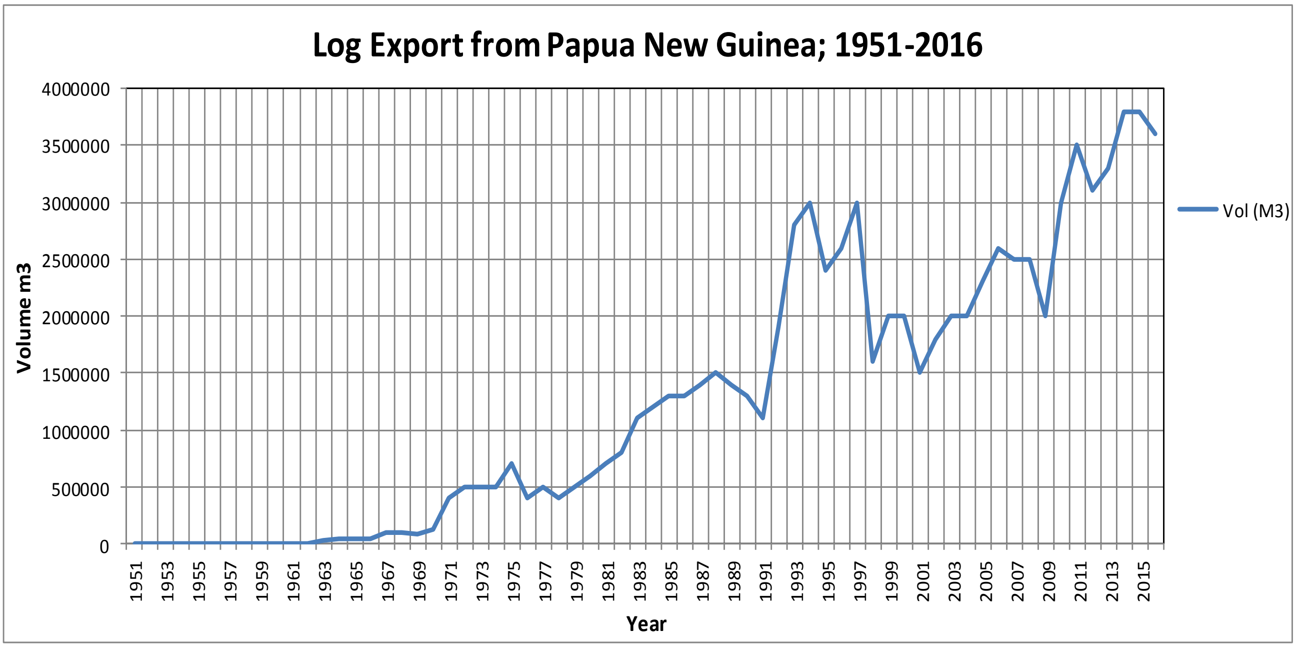

Figure 2 Graph showing Log Export trend since 1951 (Source: ODI report and PNGFA Annual Report)

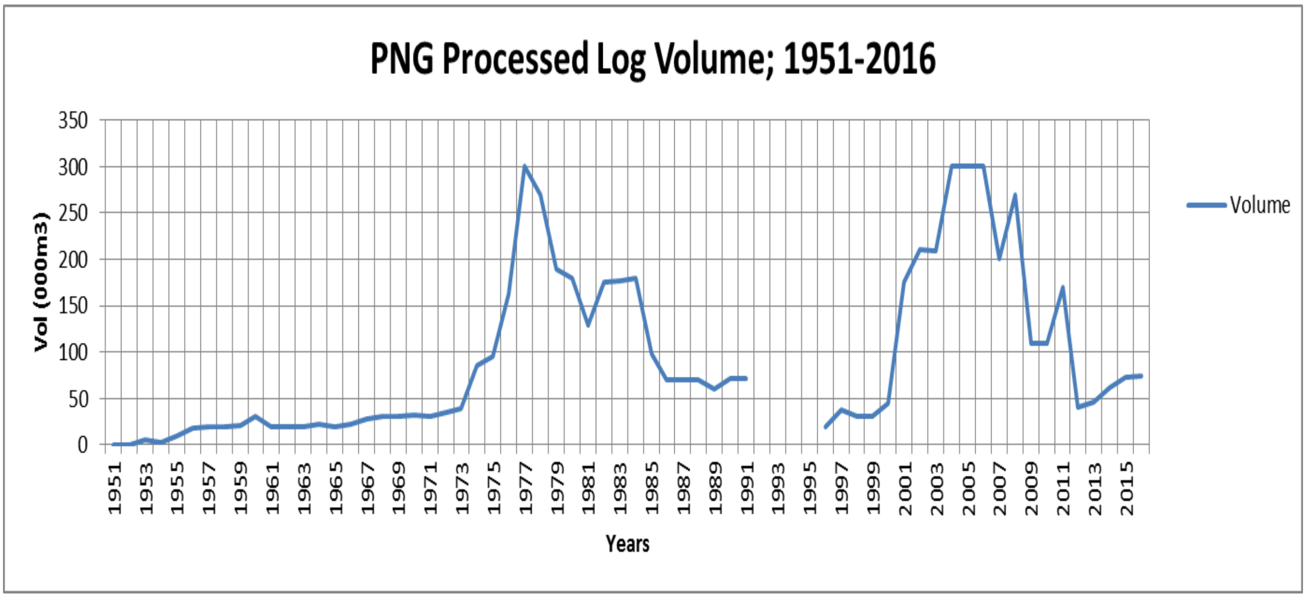

Figure 3 showing processed products exported since 1951-2016) (Source ODI Report and PNGFA Annual Report)

Reforestation: It is estimated that about 160,000 hectares of forest are cleared annually and PNG having only 68,000 hectares of plantation forest, forest replenishment is lagging far behind forest clearance. Logging is considered as one of the main drivers of deforestation and green- house gas emission. The problem has been land tenure issue as 97% of the land in PNG is customary owned through complicated land ownership pattern. It is a constitutional requirement that the forest resources must be replenished for the benefit of current and future generations. Forestry being a renewable sector has the potential of contributing towards a sustainable economy through an active reforestation program thus relieving the pressure on the natural forest.

Whilst confronted with the non-implementation of the key aspects of forest policy, the emerging issues are threatening the socio economic and environmental sustainability and are not provided for in the current forest policy. The main emerging issue is **climate change**. In PNG, logging is the major driver of GHG emission through forest degradation while shifting cultivation and commercial agricultural development are major drivers of GHG emission through deforestation. The impact of climate change is increasingly having an impact on the lives and livelihood of the people of PNG and the world at large. Forestry has an important role in mitigating the climate change impacts.
The other emerging issue affecting the exporting of forest products is **international timber regulations.** Governments of importing countries are taking regulatory measures on the importation of illegal timbers. **Forest certification** is another issue that timber producers are required to comply when exporting timber products. The forestry sector makes significant contribution to the PNG economy and hence it is important that appropriate actions are required to ensure that the marketability of forest products overseas are maintained and markets diversified.

3. Methodology

3.1 Materials

The materials that were used in the study include reading through relevant available publications which includes government policy documents, previous forest policy information, the current forest policy and legislation, research publications, workshop and seminar proceedings and reports. Forestry personal in both the private and public sector were interviewed regarding the key aspects of forestry on landowner participation, domestic processing and forest plantation development. People were also interviewed on the immerging issues via climate change, timber legality and forest certification.
People who are involved in the forestry sector have been interviewed to get a better understanding on what was like in the past and what should be done now to determine the policy directions for the future. Internet was also used to assist in the research. Forest resources data were used from Forest management agreements as well as other data from market reports. Forestry operations and communities involved in woodlot activities were also visited.

3.2 Method

The method used was literature research on the implementation of the key aspect of forestry. These key aspects are **landowner participation and benefits, domestic processing and reforestation**. Literature research was also done on emerging issues and they are **climate change, international timber regulations and forest certification.**
Interviews were also conducted with timber industry personnel, Non-Government Organizations (NGOs) landowners and PNG Forest Authority Senior Foresters to get their views through asking set questions on the said key aspects of forest policy and the emerging issues.
Specific questions on the various aspects of forestry which guided the interview with the timber industry players, Non- government organization, landowners, and PNG Forest Authority Senior Officers are in ***Section 2.3.1.***
The 1991 Forest Policy was reviewed to ascertain the degree of its implementation as it has been in existence for the last 27 years.
Field trips were also undertaken to project sites to observe the situations on the ground and interviewing industry players and PNGFA project officers.
The information gathered were used to prepare the thesis which includes discussions and drawing conclusions. Other data/information gathered is tabulated and graphs constructed to reflect trend and draw conclusions.
Case studies were undertaken on timber projects that are successfully undertaking domestic processing and reforestation. Case studies were also undertaken on timber project to ascertain the level of benefits to landowners and other key stakeholders.
For the immerging issues, which includes climate change, and international timber regulation and forest certification only literature research and the current initiatives of government were used to discuss them to decide on the way forward.

4 Aim and Objectives

4.1 Aim

The aim of my research is to investigate the weak implementation of the current Forest Policy.

4.2 Specific Objectives

The three specific objectives of this investigation are:

- **(i)** Explore/investigate why the key aspects of forestry policy in PNG namely, landowner participation, domestic processing, and reforestation, have not progressed since the enforcement of the current forest policy.
- **(ii)** Given that immerging issues such as climate change, forest certification and international timber regulations are not accommodated for in the current forest policy, this research will explore how they can be integrated with the core aspects of forestry to enhance sustainable forest management in PNG under a new forest policy.
- **(iii)** Recommend to government the findings of the investigation for its consideration.

4.3 Questions to Guide the Research work

The following questions under each of the key aspect of forest policy were intended to guide the research work.

1991 Forest Policy
How effective was the implementation of the current Forest Policy?

Landowner Participation
What effort did the government made to increase landowner participation in forest resources development? Why is it that landowners are not actively participating in forestry business despite successive policies provides for them to participate?
What are the factors impeding landowner participation in industry?
How will landowners participate meaningfully in forest industry?
Are landowners getting equitable benefits where they are not participating in industry?

Domestic Processing
What efforts did the government made to increase processing in PNG? Why is it that the forestry sector continue to be a log export oriented industry and how can it be reversed?
What role the government would play to improve the timber processing sector?
What is the market situation of processed products?

Reforestation
Has the government made any effort in promoting reforestation in the country? How can land tenure be addressed in the context of forest plantation development in PNG? Why timber companies are not committing to forest plantation development and what can be done to reverse the situation? What role the State need to play to enable improvement in forest plantation development?

2.3.2 Questions to guide the Research on Immerging Issues:

Climate Change

Can forest management practices address climate change issues? How can climate change mitigation effort be integrated into forest management practices?

Forest Certification

Is it necessary for PNG to have its own legality standards? Is the timber industry ready to have the timber legality standards? Is it necessary for PNG to have forest management standards? What are the Forest Certification Schemes, operating in PNG, and how successful are they?

International Timber Regulations

What are the requirements to enable access into the EU and the US markets for PNG's timber products given that timber export to these markets is minimal? What are the requirements to meet the US market? What are the requirements to meet the Australian markets? Is PNG in a position to meet international timber regulations?

5.0 1991 Forest Policy Review

5.1 *Forest Policy Objective*

The 1991 National Forest Policy (NFP) is a direct response to the findings of the Barnett Inquiry to address the forest and forest industry sector that was out of control. It is therefore economically oriented, giving less consideration to other aspects of forestry. The current forest policy's objective in the context of the forestry profession is that forest officer's role would be to facilitate for economic development thus limiting forest extension and eco forestry. Forestry extension and eco forestry activities where the customary owners can effectively participate to contribute to socio- economic and environmental sustainability have been considered insignificant under the 1991 NFP and hence not provided for in policy. This further limits the customary owner to participate in the management and utilization of their forest resources and continue to become spectators to the large scale commercial logging operations which are being undertaken by foreign timber companies.

5.2 *Project Planning*

The current Forest Policy calls for the execution of a National Forest inventory. This was not undertaken and instead a Rapid Resources Appraisal (RRA) done and the data collected were used to draw up the National Forest Plan. Potential production forest areas are inventoried followed by the acquisition of timber rights from customary owners of the forest resources through the forest management agreement mechanism. The NFI project and the JICA Capacity Development Project for Operationalization of PNG Forest Resources Information Management System Addressing Climate Change", both currently being implemented and when completed will further enhance this important element of forest management supported by a sound National Forest Plan and the respective Provincial Forest Plans. The completion of the NFI will enable a sound national forest plan that would take into account all factors into consideration as the inventory is multipurpose. The acquisition of forest from the resources owners under the 1991 Forest Policy by way of the Forest Management Agreement is no different to the Timber Rights Purchase mechanism to acquire the timber rights from customary owners. At this early stages of the forest development processes, a lot more could have been done. Area for forest plantation could be identified and included as part of the agreement as well as the area for conservation as per the current FMA provision and also forest classification to determine the forest type and conservation values. Feasibility study can also be done at the acquisition stage and either to form part of the FMA or a separate document which was the intent under the policy but not implemented, in its place a development option study is undertaken.

5.3 Forest Resources Acquisition and Allocation

The acquisition and allocation processes under the policy are adequately complied with, however, many including the industry and the landowners consider it as a long dwindling process. What is important to understand is how this process came about is in direct response to the commission of enquiry findings wherein the processes in the repealed legislations were very short which did not take into account all factors. This enabled large areas of forest exploited with no proper planning and control. In the course of trying to implement government policy, the PNGFA is forgetting how it came into being, let alone the acquisition process.

Forest Clearance Authority (FCA) (including Special Agriculture Business Lease (SABL)) provision in the forestry legislation is opening a can of worms for more and more forest areas to be cleared. Some do carry out forest clearance and establish the desired agricultural crop while others may not. At least the government has taken some action to allow only the FCAs that followed due processes. From a forestry professional’s point of view, we would rather continue to have selective logging with plantation forest establishment in logged over area or adjacent grassland areas to sustain a timber operation.

5.4Forest Plantation

Reforestation rate should be increased in view of the high rate of forest depletion and provide skilled and unskilled employment for the rural population. If the current rate on the demand for timber on the international market and domestic market are any indication, areas currently known to be inaccessible will be logged out. This investment decision should be backed with opportunity cost calculation bearing in mind that Papua New Guinea is not densely populated. The mechanisms to secure land for forest plantation development is not provided for in policy bearing in mind that the land is customary owned through complicated landownership pattern. PNG Forest Authority’s initiative on the operation “panim graun planim diwai” which means look for land and plant trees, must be supported vigorously to enable a sustainable forestry sector, though there are challenges

For a sustainable forest industry in Papua New Guinea and to maintain a sustainable economic contribution from the forestry sector it is important to have more of Open Bay Timbers Ltd, Stettin Bay Lumber Company Ltd and PNG Forest Product Ltd to be promoted in strategic locations of PNG. Strategies need to be geared towards replicating these operations in appropriate locations of the country.

5.5 Timber Industry

The processing sector has been at a juvenile stage for so long. Log export has dominated the industry over the last forty (40) years and continues to be at its peak consistently. The government need to look at the factors impeding domestic processing. A feasibility study need to be undertaken in each sizable timber project and following that it would reveal what activities are required to be done to ensure a viable industry to operate on a sustainable basis. Government need to put in place the necessary infrastructure and ensure resources security and investor confidence to enable domestic processing in PNG with high quality products produced by the industry that can be sold on competitive market price. The way of doing business by the government need to change where, it places the responsibility on the timber operator to build the infrastructure which results in feeling of insecurity thus promoting the continuation of increased log export. On the part of the log exporting industry, they continue to operate however the industry argues that it is struggling to operate due to high logging cost, high log export tax and limited incentives to warrant the continuity of their operation. What is necessary is to do an independent logging cost study which would then enable the development of a new revenue system. Domestic processing is further researched.

5.6 Landowner Participation in Industry

In terms of land owner participation in industry, they have been spectators in the development of their forest resources even the forest policy provide for their participation. They are involved mostly in the informal sector particularly in workabout sawmill. It is necessary that the government revisit the Forest Development Cooperation concept (FDC), existed in the 1979 forest policy where the landowners, Provincial government and the investor were to get into joint partnership operation but did not work due to the government’s inability to train landowners and provincial government personal as well as timber areas to pilot under such arrangements did not have much resources projects among other issues.

Since the coming into effect of the 1991 Forest Policy, there was no successful forest industry operation by the land owners. There is even no joint venture participation by the industry and the landowners, except for the Manus West Coast TRP project where the landowners and the provincial government have some shares in the timber operation.
Small scale forest based operations have been undertaken but at an informal level however there is high potential. Some minor forest products such as eagle wood and sandalwood have been commercialized but lack monitoring and control of production and hence their sustainability is in question. Proper coordination, permitting and monitoring supported by training of PNGFA personnel and industry personnel are required.

5.7 Timber Marketing

PNG has not been doing enough market promotion of its timber considering that it has about 400 commercial timber species, most of which are not known on the international market. Though some buyers also consider mix species, market promotion is necessary to enable competitive price for lesser known species. Further, it is important to diversify markets as currently about 80% of PNG's logs are exported to the Chinese market, while much of its processed products are exported to the Australian market. Grading rules need to be drawn up to increase the reputation of the timber sold, this is currently being sorted out under the ACIAR enhance wood processing project but yet to be tested and distributed for use by the industry.
The State Marketing Agency (SMA) as provided for under the policy is not carried out. The way forward would be to strengthen the existing log export Administration and the Timber Branch to exercise the SPO with effectiveness, market diversification and development of promotional materials among others. Forestry personnel to be located in strategic forest product export destination including potential markets to be housed with the PNG Embassies, Consulate etc.
The domestic market provisions of the forest policy has not been adequately addressed or undertaken. It is important that PNGFA understand and take control of the domestic market situation, following appropriate studies. Timbers produced and sold domestically must be of good quality and met requirements of recognized grading rules. It is important that a representative of the PNGFA is to be on the National Supply and Tenders Board as provided for under the Policy to participate in deliberation on the use of PNG timbers and limit the use of wood substitute and imported timber.
On the issue of issue of transfer prising, Societe de Generale Surveillance (SGS) (PNG) Ltd has been engaged to check randomly on all log export to prevent undervaluing of timber that are leaving the shores of PNG and it has been carrying out this independent monitoring of all log export since 1994.The program has prevented millions of Kina from being lost through undervaluing.

5.8 Forest Revenue Generation

Revenue generation and enforcement provision in the policy has been complied with. The latest being the Log Export Development Levy (LEDL). Government generate revenue through export tax while landowners benefit through stumpage royalty, premiums and various other levies. As stated earlier, a revenue system need to be worked out and put in place which would be supported by an independent study on cost of production so that there is fairness across the board in terms of revenue distribution to stakeholders. This would prevent the government from unnecessarily increasing the export tax every time it is faced with financial shortfall thus putting a strain on the industry as was the case in the 2017 budget where it increased up to 40% of log export free on board (fob) price but was later reduced to 32.5%, following negotiations between the industry and the government.

5.9 Research Training and Development

Forest research needs to be guided with full knowledge of the management, and the Board, through the establishment of the Research Advisory Committee (RAC). The RAC whilst guiding research could also serve as a research validation committee of individual research outcomes and link to policy and action plan. It is important PNGFA policy statements be supported by good research outcomes. A lot of good research results have been developed over the years by the Forest research Institute (FRI) however these needs to be validated and taken on board and developed into action plans and programs.

PNGFA need to be closely associated with the forestry training institutions through programmes and activities including curriculum development, donor project implementation, linking industry with training institutions and in the selection of student intakes among others.

5.10 National Forest Board and the Provincial Forest Management Committees

The Board is being established as per the policy which is tasked with the responsibility of dealing with policy and legislative matters as well as the operational matters. The operational matters however are normally delegated to the Managing Director. Currently, some key aspects of the operational functions are being held by the Board which affects flow of work. The Forestry Act needs to be amended to segregate the Board's responsibilities from the National Forest Service roles in which the Managing Director is in charge of. Further it is important that Board members be given ample time to discuss with the stakeholders they represent on the agenda items at hand prior to actual Board meetings in the spirit of transparency and accountability. The sub committees that should provide guidance and support to the Board are non- existence and hence they be re-established to support the Board in its work to enable sound decision for implementation.

The Provincial Forest Management Committee is the important arm of the three arms (Board, NFS, and PFMC) as decisions of project development are made at that level. It is important that the PFMC be strengthened, members of the committee be made aware of government policies on sustainable development and immerging issues so that deliberations are fruitful and sound decisions made linking to overall government objectives.

5.11 National Forest Service and Financial Autonomous

The National Forest Service had a peace full transition from the old Department of Forest to the PNG Forest Authority. It is well structured however its ability to implement forest policy has always been limited by manpower shortage and financial resources.

The Forest Policy provides that the PNGFA is to become a financial autonomous body after 5 years through revenue collection and national government support and thereafter, it should be self -financing. Twenty six years on, PNGFA is still being supported by the national government. To progress in this provision of the policy it is important that the government direct a healthy percentage of the log export tax to support the PNGFA establish forest plantations and management of the natural forest to create a revenue base for the future. Years later after creating a sound forest plantation sector linked to industry, the PNGFA can become a full financial autonomous body.

5.12 Way forward

Some aspects of the policy have been implemented and others have not been implemented .New issues have immerged and they need to be addressed to support and maintain the country's forest management capabilities. Forest policy must be seen to be evolving, given the changing circumstances and meeting societal needs. Areas of focus would be on enhance monitoring capabilities, strategies to enhance processing and building a strong plantation sector and natural forest management to support industry, community based forestry activities and emphasis to research and training. Most aspect of the policy are still relevant however, they are not fully implemented. Climate change issues are not provided for in the policy however, the activities for sustainable forest management can address REDD+ or vice versa.

6. Key Aspects of Forest Policy

Landowner Participation in Industry and Benefit, Domestic Processing and Reforestation are the key aspects of forest policy in PNG that all other aspects of forestry revolve around. These aspects are researched to ascertain the status of their implementation and identify the obstacles and impediments to decide the way forward.

The following are discussion and conclusions of the findings of each aspect of forest policy as well as for the emerging issues.

6.1 Summary for Landowner Participation in Industry Findings

From the findings it can be said that the government has not found a way to enable landowners to participate meaningfully in the development of the forest resources, even though it tried to develop ways there aren't many success stories and hence it is still searching for a mechanism where landowners can effectively participate in timber business.

The various concepts tried did not work. Business is business. Landowners are always disadvantaged by the lack of business skills know how let alone logging operation skills. Government tend to think that the foreigners who bid for a timber project only have the skills and not the landowners or Papua New Guinean for that matter. Usually landowners do not have any skills for forestry business.

The government over the years, when coming up with mechanisms such as the Forest Development Corporation Concept (FDC), operations under the Private Dealings arrangement and Incorporation of Land Group did not facilitate training for land owners to understand business and entrepreneurship and hence all efforts failed. Government therefore need to facilitate training for landowners to participate meaningfully or actually owning timber projects.

There was a proposal to establish training centre for landowners to get training on how to invest money received from logging operations in the early 2000s which did not receive government backing. That proposal could be reactivated and the scope of training to be broadened to cover skills about logging business.

The owners of logging companies may not be foresters but are business people who employ skilled manpower who are experienced in the various aspects of forestry operation to run their operation. The same thing can be done for Papua New Guineans or landowners but in here they need to be trained on business principles, code of ethic and other associated aspects first. Following that they can be broadly trained on the overall aspect of a logging operation. They can then be better equipped to participate in timber operation business.

Landowners involved in wokabout sawmill to also receive training on business as well as general aspects of logging. Currently these operations are not monitored and regulated which is an irresponsible act on the part of the government. It is important that Workabout sawmills are regulated not only that they need to follow the principles of good forest management but for government to provide training and nurture them to advance from small to medium to large scale operation. Take the scenario of a baby where he or she grows up to adult hood through stages of development. Currently workabout sawmill operations are categorized under the informal sector.

6.2 Summary on Monetary Benefits to landowners Findings

Current landowners are merely receiving benefits such as royalty and project development benefits from the logging operations only. Royalty rates have increased over the last 50 years as illustrated in ***Figure 5*** due to policy change and devaluation of the Kina against the United States Dollar and increase price of logs.

It can be seen from **Figures 5 & 6** that apart from royalties, landowners also benefit from Project Development Benefit and various other levy collections. Whether what the landowners are receiving is adequate or not as illustrated in the two case studies is still to be ascertained. From the case studies after logging cost, the amount received by the logging company is very minimal with the State receiving much higher than the landowners. Madang Timbers and Canopas are receiving K8/m3 and K20/m3 respectively after logging cost of US$45/m3 (K150/m3). State is receiving a bigger share through export tax of the two operations of K131m3 (Middle Ramu) and K124/m (Tapila Wipim).

Both companies have been operating over the last 7 years despite the high logging operational cost and the minimal return the two timber companies receive as identified in the case studies, they continue to operate and it could be the same for all other logging companies operating in the country. The price used in the two case studies is the average price of logs per cubic metre which is (K332/m3) (SGS, 2017).

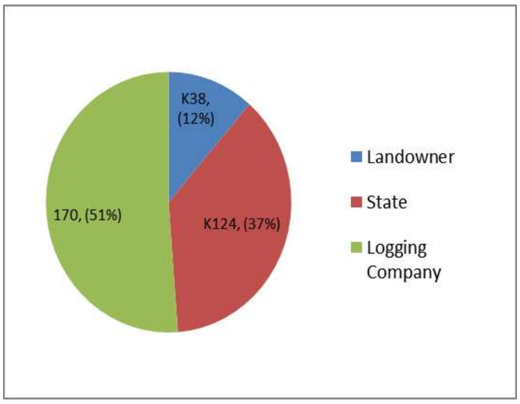

Figure 4: shows the revenue distribution for a cubic meter of log BEFORE production cost for the Tapila Wipim timber project.

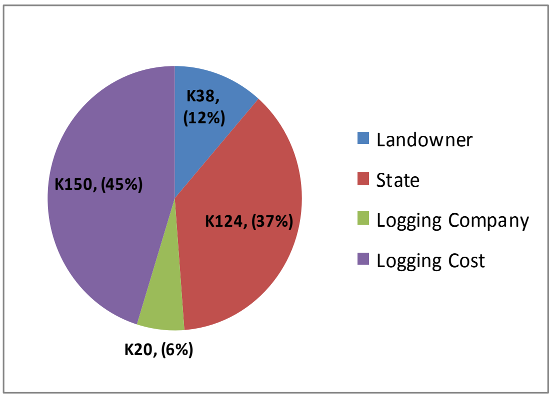

Figure 5: Shows the Revenue Distribution for the cubic metre of log BEFORE Production Cost for the Middle Ramu Block 1 Project

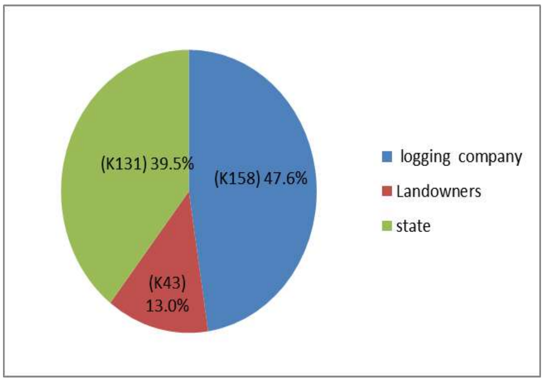

Figure 6: Shows the Revenue Distribution for the cubic metre of log BEFORE Production Cost for the Middle Ramu Block 1 Project

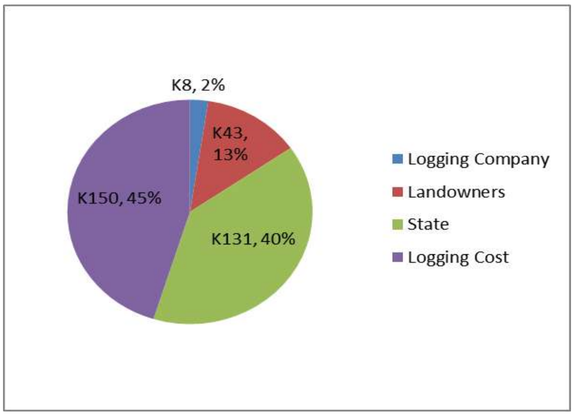

Figure 7: Shows the Revenue Distribution for the cubic metre of log AFTER Production Cost for the Middle Ramu Block 1 Project

One thing to note is that some timber concession areas have a lot more premium species which fetches much higher prices. Madang Timbers Ltd.'s operation at the Middle Ramu concession area has high volume of premium species such as Kwila which fetches a price of K766 per cubic metre and the stand density is also high (SGS, 2017). While for Canopas Ltd.'s operation at Tapila Wipim concession area has a very low stand density and not many premium timber species present in the forest.

The other matter of concern is that log export tax are increased by the government every time, when there is financial shortfall as was the case in the 2017 budget where the tax was increased from 28% fob to 40% fob. Following negotiation with the Forest Industry Association (FIA), it was reduced to 32.8%. Many years ago the log export tax was 10% of free on board (fob) price (Department of Forest, 1979). Considering the haulage distance, terrain rising cost of fuel and other associated cost and the development that timber companies are putting in the rural areas particularly in locations where logging operation are taking place, the government should apply some justification in increasing log export tax.

In order to be fair and ensuring equitable benefit to key stake holders, an independent log production study should be carried out to ascertain the actual cost of logging. The findings of the study should also assist in developing a new revenue system as a requirement under the Forestry Act. These two activities must be undertaken to put the government into perspective particularly when contemplating increasing the export tax and ensuring equitable benefits to landowners.

6.3. Summary on Domestic Processing Findings

The forest industry has continued to be a log export oriented industry over the last 65 years as reflected in ***Figures2*** under the Problem Statement in ***Section 1.3*** of this thesis**.** The forestry sector, particularly the log export sector has been considered as a fast income generating avenue to support the government budget. The logging companies take advantage of the situation and do more log export which is also compelled by the in security of the forest and the land as these are customary owned even though the resources may be secured by the PNG Forest Authority either under FMA, TRP, LFA or any other mechanisms.

The government is to facilitate for investment in the forestry sector which includes the provision of infrastructure to enable onshore processing of forest products. Using the timber project to provide infrastructure by logging companies as is the current situation is not feasible. It is important that proper feasibility study for projects intended for processing together with the provision of the necessary infrastructure by the government would enable processing in the country.

The two case studies are major timber industries in Papua New Guinea. Both WGTC and PNG Forest Product Ltd (previously owned by Commonwealth Timbers) are owned by Rimbunan Hijau Group of companies. A lot of lessons can be learnt from these companies to progress in timber processing in the country.

As explained in **Case Study 1** under ***Section 6.3***, PNG Forest Product Ltd (PNGFP) initially operated from the natural forest and then progressed to plantation forest establishment compelled by the existence of the plywood mill and the closure of the gold mine for the continuity of the economy and the services to the people of Bulolo. The underlying factor regarding PNGFP's success is that the land in which the plantation was established is on State land as well as both the State and the company participated in establishing the forest plantations. Further the PNG government have shares in PNGFP.

In the case of WGTC, the situation is quite different as it is still extracting logs from the Wawoi Guavi Timber Rights purchase areas. Though the company is undertaking second harvest of the natural forests, the acquisition period of these timber rights purchase areas are nearing expiry via; Block 1 in 2021, Block 2 in 2025 and Block 3 in 2029. (PNG Forest Authority, 1998). The PNGFA is to look at making plans to reacquire these areas under FMA as per the current Forestry Act as when their TRP period expires it will be illegal to operate. Though the company has high log input capacity for processing in both the saw mill and the veneer mill, there is no plantation to warrant the continuity of the operation. Further, the forest industry operation is the sole economic activity taking place in this sparsely populated part of the country. The government is to move quickly to reacquire the forest area under FMA at the same time negotiate with the customary landowners of the timber area to secure land for establishing forest plantation development to ensure the sustainability of the operation.

6.4 Summary on Reforestation Findings

The success and failures of past and current plantation programs would provide as a good lesson to set the direction for now and into the future. It is evident that where there is government involvement whether in securing land, having shares, plantation seems to be successful, example Stettin Bay Lumber Company (SBLC), Open Bay and PNG Forest Product in Bulolo. Even though State share is not clear at this stage, by nature of its establishment at the beginning where it involved the State, these companies could have felt comfortable and hence showed serious commitment to plantation development with the aim to sustain the forest industries. Lease, Lease-back arrangement appears to be the viable and appropriate option securing land as the land will still remain with the land owners as well as their monitory benefits will be clear as with the oil palm industry and Jant chip mill when it was in operation.
Using the lessons learnt any new sizable natural forest resources allocation should be tied to plantation forest establishment as well as existing big timber concession areas where the government can renegotiated with the operators to establish forest plantations for the long term sustainability of the operation. The ideal balanced forestry operation should be forest harvest plus tree planting is sustainable. Similarly forest harvest plus no tree planting is unsustainable; it does not add up for sustainability, which appears to be the case with most timber operations in PNG. Wawoi Guavi Timber operation can be renegotiated to undertake forest plantation development as it has two huge processing plants, a sawmill and a veneer mill with a capacity of 30,000 and 70,000 cubic metres log input. Sonolong, (1998) noted that "where there is stable political, economic and social situations, any decision to undertake forest plantation would be favourable as these factors influence success rates". Wawoi Guavi is better placed to progress into plantation development as there is low population density and the timber operation is the only economic activity in the area.
Noting that a number of early plantations have been reverted to the original landowners by court decisions, landowners recognition be given priority in any future forest plantation establishment. Landowners need to be clearly identified and their involvement and proper security would be the key to a success full plantation program for Papua New Guinea.

7. Summary on Emerging Issue Findings

Many emerging issues are cutting across all sectors of development. In the forestry sector, a number of emerging issues are critical to sustainable forest management and they are; International Timber Regulations and Forest Certification and Climate Change and they have been investigated and researched. Hereunder is the summary of the findings.

7.1 Summary on International Timber Regulations and Forest Certification Findings

The ITTO diagnostic mission considered that PNG has in place adequate forestry laws however to implement them is problematic due to finance and manpower constraints (ITTO, 2007 p20). The financial appropriation support to the PNG Forest Authority by the government will continue to remain the same as was the case for the last twenty years. With the ever increase cost of goods and service and increase forestry activities, PNGFA will continue to spread its resources very thinly, to the point where critical areas in forest management and monitoring are being overlooked. If at some point, the government think reasonably and decide to opt for the first call on the revenue generated from forestry will be to support forest management including monitoring of forest operations, there will be some improvement to what is happening now.

With the development of the Decision Support System (DSS) and the Timber Legality Standard (TLS), the utilization of the tools and process developed will improve PNGFA's monitoring capabilities and overall management of the forest resources in PNG and decision making. It is hoped that the TLS and DSS once recognized will signal to other potential timber importing countries which will enable the diversification of markets for PNG timber at competitive price. Most likely international market attraction will be Europe, United States, Australia and

New Zealand and this will prompt maximum processing for forest products as these countries import processed timber products that meets legality requirements.

China is the major buyer of PNG timbers, particularly logs, where in 2015, 85% of the volume of logs was sold to and the trend has been the same in previous years (PNGFA, 2015. p11). The Chinese Timber Legality, Traceability and Verification (TLTV) System is very important to PNG and hence it must be complied with to prevent it from losing the market. A MoU between PNG and China is under process which among other aspect incorporates timber trade matters between the two countries, and it is expected to be signed soon or during the APEC meeting in Port Moresby, later in 2018.

PNG is making good progress in meeting the prerequisite of entering into a VPA with the EU. EU is increasingly becoming a major development partner and the government of PNG has to decide on the pros and cons of entering into such agreement. If the government decides to enter into a VPA with the EU it must be agreed to by stakeholders, particularly the timber industry and the landowners.
The Asia Pacific Economic Cooperation (APEC) leaders meeting which developed economies will also attend provides an excellent opportunity for Papua New Guinea to create dialogue with them to develop market access in other countries. The DSS and the TLS once successfully rolled out and if displayed during the APEC meeting will enable member economies to negotiate with PNG to establish trade relations for the exportation of timber products, apart from the established markets.

Forest Certification schemes or programs must still be promoted as it brings credibility to the industry that is certified under any certification system and the credibility of forest products leaving the shores of PNG as well as promoting good forest management.

It is important that the government must develop its own forest management standards by using the lessons learnt in forest management practices and other initiatives including the TLS and the DSS. The TLS once fully rolled out be imposed on timber companies to follow and comply with to enhance sustainable forest management in the country.

7.2 Summary on Climate Change Findings

The impact of climate change is enabling countries to rethink their utilization strategies of the forest resources as many have had uncontrolled logging operation and forest clearance through other land uses.

Climate change impacts are cutting across all sectors of development and forestry has a very significant role to play to mitigate the impacts. As highlighted in the introductory part of this section of the thesis, when forest is harvested or destroyed by fire it not only emits GHG but also removing the source of oxygen production, carbon dioxide conversion and carbon mono oxide sequestration (Saulei, 1998. P70-71). However, forestry is a resource and it is important for PNG as a developing country to utilize it to contribute to socio economic development as the country's development aspiration are reliance on the development of forestry and other natural resources.

Papua New Guinea is a leader in climate change mitigation initiative and it has initiated reduced emission through deforestation (RED) at COP 14 in 2005 which was endorsed by members of the Parties and later strengthened it to become REDD+ after the inclusion of degradation and sustainable forest management and forest conservation during the subsequent COP meetings.

It is good to note that REDD+ is now becoming an international financing mechanism which is a positive sign for forest management. PNG is having significant challenges in undertaking sustainable forest management practices however REDD+ is presenting a good opportunity for PNG to realign its pathway in progressing towards achieving sustainable forest management as well as addressing climate change impacts. The proposed Green Climate Fund project through the Forest Carbon Partnership Facility (FCPF) Project 2 included elements of forest management activities such as reforestation, research; processing, natural forest management and others would improve sustainable forest management. It is anticipated that the project while strengthening the existing activities, will build capacities of the various institutions that will be collaborating in the implementation of the project.

PNG is progressing well in complying adequately with the UNFCCC and the various COP meeting resolutions. The four components of REDD+ namely the NRS, FRL, NFMS, and SIS have been progressing well which will then enable PNG receive result based payment on REDD+ activities.

The 4 activities of REDD + relates to sustainable forest management and PNG as a country must embrace and take appropriate actions at the operational level of the core functions of the PNG Forest Authority

8. Conclusions

It is appreciated that the forestry sector has made significant contribution to the socio economic development of Papua New Guinea both during the pre- independence and post-independence and continues to do so. It is with this appreciation the government and the stakeholders have an obligation to manage the forest resources in a more responsible way so that it continues to provide the benefits we enjoy now and in doing so address emerging issues such as the impact of climate change. The pre independence policies though most were in the form of statements, they were more coordinated and in a progressive manner which enabled their effective implementation to achieve the desired objective and the positive outcomes which are still visible today.

The commission of inquiry (CoI) into aspect of forestry and forest industry in the late 1980's intervened at the right time to put a brake on the uncontrolled exploitation of the forest resources at the expense of good forest management. Hence the 1991 Forest Policy was a direct response to the CoI as most if not all of its recommendations made were accommodated for in the forest policy, wherein the role of foresters is geared towards facilitating for timber harvesting and monitoring operation. Like any other policies, the 1991 Forest policy outlines the intensions of the government and was supported greatly by stakeholders considering the adverse situation prior to the Barnett Inquiry. However implementation is a problem due to financial constraint and manpower shortage.

Land owner participation is not well understood by the government as implementation is not visible, though provided for in policy. How land owners are going to participate effectively in forest development has not been given serious thought, though attempts have been made through the 1979 Forest policy's Forest Development Cooperation (FDC) concept and the 1991 forest policy. In order for land owners to participate, the approach taken need to be regulated to provide for in legislation and supported with training of landowners on forestry business and business principles. Establishment of a forestry training centre for landowners would be a way forward in realizing their meaningful participation.

It is important that the government commission an independent study on the cost of logging in Papua New Guinea, considering that much of the country's accessible forest areas have all been logged out and companies have to travel longer distances to reach their concession areas to harvest and transport logs for export purpose and for processing. . Example, Madang Timbers Ltd logging operation at Middle Ramu Block 1 forest management areas is about 100 kilometres from the log export point near Madang and it is the same for many logging companies and this is just one aspect of logging. Tree species composition and stand density to also be taken into consideration when conducting the study as some timber areas have high stand density with more premium species than others. The independent study outcome would trigger the development of new revenue system that would aim at enabling equitable benefits to stakeholders including landowners. The study would also put into perspective the government, particularly Treasury and Planning when considering increase the log export tax particularly when there is a shortfall in the government budget.

Small scale saw mill particularly, workabout sawmill need to be regulated to understand the extent of landowner participation and with appropriate guidance and training facilitated by the government should progress to medium type operation. A systematic approach need to be designed to ascertain the number of wokabout sawmill, the location which they are operating and the quantity of timber harvested.

The current forest policy provides for onshore processing of forest product in PNG and it is further reinforced by the medium term policy statements such as the National Forest Development Guidelines and the Strategic Development Plan. However, onshore processing of forest product has been at a juvenile stage for a long time. Despite some processing industries have closed down, there are some that continue to operate for decades. These companies include PNG Forest Product, Stettin Bay Lumber Company, and Rimbuanan Hijau Ltd operation at Wawoi Guavi. The Fortech study concluded that it is difficult to do domestic processing but need to start somewhere to expand. The government need to be strategic and by using the lessons learnt, decide the way forward including providing the necessary infrastructure. To have a long term industry, it is important that a feasibility study need to be done to identify the viability of the project taking in to account all factors including product out-put to be competitive with international market. It is important that the government progress to secure land for forest plantation for the Wawoi Guavi operation as it has two big processing facilities, a sawmill and a veneer mill.

The future sustainability of forestry operations in Papua New Guinea remains with forest plantation development. It is ascertained that where there is state involvement, the success of plantation program is realized. State therefore need to take the lead in ensuring that land is secured through the various mechanisms available under the Land Act and the most preferable option would be the Lease, Lease –Back arrangement under the *Act No.45 of 1996* (as amended) due to its success with the oil palm industry and the Jant Ltd, (Chip mill operation) when it was in operation. Learning from the success in forest plantation mentioned above, any future allocation of forest resources would be to timber companies that will be committed to forest plantation development and timber processing. Other plantations can be established to meet emerging market demand such as bio fuel energy to provide electricity. What is more important is that, a couple forest plantations formally owned by the State have been reverted to the original landowners by District land Court decisions as land were not properly acquired at that time. Using the lesions learnt government can to try to develop mechanisms to enable landowners to participate and actually having shares in the plantation development. Outright land acquisition should not be considered as an option as it may go down the same road as those forest plantation land that were reverted to the original customary owners of the land.

The credibility of forest products leaving the shores of PNG is very significant to maintaining existing market as well as diversifying markets to enable competitive price. Improved forest management practices and verifying timber legality would be keys to attracting market for PNG timbers. The Timber Legality Standard (TLS) and the Decision Support System (DSS) that the PNG Forest Authority is testing and rolling out would strengthen the forest monitoring and management capabilities. The two systems have the potential of meeting any market requirements and hence upon successful testing, they should be demonstrated/ displayed during the coming APEC meeting in Port Moresby in 2018.

PNG is having significant challenges in undertaking sustainable forest management practices. However with challenges, opportunity comes with it and REDD+ is presenting a good opportunity for PNG to realign its pathway in progressing towards strengthening sustainable forest management as well as addressing climate change impacts. It is good to note that REDD+ is now becoming an international financing mechanism which is a positive sign for forest management. Given that the land in PNG is owned by the people and the increase in stakeholder for the forestry sector, any strategic actions including policy development must be people oriented.

From the review of the 1991 forest policy it is viewed that most requirements of policy have been implemented particularly the administration set up. At the same time some aspects of forestry have not been adequately implemented due to resources constraints, particularly in reforestation, domestic processing and landowner participation. The government need to be strategic to ensure that key aspects of forestry are implemented through a funding source like the first call on revenue generated from forest based industries is to fund these key aspects of forestry to enable the sustainability of the forestry sector.

The framing of the current forest policy is seen as responsive to the recommendations of the Barnett Inquiry and limit other important aspects of forestry that did not feature in the investigation. Community forestry is one such area and therefore there is no clear policy statement to drive this aspect of forestry. Community forestry is very important in enabling landowner participation in various forestry activities that can be undertaken at that level including observing climate change impacts and taking responsible actions to contribute towards mitigation and adaptation efforts. The other area and closely associated with community forestry is the development of non -timber forest products which has high economic potential for the rural community. The eco-forestry policy, currently in draft form needs to be finalized and concluded to provide strategic direction for community forestry and the development of non- timber products.

A paradigm shift following the conclusion of the multi- purpose national forest inventory (MPNFI) is possible, where reliable data will be available to develop a sound national forest plan which would form the basis of sound forest management. The integration of climate change issues into the forest legislative framework and action plans will change the mentality of business as usual.

Future research areas would be on forest research. The PNG FRI has done a lot of good researches on various aspects of forestry but most may have not been translated into policy and action plan to drive the forestry sector. A study need to be carried out to look at the various research results relevant to PNGFA priorities that can be validated and developed into policy and action.

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NFI Cluster Accessibility Assessment Using Open Foris Collect Earth

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Abstract

A total of 1000 sampling sites purely in forest areas in PNG were proposed to be visited to conduct the forest and biodiversity inventories. The objective of this paper is to determine the feasibility of the selected plots by visual interpretation. These assisted the PNG Forest Authority to plan logistics, cost of travel and proposed length of stay for the actual NFI.

The assessment showed that only 21% (207) of the 1000 clusters are easily accessible and 25% (255) are partly accessible. The remaining 54% (538) of the clusters are either 'almost inaccessible' or 'inaccessible'. Out of the 21% easily accessible clusters, 33% (69) can be accessed by 'vehicle and foot', 45% (94) requiring outboard motor and foot or by vehicle whilst 21% (44) of the clusters require air transportation then by vehicle or foot.

About 65% of the clusters are found in slopes ranging from 0- 10 degrees. Out of the 65%, easily accessible clusters are 29% (192), partly accessible 24% (162), and almost inaccessible 31% (204) and inaccessible 14% (94). On the other hand, about 4% (40) of the clusters are located on sites with slopes more than 30 degrees. Out of this, 65% (26) are confirmed as inaccessible of which 1% partly accessible and 25% almost inaccessible. The balance of 30.8% (308) falls between slopes ranging from 10 to 30 degrees.

The FAO Open Foris Collect Earth tool was used to assess the potential of a cluster to be reached and entered by the field team during the reconnaissance survey or during the actual inventory work. Measure of accessibility is how easy and how difficult a cluster plot-center can be reached or entered. Accessibility interpretation is classified into 3 travel methods feasible to NFI operations. These are by land, sea/water (river) and by air. There are 3 types of ruler in Google Earth; line, path and pro. For this assessment we used the path tool to measure distance in kilometers between multiple points on the desktop.

1. Introduction

After the 4 km by 4 km stratification was completed for NFI a total of 1000 sampling sites purely in forest areas were proposed to be visited to conduct the forest and biodiversity inventories. To be visited? What do we want to visit? A sample land area or a sample of trees, plants, birds, insects, or even the people! With the aid of geographical coordinates, the sampling sites centers are easily identified on a computer with the aid of satellite imagery which land use and landform surrounding the sites are then pre-determined. This develops an understanding of 'the quality of being able to reach or enter' the unknown inventory site eventuates.

The objective of this paper is to determine the feasibility of the selected plots by visual interpretation and formulate an allow field officers develop appropriate inventory budget. Under the Open Foris Initiative by FAO, Collect Earth is one application tool developed, which can be customized by the user in this case the country like PNG ideally depicting the country's current circumstances. The 1,000 plots were selected on the pre-determined forest strata/forest types found in PNG. At the pre-planning stage; desktop assessment to determine proximity of the clusters for existing entry points (road, tracks, settlements, etc.) which are possible by means of accessing these sites as there are factors that cause logistical constraints i.e. remoteness and rugged terrain. With the desktop assessment information, it assist to make informed decisions for strategic planning for effective budget preparation and as well as allocation of available resources (man power/personnel/expertise and equipment). The prepared desktop information was disseminated to the provincial forest officers for field verification through awareness (identification of genuine landowners and seeking consent to have access to these plots) and reconnaissance (determination of plot location and establishment of plot centre).

2. Methods

The FAO Open Foris Collect Earth tool was used to assess the potential of a cluster to be reached and entered by the field team during the reconnaissance survey or during the actual inventory work. These assisted the PNG Forest Authority to plan logistics, cost of travel and proposed length of stay for the actual NFI. Collect Earth is a user-friendly GIS tool that uses a Google Earth interface in conjunction with an HTML-based data entry form, which can be customized to suite country-specific land use and forest classification schemes. The data entry form for PNG LULUCF was customized into a single form with new entries for assessing site accessibility. The entries include accessibility interpretation, measure of accessibility, and distance to settlement, remarks, and land use type. Collect Earth facilitated the interpretation of high and medium spatial resolution imagery in Google Earth and Bing Maps. Google Earth Engine was not often used, unless the plot was under a known disturbance. Most of the accessibility assessment was done in Google Earth using 3-Dimensional (3D) capabilities. Firstly, the overview terrain condition was viewed by tilting the map forming a real-world scenario where we could judge the terrain formation. Secondly, the plot centre site was assessed by zooming-in on the plot enabling direct view of the steepness of the site. This depended on existence of high resolution imagery. If there is no high resolution imagery then Landsat imagery is the available background image which 3D capabilities are possible.

2.1. Measure of Accessibility

Measure of accessibility is how easy and how difficult a cluster plot centre can be reached or entered. The measures are grouped into Easily Accessible, Partly Accessible, Almost Inaccessible and Inaccessible. The qualities of each class are determined from the accessibility interpretation classes and the distance to nearest settlement. If a cluster centre proximity to a nearest settlement or road is less than 5 kilometres then the cluster can be reached firstly by a land/sea transport mode such as a vehicle/outboard motor and then reached by foot.

Table 1 Classification used for measures of accessibility and subclass links (accessibility interpretation and distance)

Code	Class	Accessibility interpretation	Distance to settlement
A	Easily accessible	A, B	< 1 km
B	Partly accessible	B, C	1-4 km
C	Almost inaccessible	C, D	4-5km
D	Inaccessible	E	> 5km

2.2. Accessibility Interpretation

Accessibility interpretation is classified into 3 travel methods feasible to NFI operations. These are by land, sea/water (river) and by air. From land two travel modes identified are; vehicle and foot. By sea or water one transport mode identified is through the use of outboard motor. From air is any smaller aircraft that can be used to reach the nearest airfield from the main town/city airport. High priority is given to land and sea based travel methods then air methods. Based on these travel modes 5 classes (see Table 2) are created to generally include all modes of travel required to estimate the cost of travel to reach the inventory site. After satellite imagery observation and determination of distance an assessor decides on the class of accessibility interpretation.

Table 2 Accessibility Interpretation code and description

Code	Class
A	By vehicle and foot
B	By outboard motor and foot
C	By air then by vehicle/outboard motor/by foot
D	Not accessible by air, or vehicle, or outboard motor but settlement nearby
E	Too remote and no options for A,B,C or D

2.3. Distance measurements

There are 3 types of ruler in Google Earth; line, path and pro. For this assessment we used the path tool to measure distance in kilometres between multiple points on the ground. If the distance to the nearest settlement was less than 1 kilometre the readings recorded in meters. For NFI it was vital to determine proximity measurements to any human infrastructure or any land feature that allow human access using various transport modes. While performing the terrain assessment an assessor is able to identify if there is any possible human settlement, roads or rivers that are potential for access to the cluster centre. With the use of the path tool the assessor determines the distance by clicking at multiple points on the image starting from the plot to the nearest human settlement, or to any existing road or to the large river or stream. This is done on either in 3D mode or in 2D (flat plane) mode in Google Earth. Bing map becomes handy when Google Earth has no coverage of high resolution imagery of the site. There are almost 10 % chances of both web-maps (Bing and Google) to have no high resolution images at all, although Google Earth has the capabilities of applying 3D onto high, medium or low resolution images throughout the globe.

Table 3 Four distance measurement classes in kilometres used to determine distance from centre of plot to the nearest settlement

Distance in km
<=1
1-4
4-5
>=5

3. Results

The assessment showed that only 21% (207) of the 1000 clusters are easily accessible and 25% (255) are partly accessible. The remaining 54% (538) of the clusters are either ‘almost inaccessible’ or ‘inaccessible’. Out of the 21% easily accessible clusters, 33% (69) can be accessed by ‘vehicle and foot’, 45% (94) requiring outboard motor and foot or by vehicle whilst 21% (44) of the clusters require air transportation then by vehicle or foot.

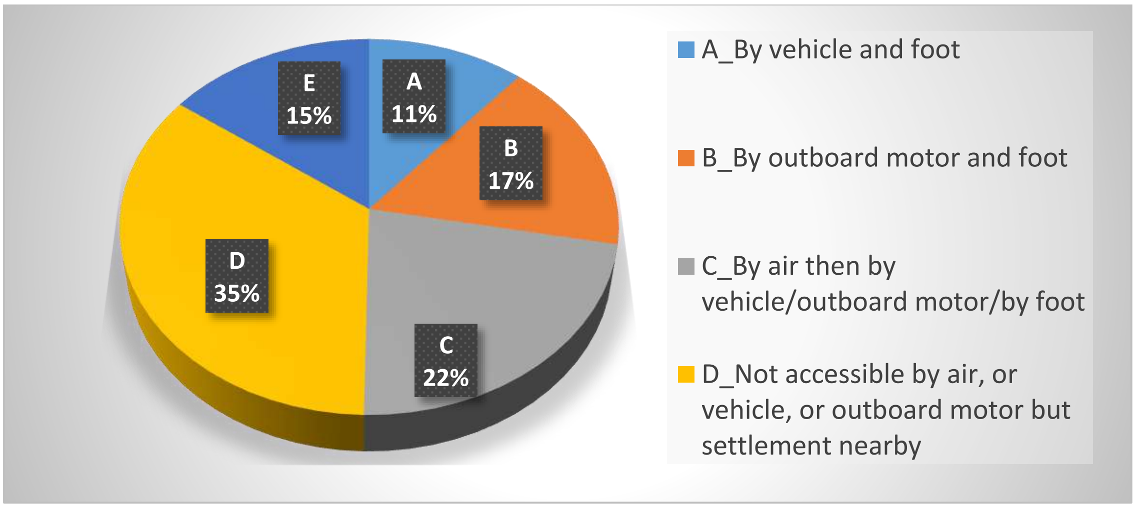

Fig. 1 Chart showing the percentage of clusters for each category of accessibility interpretation

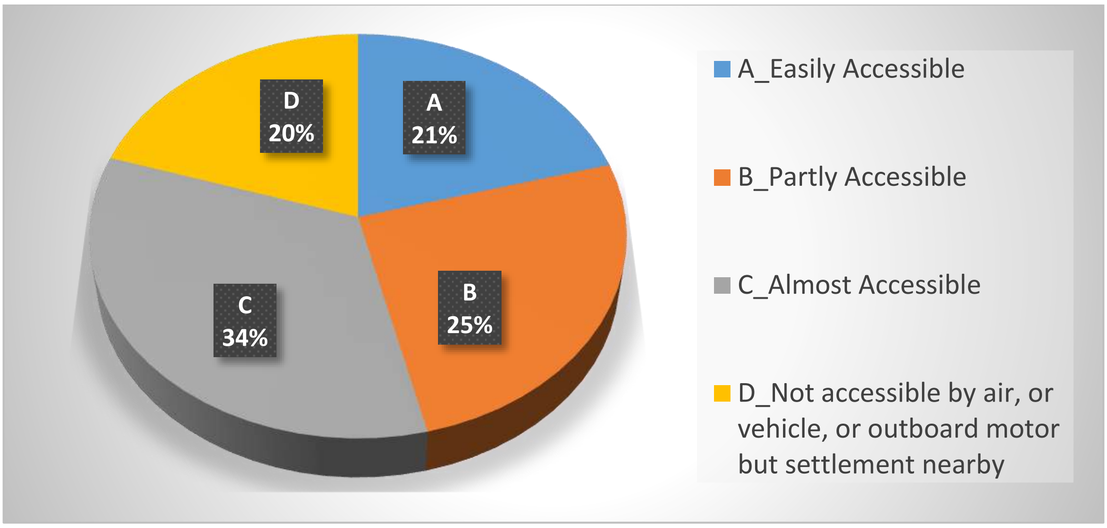

Fig. 2 Chart showing the percentage of clusters which are accessible and inaccessible

About 65% of the clusters are found in slopes ranging from 0- 10 degrees. Out of the 65%, easily accessible clusters are 29% (192), partly accessible 24% (162), and almost inaccessible 31% (204) and inaccessible 14% (94). On the other hand, about 4% (40) of the clusters are located on sites with slopes more than 30 degrees. Out of this, 65% (26) are confirmed as inaccessible of which 1% partly accessible and 25% almost inaccessible. The balances of 30.8% (308) fall between slopes ranging from 10 to 30 degrees.

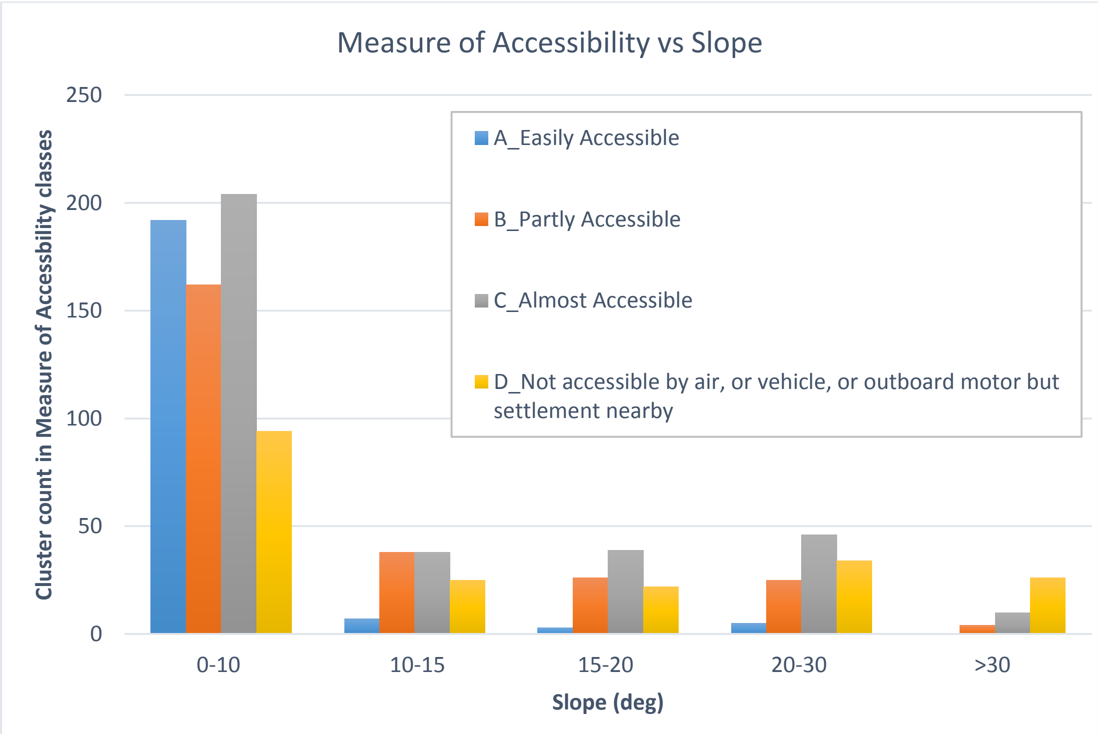

Fig. 3 Graph showing the clusters 'measure of accessibility' against slope ranges

4. Discussion

With the aid of the Collect Earth it was easier to determine the feasibility of these plots which has led the development of maps which can be verified by the provincial forest officers. The visual interpretation has been vital in establishing the entry points or means of accessing these plots with the guided criteria to main consistency and common understanding of the information developed or generated. The information can be validated if there is a discrepancy or an error which is an advantage using the Collect Earth tool. As previously stated, the information generated is importance in making informed and critical planning in the initial stages before conducting the field inventory.

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Estimation of the targeted number of NFI plots and clusters

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Abstract

Earlier determination of the NFI 1000 clusters consisting of 4000 plots resulted from the NFI Remote Sensing component to determining the most appropriate forest stratification and the targeted number of plots per strata. The PSP data was utilized to estimate the variability of AGB in different forest strata between the plots.

In this paper, we utilized the available 22 clusters (consisting of 78 plots) of the NFI data to estimate the targeted number of clusters and plots. Instead of Brown's models, we applied Chave *et al* (2005) model to compute the AGB estimate for each tree. Chave's model takes into account tree diameter, height and wood density (and it can be considered as more accurate), whereas Braun models contain only tree diameter as input variable.

Introduction

The National Forest Inventory is following a three phase approach since its commencement in October 2013. Phase One focused mainly on remote sensing based assessment in order to determine the most appropriate forest stratification scheme and the initial targeted number of plots per strata for the phase 2 ('Field measurement' phase). With the aid of the JICA/PNGFA project "*Capacity Development on Forest Resource Monitoring for Addressing Climate Change in PNG*", PNGFA has developed the forest base map containing 17 confirmed broad vegetation/forest types in the country which form the basis for the stratification of the NFI *(as cited in the PNG Biophysical Field Manual 2018*). At the end of the phase one, a total of 1 000 clusters holding 4 000 plots as a target were identified within 15 different forest strata. However, it should be kept in mind that the final forest inventory design is always a compromise between targeted accuracy, time and funding resources.

Methods

Previously, there was no representative field data available to actually determine a sufficient number of clusters to be sampled. Therefore FRI's Permanent Sample Plot (PSP) data was used to estimate the number of samples. Firstly, the main target using this data was to estimate current variability of above-ground biomass (AGB) in different forest strata between the plots. In this part, two AGB models were applied (called as *Brown model 1 & 2;* Brown and Iverson 1992) to compute plot level AGB estimates, and then analysis was done to get coefficient of variation between sample plots (by strata) using both of these models. Therefore, two different estimates for variance were computed.

Depending on the area covered by the different forest strata and using expert-knowledge regarding, a targeted accuracy percentage was allocated to each stratum (Table 1). Based on the estimated Coefficient of Variation (*CV*) and this accuracy target (*E*), the following formula was applied in order to determine the required number (*n*) of plots (Cochran 1977)[3]:

[3] See also http://www.fao.org/docrep/005/AC838E/AC838E12.htm

$$n_{i+1} = \left(\frac{t_{n_i-1,\,\alpha/2} \mathrm{CV}}{E} \right)^2$$

Table 1: Forest inventory design based on FRI's Permanent Sample Plot data

			Number of plots *	Required precision (95% CI)	Required number of clusters** Brown 1	Brown 2	1000 clusters to be visited
Low altitude forest on plains & fans	Primary		2,276	5%	80	60	150
	Degraded	Logged	1,306	10%	20	15	50
		Other disturbance	1,078	10%	20	15	50
Low altitude forest on uplands	Primary		3,732	5%	80	60	150
	Degraded	Logged	1,229	10%	20	15	50
		Other disturbance	1,528	10%	20	15	50
Lower montane forest	Primary (including 21 montane coniferous forest)		3,452	5%	80	60	150
	Degraded (inclding 14 montane coniferous forest)		1,344	10%	20	15	50
Swamp forest			1,141	10%	20	15	50
Woodland			815	10%	20	15	50
Dry seasonal forest			750	10%	20	15	50
Savanna & Scrub			592	10%	20	15	50
Littoral & Seral			274	20%	5	4	25
Montane (including 8 M/coniferous above 3000m)			242	20%	5	4	25
Mangrove			179	20%	5	4	25
					435	**327**	975+25 (M/coniferous forest)

A total of 22 accessible clusters (containing 78 sample plots) have been assessed this far and data has been stored into the NFI database (Table 2). New analysis was conducted by using the latest available NFI data. In the new analysis, the AGB model by Chave *et al.* (2005) was applied in order to compute AGB estimate for each tree, instead of Brown's models. The reason is that Chave's model takes into account tree diameter, height and wood density (and it can be considered as more accurate), whereas Braun models contain only tree diameter as input variable.

AGB estimates were computed for a plot level so that plot level AGB estimates were expressed per hectare basis (i.e., tons ha^{-1}). Targeted error level was taken from the original NFI design (Table 1), but an adjusted new error levels were added for facilitate further discussions on the topic.

Table 2: Number of recorded NFI sample plots (September 2018)

Forest type / Land use type	**Forest status**	**Plot count**
Low Altitude Forest on Plains and Fans	Primary	22
	Commercially logged	8
	Disturbed other than commercial	2
Low Altitude Forest on Uplands	Primary	8
	Commercially logged	8
	Disturbed other than commercial	1
Lower Montane Forest	Primary	18
	Degraded	4
Swamp Forest	Primary	1
Forest plantation	Commercially logged	1
Grass Land		1
Crop Land		4
	Total	**78**

Results and Discussion

However, the project will be closed at the end of 2018, and only 2.2% of initially target number of 1 000 clusters has been assessed. So, in short we will run out of time, and a representative sample of PNG's forests is still yet to be captured. However, currently there is some preliminary data available, and these data has been used to recalculate the coefficient of variation for the number of plots within the different strata (Table 3).

The coefficient of variation was computed for each stratum (with more than 4 observations) and the maximum value was chosen for the analysis. In Table 3, only data from Forest Land sample plots were processed. *Target1* refers to the original NFI design (Table 1), and an adjusted Target2 levels is there for comparison of the effect of the changes in error levels. The missing coefficients of variation (CV) were selected according to the color-coded groups, so AGB CV of *Low altitude Forest on Plains and Fans (Primary)* was used to compute results for all other forest types marked with green cell color.

Table 3: Estimated number of required plots and clusters (February 2018)

Stratum		Number of plots	AGB (t/ha)	AGB Coefficient of Variation	TARGET 1 Target error level	TARGET 1 Plots	TARGET 2 Target error level	TARGET 2 Plots
Low Altitude Forest on Plains and Fans	Primary	22	263.7	20.9%	5%	67	10%	17
Low Altitude Forest on Plains and Fans	Commercially logged	8	93.7	47.7%	10%	87	10%	87
Low Altitude Forest on Plains and Fans	Disturbed other than commercial logging	2	265.0		10%	87	10%	87
Low Altitude Forest on Uplands	Primary	8	159.0	41.3%	5%	67	10%	17
Low Altitude Forest on Uplands	Commercially logged	8	191.1	57.6%	10%	87	10%	87
Low Altitude Forest on Uplands	Disturbed other than commercial logging	1	191.1		10%	87	10%	87
Lower montane forest - Primary	Primary	18	233.3	32.2%	5%	159	10%	40
Lower montane forest	Degraded	4	258.7		10%	87	10%	87
Swamp forest		1			10%	17	20%	4
Woodland					10%	17	20%	4
Dry seasonal forest					10%	17	20%	4
Savanna and Scrub					10%	17	20%	4
Littoral and Seral forest					20%	4	20%	4
Montane forest					20%	10	20%	10
Mangrove					20%	4	20%	4
Total (number of plots)		**72**				**815**		**545**
					clusters	**204**		**136**

When comparing the initial estimates (Table 1) by using the FRI's PSP data, PSP data gives higher variation compared with the current results shown in Table 3. Similarly, number of required plots is higher in the earlier estimation.

The challenge in both estimations (PSP data) and current NFI data is the limited number of observations by strata. The situation will improve when more plots are recorded. But it is a well-known fact that the variation in AGB tends to be the highest in logged-over forest lands, and variation in this forest category will give us a good guidance for continuously following the targeted and achieved accuracies.

The disadvantage of this method is that it does not take into account the reporting required for smaller land areas than for the whole country, as for regions. Secondly, this method cannot take into account the species diversity aspects. Nevertheless, this is a robust and globally widely used method in design phases of NFIs.

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Estimating forest carbon stocks from four major forest types in Papua New Guinea

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Abstract

A total of fifteen (15) clusters have been assessed under the NFI project in PNG between May to November 2017. These clusters were stratified over four different forest types ranging from an altitudinal range of between 50 – 2773 m (ASL). Preliminary analysis of data from the clusters comprising a total of 53 nested plots indicate the following observations; 1) above ground biomass of 315.98 t/ha was found in cluster 22133794 at an altitude of 2728 m asl which occurs in primary montane forest type, 2) clusters/(plots) occurring in primary forest have significantly higher mean AGB values than those in logged forest areas regardless of forest type and/or altitude; 3) Cluster 83331 located 73 m asl recorded a mean agb of 305.50 t/ha, the cluster being situated in primary low altitude forest on plains and fans. The higher values found in these two clusters correlate to a high frequency of large trees (diameter at breast height ≥ 50 cm). The choice of allometric model (Chave 2005) to estimate AGB using stem diameter, height and wood density gave a mean value of 192.12 t/ha compared to 240.36 t/ha (Brown 1992) when height was excluded. Preliminary results suggest that primary montane forest may contain greater AGB than previously thought.

1. Introduction

Forests play an efficient role in carbon sequestration and thus mitigating climate change. However, there is great uncertainty in estimating above ground biomass (agb) over wide range of forest types at a national scale. National forest inventory (NFI) data have commonly been used as a basis to provide credible estimates of forest carbon stock and stock change. The current study attempts to estimate the amount of carbon stored in four major forest types in Papua New Guinea (PNG) namely; lowland forest on plains and fans, low altitude forest on uplands, lower montane and montane forest. Hence, using NFI data from clusters visited together with existing allometric models can assist to quantify above-ground biomass (carbon stocks) to strata and/forest type level.

To contribute towards Papua New Guinea's (PNG) preparedness towards participating in Reduced Emissions from Deforestation and Forest Degradation ($REDD^+$) schemes, it is a requirement for the country to undertake its first multipurpose national forest inventory. In the context of REDD+, the National Forest Inventory is one of the technical pillars which forms the country's National Forest Monitoring system (NFMS), apart from the Satellite Land Monitoring Systems (SLMS), and Greenhouse Gas Inventory (GHGi). The NFI can be used to estimate forest carbon stock and Emission Factors; while the SLMS can be used to estimate Activity Data, which are then combined into a GHG inventory report. The development of NFMS is a requirement for countries like PNG which intend to participate in the REDD+ mechanism under the UNFCCC, with modalities defined by UNFCCC decisions 11/CP.19 and 14/CP.19.

The capacity on forest monitoring in PNG using remote sensing technology has significantly been improved in recent years. However, a large information gap still remains. National scale information on carbon stocks in the diverse forests types and there different disturbance status is poorly known. Previous studies were either too scattered (confined to specific localities), or concentrated on certain forest types and disturbance status hence the estimation of average carbon stock in PNG forests have often been contradictory or accurate only at the local scale. With the completion of NFI, PNG will be able to accurately estimate its total carbon stocks as well as the Green House Gas emissions form forest and land use change, the quality meeting the requirement of Tier 3 level of REDD+.

The use of national forest inventory (NFI) data for better understanding, planning and management of PNG forest will be greatly enhanced and will form the basis for policy development.

2. Objective

Problem Statement

How do forest carbon stocks vary between primary and disturbed forests in the four major forest types in PNG?

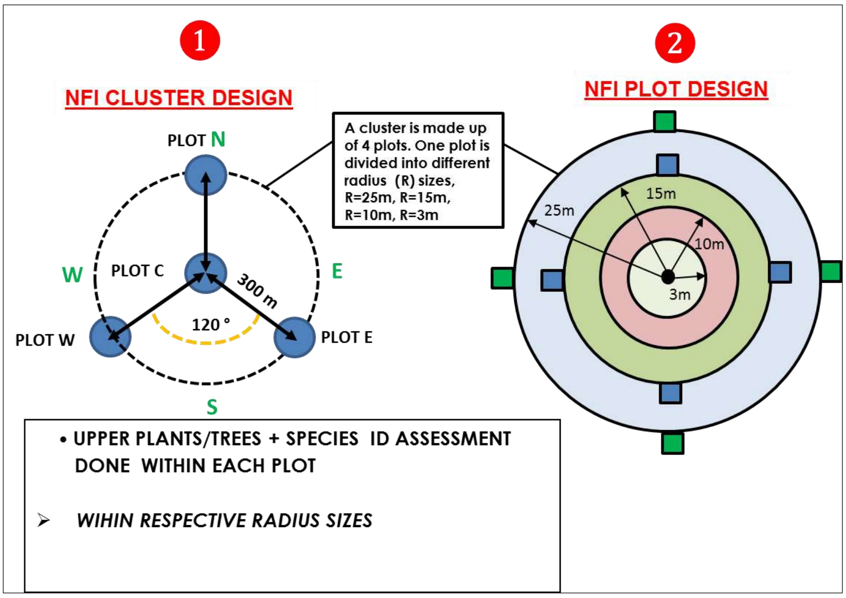
Research Questions

1. What are the extents of primary and degraded forests these four forest types?
2. How much carbon (Above-ground biomass) is stored in primary and degraded forest in these four forest types?
3. What is the total carbon stock (Agb) in these four forest types?

3. Methodology

This study was undertaken using the NFI data collection design and methodology. Data collection was carried out from within a cluster of four circular nested plots, each plot being treated as an individual plot. (Refer to Figure 1 below):

Figure 1 NFI Cluster and Plot Design



Each plot consists of four concentric circles (nested sub plots) from which the following measurements were taken;

Nested plot measurement criteria

1 3m radius plot All plants ⩾ 1.0cm dbh

2 10m radius plot All plants ⩾ 10 cm dbh

3 15m radius plot All plants ⩾ 20cm dbh

4 25m radius plot All plants ⩾ 40cm dbh

Parameters Measured

Each tree was assessed and measured according to, 1) Species (ID), 2) Stem diameter (dbh) in centimetres (cm) and 3) Tree height (m). Height measurement consisted of four readings taken accordingly as: 3.1) Height angle to Tree Base, 3.2) Merchantable height, 3.3) Height to top of height Pole (10m) and 3.4) Total Tree Height. All trees having a dbh of ⩽ 10 cm were measured directly using the height pole. Height measurement was only carried out on every fifth tree encountered. Apart from that all trees with dbh ⩾ 40 cm, including; palms, tree ferns, lianas and pandanus had their heights measured during the assessment. Height measurement was undertaken using Suunto clinometer and Range finder **Vertex Laser 5 (VL5).**

4. Results

Data analysis was done using Open foris *Calc and Saiku*. The allometric equation for tropical wet forests derived by Chave *et al*. (2005) was used to estimate above-ground biomass: AGLB (in kg) = $\rho^{(-1.239 + 1.980 \ln (D) + 0.207(\ln (D))\ 2 - 0.0281(\ln (D))\ 3)}$, where ρ is wood specific gravity (g/cm^2) and D is diameter (cm).

Wood density

Wood specific gravity is obtained from available databases such as the 81 World Agroforestry Centre Wood density database (81); Eddowes 1977; and using IPCC default 0.477 for unknown species). The Chave (2005) model was used for biomass computations based on its relevance to PNG and the similar geographic locations of the work from which it was developed. Preliminary results from the 15 clusters assessed are shown in Table 1 below:

Table 1 Mean above-ground biomass per cluster

Cluster Id	Mean Tree_Agb_ipcc	Mean Tree_Agb_Brown	Mean Tree_Agb_Chave2014
62751	168.61	227.70	204.02
64259	58.33	125.17	68.65
75788	188.07	301.23	229.82
76797	199.62	238.83	246.40
82838	233.53	247.48	298.24
83331	305.50	288.86	388.07
83850	193.42	229.43	237.11
95374	139.47	180.98	166.65
96863	207.84	262.30	258.03
97382	200.84	230.81	254.42
97885	219.36	269.15	278.87
108924	221.60	226.24	281.13
22124812	168.15	227.75	204.63
22130649	73.79	151.81	85.01
22133794	315.99	397.69	390.94

Figure 2 Mean agb by plots in logged and primary forest; along altitudinal gradients

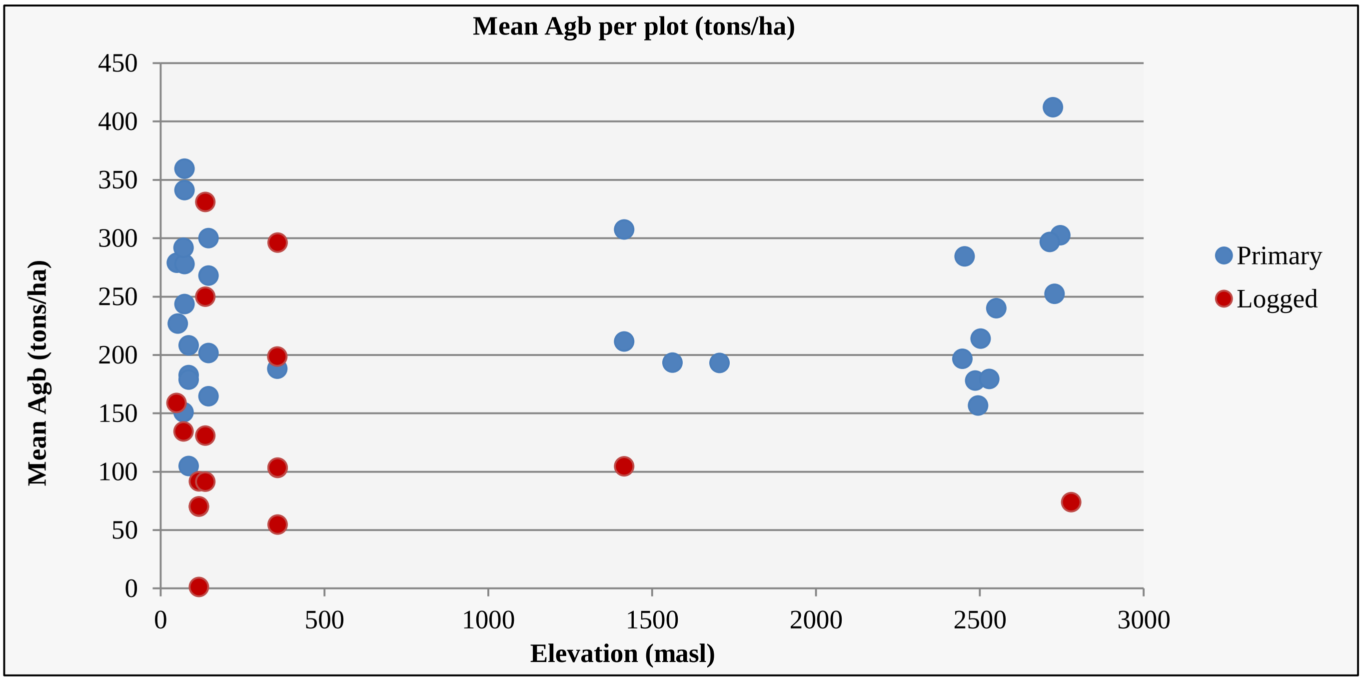
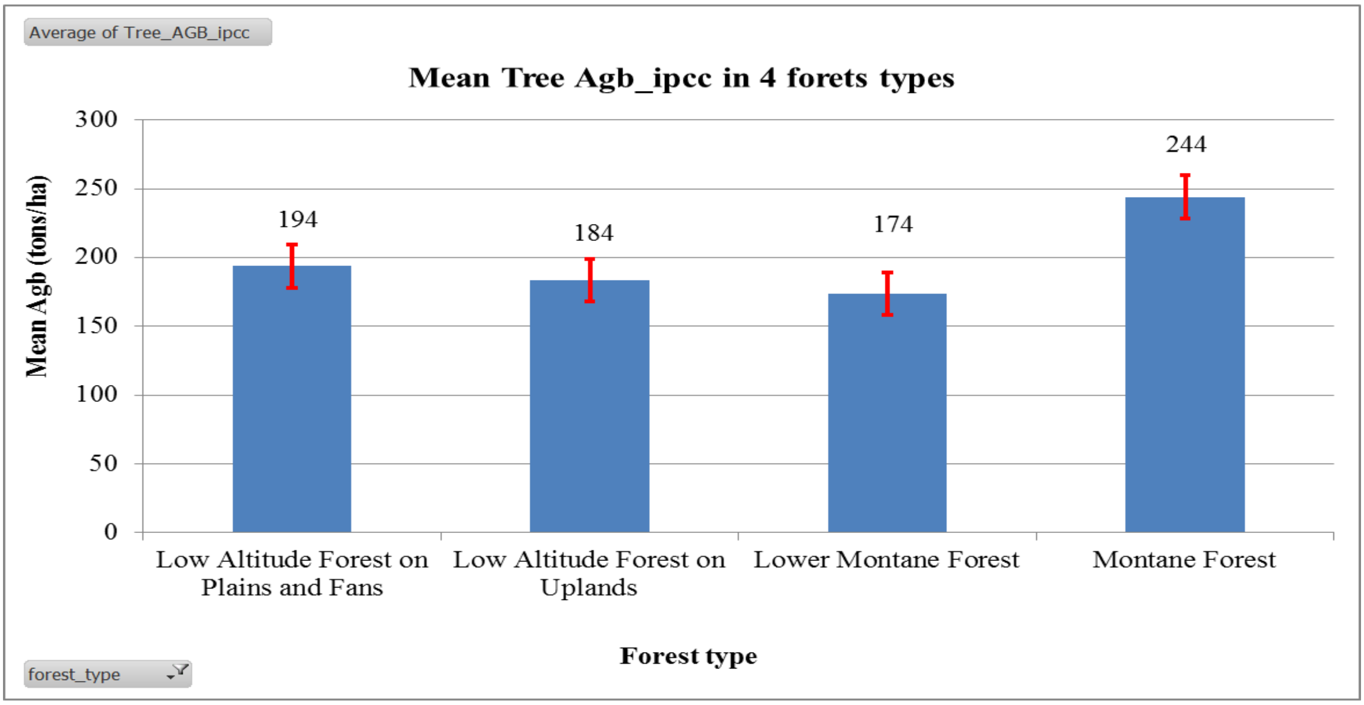


Figure 3 Comparison of mean agb by clusters between forest types



5. Discussion

This study has attempted to estimate the e AGB stock of each forest type using data from sampling plots that have been correctly set up and measured using the above mentioned methodology. The main parameters used in the calculations are; diameter at breast height (dbh), total tree height and wood specific gravity.

Preliminary results from the current dataset indicated a high Agb mean of 315.98 t/ha for cluster 22133794 (Montane forest, 2728m ASL), followed by cluster 83331with 305.50 t/ha, followed by cluster 82838 on 233.53 t/ha. This trend is attributed to the high frequency of large size diameter trees dbh $\geqslant$ 50cm found in plots within these clusters. It further shows that clusters (plots) occurring in primary forests generally have significantly higher mean AGB values than those in logged forest areas regardless of forest type and altitude.

Cluster 83331 (Lowland Forest on Plains and fans, 73m ASL) recorded a mean of 305.50 t/ha agb. This proves not only the number of large size trees but also the species with high wood density as proven by the abundance of high wood density species such as *Intsia bijuga* and *Pometia pinnata*. The total mean of all clusters (plots) assessed is 198.85 t/ha (Agb).

The choice of allometric model (Chave 2005) to estimate AGB using stem diameter, height and wood density gave a mean value of 198.85 t/ha compared to 240.36 t/ha (Brown 1992) when height was excluded. Current indications from the preliminary analysis suggest that lower montane forest in PNG do contain greater AGB than previously thought. It can also be deduced from these results that agb is highly variable between forest types depending on site quality as well as being species specific. Although there are no major trends in Agb distribution between forest types as yet, the general observation is that the agb or carbon stock in primary forest plots is generally higher than those in logged plots.

A numbers of similar studies carried out in the past have shown higher carbon stock values than the preliminary NFI result, however the trend between primary and logged forest is the same. Examples of past studies include;

Fox J, *et al.* (2010)	106.3±16.2 Mg C/ha. (Primary) 66.3±3.5 Mg C/ha (Logged)
Fox J, *et al.* (2010)	210.72 Mg ha^{-1}
John B. Vincent, *et. al* .	111.34 Mg C ha^{-1}
Bryan *et. al.*	120.8 Mg C/ha
Fox *et al*. (2010)	169.9 Mg C ha^{-1}
Bryan *et al*. 2010b	147–153 Mg C ha^{-1}
Saatchi *et al*. 2011	137.3 Mg C/ha
	292.2 Mg AGLB /ha
Mika R. Peck *et. al*. (2017)	198.85 t/ha (Agb)
PNG NFI	198.85 t/ha (Agb) (**99.42 Mg ha^{-1}**)

When comparing the above ground biomass figures with results from other regions, our estimate is 198.85 t/ha (99.42 Mg ha^{-1}) agb for trees ⩾ 10 cm. This is quite low in comparison to the global mean estimate of (373.7 Mg ha^{-1}) and other estimates for lowland rainforests of the Americas (287.9 Mg ha^{-1}), Asia (393.24), Africa (393.3) (Slik et al. 2013), and Australia (513.6 Mg ha^{-1}) (Bradford et al. 2014; Murphy et al. The major factor here is the insufficient number of samples assessed in each of the forest types. It can be concluded that the low agb value is still preliminary at this stage, hence the need for more observations in the field which requires more plots to be measured to achieve the required 95% CI. There is generally a high variability in the amount of above-ground biomass and C stock across forest types.

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Tree Species Diversity in Relation to Altitudinal Gradients and Forest Types in Papua New Guinea

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Abstract

This study assessed the tree species diversity in 15 clusters comprising 53 plots from low altitude forest on plains and fans in the lowland to montane forest in the highlands. Assessment of trees was done in a 25m circular plot and divided into different radius sizes of sub-plots 3m, 10m, 15m and 25m. All tree species were identified in field with vouchers collected for further identification and confirmation at the National Herbarium. A total of 2,222 living trees comprising of 228 unique tree codes by genera and 240 unique codes by species were observed with DBH ≥ 1.0cm (unknown species were not included here). Preliminary Statistical analysis using Shannon-Weiner Index, Simpson's Index and Evenness do not differ significantly between plot and cluster in altitudes and forest types. One-way Anova-test indicated difference in evenness between altitudinal ranges between low altitude forest on plains and fans and lower montane forest. More data from Lower Montane and Montane forest would provide better comparisons between cluster and plot in different forest types along different altitudinal gradients for tree species diversity for PNGs first ever National Forest Inventory.

Introduction

Forest in PNG is classified into 12 forest types; 11 natural forest and forest plantations (PNGF, 2017) that range from the mangrove forest at sea level, wetlands, swamps, open grassland and savannah, low and frequently inundated flood plains, hills and ridges to alpine forest at very high altitudes (Saunders, 1995). Three major forest types include; Low Altitude Forest on Plains and Fans, Low Altitude Forest on Uplands and Lower Montane Forest (PNGFA, 2017; Hammermaster et. al, 1995).

The major use of forest resources in PNG has and still being used for traditional purposes by the local people. According to ITTO, 2011; Status of Tropical Forest Management, Technical Series 38 states that "about 80% of the PNG population is rural and dependent on forest for a wide range of subsistence need, including food, fuel, shelter, medicines and cultural aspects, as well as to supply that is used in shifting agricultural systems".

Tropical rainforest has multiple three layers, from the emergent layer to the canopy layer and down to the forest floor. The composition of diversity of tree species, density of trees and irregular shapes and size of tree crowns affect the canopy structure (Song et al., 2009 cited in Sumareke, 2015). Many biodiversity studies have been conducted in tropical forest looking at their structure, composition, species diversity and species density. These studies have contributed significantly in the management of forest resources. Conducting the country's first ever NFI will provide an opportunity to assess tree species diversity to have some data available to compare with other similar studies.

The main aim of this study is to assess tree species diversity in relation to different altitudinal gradients and forest types in Papua New Guinea to better our understanding of tree diversity in the forest ecosystem.

Study Sites

This study was conducted in five provinces looking at tree diversity in rainforests from Low Altitude Forest on Plains and Fans to Montane Forest at different altitudinal elevations. A total of 15 Clusters were surveyed; one in

Oro Province, two in Madang Province, seven in Morobe Province, two in Eastern Highland Province and three in Western Highlands Province. Site selections of the study sites were randomly determined by remote sensing to stratify the forest in PNG and are part of the targeted 1000 Clusters distributed throughout the country for the purpose of the country's first ever National Forest Inventory.

Table 1 Table showing study sites, forest types, altitudes and number of plots assessed

Site	Cluster No.	Province	Altitude (m)	Elevation Class	Forest Type	Accessible Plots
1	108924	Oro	50	0-499m	Low Altitude Forest on Plains and Fans	3
2	97885	Morobe (Eware)	70	0-499m	Low Altitude Forest on Plains and Fans	4
3	83331	Morobe (40Mile)	73	0-499m	Low Altitude Forest on Plains and Fans	4
4	62751	Madang (Baisarik)	86	0-499m	Low Altitude Forest on Plains and Fans	4
5	64259	Madang (Paia Mtn)	117	0-499m	Low Altitude Forest on Plains and Fans	4
6	97382	Morobe (Kobio)	137	0-499m	Low Altitude Forest on Plains and Fans	4
7	82838	Morobe (Yalu)	147	0-499m	Low Altitude Forest on Plains and Fans	4
8	83850	Morobe (Bukawa)	356	0-499m	Low Altitude Forest on Plains and Fans	2
9	95374	Morobe (Paiawa)	357	0-499m	Low Altitude Forest on Plains and Fans	4
10	96863	Morobe (Biaru)	1415	1000-2500m	Lower Montane Forest	3
11	22124812	WHP (Baiyer)	1559	1000-2500m	Lower Montane Forest	4
12	75788	EHP (Bena)	2462	1000-2500m	Lower Montane Forest	4
13	76797	EHP (Henganofi)	2491	1000-2500m	Lower Montane Forest	4
14	22133794	WHP (Tambul)	2727	2500+ m	Montane Forest	4
15	22130649	WHP (Kumul)	2779	2500+ m	Montane Forest	1

Methodology

Many tree species diversity surveys have been conducted using squares (1 ha) divided into 20m x 20m plots (Wright et al, 1997; Fangling et al, 1997; Pitman et al, 2002; Gentry, 1988), rectangular or long narrow transects (Pitman et al, 2002) and belt-transects (Kumar et l, 2006) with tree DBH ≥ 10.0cm.

This study used circular plot of radius 25m (0.2 ha) with tree DBH ≥ 1.0cm (Fig. 1). The Clusters were randomly determined by remote sensing where a cluster consists of four plots. The plots are located 300m apart from each other in the cluster. There are four circular plots in different radius within each plot. Each plot within a cluster has four circular sub-plots with radius 3m, 10m, 15m and 25m. Within radius 3m, trees with DBH ≥ 1.0cm were measured; within 10m, trees with DBH ≥ 10.0cm were measure; within 15m radius, trees with DBH ≥ 20.0cm were measured and within 25m radius, trees with DBH ≥ 40.0cm were measured. Every fifth tree, ferns and pandanus in the plot assessed, heights were measured using pole height or clinometer.

All trees assessed were identified to genus level in the field with specimens collected and brought to the National Herbarium, Lae, Morobe Province (PNG Forest Research Institute) for further identification and confirmation. Dead Standing Trees, Shrubs, Ferns, Pandanus and Lianas were not considered in this study.

Cluster and Plot Design

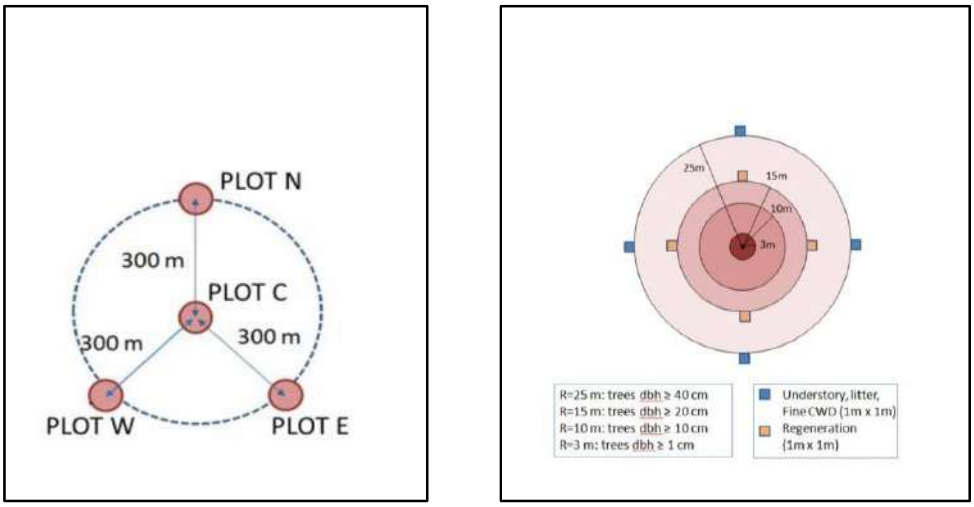

Figure 1 NFI Cluster and Plot design

Statistical Analysis

Excel and Software Saiku (Calc Software in Open Foris) were used to compute tree diversity (Shannon-Weiner Index), species richness (Simpson's Diversity Index) and species Evenness based on the number of trees of each species in relation to altitudinal range and forest types. Analysis of variance (ANOVA) was used to test for significance of differences in the number of observed species, Shannon-Weiner diversity, Simpson's Diversity Index and Evenness.

Results

Diversity between Clusters

Tree species diversity along altitudinal gradients between clusters (Table 2) do not differ significantly. The Shannon Index ranges from 2.13 – 3.96 with the lowest tree diversity observed in Cluster No. 22130649 (Kumul) at 2,779m (MF) above sea level (asl) and the highest diversity was observed in Cluster No. 97382 (Kobio) at 137m (LAFPF) asl.

Table 2 Details of Clusters of forest types along altitudinal gradients showing tree diversity using Shannon-Weiner Index, Simpsons Index and Evenness. Forest types acronyms explained: LAFPF=Low Altitude Forest on Plains and Fans, LMF=Lower Montane Forest, MF=Montane Forest

Cluster No.	Province	Elevation	Elevation Class	Forest Type	Acessible Plots	Rare tree species	Shannon	Simpsons	Evenness
108924	Oro	50	0-499m	LAFPF	3	50	2.83	0.92	0.72
97885	Morobe (Eware)	70	0-499m	LAFPF	4	69	3.28	0.94	0.78
83331	Morobe (40 Mile)	73	0-499m	LAFPF	4	58	3.27	0.94	0.81
62751	Madang (Baisarik)	86	0-499m	LAFPF	4	78	3.61	0.96	0.83
64259	Madang (Paia Mtn)	117	0-499m	LAFPF	4	44	2.74	0.91	0.72
97382	Morobe (Kobio)	137	0-499m	LAFPF	4	94	3.96	0.98	0.87
82838	Morobe (Yalu)	147	0-499m	LAFPF	4	69	3.56	0.96	0.84
83850	Morobe (Bukawa)	356	0-499m	LAFPF	2	48	3.31	0.96	0.85
95374	Morobe (Paiawa)	357	0-499m	LAFPF	4	64	3.50	0.96	0.84
96863	Morobe (Biaru)	1415	1000-2500m	LMF	3	41	2.23	0.84	0.60
22124812	WHP (Baiyer)	1559	1000-2500m	LMF	4	75	3.47	0.96	0.80
75788	EHP (Bena)	2462	1000-2500m	LMF	4	49	2.87	0.91	0.74
76797	EHP (Henganofi)	2491	1000-2500m	LMF	4	55	3.19	0.94	0.79
22133794	WHP (Tambul)	2727	2500+ m	MF	4	44	3.01	0.92	0.79
22130649	WHP (Kumul)	2779	2500+ m	MF	1	16	2.13	0.85	0.77

Diversity between Plots

Tree species diversity along altitudinal gradients between plots (Table3) differ significantly. The Shannon Index ranges from 0.84 – 3.10 with the lowest tree diversity observed in Cluster No. 64259 (Paia Mtn) at 117m (LAFPF) asl and the highest diversity was observed in Cluster No. 97382 (Kobio) at 137m (LAFPF) asl. The low tree diversity in Cluster No. 64259 was the result of commercial logging by Madang Timbers Limited for its timber value some years back. Similarly, Cluster No. 97382 is a disturbed forest with commercial logging the main human activity for its timber value.

Table 3 Details of Plots of forest types along altitudinal gradients showing tree diversity using Shannon-Weiner Index, Simpsons Index and Evenness. Forest types and Forest Status acronyms explained: LAFPF=Low Altitude Forest on Plains and Fans, LAFU=Low Altitude Forest on Uplands, LMF=Lower Montane Forest, MF=Montane Forest, SF=Swamp Forest, N/A=Disturbance other than logging, CL=Commercial logging

Elevation	Cluster No.	Province	Plot Id.	Elevation Class	Forest Type	Forest Status	Rare Tree Species	Shannon	Simpsons	Evenness
49	108924	Oro	W	0-499m	LAFPF	N/A	23	2.03	0.84	0.66
50	108924	Oro	C	0-499m	LAFPF	Primary	27	2.33	0.87	0.72
53	108924	Oro	E	0-499m	LAFPF	Primary	24	2.24	0.87	0.72
70	97885	Morobe (Eware)	C	0-499m	SF	N/A	17	1.86	0.82	0.67
70	97885	Morobe (Eware)	E	0-499m	LAFPF	Primary	22	2.59	0.91	0.84
70	97885	Morobe (Eware)	N	0-499m	LAFPF	CL	26	2.35	0.87	0.72
70	97885	Morobe (Eware)	W	0-499m	LAFPF	Primary	20	2.10	0.84	0.70
73	83331	Morobe (40 Mile)	C	0-499m	LAFPF	Primary	21	2.21	0.85	0.73
73	83331	Morobe (40 Mile)	E	0-499m	LAFPF	Primary	27	2.79	0.93	0.85
73	83331	Morobe (40 Mile)	N	0-499m	LAFPF	Primary	18	2.11	0.85	0.75
73	83331	Morobe (40 Mile)	W	0-499m	LAFPF	Primary	25	2.28	0.86	0.71
86	62751	Madang (Baisarik)	C	0-499m	LAFU	Primary	33	2.83	0.93	0.82
86	62751	Madang (Baisarik)	E	0-499m	LAFPF	Primary	28	2.71	0.92	0.83
86	62751	Madang (Baisarik)	N	0-499m	LAFPF	Primary	35	2.72	0.91	0.79
86	62751	Madang (Baisarik)	W	0-499m	LAFPF	Primary	31	2.11	0.82	0.62
117	64259	Madang (Paia Mtn)	C	0-499m	LAFPF	CL	3	0.84	0.54	0.77
117	64259	Madang (Paia Mtn)	E	0-499m	LAFPF	CL	18	2.19	0.84	0.76
117	64259	Madang (Paia Mtn)	N	0-499m	LAFPF	CL	7	1.32	0.69	0.68
117	64259	Madang (Paia Mtn)	W	0-499m	LAFPF	CL	21	1.84	0.75	0.61
137	97382	Morobe (Kobio)	C	0-499m	LAFPF	CL	38	2.98	0.94	0.82
137	97382	Morobe (Kobio)	E	0-499m	LAFPF	CL	29	3.10	0.95	0.92
137	97382	Morobe (Kobio)	N	0-499m	LAFPF	CL	28	2.79	0.93	0.84
137	97382	Morobe (Kobio)	W	0-499m	LAFPF	CL	30	2.82	0.93	0.83
147	82838	Morobe (Yalu)	C	0-499m	LAFPF	Primary	23	2.30	0.86	0.73
147	82838	Morobe (Yalu)	E	0-499m	LAFPF	Primary	27	2.72	0.92	0.84
147	82838	Morobe (Yalu)	N	0-499m	LAFPF	Primary	28	2.65	0.92	0.80
147	82838	Morobe (Yalu)	W	0-499m	LAFU	Primary	17	1.89	0.79	0.67
356	83850	Morobe (Bukawa)	C	0-499m	LAFU	Primary	31	3.03	0.95	0.88
356	83850	Morobe (Bukawa)	W	0-499m	LAFU	N/A	27	2.53	0.90	0.77
357	95374	Morobe (Paiawa)	C	0-499m	LAFPF	CL	16	1.92	0.80	0.69
357	95374	Morobe (Paiawa)	E	0-499m	LAFPF	CL	22	2.39	0.89	0.79
357	95374	Morobe (Paiawa)	N	0-499m	LAFPF	CL	19	2.18	0.84	0.74
357	95374	Morobe (Paiawa)	W	0-499m	LAFPF	CL	29	2.90	0.93	0.86
1415	96863	Morobe (Biaru)	C	1000-2500m	MF	Primary	17	2.01	0.79	0.71
1415	96863	Morobe (Biaru)	E	1000-2500m	LMF	Primary	18	2.05	0.83	0.71
1415	96863	Morobe (Biaru)	W	1000-2500m	LMF	N/A	14	1.59	0.76	0.60
1455	22124812	WHP (Baiyer)	N	1000-2500m	LMF-N/A	N/A	21	2.26	0.86	0.74
1514	22124812	WHP (Baiyer)	W	1000-2500m	LMF-N/A	N/A	21	2.39	0.88	0.79
1562	22124812	WHP (Baiyer)	C	1000-2500m	LMF	Primary	32	2.78	0.92	0.80
1706	22124812	WHP (Baiyer)	E	1000-2500m	LMF	Primary	20	1.62	0.66	0.54
2350	75788	EHP (Bena)	E	1000-2500m	LMF-N/A	N/A	6	1.17	0.56	0.65
2447	75788	EHP (Bena)	C	1000-2500m	LMF	Primary	29	2.24	0.81	0.67
2454	76797	EHP (Henganofi)	W	1000-2500m	LMF	Primary	24	2.36	0.88	0.75
2486	76797	EHP (Henganofi)	C	1000-2500m	LMF	Primary	28	2.37	0.85	0.72
2495	76797	EHP (Henganofi)	N	1000-2500m	LMF	Primary	24	2.36	0.87	0.75
2503	75788	EHP (Bena)	N	2500+ m	MF	Primary	24	2.30	0.87	0.73
2529	76797	EHP (Henganofi)	E	2500+ m	MF	Primary	12	1.44	0.63	0.62
2550	75788	EHP (Bena)	W	2500+ m	MF	Primary	15	1.75	0.79	0.66
2714	22133794	WHP (Tambul)	W	2500+ m	MF	Primary	29	2.53	0.90	0.75
2723	22133794	WHP (Tambul)	N	2500+ m	MF	Primary	23	2.10	0.78	0.67
2728	22133794	WHP (Tambul)	C	2500+ m	MF	Primary	19	2.23	0.85	0.76
2746	22133794	WHP (Tambul)	E	2500+ m	MF	Primary	24	2.38	0.87	0.75
2779	22130649	WHP (Kumul)	C	2500+ m	LMF	CL	18	2.13	0.85	0.77

Anova-Test

Table 4 One-way Anova Test between forest types along altitudinal gradients

	F	P-value	F crit	Difference
Species count	1.069155	0.351675	3.199582	No
Shannon	1.520442	0.229398	3.199582	No
Simpson	1.694834	0.194895	3.199582	No
Evenness	3.677893	0.03298	3.199582	Yes
Evenness (LAFPF & LMF)	5.526299	0.023883	4.091279	Yes
Evenness (LMF & MF)	0.341917	0.567417	4.543077	No
Evenness (LAFPF & MF)	2.865701	0.098671	4.098172	No

One-way Anova Test (Table4) between forests types between altitudinal ranges observed indicates that there is no significant difference between forest types using Shannon Index and Simpson's Index. However, there is significant difference in Evenness between forest types. Further analysis showed that the forest types between low altitude forest on plains and fans and lower montane forest showed significant difference.

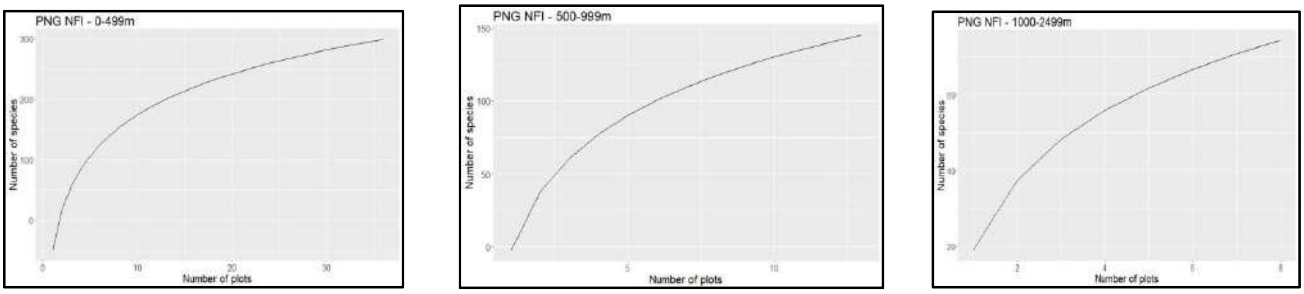

Figure 2 Number of plots between altitudinal ranges against tree species diversity

Tree species (number of trees) increases as the number of plots is surveyed between plots (Figure 2) along altitudinal gradients. This is expected to increase as more clusters are surveyed.

Table 5 Study by Katovai *et al* (2015) on Plant Diversity: Forest type acronyms explained: RSF = Riverine succession forest, LMF = Lower montane forest, HF = Hill forest and RMF = Riverine mixed forest

Forest Type	Altitude (m)	Mean species richness	Shannon Index	Est. Forest height (m)	Tree stand density	Est. mean biomass (t)
RSF	~874	31±2.2^{D}	2.60±0.09^{B}	22.8±0.6^{C}	62.3±4.6^{A}	277.4±26.8^{C}
LMF	~1174	44.8±1.0^{C}	2.73±0.15^{B}	21.2±1.4^{C}	41.3±1.5^{B}	314.9±24.3^{BC}
HF	~665	50.3±2.6^{B}	3.07±0.04^{A}	25.9±0.7^{B}	47±1.8^{B}	441.5±31.9^{B}
RMF	~173	55.3±1.9^{A}	3.2±0.09^{A}	31.6±1.4^{A}	41.5±3.1^{B}	1113.2±141^{A}

Source: Katovai *et al* (2015)

Discussion

A total of 2,222 trees were enumerated from 53 plots surveyed comprising of 228 unique tree codes by genera and 240 unique codes by species (unknown species were not included here). Preliminary results using Shannon-Weiner Index, Simpson's Index and Evenness indicate that there is no difference in tree diversity along altitudinal gradients between clusters (Table 2) but differ slightly between plots (Table 3). As expected the disturbed forest along altitudinal gradients with some form of human activities display low tree diversity. Conversely, the plots that remain in their natural state tend to have high tree diversity. Although ANOVA test indicate that there is no significant difference between forest types using Shannon-Weiner Index and Simpson's Index, it showed significant difference in Evenness between low altitude forest on plains and fans and the lower montane forest. On the other hand, tree species (number of trees) increases as the number of plots is surveyed between plots (Fig. 2) along altitudinal gradients. This is expected to increase as more clusters are surveyed. Current study when compared with a diversity study conducted by Katovai et al (2015) on forest type LMF, results on Shannon-Weiner Index are comparable. Shannon Index in study by Katovai et al (2015) recorded 2.73 (Table 5) whilst this study with similar forest type in cluster 96863 (Biaru) and cluster 75788 (Bena) had Shannon Index of 2.23 and 2.87 respectively indicating that diversity is quite similar. Diversity in cluster 22124812 (Baiyer) and cluster 76797 (Henganofi) with similar forest type had Shannon Index of 3.47 and 3.19 respectively indicating more diversity within similar forest type.

Although, only 15 clusters (53 plots) of the targeted 1000 clusters have been surveyed to date, results of tree species diversity showed some interesting results between plots and clusters using the Shannon-Weiner index, Simpson's Index and Evenness. More data would provide better comparisons between cluster and plot in different altitudinal gradients in different forest types for tree species diversity for PNGs first ever National Forest Inventory.

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Patterns of Fern Species Richness and Beta-Diversity in Highland Ecosystem of Papua New Guinea

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Abstract

In this study, I assessed the species beta-diversity, species distribution pattern of terrestrial, epiphytic and tree ferns from 11 cluster forest composed of four 10m radius plots distributed in the highland ecosystems of Papua New Guinea primary rainforests. The 10m radius plots were laid in the field which examined from the center plot. Fern species are identified within the process of enumeration of non-tree plant species biodiversity assessments during Papua New Guinea Multipurpose National Forest Inventory. A total of 49 morph species (31 Terrestrial ferns, 13 Epiphytes ferns, 3 tree ferns and 2 climbing ferns) belonging 38 genera and 21 families were documented from multipurpose national forest inventory survey.

Summarized results: The tested model was significant (r=0.08209, P=0.002).

Introduction

Ferns are distinctively challenging group to determine species due to poorly described index of numerous volume of species being overlooked and widely distributed in the rainforest (Katovai, Katovai, Edwards, & Laurance, 2015; Kessler, Salazar, Homeier, & Kluge, 2014; Roberts, Dalton, & Jordan, 2005; Testo & Sundue, 2016). The Pteridophytes are globally species rich and dubious groups of plant, thus requires critical assessments for accurate botanical species determinations and descriptions (Katovai *et al*., 2015; Roberts *et al*., 2005; Testo & Sundue, 2016). In New Guinea (NG) rainforest, ferns are being one of the obscure and rarely documented orders of primordial plant dues to lack of documentations (Katovai *et al*., 2015). Although ferns existed before the flowering plants(Van Konijnenburg-van Cittert, 2002), ecological knowledge of ferns has been poorly enumerated for better understanding and fern research in the rainforest to contribute in forest conservation and carbon assessment. For instance, a flimsy fern like Hymenophyllum requires careful assessment and special collection methods where ample effort is given for thorough checks in the clefts of rocks, soil, buttresses, barks, stems and twigs of trees (Mandl, Lehnert, Kessler, & Gradstein, 2010). As such, patterns of fern distribution, community structure, functional diversity, species richness and abundances including other ecological variables could be essentially understood.

Examining fern sampling together with other upper plant sampling in the field with the multipurpose national forest inventory (NFI) are most likely to omit most of the flimsy fern species. In an intense research covering multiple taxa, more collections were done on obvious ferns that are of larger leaves and diameter at breast height (dbh) >5cm.

This study aimed to estimate the fern species distribution, species richness and beta diversity of ferns in the highland ecosystems (> 1000m) of Papua New Guinea, where it captures the base line information for species determination which could lead to broader understanding of fern communities in diverse rainforests stratum.

Methods

1. *Study Sites and plot designs*

This study was conducted on several satellite clusters composed of four radius forests plots ascending from sea level to higher altitude (approximately 50m-2700m.a.s.l) along disjointed mountain ranges (the Owen Stanley Range and

Bismark Range). These plots were randomly selected using GPS Map Garmin 511 GIS remote sensing model. All the plots were accessible by sea, rivers and roads. On the forest floor, the centre radius plot was divided into eight segments to ease the sampling of plants in the plot. This method was replicated in 11 clusters. Five clusters were completed in the highland (>1000 m.a.s.l) and six clusters in the lowland (<1000m.a.s.l) primary forests using the similar methods.

All the forest types were stratified into 11 categories (Table 1) based on standardized vegetative characteristics (Cornelissen *et al*., 2003).

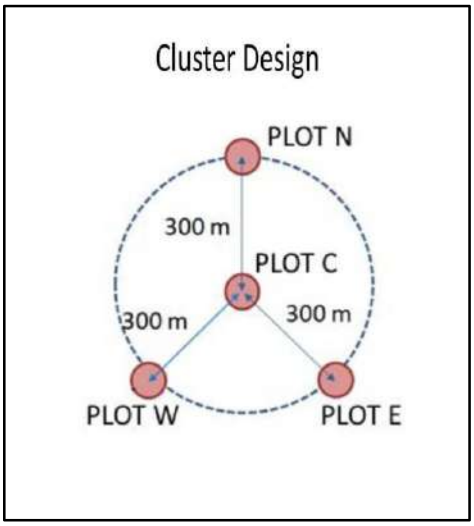
2. *Diversity Measurements*

Pteridophytes were collected among other species of low story plants from the supper plot. Supper plot in this term is defined as the plot in the centre of the cluster and has been specifically marked 10m radius limited to collect all species found within this parameter from the ground level to low storey trees (tree layers at 10m height). Furthermore, supper plots were specifically considered for biodiversity survey among three other plots within the cluster.

In each clusters, four 25m radius plots were established and distanced 300m apart, starting from the Centre plot to North plot, then North East plot and South West plots (Fig. 1) that forms a triangular pattern where ferns are being captured during the survey.

Table1 The forest types and altitudes of fern sampling sites

Study Sites	Forest Types (Description)	Altitude (m)
Tambul	Lower Montane (Primary Forest)	2728
Henganofi	Montane Forest	2486
Bena	Lower Montane Forest	2447
Baiyer	Low Altitude Forest	1562
Biaru	Lower montane Forest	1450
Paiawa	Low Altitude Degraded Primary forest	357
Bukawa	lower altitude Primary forest	356
Yalu	Low altitude forest Degraded	147
Kobio	Lower Altitude Forest	137
40 Mile	Low altitude Forest	73
Eware	Low altitude forest fan	70



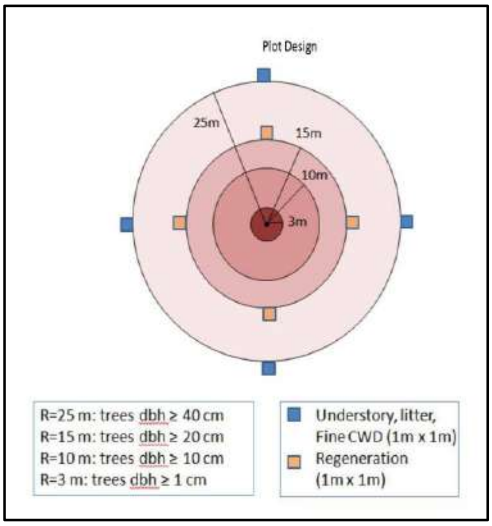


Figure 1 Cluster and plot sampling designs

3. Sampling Design

Compared to previous studies on ferns done in quadratic designed plots to estimate abundance and species richness (Kessler *et al*., 2014). However, 10m radius plots adds value for diversity estimations which could be used on remaining uninterrupted tract of mature forest that spans such a large altitudinal gradient on central mountain ranges (Owen Stanley, Bismarck Ranges, Finisttere ranges etc.) from southern part of PNG towards the Indonesian border.

Results

A total of 49 morpho-species (31 Terrestrial ferns, 13 Epiphytes ferns, 3 tree ferns and 2 climbing ferns) belonging 38 genera and 21 families were documented from multipurpose national forest inventory survey.

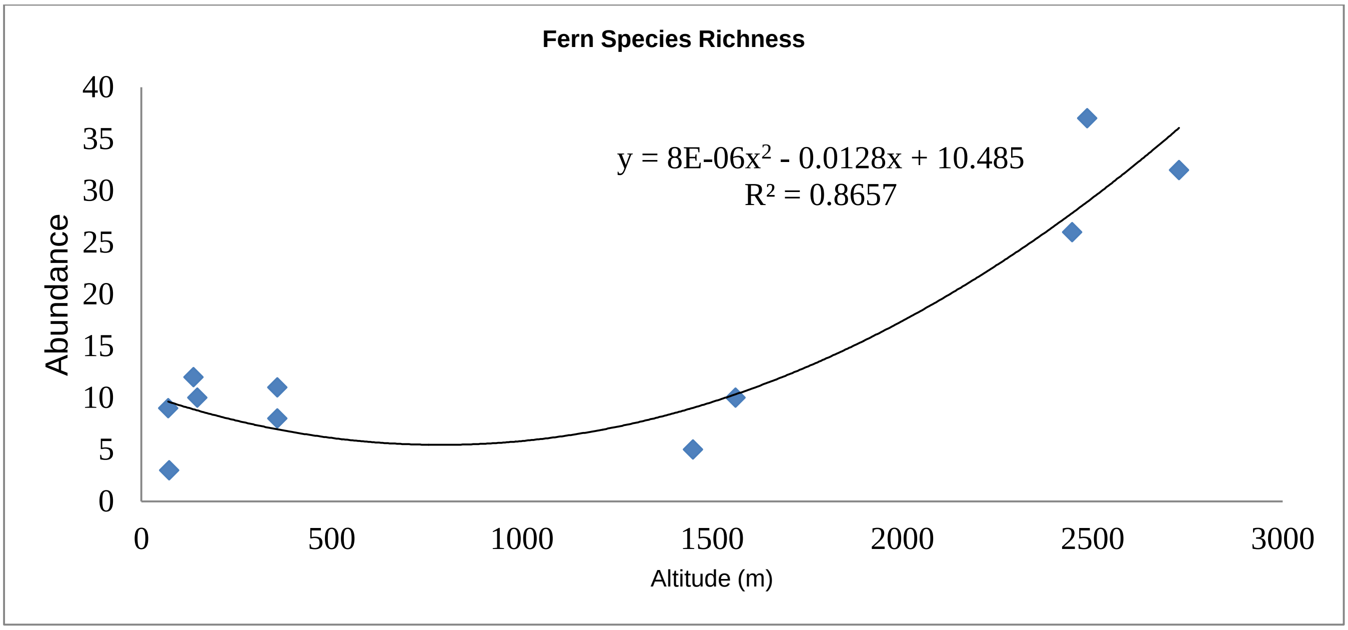


Figure 2 Exponential growth of fern abundance with increasing elevation

The result best fitted with significant (r=0.08209, P=0.002) result (figure.2) when using Statistic species test model. Even calculating the species using the Shannon (H’) Weiner species diversity index for the entire 11 clusters, the result was significant. Further calculation using the H’ to calculate alpha diversity was problematic due to no samples captured for some species with increasing singletons.

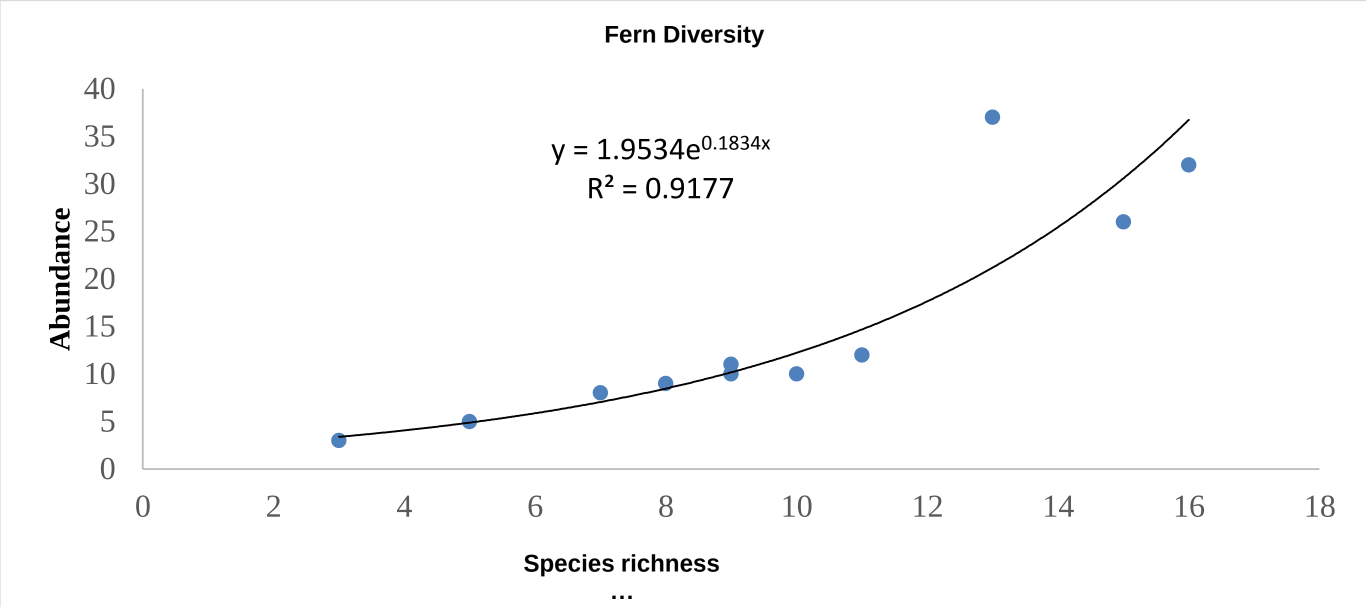


Figure 3 Species richness verses abundances ranking plots for species diversity

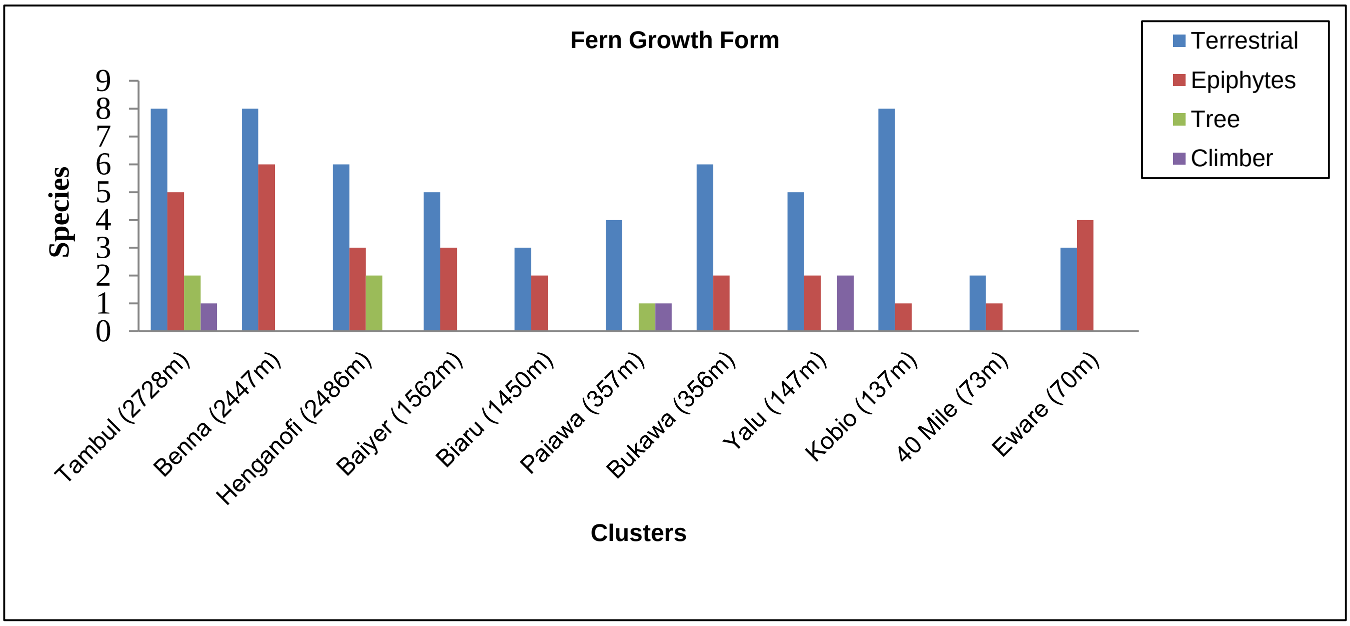


Figure 4 Species richness of terrestrial, Epiphytes, tree and climbing ferns between elevation forest plots

Discussion

Although many fern surveys were done using quadratic (20m x20m) plots as standardized scientific methods to assess ferns (including other plants) in the rainforest(Kessler, Hofmann, Krömer, Cicuzza, & Kluge, 2011), however, this study shows significant results ($r=0.08209$, $P <0.05$) from a radius plots design on multi-purpose intensive forest inventory. The study also suggests that there is no difference in conducting botanical plant diversity survey using either quadrat (20mx20m) or the 10m radius plots (Figure 2). Species richness and abundance in figure 3 depicts the plot with species diversity at each elevation, Tambul plot tends to be leading with species rich plot whereas most of the plot in the lowland were capturing poorly on species accumulation.

Species growth form assessment (Fig.4) shows that there are more ferns at terrestrial level that are easy to collect only if they were large and visual on the forest floor, whereas the epiphytes are mostly collected from reachable height up to 10m from the ground level. Only few tree ferns were captured from the center plots from the clusters were most likely absent. General observations record shows that there were more ferns outside the radius plot located for fern enumeration.

The rainforest where the NFI clusters being established and centered with plots are unexplored forest areas for biodiversity assessments. The rainforest of Papua New Guinea reserves vast volume of fern species yet one of the least explored pristine tropical forest region in the world (Katovai *et al*., 2015) to understand the limits of species richness, evenness, composition, beta diversity and spatial distributions in the terrain, mountains, trunks and valleys as the niches that encourages ferns (Kessler *et al*., 2014).

Forest strata and topography plays a significant role on fern species distributions patterns in the rainforest ecosystems(Kessler *et al*., 2014). The forest where the plots radiated were mostly mossy and wet. The Cyatheaeae were the common species with frequently sampled species at all 11 plots from different elevations followed by the Dicksoniaceae species.

Furthermore, simultaneous scrutiny of vegetal studies in an intensive biodiversity exploration, most of the flimsy ferns were fairly collected thus considered to be trivial and won't be easily captured in an intensive study. However, specific fern sampling methods and design are crucially regarded as an important exercise to avoid trifling epiphytes ferns, terrestrial ferns and climbing ferns.

In conclusion, the exponential increase for fern species won't continue to increase with plot size but it tends to drop to form a concave binomial distribution pattern.

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Tree species composition and forest structure in primary and secondary forests along elevation gradient in the Upper Mape Area, Papua New Guinea

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Abstract

Little is known about the potential responses of tree species in Papua New Guinea (PNG) to climate change. The relationship between altitude and tree species serve as proxy for understanding species response to change in temperature therefore providing insights into the potential effects of climate change. In this study we investigated the distribution of dominant tree in the Upper Mape forest area on the Huon Peninsula, in Morobe Province, PNG. All trees ≥ 10cm diameter breast height and seedlings and saplings were assessed in quadrats of 1 m^2 and 4 m^2 respectively were assessed in 400 m^2 that occur across an altitudinal gradient ranging from 400 m to 1300 m in elevation above sea level.
The assessment recorded a total of 78 different tree genera in 48 families. Average stand density was 621 stems per hectare with 90% of trees less than 40 cm in diameter at breast height. Tree species diversity decreased as altitude increased. An ordination analysis showed clear demarcation between primary and secondary forests and high level dissimilarities in the distribution of tree species in different sites. Trees in the families of Lauraceae and Myristicaceae were dominant in low-altitude forests in both over storey and regeneration. In-mid altitude forests, Syzygium, Litsea and Castanopsis were the dominant genera and Syzygium and Castanopsis were also dominant in high-altitude forests. In secondary forests, the introduced species Albizia chinensis was dominant in overstorey, and saplings of Piper anducum were the dominant. Regeneration of primary forest tree species in some secondary forest sites was observed. The overall pattern indicated that species diversity, tree density and diameter size decreased with increasing altitude in both primary and secondary forests and that species varies with elevation and forest types.

Key words: climate, Papua New Guinea, primary forest, secondary forest, tropical forests.

1. Introduction

In tropical forests, human-induced disturbances and their impacts on forests species diversity and community structure are considerable. Shearman et al (2008) claimed that PNG's forests have suffered considerably through deforestation and degradation mainly due to logging and shifting cultivation. The studies by Abe (2007) revealed that the residual forests recover positively after selective harvesting, while clear felling sites showed rapid forest succession and regeneration of primary tree species (Saulei et al 1999). Shifting cultivation is the dominant disturbance driver of the country's forests, with 85% of PNG's population being subsistence rural dwellers that continuously modify forest landscapes (Burley et al 2011).
Baseline studies and inventories are vital for determining the structure, species diversity, spatial distribution of species, stand dynamics and growth rates of species (Anitha et al 2010). These studies are lacking in PNG. Few studies have been conducted on undisturbed natural forests in PNG. At Crater Mountain Wildlife Management Area, Weiblen (1998) studied forest composition and structure at 550 m above sea level while Wright et al (1997) studied tree and liana enumeration and diversity at 900 m a.s.l. Balun et al (2002) found that species diversity and spatial pattern varied along different altitudinal gradients and Paijman (1970) investigated the interrelationship of structure, floristic and habitat on two forest types, forests on mid-slope and forest on plateaux.
Studies across different elevational gradients are important for understanding how forest composition changes with changes in environmental conditions (Hua 2003). McCain and Grytes (2010) pointed out that several factors change with increasing elevation and the most obvious one is a decrease in temperature. Temperature decreases by an average of about 0.68°C for every 100m increase in altitude (Barry 2008). Other climatic and biotic factors which change with increasing elevation are air pressure, solar radiation, precipitation and cloud. These variations in climatic and abiotic conditions along elevational gradients can cause changes in species richness and composition (Grytes et al 2006). Elevational gradients can serve as baselines for comparison of population declines, range shifts and extinction risks under climate change (Parmesan, 2006). The FAO (2012) reported that little information exists on impacts of climate change on tropical forests and how tropical forests will respond. These impacts can potentially be assessed by studying how forest composition varies across environmental gradients.
The current study assessed tree species composition and structure in primary and secondary forests across an elevation gradient in a rural location in PNG where forests are used for rural subsistence purposes. This study aimed

to determine the following: (i) The variability in forest composition and diversity along an altitudinal gradient (ii) The variability in forest structure (density, diameter distribution and basal area) along altitudinal gradient; and (iii) The impacts of shifting cultivation on forest composition and diversity along an altitudinal gradient.

2. Methodology

2.1 Site Description

2.1.1 Locality

The study area is in in the Upper Mape region in the Huon Peninsula in Morobe Province, PNG. The elevation rangers from 400 m and 1300 m and contain lowland and montane forest zones.

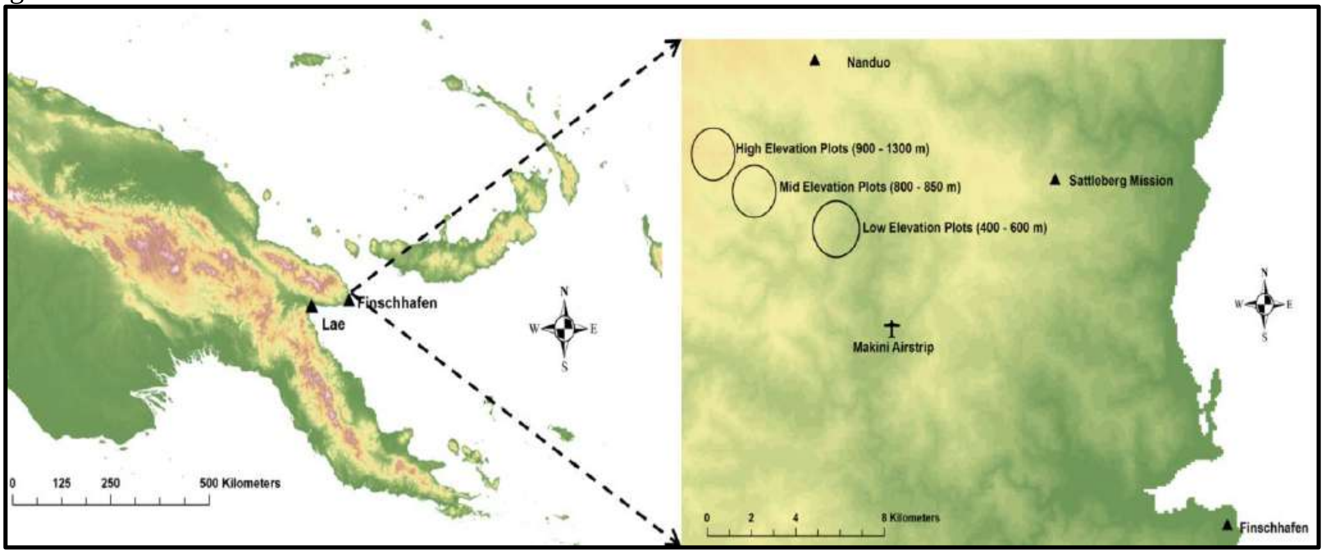

Figure 1 A map of the study area

The study area is located about 35 kilometres northwest of the township of Finschhafen in Morobe Province, PNG. The site accessed by ferry from Lae to Finschhafen then by vehicle from Finschhafen to Nanduo. It then takes a day to walk from Nanduo to the study site.

2.1.2 Climate

The Upper Mape region receives 1800–3500 mm of annual rainfall (McAlpine 1983). The wet season occurs between May and October. The wettest months are July and August and the driest months are January and February. In wettest months, the area receives continuous rainfall daily.

The temperature varies considerably along the altitudinal gradient. On average, the area has the maximum temperatures between 22-30^{o}C and the minimum temperatures between 12-19^{o}C (Bellamy and McAlpine (1995). During wet seasons, 50% cloud cover is common (McAlpine 1983).

2.1.3 Vegetation and Forest types

The study area contains lowland and lower montane zones. Lowland forest occurs at around 400 m a.s.l and is characterised by the occurrence of *Pometia pinnata*, *Pangium edule*, *Chisoheton sp* and *Celtis spp*. Lower montane forest occurs from 500 m and extending up to 1300 m. It is characterised by the presence of *Castanopsis acuminatissima* which can form a pure stand in certain locations. Associated species of trees are *Araucaria hunstenii*, *Lithocarpus spp* and Lauraceae and Myrtaceae families. *Anistoptera thurifera* is found mainly on ridges and top of plateaus, coniferous tree species such as *Decussocarpus sp* and *Prumnopty spp* are present in mountain tops (Johns 977 and Paijmans 1975).

2.2 Sampling approach and measurements

Forest assessment was conducted in both primary and secondary forests at three locations at three elevations that range in altitudes from 400 to1300 meters. In these altitudinal zones, a total of thirty-five (400 m^2) plots were established – 23 in primary forests and 12 in secondary forests resulting from shifting cultivation. Secondary forests were 13-15 years old. Sampling plots in primary forests were purposefully located in accessible and sufficiently large remnants.

In these plots all trees with diameter breast height (DBH) ≥10 cm were measured using a steel diameter tape and the genus identified and recorded. While identification to species level was possible for many trees, the genus is reported in this study. In each plot, four 1 m x 1 m (1 m^2) quadrats were randomly established and seedling ≥30 cm height was enumerated and the genus recorded. Saplings up to 1.5 m in height in each plot were assessed in four 2 m x 2 m (4m^2) quadrats (McKinty 1999 and Vatassan1989.)

2.3 Data analysis

2.3.1 Quadratic Mean Diameter

In this study, arithmetic mean and mean diameter quadratic mean diameter (QMD) were determined (Curtis and Marshall 2000) in order to calculate basal area and provide a metric of stand structure.

$$\sqrt{\frac{\sum D_i{}^2}{n}}$$

Where D_i is the Diameter at breast height (DBH) of the i^{th} tree, and n is the number of individuals.

2.3.2 Basal area

The basal (BA) was calculated using quadratic mean diameter using formula below:

$BA = (\pi D^2)/4*10000$

Where BA = Basal Area (m^2), D = Diameter at breast height (cm), is QMD and π = (3.142)

2.3.3 Species Composition

To determine if differences in composition exists between primary and secondary forests and between different elevations within a forest type used for ordination analysis on species abundance data PRIMER (version 6.1.1.5), Multi-Dimension Scaling (MDS) Clarke and Gorley 2006) was used for ordination based on Bray Curtis similarity. Similarity percentage analysis (SIMPER, Clarke (1993)) of the field collected abundance data was used to identify the main species contributing to differences in composition with respect to forest type and elevation. The analyses were performed on two abundance datasets, density and basal area for trees and for regeneration (seedlings and saplings).

3. Results

3.1 Tree species composition

Species accumulation curve was developed to illustrate the diversity of tree species recorded at different elevations. A greater number of species were found as the sampling size increased in lowland and mid-altitude forests compared to the high-altitude sites. The curves for both mid-altitude and high-altitude forests appear to approach an asymptote, while in the lowland forests the curve continues to increase, indicating that sampling did not capture the complete range of tree diversity in the lowland sites (Figure 2). Lowland and mid-altitude forests were found to have a higher richness of tree species compared to high-altitude sites. The overall pattern suggests that lowland forests are more diverse than the forests in the mid and higher elevations.

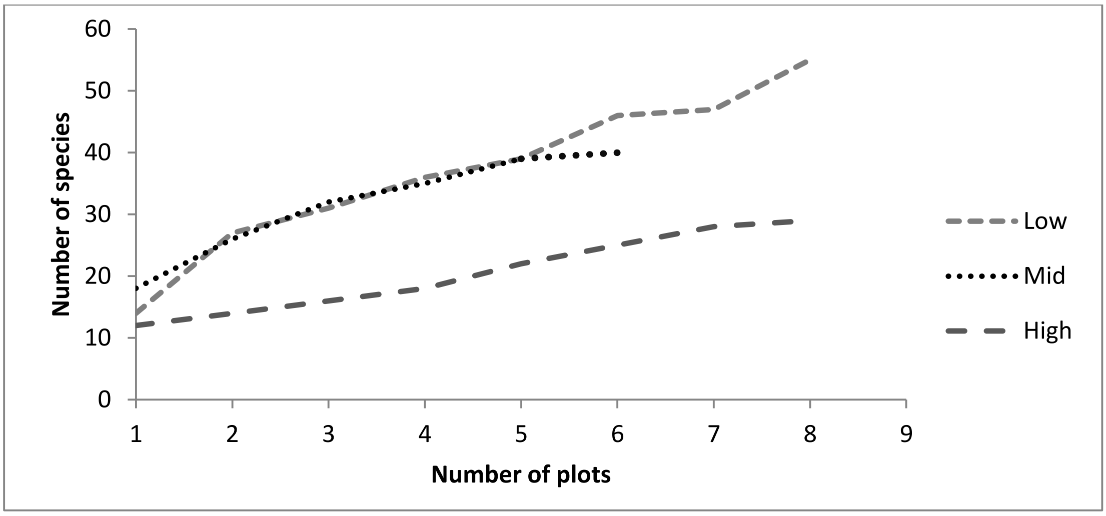

Figure 2 Species accumulation curve for plots at low mid and high elevations

For primary forests, three distinctive groups were identified based on the ordination analyses align closely with the stratified elevational gradient. There appeared to be an overlap in composition between one of 900 m high altitude plots an mid-altitude plots (800-850) metres suggesting that 900 m likely the ecotone between mid and high elevation forest types.

Primary forests were clearly separated from secondary forests along the elevation gradient. Unlike with the primary forests, secondary forest stands did not follow ordinate strongly along the elevation gradient except for the two highest sites (Figure 3a). These results indicate that the composition of primary forests is strongly influenced by elevation while secondary forest composition is not. Similar to the pattern observed for the overstorey three communities; there was a clear separation between regeneration of primary forests and secondary forests (Figure 3b). The overall pattern suggests the composition of regeneration in primary forests varies along the elevation gradient however there is a greater overlap between lower and mid elevation sites and mid and high elevation sites than found for overstorey composition. Regeneration in secondary forests showed a higher degree of dissimilarity than observed in the overstorey composition of secondary forests.

The ordination analysis based on abundance derived from BA yielded a similar pattern as based on abundance based on density (see Figure 3). The only difference being for secondary forests where all plots overlapped suggesting no differences in composition based on basal area across the studied elevation gradient.

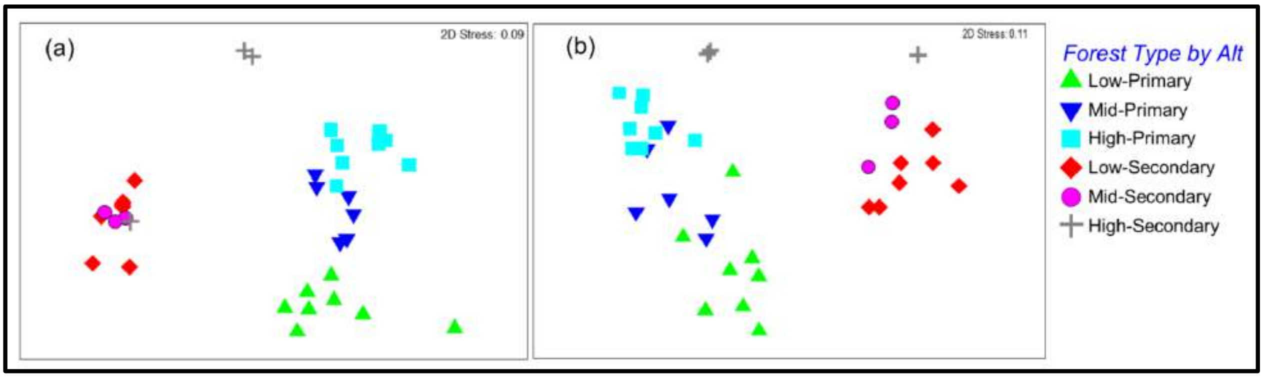

Fig 3 Ordination of tree genera in primary and secondary forests in low, mid and high-altitudes for tree compostion (a) and composition of regeneration (b)

The SIMPER analysis found that for the overstorey compostion, Lauraceae and Myristicaceae (*Litsea spp*, *Horsfieldia spp*, *Cryptocarya spp* and *Myristica spp*) were responsible for differences in composition compared to the mid and high elvation sites. (Table 1). For the mid-altitude forests, the genus *Syzygium* followed by *Litsea* and *Melastoma* contributed the most to compostional differences For high-altitude plots, the genus *Syzygium* and *Castanopsis acuminatissima* were largely responsible for discriminating the composition of these plots (Table 2). Regeneration of these two three species contributes more than 65% of species composition at this altitude. *Syzygium spp* were found in both overstorey and regeneration across elevation gradient.

For the understorey compostion, Lauraceae and Myristicaceae species, in particular *Litsea* spp., were again responsible for discriminating between lowland and higher elevation plots. In the mid-altitude stands, *Syzygium* and *Litsea* were the most important species while at high elevations. *Castanopsis acuminatissima* and *Syzygium* were again the most important species for discriminating high from lower elevation plots (Table 2). *Cryptocarya*, a dominant genus in lowland forest overstorey, was also present in the understorey at higher elevations but not in the overstorey. The genus *Aglaia* was found in primary forests across the elevation gradient, though only found in the regenerating cohort in lowland sites.

Table 1 Tree genera in the overstorey (OS) and regeneration (REG) in primary forests at low, mid and high-altitude

Genus	Family	LOW OS (%)	LOW REG (%)	MID OS (%)	MID REG (%)	HIGH OS (%)	HIGH REG (%)
Litsea	Lauraceae	30.8	36.0	16.3	29.5	0.0	0.0
Horsfieldia	Myristicaceae	16.7	12.0	0.0	0.0	0.0	0.0
Cryptocarya	Lauraceae	13.9	22.7	0.0	9.8	0	9.5
Myristica	Myristicaceae	8.60	0.0	0.0	5.0	0.0	0.0
Ficus	Moraceae	5.0	0.0	0.0	0.0	0.0	0.0
Melastoma	Metastomataceae	0.0	0.0	14.0	0.0	0.0	5.8
Elaeocarpus	Elaeocarpaceae	0.0	0.0	9.9	0.0	3.1	2.6
Alphitonia	Rhamnaceae	0.0	0.0	7.1	0.0	0.0	0.0
Cinnammomum	Lauraceae	0.0	0.0	5.4	0.0	0.0	0.0
Gordonia	Euphorbiaceae	0.0	0.0	5.1	0.0	0.0	0.0
Syzygium	Myrtaceae	4.0	6.5	19.4	33.8	33.9	34.3
Castanopsis	Fagaceae	0.0	0.0	5.0	14.0	28.1	30.7
Eurya	Pentaphyllaceae	0.0	0.0	0.0	0.0	10.0	0.0
Aglaia	Meliaceae	0.0	7.00	2.95	0.0	9.1	6.5
Weinmannia	Cunoniaceae	3.3	0.0	0.0	0.0	0.0	0.0
Lithocarpus	Fagaceae	2.9	3.0	0.0	0.0	0.0	0.0
Flindersia	Rutaceae	2.8	0.0	0.0	0.0	0.0	0.0
Sterculia	Sterculiaceae	1.9	0.0	0.0	0.0	0.0	0.0
Neonauclea	Rubiaceae	1.7	0.0	0.0	0.0	0.0	0.0
Buchanania	Anacardiaceae	0.0	0.0	2.4	0.0	0.0	0.0
Canarium	Burseraceae	0.0	0.0	4.5	0.0	0.0	0.0
Engelhardtia	Jungladaceae	0.0	0.0	0.0	0.0	3.4	0.0
Sloanea	Elaeocarpaceae	0.0	4.7	0.0	0.0	4.1	0.0
Palaquium	Sapotaceae	0.0	0.0	0.0	0.0	0.0	2.7

Secondary forests had a lower diversity of common species than primary forests with similar compositions identified between low and mid-altitude sites. Only seven trees species were found to be important contributors to the overstorey in these plots. *Albizia chinensis* and *Macaranga spp* were found to be the dominant species in the secondary forest overstorey at low and mid elevations but not at high elevations where *Eurya*, *Elaeocarpus*, *Vernonia*, *Elmerrillia*, and *Castanopsis* were the most important species (Table 2). Of these species only *Castanopsis* was an important species for discriminating high elevation primary forest stands from lower elevation plots.

Of the tree species sampled, only five tree species were found to contribute significantly to differences in the understorey between lowland and mid elevation secondary forests. *Piper anducum*, which is an alien tree species, was found to dominate the disturbed sites below 900 m but did not contribute to higher elevation sites. The *genus Litsea* was found regenerating in both lowland and mid elevation secondary forest sites while *Szygium* was found to be the largest contributor for differentiating high elevation secondary forest stands from lower elevation stands. *Litsea* and *Szygium* are therefore important species for discriminating primary and secondary forests composition along the sampled elevation gradient.

Table 2 Percentage contribution to basal area of tree genera in the overstorey (OS) and regeneration (REG) in secondary forests at low and high-. Species are ordered in decreasing proportion of basal area for the low-altitude overstorey forest to demonstrate the separation in species composition between sites

Genus	Family	LOW OS	LOW REG	MID OS	MID REG	HIGH OS	HIGH REG
Albizia	Fabaceae	21.7	0.0	30.6	0.0	0.0	0.0
Macaranga	Euphorbiaceae	20.1	0.0	19.5	0.0	0.0	0.0
Trema	Ulmaceae	13.8	0.0	9.9	0.0	0.0	0.0
Althoffia	Tilliaceae	13.5	0.0	13.3	0.0	0.0	0.0
Homalanthus	Euphorbiaceae	8.3	0.0	9.9	0.0	0.0	0.0
Ficus	Moraceae	8.3	11.7	10.0	25.4	0.0	0.0
Commersonia	Sterculiaceae	7.0	0.0	0.0	0.0	0.0	0.0
Eurya	Pentaphyllaceae	0.0	0.0	0.0	0.0	45.11	17.7
Elaeocarpus	Elaeocarpaceae	0.0	0.0	0.0	0.0	16.83	11.1
Vernonia	Asteraceae	0.0	0.0	0.0	0.0	16.83	0.0
Castanopsis	Fagaceae	0.0	0.0	0.0	0.0	10.62	0.0
Elmerrillia	Magnoliaceae	0.0	0.0	0.0	0.0	10.62	0.0
Euodia	Rutaceae	0.0	6.9	0.0	25.4	0.0	17.7
Piper	Piperaceae	0.0	52.9	0.0	27.9	0.0	0.0
Litsea	Lauraceae	0.0	13.5	0.0	16.8	0.0	0.0
Glochidion	Euphorbiaceae	0.0	6.1	0.0	0.0	0.0	0.0
Syzygium	Myrtaceae	0.0	0.0	0.0	0.0	0.0	31.3
Canarium	Burseraceae	0.0	0.0	0.0	0.0	0.0	11.1
Melastoma	Melastomataceae	0.0	0.0	0.0	0.0	0.0	11.1

3.2 Forest structure

Forest structure varied considerably between the three altitudinal zones (Table 3). Mid-altitude had a highest mean stand density (842 spha) compared to low-altitude forest (609 spha) and to high-altitude forests (468 spha). The lowest stand density of 375 spha was in a plot in the low-altitude and the highest was 1100 spha was recorded in a plot in mid-altitude. The overall density of the forest area between 400 m and 1300 m altitudes is 621 spha.

The average QMDBH for was 32.4 cm in low-altitude plots, 28.7 cm for mid-altitude and 29.3 cm for high-altitude forest plots. The maximum diameters for each altitudinal zone are 113 cm for low-altitude, 85.9 cm for mid-altitude and 71.5 cm for high-altitude forest. Mid-altitude forest had the smallest MQDBH but had the largest average basal area per hectare of 54.57 m^2/ha.

Table 3 Summary of forest structure for plots in primary forests in the Upper Mape region

Location	Alt Zone	Alt (m)	SPH	QMDBH (cm)	Min DBH (cm)	Max DBH (cm)	BA (m^2/ha)
Fake	Low	400	375	25.7	11	44	19.37
Doing 1	Low	500	800	26.4	11	63.2	43.75
Doing 2	Low	500	825	26.8	10.1	63.6	46.57
Qaro 1	Low	500	600	38.1	10.2	113	68.48
Qaro 2	Low	500	625	32.0	11.2	63.1	54.15
Kambu 1	Low	600	600	36.7	11.2	78	63.60
Kambu 2	Low	600	675	36.3	13.3	71.1	69.86
Zimbo	Low	600	325	37.0	11.9	76.6	34.90
Mean Low	Low	400-600	609	32.4	10.1	113	50.09
Kanze 1	Mid	800	875	30.4	10.3	68.2	63.67
Kanze 2	Mid	800	1000	23.0	10.2	61	41.55
Gugang 1	Mid	800	1050	32.9	10	85.9	89.43
Gugang 2	Mid	800	1100	32.8	12	83.7	92.70

Zizi 1	Mid	850	525	22.4	11.5	38.4	20.62
Zizi 2	Mid	850	500	22.3	11.8	38.5	19.45
Mean Mid	Mid	800-850	842	28.7	10	85.9	54.57
Momori 1	High	900	425	30.2	10.8	65	30.41
Momori 2	High	900	500	28.7	11.2	60.1	32.31
Zazae 1	High	950	475	24.3	10.2	55	21.93
Zazae 2	High	950	525	30.8	10.8	65	32.37
Kobu 1	High	1000	425	32.22	11.1	70.4	34.64
Kobu 2	High	1000	475	29.5	11.6	65	32.37
Kabing 1	High	1300	475	29.6	10.2	19	32.68
Kabing 2	High	1300	450	35.2	10	71.5	43.85
Mean High	High	900-1300	468	29.6	10	71.5	32.27
Mean Overall		400-1300	621	30.3	10	113	44.76

3.3.1 Diameter distribution

The results in Table 4 showed that low- altitude forests had larger tree size (32.4 cm) than mid-altitude forests (28.7 cm) and high-altitude (29.6 cm) and the overall QMDBH is 30.3 cm. The boxplot in Figure 5 shows that this forest area has many trees. The maximum diameters for each altitudinal gradient are 113cm – low, 85.9 cm mid and 71.5 cm high (Table 3). Therefore, based on the maximum and the minimum DBH the obvious pattern is that the diameter size decreases as altitude increases, while QMDBH showed minimal differences in the distribution at each altitude.

Table 4 Summary of forest structure for plots in secondary forests in the Upper Mape region, Huon Peninsular, PNG

Location	Alt Zone	Alt (m)	SPH	QMDBH (cm)	Min DBH (cm)	Max DBH (cm)	BA (m^2/ha)
Fake	Low	400	375	18.8	11.7	30.9	10.38
Doing 1	Low	500	450	20.6	10.1	50.4	15.02
Qaro 1	Low	500	725	19.7	15.5	27.5	23.68
Qaro 2	Low	500	625	19.1	14.2	25.5	17.90
Kambu 1	Low	600	750	18.3	12.4	25.3	19.63
Kambu 2	Low	600	825	18.5	11.3	25.5	22.19
Zimbo	Low	600	550	21.8	10.9	61.4	20.52
Mean Low	Low	400-600	621	19.4	10.1	61.4	18.47
Kanze 1	Mid	800	750	17.8	11.3	25.3	18.70
Kanze 2	Mid	800	625	19.9	10.1	34.4	19.42
Gugang 1	Mid	800	800	18.4	11.2	23.8	21.15
Mean Mid	Mid	800	725	18.6	10.1	34.4	19.26
Kobu 1	High	1000	600	23.7	10.3	50.2	25.52
Kabing 1	High	1300	700	16.7	10	30.5	15.29
Kabing 2	High	1300	625	16.2	10	30.5	12.94
Mean High	High	1000-1300	641	19.0	10	50.2	18.25
Mean Overall		*400-1300*	*650*	*19.2*	*10*	*61.4*	*18.72*

The patterns of SPH, QMDBH, maximum and minimum DBH and BA at three altitudes in secondary are similar to the patterns shown for primary forests.

Secondary forests in mid-altitude had a highest stem per hectare (725) than high-altitude forests (641) and low-altitude forests (421). The lowest stand density of 375 spha was in a plot in the low-altitude and the highest was 825 spha was recorded in a plot in also in low-altitude. The overall stem per hectare in secondary forest for the forest area between 400 m and 1300 m altitudes is 650.

The average QMDBH of the area as shown in the Table 4 are 19.4 cm for low-altitude area, 18.6 cm for mid-altitude and 19.0 cm for high-altitude forests. The maximum diameters for each altitudinal gradient are 61.4 cm for low-altitude, 34.4 cm for mid-altitude and 50.2 cm for high-altitude forest. Even mid-altitude forest had the smallest

MQDBH but had the largest basal area per hectare of 19.26 m^2. This was principally due to the size of the stand density.

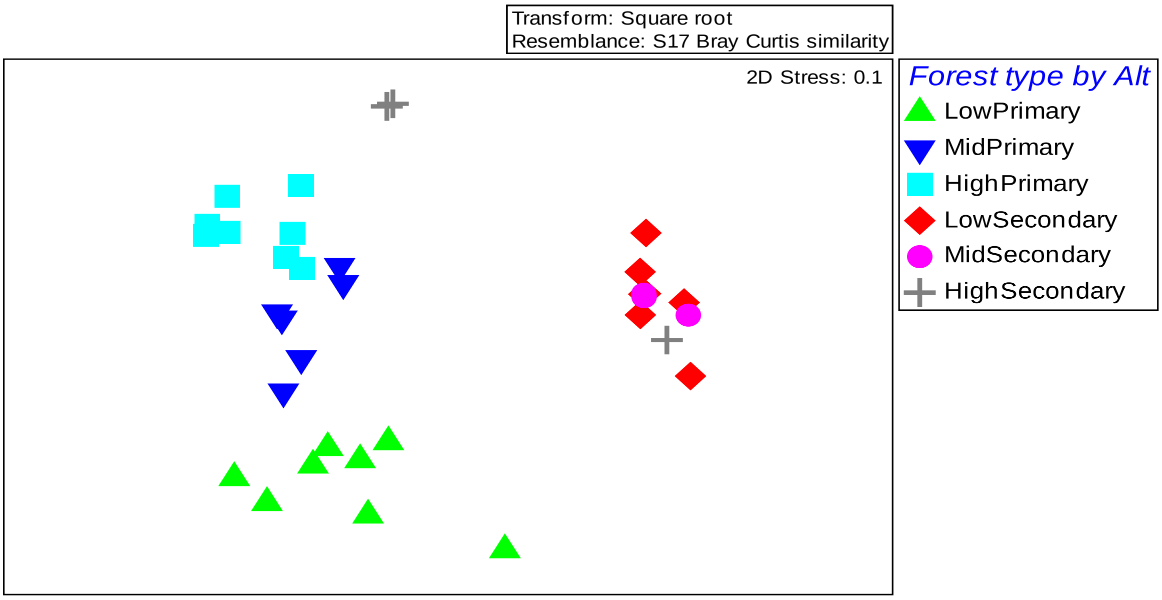

Figure 9 Ordination of BA for both primary and secondary forests along altitudinal gradient. The distribution pattern of BA shown in Figure 8 is almost similar to the distribution pattern of tree density as shown in Figure 3. However, only difference is in secondary forests is where there are overlaps of plots in all three altitudinal gradients

4. Discussion

4.1 Tree species composition, dominance and diversity

In this study, a total of 74 genera (species) from 43 families were recorded along the altitudinal gradient between 400 m and 1300 m a.s.l. Past studies in PNG have a greater diversity of tree species. Paijmans (1970) found 116 to 147 species in the forests at 600 m near Sibium in the Owen Stanley Range, while Wright et al (1997) found 228 trees and liana species at altitude of 900 m in Crater Mountain Wildlife Management Area. Weiblem (1998), in a site at an altitude of 550 meter also in Crater Mountain Wildlife Management Area found 174 species and 95 genera of trees in 46 families. Studies in Asian tropical rainforests have found comparable levels of tree diversity.

While there was a relatively high number of species, SIMPER analysis indicated that a few genera were dominant at each altitude. According to the results, trees in the families of Lauraceae and Myristicaceae are dominant in low-altitude forests in both the overstorey and in regeneration. Occurrence of tree species in these families is similar to forests at this altitude in Crater Mountain Wildlife Management Area (Weiblen 1998 and Wright et al 1997) and in lowland forests in Madagascar where tree species in these families are dominant (Armstrong et al 2011). In mid-altitude plots, *Syzygium spp*, *Litsea spp* and *Castanopsis acuminatissima* are dominant with *Syzygium spp* and *Castanopsis acuminatissima* also dominant in high-altitude forests. *Cryptocarya spp* are present in regeneration across all three altitudes. The occurrence of tree species found in Lauraceae and Fagaceae families in the t mid-altitude plots is similar to findings from the forests below 1500 m in the Tari Basin (Haberle 2005).

Syzygium was another dominant genus found in both overstorey and regeneration in primary forests along the altitudinal gradient. Past studies in both PNG and Asian tropical forests have not reported the occurrence of Syzygium as dominant tree in these altitudes. However, In Sierra de Manathland *Syzygium* was found in altitudes between 1500 m and 2500 m (Vazquez and Givnish 1998) and in Lamington National Park in Australia Syzygium occurred in sites where *Nothofagus* was found (Ashton et al 2011).

Two tree species, *Eurya sp* and *Engelhardtia rigida* were listed as having dominance in primary forest but only confined to forest areas at 1300 m altitude. In Tari Basin in PNG, *Eurya sp* was recorded in secondary forest at altitude up to 1500 m (Haberle 2005. These studies indicate that in the current study the tree species might have present in gaps. This is apparently obvious that in primary forests, *Eurya sp* had only 10% contribution whereas in secondary, the species contributed 45% which is the highest, taking over from Albizia which is an exotic tree species had dominance in secondary forests along the altitudinal gradient up 1000 m.

There were noticeable variations in species occurrence at various sampling plots, as displayed by the results of ordination. The pictorial presentation certainly demonstrated that the forest area has variation in the trees species occurrence both within and along altitudinal gradient. These were due to a number of factors which influenced presence or absence of species. The most obvious ones are broadly classified into biotic and abiotic factors. The abiotic factors are mainly the attributes of landscape and availability of resources while biotic factors are soil microorganisms and other competing plant species (Begon et al 1996). The magnitude of species variation in the tropics is high and is controlled by climate and soils (Whitmore 1996). It was noticeable in this study that the variation in species diversity declined as altitude. The trend is common in the tropics (Gentry 1988) and seen in Costa Rica forests (Lieberman et al 1996), Sierrade Manantlan forests (Vazquez and Givnish 1988), Andean forests (Kessler et al 2002), (Aiba and Kitayam 1999) and Borneo forests (Grytnes and Beaman 2006). This is due to decline in temperature (Barry 2008). Human disturbance also contributes to the composition, dominance and diversity of trees in different sites landscapes (Burley et al 2011 and Balick and Cox 1997).

4.2 Forest structure: density, diameter and basal area

Forest structure can be used to determine variations and relationship in different tree genera and forest types (Tomlinson 1983 and Adekulen et al 2013). The forest structure is classified into horizontal and vertical dimensions (Bourgeron 1983 and Brun 1983). Unfortunately, in this study, only stand density, breast height diameter distribution and basal area were used for forest structure analysis. The study revealed that the Upper Mape forest area has stand density of 544 trees per hectare and basal area of 35.8 m^2/ha. These are almost consistent with the results of a study in Crater Mountain Wildlife Management Area which had 615 stem per hectare (Weiblen 1998) and 37.1 m^2 per hectare (Wright et al 1997). The results are also similar to data from two Indonesian forest areas as reported an average stand density of 422 stems per hectare for Borneo rainforest by Small et al (2004) and as high as 544 for a primary forest in Indonesia by Kessler et al (2005). In a Mexican tropical deciduous forest, 347 stems ha-1 in 148 species distributed among 42 families were reported (Duran et al 2006).

Diameter distribution for the forest area can be made reference to on Tables 3 and 4 and Figures 5 and 6. Tables 3 and 4 provide diameter information as mean quadratic diameter breast height (MQDBH) and the usual diameter at breast height (DBH) and latter has data on minimum and maximum DBH. If maximum diameter data is used to determine diameter distribution of the area, the results would be displayed as the reverse J-shape pattern. On the other hand, a normal distribution pattern would be produced if QMDBH is used as it is based on central limit theorem (Curtis and Marshall 2000). From maximum DBH data, it is obvious that the tree size decreases as altitude increases and this is due to falls in temperature (Barry 2008). This pattern has been also found in studies in other tropical forest region, for instance in East Kalimantan (Aiba and Kitayama 1999).

One structural feature of this forest is the size of trees within the diameter classes. The results indicated that in primary forests, about 90% the trees have diameter at breast height less than 50 cm. The cause of this is due to firstly site conditions which have availability of resources for the survival and development of trees could have impacts on the tree size (Hartshorn (1980). The second is the impacts of human (Burley et al 2011). In this forest area trees with good stem forms are extracted frequently for different construction purposes. Trees with diameter size of 50 cm are highly targeted for timber. This problem is common for dwellers of tropical forests as recorded in Kalimantan forests (Hadi et al 2009), Madagascar (Ingram et al 2005) and Nigeria (Aigbe and Omokhua 2014).

The expected pattern was for BA to decline with the increased in altitude. However, in this area, BA of trees in primary forests in mid-altitude had higher BA than BA of trees in both low and high-altitude forests. The low BA in low-altitude forests was entirely due to extraction of good quality tree from the stands for various construction purposes. In contrast, mid-altitude forests had not had the magnitude and intensity of disturbances as experienced in low-altitude areas due to human influences.

4.3 Exotic Species

Piper anducum, a native plant of South America was first recorded near the study area in 1935 is becoming increasingly abundant in the region (Hartemink 2001). In 1970’s it was not widespread, but since 1990’s it has spread widely and profusely across lowland landscapes up to 2000 m a.s.l. More recently, it has been observed “marching” into high elevation areas (Hartemink 2001) potentially in response to recent climate change (Masters and Norgrove 2010). In the study area, this species profusely forms a pure stand in the secondary forest landscape.

Albizia chinensis is a fast growing species originating from Southeast Asia. It is better suited to poor sites and grows up to 1300 m elevation where annual rainfall is 1000-5000 mm (National Academy of Sciences 1979). In Upper Mape area it was introduced in 1980’s as a cover and nutrient amelioration plant species in coffee farms. It has now become significantly dominant tree species in secondary forest landscapes in the area. From its performance in the area, it has been observed that the species is aggressive in its survival because it regenerates from seeds, roots and branches. It also produces multiple stems from stumps. In this study, it was found that *Albizia chinensis* has dominance in the secondary forests along all three altitudes and it is ranked one of important tree species of the area.

5. Conclusion

This study revealed that there is variation in the species composition, diversity and density along the altitudinal gradient. Dominant tree species at each altitude were different. It was found that all of these attributes vary at different altitudes, and diversity and density decline as altitude increases. This could suggest that temperature a key factor in governing forests.

There were variations in diameter distribution and basal area of the forest area along the altitudinal gradient. Again, the tree size decreased with increasing altitude, and 90% of trees in this forest area had diameter less than 50 cm. This indicates that the forest area has a significant number of trees falling in smaller size diameter, characterizing by reverse J shape. However, the used of the QMDBH showed less variation in the size of the trees.

The information used in this study is from the primary forests which had various forms of disturbance on the distribution and dynamics of plant populations. The existing primary forests are not continuous but in a number patches created by mainly by shifting cultivation. These forests are reserved mainly to use for extracting various kinds of products. Based on the current state of the forests and disturbance pattern, changes in the stand composition and structure are expected in significant magnitude due to climate change and increased in human population.

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Non-Tree Plant Diversity in Lowland and Montane Rainforest in Papua New Guinea

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Abstract

Non- tree plant diversity were assessed in eleven 0.0314 ha plots (at 70-2800 meters) in lowland and montane rainforest in Papua New Guinea using the First Multipurpose National Forest Inventory data collected in 2016/2017. Floristic composition, species richness and species diversity were computed for eleven plots. A total of 5866 individuals (including trees & non-trees species) belonging to 140 families, 357 genera and 1438 species were recorded. Non- Tree species has a total record of 2177 individual with 795 species. Rubiaceae had the maximum number of species (52 species, 10 genera) Piperaceae (50 species, 1 genus), Urticaceae (41 species, 10 genera), Arecaceae (37 species, 11 genera), Zingiberaceae (36 species, 6 genera), Araceae (36 species, 6 genera), Orchidaceae (35 species, 16 genera), Gesneriaceae (31 species, 2 genera), Polypodiaceae (27 species, 10 genera) and Pandanaceae (25 species, 2 genera). Orchidaceae has the species rich genera. Shannon-Weiner Index ranges from 3.00 – 5.00 for non-tree plants in all plots. The low value of Shannon index for non-tree species was obtained in 40 Mile plot ($H^1=3.36$) whereas the highest value was obtained in Henganofi plot ($H^1=4.75$). There is an observable difference in floristic composition and species richness for non-tree species in lowland and montane forest super plots. The calculated indices (H') revealed high taxonomic diversity of plants between lowland and montane forest plots.

1.0 Introduction

Tropical forest are the subject of several studies to better understand the role they could play in sustainable development, climate change, and floristic biodiversity (Lewis *et al.*, 2009; Djuikouo *et al*, 2010). Tropical forest is the richest biological communities on earth and has been recognized to harbor a significant proportion of global biodiversity (Myers *et al.*, 2000; Baraloto *et al.*, 2013). These forest are essential in providing many goods and ecosystem services, such as prevention of soil erosion and preservation of habitats for plants and animals (Parthasarathy and Anbarashan, 2013; Armenteras *et al.* 2009). Globally, 52 % of the total forest is in tropical regions and they are known to be the most important areas in terms of biodiversity (Djuikouo *et al.*, 2010; Holdridge, 1967). In Papua New Guinea, 60 percent of the forest is undisturbed (NFI Concept Note, 2018).

Many tropical forests are under great anthropogenic pressure (such as logging, mining and agriculture) and require management interventions to maintain the overall biodiversity, productivity and sustainability (Kumar *et al.*, 2006). Understanding species composition and richness and abundance is vital for assessing the sustainability of the forest, species conservation, and management of forest ecosystems (Kacholi, 2014).
Non- tree plant species are a very important component of vegetation that must be assessed or studied to in order to understand successional processes toward maintaining species and habitat diversity. Several studies have been done in PNG on species diversity, however, they are more specified on trees (Katovai *et al.*, 2015; Wright *et al.*,1997) and also the design of each assessments are different from the current NFI design. To my knowledge this assessment is the first detailed quantitative study of non-tree plant diversity in PNG at a national scale.

This assessment aims to identify and quantify non-tree plant diversity in lowland and montane rainforest in Papua New Guinea with specific objectives of (i) quantifying floristic composition and species richness for non-tree species and (ii) measure diversity of non- tree species using diversity index.

2. Methods

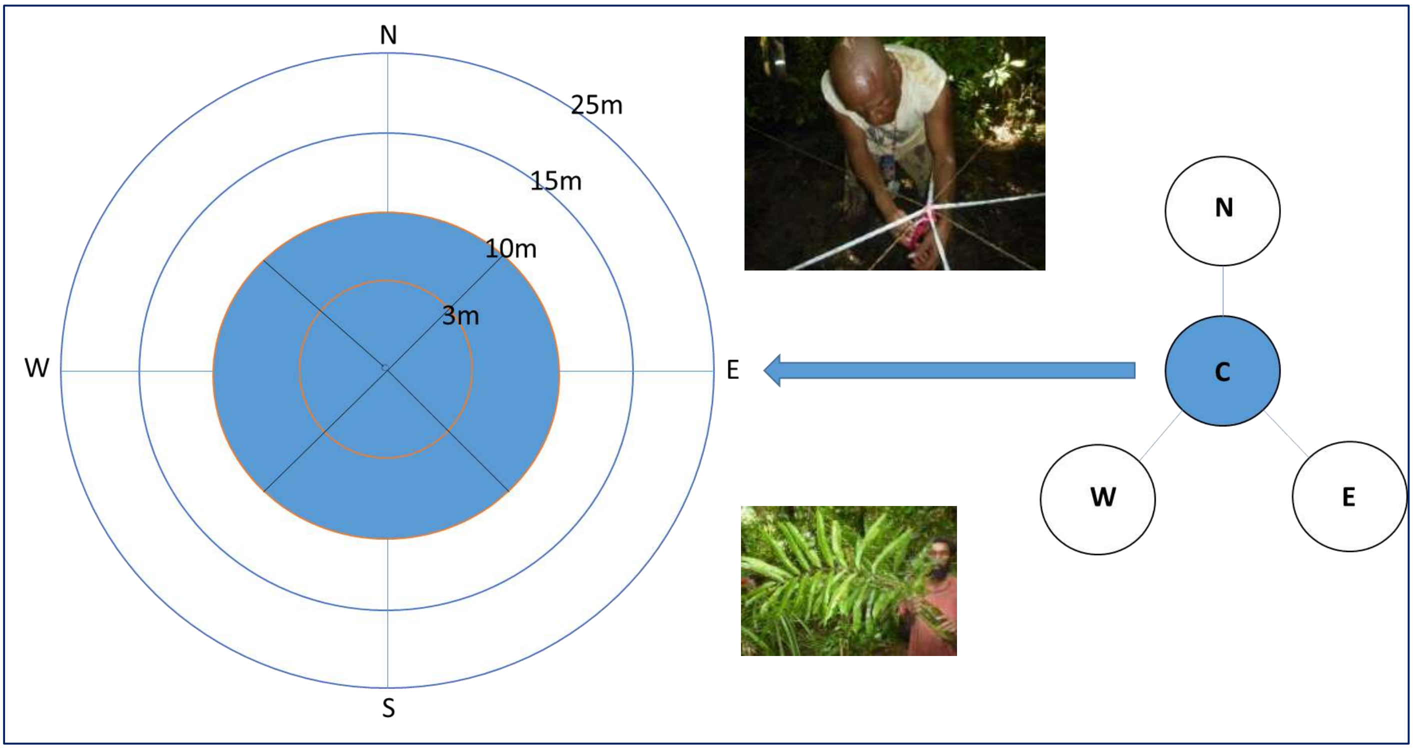
2.1 Study Area

The assessed data for this report were initially from the Highlands (EHP, WHP) and the Morobe clusters. The highlands cluster were from Henganofi (76797), Bena (75788), Tambul (22133794), Baiyer (22124812) and the Morobe cluster are from Kobio (97382), Eware (97885), 40 Mile (83331), Biaru (96863), Yalu (82838), Paiawa (95374) and Bukawa (83850).

2.2 Sampling and Data collection

Sampling and data collection followed the format as described by FAO/PNGFA and was done in circular plots within 10m radius of a 25m radius plot as shown in Figure 1. Initially, plot were set into four quadrates and then further subdivided into 8 segments to ensure no plants species are left out during enumeration. (Figure 1). All plants species below 3m in height, including trees less than 10cm dbh were enumerated. Plant samples were collected and recorded using updated botanical name. Most plant species were assigned to Families and Genus, while those unsure were brought back to Lae Herbarium for identification and verification using reference specimens from the herbarium.

Figure 1 Circular plot design for enumerating non-tree plant species



2.3 Statistical analysis

2.3.1 Species diversity

To ascertain species diversity, I used the Shannon Weiner diversity index (*H'*) as a measure of species abundance and richness to quantify diversity of understory species in each super plot of each clusters. This index takes both species abundance and species richness into account. Shannon diversity index is the most commonly used index in ecological studies:

$$H' = \sum [(n_i/N) \times \ln (n_i/N)]$$

Where n_i = number of individuals or amount (e.g. biomass) of each species (the *ith* species) and N = total number of individuals (or amount) for the site, and ln = the natural log of the number. The values range from 0 to 5, usually ranging from 1.5 to 3.5, rarely reaches 4.5 (Merganič *et al.*, 2012).

Data on the composition of species and types of habitats were organized and analyzed using Microsoft excel version 2013.

3. Results

3.1 Floristic Composition and Species Richness

A total of 5,866 individuals belonging to 1438 species among 357 genera and 140 families from eleven 0.0314 ha plots were enumerated (Table 1) in lowland and montane rainforest of PNG. Out of these, 97 families comprising 213 genera, 795 species, and 2177 individuals were recorded as **non-tree species** (Shrubs, Herbs, Liana). Diversity of non- tree species in the assessed plots calculated using the Shannon–Weiner index (H') showed that the lowest diversity was in 40 Mile plot (*3.36*) and the highest diversity was in Henganofi plot (*4.74*).

Table 1 Floristic richness, number of individuals, and diversity indices for the eleven 0.0314 ha plots in the lowland and montane rainforest of PNG

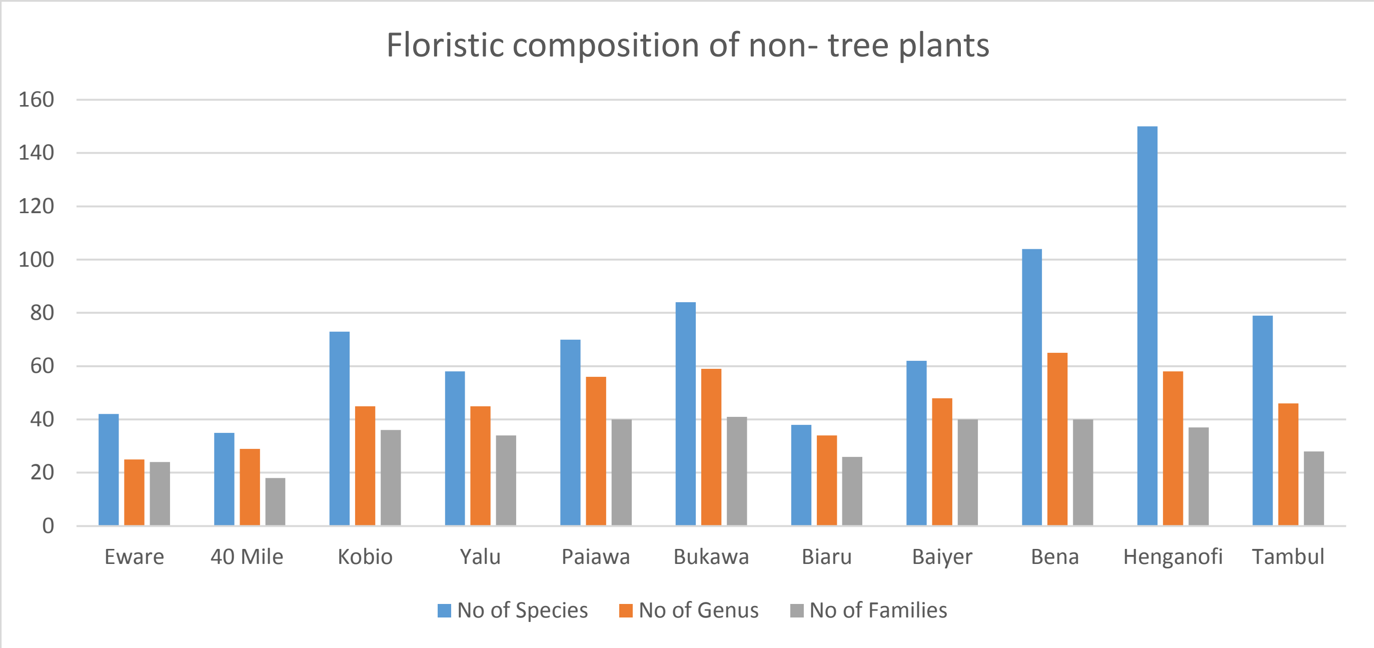
Variable		**Eware**	**40 Mile**	**Kobio**	**Yalu**	**Paiawa**	**Bukawa**	**Biaru**	**Baiyer**	**Bena**	**Henganofi**	**Tambul**
No of Species		42	35	73	58	70	84	38	62	104	150	79
No of Genus		25	29	45	45	56	59	34	48	65	58	46
No of Families		24	18	36	34	40	41	26	40	40	37	28
Shannon Weiner	**Non-Tree Species**	**3.55**	**3.36**	**4.01**	**3.88**	**4.04**	**4.21**	**3.37**	**4.00**	**4.40**	**4.75**	**4.14**
	Tree Species	2.96	3.56	4.49	3.85	4.25	4.25	3.00	3.86	3.11	4.15	3.22
	Shrubs	1.98	1.63	2.87	2.26	3.06	3.13	2.40	2.93	3.21	3.78	2.75
	Herbs	3.32	3.17	3.63	3.61	3.57	3.80	2.95	3.46	4.03	4.27	3.87
	Liana	0.00	0.00	0.00	0.68	0.00	0.00	0.00	1.30	0.00	0.00	0.00
Elev. (m)		70	73	137	173	314	356	1415	1562	2447	2486	2728
Forest Types		LAF_P&F	LAF_P&F	LAF_U	LAF_P&F	LAF_U	LAF_U	L	L	Mo	Mo	Mo

LAF_P&F = Lowland Altitude Forest_Plains & Fans, LAF_U= Lowland Altitude Forest_Uplands, L= Lower Montane, Mo= Montane Forest

The number of non- tree plant families in the assessed plots was 97 with taxonomically well-represented families. Rubiaceae had the maximum number of species (52 species, 10 genera, Piperaceae (50 species, 1 genus), Urticaceae (41 species, 10 genera), Arecaceae (37 species, 11 genera), Zingiberaceae (36 species, 6 genera), Araceae (36 species, 6 genera), Orchidaceae (35 species, 16 genera), Gesneriaceae (31 species, 2 genera), Polypodiaceae (27 species, 10 genera) and Pandanaceae (25 species, 2 genera). Orchidaceae is the species rich genera.

The highest number of non- tree species recorded was in Henganofi (*150 species*) and the lowest in 40 Mile plot (*35 species*). Variation in family, generic and species number can be seen in figure 2.

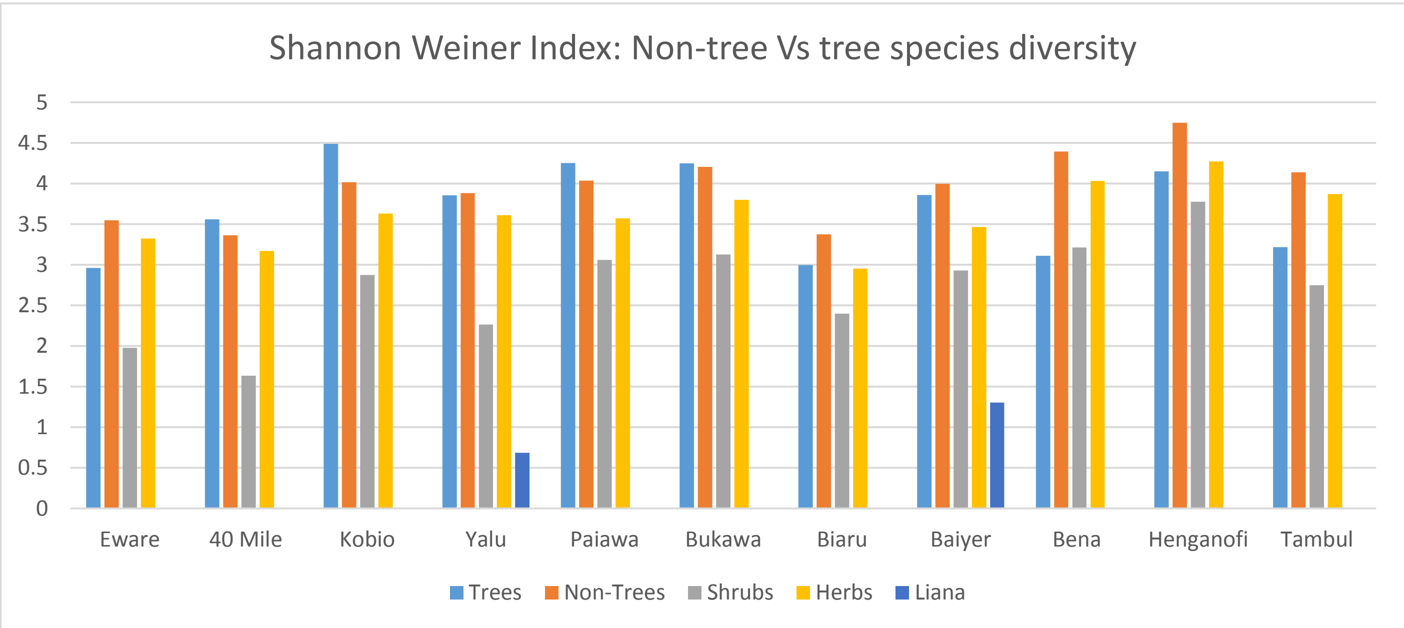
Figure 2 Floristic composition of non-tree plants (*Family, Genus, and Species*) in lowland to montane forest clusters



3.2 Species diversity

Diversity of non- tree species in the study plots calculated using the Shannon–Weiner index (H') showed that the highest diversity was in Henganofi plot (H^1 = *4.75*) and the lowest diversity was in 40 Mile plot (H^1 = *3.36*). In comparison, all plots have Shannon Weiner Index ranging between 3.0 and 5.0, indicative that the plots assessed are rich and diverse.

Figure 3 Diversity index measurements for eleven super plots from PNG



4. Discussion

4.1 Floristic composition and species richness

The non-tree plant diversity is a very important component for PNG's First Multipurpose National Forest Inventory. Floristic composition and species richness differs in all forest types and this is due to many underlying factors and causes. Species composition and richness are high in lowland forest and as you go higher in elevation, the diversity or species composition decreases (MacArthur, 1972). However, here in these plot based assessment, the montane forest tend to be richer than plots from the lowland forest. From the data, it reveals that the family of Rubiaceae had the maximum number of species (52 species, 10 genera, Piperaceae (50 species, 1 genus), Urticaceae (41 species, 10 genera), Arecaceae (37 species, 11 genera), Zingiberaceae (36 species, 6 genera), Araceae (36 species, 6 genera), Orchidaceae (35 species, 16 genera), Gesneriaceae (31 species, 2 genera), Polypodiaceae (27 species, 10 genera) and Pandanaceae (25 species, 2 genera). The ushering presence of Rubiaceae and allied families such as Euphorbiaceae generally represents the typical character of understory species within tropical rainforest as noted by Reynal-Roques (1994). The abundance of Fabaceae, Caesalpiniaceae and Clusiaceae are proof of old aged or matured forests (Cusset, 1989). From the results so far for the eleven plots, it was observed that most taxa represents secondary species and from most of the forest plot, the physiognomy indicates and shows patterns of disturbance (e.g. logging). Few plots along Morobe Coast are situated within forest that has been logged in the past so species composition changes overtime and that allows many secondary species to grow especially in understory form.

It is also important that climate conditions have had a major influence on the occurrence and diversity of species in forest plot in Highlands and Morobe province. Some plants are in favor of cold climate and others in warmer or hot climate. Indeed, the altitude highly contributes to species diversity (richness and abundance) for plots already assessed. From assessed data, montane forests tend to be more diverse for lower plants (understory).

4.2 Species diversity

Species diversity is one of the most important indices used for evaluating the stability and sustainability of forest communities. Information on the species composition of a forest is essential for its wise management in terms of economic value, regeneration potential (Wyatt-Smith, 1987) and ultimately may be leading to conservation of biological diversity (Verma *et al*. 1999). Considering Shannon diversity index, the forest plot assessment showed that 40 Mile plot (H=3.36) has the lowest index while Henganofi plot (H=4.75) has highest diversity index value. Most of the other plots fall between 3 and 5. Higher species richness is a hallmark of many tropical forests (Gentry *et al.* 2010).

Low diversity index in 40 Mile super plot ($H=3.36$) could be explained by the fact that the plot is situated on a frequent flood plain and may have contributed to the plot having less taxa. Similarly, Biaru super plot ($H = 3.37$) is situated on a rocky surface and that has contributed to lower diversity of species assessed. Eware, Kobio, Paiawa super plots falls in lowland rainforest which have been logged and understory species are dominated with secondary plants species due to these disturbances. Yalu, Bukawa and 40 Mile are lowland primary forests which species compositions reflect the forest types. In montane forest, floristic composition, species richness and diversity of non-tree species are high as shown from the calculated diversity index. In those plots, soil fertility, climate and elevation could be the environmental variable contributing to plant diversity and floristic composition. However, it could also be rainfall, tree mortality or other environmental variable effects. Higher species diversity is generally thought to indicate a more complex and healthier community because a greater variety of species allows for more species interactions, hence greater system stability, and indicates good environmental conditions.

5. Conclusion

Non-tree plant diversity assessment is a very important component of this First Multipurpose National Forest Inventory and the results revealed a high floristic diversity. A total of 795 species (213 genera and 97 families) were recorded for a total of eleven clusters constituting of four forest types. *Rubiaceae* was the dominant non-tree plant family for all the forest types with 52 species and *Orchidaceae* is generically rich with 16 genera. The most diverse plot is Henganofi (*H= 4.75*) and the least diverse is 40 Mile plot (*H=3.36*). There was a high taxonomic diversity of plant taxa recorded among lowland and montane forest in PNG.

Acknowledgements

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A Preliminary Data Interpretation and Analysis on Understorey Vegetation Cover along Five Forest Types of Papua New Guinea

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Abstract

The preliminary data interpretation and analysis here on vegetation coverage represents five different forest types identified during assessment of Non- Tree Plant Diversity of the Multi National Forest Inventory (MNFI) in Eastern Highlands, Western Highlands and Morobe Provinces of Papua New Guinea in which eleven clusters were assessed. The main structural indicator attributes of understorey herbs, shrubs and giant herbs apart from tree data are an essential biodiversity proxy to measure of structural complexity. Based on preliminary data interpretation, Lowland altitude Forest on Uplands (H) which represents two clusters in Morobe has the highest vegetation coverage compared to Montane Forest (Mo) which represents about four clusters in Eastern and Western Highlands respectively. Vegetation coverage per cluster locations of the total eleven clusters has a significant variation from the lowlands to the highlands clusters which Bukawa and Biaru clusters have the greatest understory vegetation coverage compared to Tambul and Bena clusters. To predict correlation of all cluster plots, a Principal Component analysis (PCA) of ordination was used to compare each plot against their Basal Area within 10-meter radius and mean elevations. However, the environmental variables (Basal Area and Mean Elevation) considered here as examples has no significant correlation with vegetation cover of each plots measured but shows a significant similarity of vegetation coverage within and across some sites. Also, Swamp Forest (S) type showed a uniquely vegetation coverage based on the PCoA analysis that each plot within the cluster measured showed no correlation to each other and others also showed no correlation regardless of some cluster being in the same forest types along an elevation gradient.

Introduction

The Island of New Guinea is the third largest tropical rainforest on the planet apart from the Congo Basin and the great Amazon forest (Testolin *et al*. 2016). The island itself contains at least 5-7% of the total richness, making it one of the biodiversity rich hotspots in the world (Shearman and Bryan 2010) and having one of the richest flora in the world (Paijman 1976). Paul (2011) stated that forest in PNG holds a very distinctive species composition and density of tree flora and Wright et al. (1997) comparing to other studies pointed out that diversity study in one hectare plot in Crater Mountain, was listed as one of the most diverse plot worldwide with Shannon index of 4.91 for the overstorey and 4.19 for the understorey plot. Furthermore, other studies in PNG have emphasized the importance and contribution of plant species richness, abundance and composition towards biodiversity (Kiapranis 1992, Gebia 2001, Paul 2011, Whitfeld et al. 2014, Katovai et al. 2015, Fibich et al. 2016). Essentially, it is important to appreciate the fauna and flora of tropical rainforest and their contribution towards total global species richness.

However, in recent decades, most tropical rainforest have been under stress from forest degradation and deforestation resulted from logging and other land use changes having greater threats to species diversity. Bryan et al. (2015) reported a significant forest change from 2002 to 2014 in which a total of 3 752km^2 of rainforest was logged which accounts for 21% in the last 12 years from 2002 to 2014 and study by Johns (1992) revealed that normally 20 to 30 m^3 per hectare of harvested volume is expected from at least five to six tree but trees extracted in Mongi-Busiga forest concession were 17 trees per hectare which was predicted to be much higher than the usual harvested volume (Abe et al. 2000). But recent study by Gamoga (2017) stated that PNG has 78% of intact dense forest of which forest disturbances from logging (10.7%), gardening (8.3) and fire (3.1%) are occurring in mostly low altitude forest on plains and fans, lower montane forest and savannah with gardening and logging as main drivers of deforestation and forest degradation especially in the provinces of Bougainville, Western Highlands, and West New Britain.

Anthropogenic disturbances like logging has encouraged invasion of non-native to invasive plant species encroaching into dominance and affecting recovery of native species diversity (Brown and Gurevitch 2004), while Testolin et al. (2016) using Permanent Sampling Plots (PSPs) concluded that there some significant effects on biodiversity and structure in PNG tropical rainforest. Also, data from study in tropical Madagascar suggest that even after 150 year of forest recovery, invasive plant species have prevented native species to be established thus altering composition and structure (Brown and Gurevitch 2004). Although there are controversy surrounding species loss through logging, studies indicate otherwise that tree species richness were similar between logged and unlogged forest area where logging only explained a small variation (7%) of trees and liana composition (Cleary 2017), while low to medium harvesting intensity used in logging may be an appropriate approach to retain biodiversity (Behjou and Mollabashi 2016). Although selective logging may seem to alter biodiversity in some context, these assertions needed more data and studies to show patterns of change.

To ascertain such issues, it is vitally important for PNG to enumerate its forest resources and in recent years the PNG Government through PNG Forest Authority (PNGFA) has embarked on the first Multipurpose National Forest Inventory (MNFI) project for the country. With funding initiative from European Union (EU) and Food and Agriculture Organization (FAO), the MNFI project commenced its data collecting in 2015. The data will be used as a significant monitoring component for assessing Reducing Emission from Deforestation and Forest Degradation (REDD+) and Green House Gas (GHG) as an obligatory part of the United Nations Framework Convention on Climate Change (UNFCCC) mechanism.

The aim of MNFI is to quantify the forest values such as carbon sequestration, commercial log values and biodiversity values. Basically, the biodiversity component of MNFI will provide some highlights into PNG flora and fauna with a range of biodiversity proxies particularly the Non-Tree Plant Diversity (NTPD), Entomology and Ornithology to be sampled across different forest types and various ecosystem habitats in PNG. These biodiversity proxies will effectively provide the scientific basis into understanding the impacts of deforestation and forest degradation on biodiversity in tropical forest of PNG.

With this current study, the aim is to provide a basic understanding on the coverage of NTPD as a stand structural biodiversity indicator or normally referred to as vegetation cover for five different forest types in PNG. Vegetation cover are mainly centred on understorey vegetation especially shrubs, terrestrial grounds herbaceous plant species and giant herbaceous plant species. Data analysis will be based on preliminary data collected from eleven completed MNFI clusters in the Highland and Morobe. It is understood that Mountain Partnership who are also a partner in MNFI are responsible for NTPD component has already set out its goals and objectives however, this current study is will only be concentrating on data analysis to predict some trends using Basal Area (BA) and Mean Elevation as predictor variables to show relationships between plots using multivariate analyses techniques.

Therefore, this study will look for (a) variation of vegetation cover among the forest types; (b) variation of vegetation cover along mean elevation; (c) correlation between vegetation cover and predictor variables (Basal Area and Mean Elevation); (d) correlation between vegetation cover plots and predictor variables (Basal Area and Mean Elevation); (e) similarity or dissimilarity among vegetation cover plots and forest types.

Study Site

The eleven clusters are spatially located in five different forest types mostly from Eastern Highlands (2); Western Highlands (2) and Morobe (7) provinces (figure 1). The Eastern Highlands clusters are located in Henganofi (-6.07197 S, 145.456 E) and Bena (-6.040017 S, 145.479983 E) with a mean elevation of 2486 m a.s.l and 2447 m a.s.l respectively. The higher elevation is of a typical montane moist mossy forest which ranges from 1000-3000 meters a.s.l and characterized by an evergreen forest having long slopes, spurs and ridges while canopy structure between 20 to 30 m high (Paijman 1976).

Western Highland clusters are located in Tambul (-5.93996 S, 143.88004 E) and Baiyer (-5.54000855 S, 144.2400604 E) with mean elevations of 2728 m a.s.l. 1562 m a.s.l respectively. Tambul cluster is located on a very distinctive montane forest having mostly grasslands on forest edges and a forest situated on a stable gentle slope of plateau leaning towards Mt. Giluwe. Baiyer cluster is a classic example of a lower montane forest with altitude (≥1000 m). Generally, forest is even to slightly undulated canopy height of 20-30 m with canopy closure slightly from dense to somewhat open.

The Morobe clusters are located in Mare (-6.63996 S, 146.60001 E, alt: 73 m a.s.l), Yalu (-6.5998 S, 146.91995 E, alt: 173 m a.s.l), Biaru (-7.72007 S, 146.80002 E, alt:1415 m a.s.l), Bukawa, (-6.40481 S, 147.19114 E, alt: 356 m a.s.l) Kobio, (-7.76 S, 147.51999 E, alt: 137 m a.s.l), Paiawa (-7.59987 S, 147.36002 E, alt: 357m a.s.l) and Eware (-7.79984 S, 147.59996 E, alt: 70m a.s.l). Eware cluster is located on a mix swamp forest with an irregular often open to medium crown of mostly 20-30 m height. Typically, understory of sago palms are visible with mangrove habitats characterized by estuaries of rivers carrying fine sediments flowing into and gradually forming coast line dunes. Clusters in Mare and Yalu are located on low altitude forest on plains and fans which is characterized of having canopy height of 30-35 and floristic rich with very mixed stands. Clusters in Bukawa, Kobio and Paiawa are located on lowland altitude forest on uplands characterized by canopy height of 25-30 m. The forest is slightly uneven to undulated steep slopes. Biaru cluster is located on lower montane forest characterized by small stands of 30-49 cm and medium stands of 50-60 cm. Thus, canopy height usually, decreases with increasing altitude with a dense to slightly opened canopy.

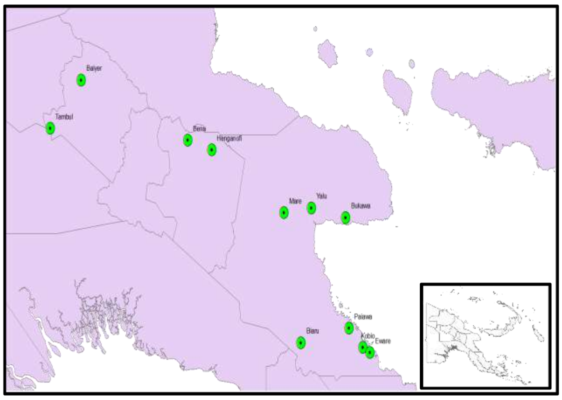


Figure 1 Map showing location of eleven clusters

Method

Vegetation cover was sampled using the methodology for NTPD manual (De Sanctis et al. 2016). NTPD for structural diversity was divided into three groups i.e. shrub layers, herb layers and liana but liana was not considered whereas shrubs and herbs were the only two categories sampled. All clusters comprised of four plots, and located at least 300 meters away from each other (Kuroh et al. 2018). Established plots are nested circular plots with sub-plots ranging from 3 meter radius, 10 meter radius, 15 meter radius and 25 meter radius which are the main plot. The 10 meter radius sub-plot (314 m^2) was used here as the main sample plot for data collection. Poulsen and Balslev (1991) descriptive definition of herbaceous plants will not be considered in this research because of the fact that the study included those “obligate and facultative” terrestrial herbs which their roots may have some climbing part or epiphytic individuals. This research will be strictly collecting herbaceous plants which have their rooting system impeded into the soil and those climbers, epiphytes, creepers will be excluded. Thus, this research will in-cooperate the definition in NTPD manual, (De Sanctis et al. 2016).

Data Collection

In May 2017, MNFI started its data collection for NTPD in two clusters in Heganofi and Bena, Eastern Highlands. Two team composed of ten specialized personals from PNGFA, PNGFRI and Binatang Research Centre (BRC) were sent to the respective clusters and spent at least a week collecting data. Again in June 2017, two more clusters were sampled in Tambul and Baiyer, Western Highland Province with the same composition of personals and collected data from 17th May to 22nd May, 2017. Then, in October to November, 2017, seven clusters were sampled in Morobe. Because of the work load experienced in Highlands clusters, personals were increased to 14 men per team and team was also boosted to three teams with two teams’ sampled two clusters each and one team sampled three clusters.

Within the 314 m^2 of all plots, ground herbs layers, shrub layers and giants herbs were sampled through visual estimation based on four classes: (1)<10% (2)10-40% (3)40-70% (4)70-100%. Shrub layer was defined by visual estimation all plant species of height between 1 to 3 meters and ground herbs layer included all vascular plants <1 meter high and giant herbs are considered here as tall herbaceous plant species like those in Araceae, Aracaceae, Zingiberaceae, Cyatheaceae, etc. Thus, data were collected successfully from all eleven clusters.

Data Analysis

To show trends on the data, this study will only base on Multivariate analysis techniques particularly, using Principal Component Analysis (PCA) and Principal Coordinate Analysis (PCoA) ordination principals to show correlations of plots to each of the identified forest types. Also, an ordination technique was used to determine similarity or dissimilarity among the plots by using Bray-Curtis distance similarity/ dissimilarity index.

Also, tree diameter measurement were collected from all standing tress ≥ 1cm to ≥10 cm within all 10 meter radius sub-plots for calculating stand basal area for individual standing tress. All standing dead trees were eliminated from the analysis and stand basal area was expressed using the formula:

Basal Area (BA) = 3.142 x D^2 where 3,142 is constant and D is diameter at breast height.

Results

Variation of Herbaceous Cover along Mean Elevation

The graphs (figure 2) below shows positive variations of herbs cover along mean elevations. Mostly all ground herbaceous and giant herbaceous coverage ranges from at least 3-30% on average from a varying elevation but few elevations have almost 40-80% cover. Basically, it predicts a heterogeneous cover of herbs composition moving from a lower elevation to higher elevation of different forest types. This suggests a higher species density and composition of herbaceous plants across all the clusters.

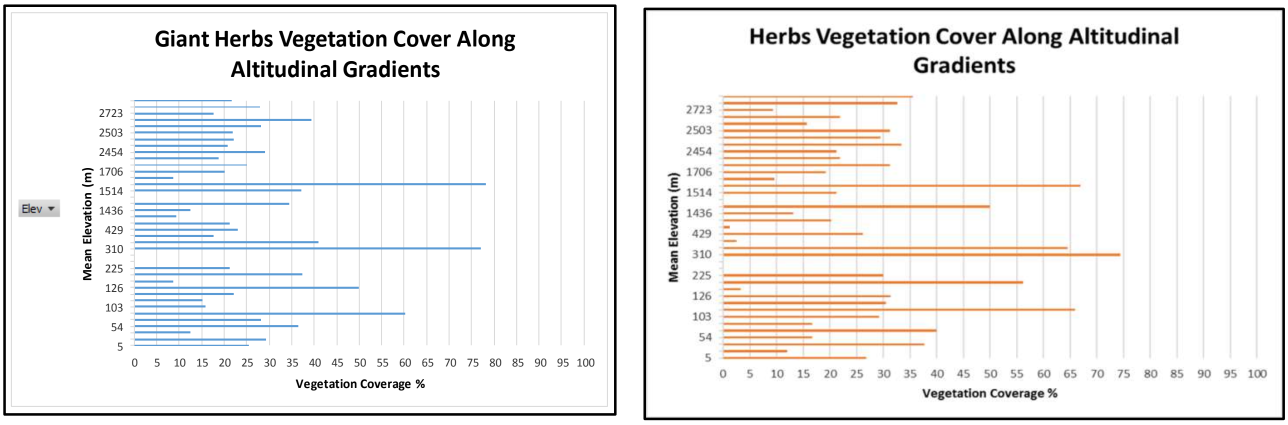
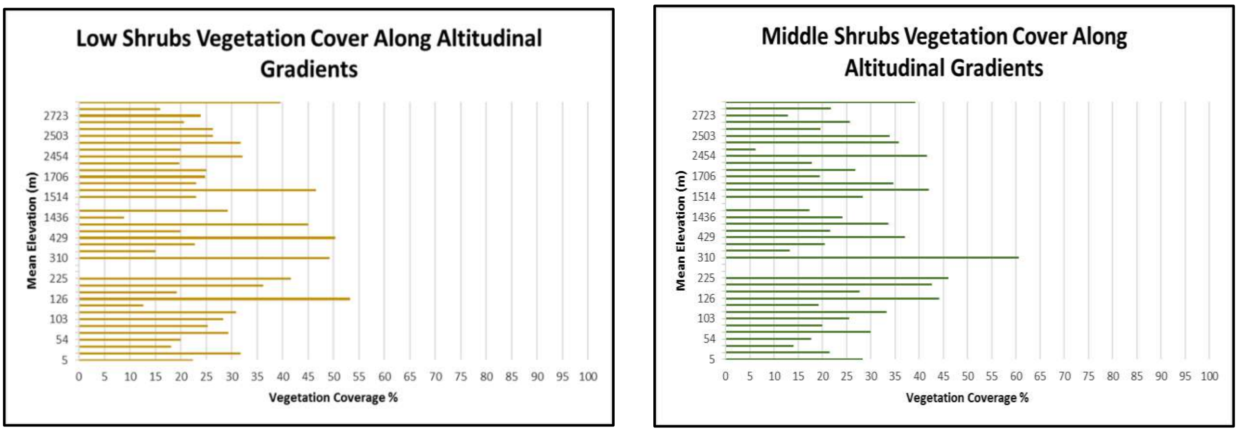


Figure 2 Graph showing Herbs cover variation along Mean Elevation

Variation of Shrubs Cover along Mean Elevation

Shrubs layers from graphs (Figure 3) also show a strong variation among all elevation from lower to higher altitudes. Composition of lower shrubs coverage ranges from 8-55%, medium shrubs from 6-60% and higher shrubs from 6-75%. Lower shrubs represent a gradual composition of shrub layers of species of which contributes a significant coverage in varying elevations. Medium to higher shrubs composition varies considerably regardless of varying elevations. This suggests a high diversity of species per cluster or otherwise plots within each forest types and as a result of high density of species richness from the understory shrub layers. The medium shrubs covers represented by 1-2 m are presumably the shrubs which will eventually grow into the expected height class of 2-3 m higher shrub layers.



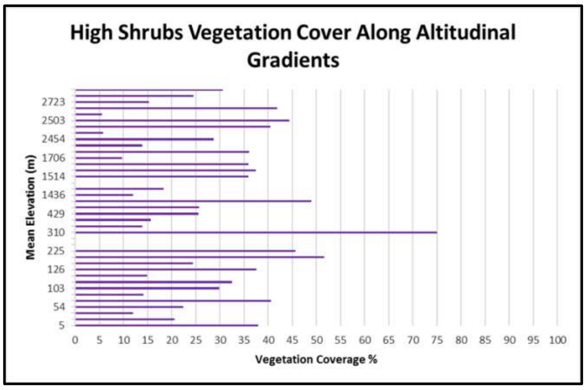
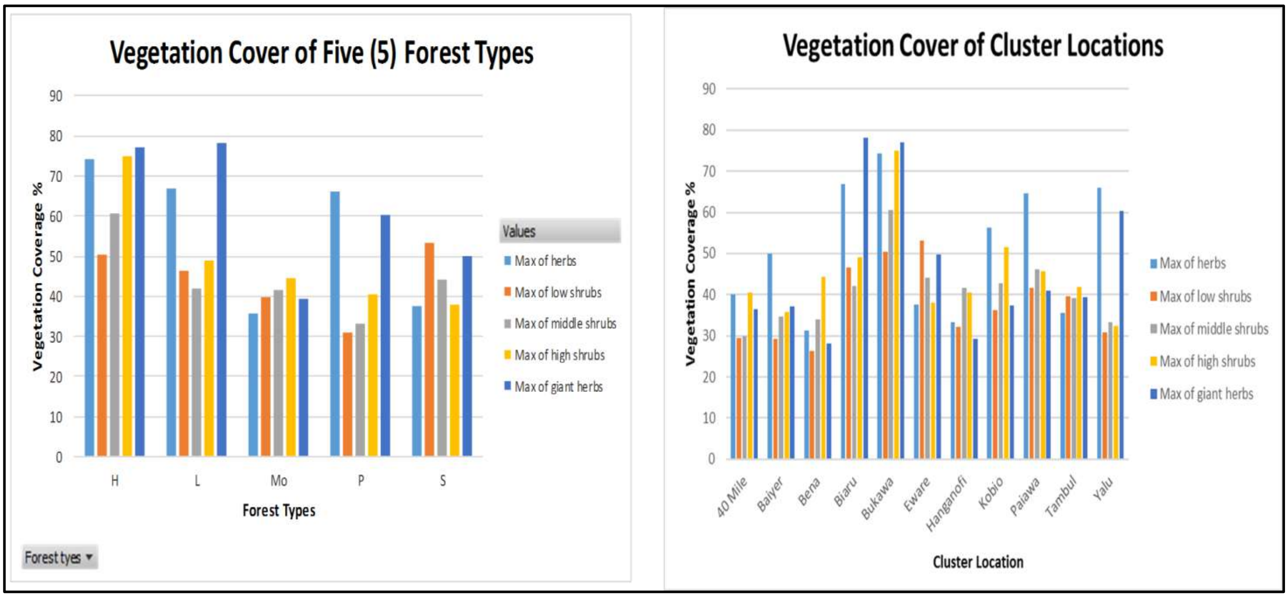


Figure 3 Graphs showing Shrub layers variation along Mean Elevation

Total Vegetation Cover in five Forest Types

The graph (figure 4) represents a strong variation of total vegetation cover among the five forest types measured. But vegetation cover in Lower montane forest (L) ranges from 43-78% and Lowland altitude forest on uplands (H) ranges from 50-75, both almost showing a similar compositional stand cover of total vegetation dominating the five forest types. There is also a strong variation across each cluster from the same forest types as well. Although Bukawa, Kobio and Paiawa clusters are lowland altitude forest on uplands (H), they show a spatial dissimilarity in vegetation cover depicting a distinct understorey vegetation structure mainly of densely rich herbs and shrub species layers. This is also evident in clusters in Biaru and Baiyer which are represented by lower montane forest. Clusters representing montane forest especially, Henganofi (30-41%), Bena (28-43%) and Tambul (37-42) show little variation portraying a more densely vegetation cover seemingly dominated by only few stands of a common shrub and herbs species layers which is also obvious in cluster from Eware (S) and 40 mile and Yalu (P).

Figure 4 Graphs showing Total Vegetation Cover in Five Forest Types and Cluster Location



Multivariate Analysis on Vegetation Cover and Basal Area (BA) and Mean Elevation

The Principal Component Analysis (PCA) used in this analysis explained at least 54% variance on pc 1 axis to correlate herbs and shrubs cover vs. basal area and mean elevation while having no significance association within the five forest types. Mostly all plots in the clusters representing five forest types are spatially distributed across the graph (figure 5) showing a non-correlated to the tested attributes (BA and Elevation). However, the ordination shows few plots in Mo, L, and S showing a positively correlation of vegetation cover specifically with ground herbs and shrub layers between plots i.e. 76797-C (Henganofi) and 96863-E (Biaru) respectively and 97885-W (Eware) to giant herbs. Although, plots in Henganofi and Biaru are geographically located from two different forest types and nearly about 240 km away from each other, there is a strong similarity of composition of ground herbs and shrub layers structures within and between the plots.

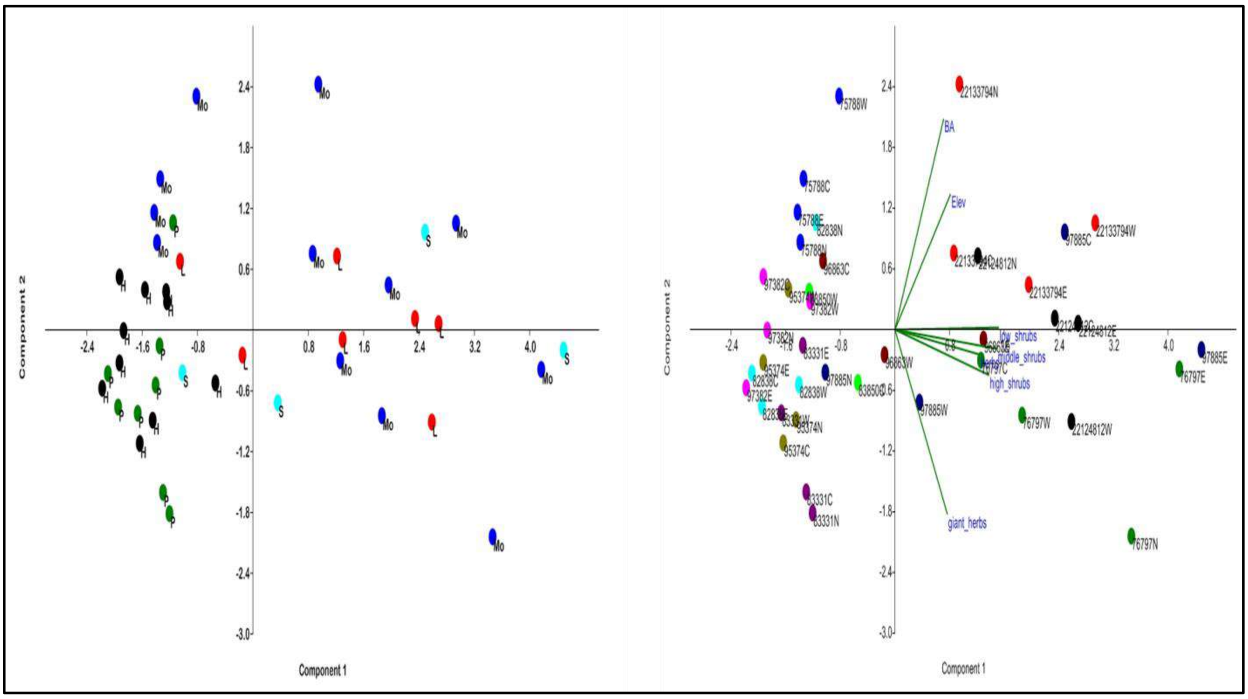


Figure 5 Principal Component Analysis of cluster plot

Here Principal Coordinate Analysis (PCoA) was used to test similarity or dissimilarity of vegetation cover with each forest types. PC 2 from the graph (figure 6) explained the most variance of 50% from the second axis. The graphs show that plot from all forest types are spatially distributed along the two explained axis thus concluding a significant dissimilarity between plots in the forest types. Few plots almost tend to clusters together e.g. those from Mo and H, but mostly are scattered from the left to right axis suggesting a variations of vegetation cover. S plots shows a uniquely pattern of vegetation change from a distinctive scatter of plots across the graph. Although the plots are located 300 meters away from each other, the plots predicts a vegetation stand structure of herbs and shrub layers densely populated with a common species having compositional dominance of each plots.

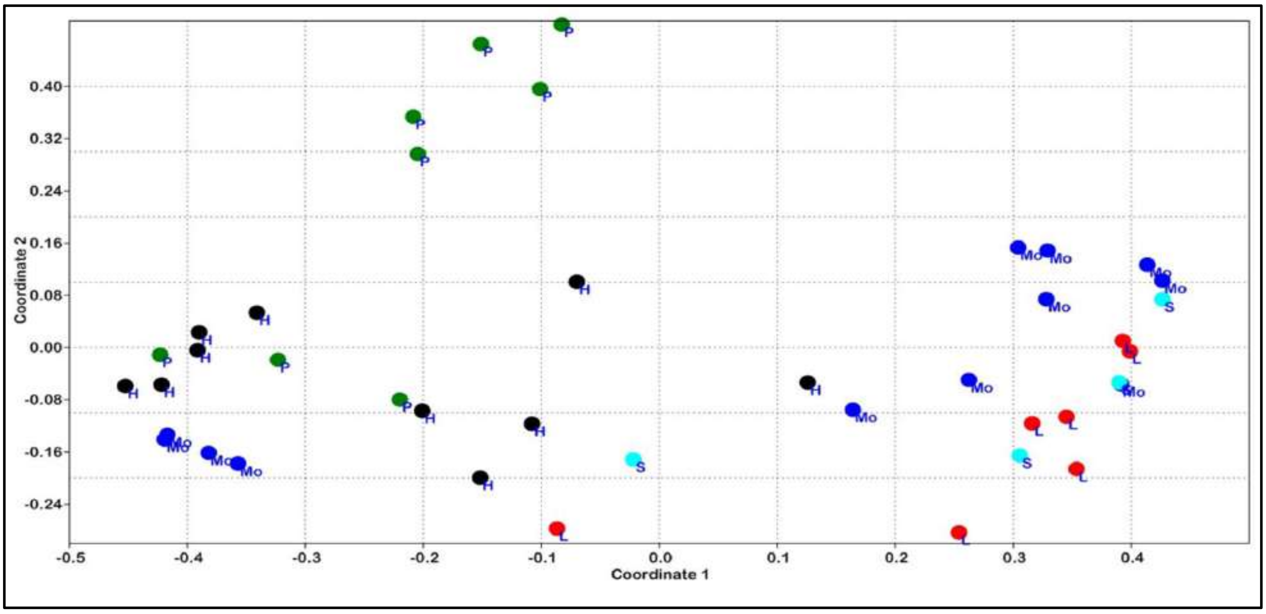


Figure 6 Graph of Principal Coordinate Analysis showing dissimilarity between cluster plots

Discussion

It is important to understand how the forest overstorey affects understory plant community especially from variables derived from overstorey such as basal area and mean elevation. The results from distribution of vegetation cover especially from herbs and shrubs layers along the mean elevation predict a strong variation from varying altitudes. The strong variation depicts that certain herbs and shrub species abundance response to certain environmental abiotic factors which are obvious from the analysis. Understory species diversity suggest that soil was the main determinant of species abundance and richness, (Huston 1980), and Gentry (1988) alluded that rainfall was main predictor to species abundance and diversity. Generally, the competition of light, water, and soil nutrients can be considered here as the main environmental factors influencing abundance and distribution of understory vegetation cover. Although, plots in the clusters are located at least 300 m away from each other, there is a strong notion that some herbs and shrubs species are confined to certain habitat types thus increasing habitat heterogeneity for some forest types. However, more data is needed to be collected and analysed to understand the main source of abiotic factors influencing variation of the understory community along varying elevation from different forest types.

Multivariate analysis from PCA techniques used here was basically to correlate two attributes (BA, Elevation) with forest plots however the results predicted a non-significant relationship. Essentially, it is important to understand here that vegetation cover from herbs and shrubs from all the plots are scattered across the graphs portraying a very distinct distribution of species from the different forest types. Here the result is projecting that vegetation cover from varying elevations and forest type are very unique and very dissimilar in terms of species abundance and composition. Therefore, the chances of expecting an increased composition and species heterogeneity are very much higher. But, few clustered plots from H, P and Mo shares a common vegetation cover density from three different types which simply depicting that these plots are densely dominated by either few of a common herbs and shrub species or the plots are densely populated by just by a community of a single species of herbs and shrubs.

Multivariate analysis using PCoA techniques was a fundamental technique to correlate similarity and dissimilarity of plots in respect to vegetation cover. Results show no similarity between the plots from different forest types in response to vegetation cover. However, few plots indicated some significance of similarity of vegetation within each clusters respectively. Interestingly, some plots especially, S plots in swamp forest, H plots in lowland altitude forest on uplands, and L plots in lower montane forest are spatially distributed across the graph representing a unique pattern of spatial distribution and abundance of vegetation communities in these forest types. Although, these plots are located just 300 m away from each other, vegetation cover predicts that abundance and composition from each plots signified a significant diversity of species pool of herbs and shrubs layers. Notions can be drawn from this assertion by various factors however, to substantiate and validate the main determinants of species abundance and composition, more environmental data is needed to understand these patterns of change. Thus, as this is preliminary study, more recommended environmental data such as disturbance regimes and intensity, soil chemical and physical properties, rainfall, temperature as well as climatic data are essential abiotic data which will be considered in later in this study.

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Preliminary Assessment on Syzygium (Myrtaceae) Species Presence in Two Different Extremes (Ecological and Biogeographical)

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Abstract

Syzygium genus in the family Myrtaceae is reported to be rated as 16th out of 52 most species rich genera globally. In Papua New Guinea it is also known to be one of the most species rich tree genera with more than 200 species. It is distributed widely from the lowlands at the sea level to the highlands up to 3000 m above sea level. The Lae Herbarium data base contain 4000 records of the genus collected from all over PNG and from these records the distribution of the species were noted. There are several species that are considered generalist and they are distributed throughout, from the low lands at sea level to the highlands up to 3000 m a.s.l. There are those that occur only on certain elevation while some were noted to be occurring only in certain provinces.

The data for this paper was extracted from NFI plots assessed in the Highlands (Eastern and Western highlands) and Morobe provinces. The results are preliminary consisting of data collated from four different clusters within those respective provinces, two from the highlands (high altitude forest) and two others from the lowlands (low altitude) forest at the sea level. The analysis is based on presence and absence of *Syzygium* within clusters and between plots. Presence and absence of *Syzygium* is also assessed within and between clusters. Simpsons species and Shannon Weiner diversity index is used to assess the species diversities and Jaccard similarity index is used to assess the similarities within and between clusters.

There is a question of why this tree genus *Syzygium* widely distributed throughout Papua New Guinea so this paper looks at presence and absence, density and diversity of species in different bio-geographical and ecological extremes to see if the wide distribution habit of the genus is dependent on the bio-geographical and ecological attributes.

1.0 Introduction

There are over 4,000 tree species within the forests of Papua New Guinea. This genus *Syzygium* is a tree genus in the Family Myrtaceae. It contributes to almost 5% of the tree species in Papua New Guinea. While taxonomically it is poorly known, several of known species such as *Syzygium buettieriainum, Syzgium effussum, Syzgium paclycladum* and many others are marveled for sawn timber by the timber industry in PNG.

The genus is commonly characterized by its fleshy, sweet tasting fruits that are usually eaten by birds, animals and humans. The two most common species desired for the sweet tasting fruits are *Syzygium malacense and Syzygium aquaeum.* In PNG the genus is widely distributed from the low lands to the highlands to just below 3000 m above sea level. Lea Herbarium collections records shows that the species *Syzygies delphicum* was collected from 2000 m above sea level. While the species collected from low lands at a littoral forest (sea level) was *Syzygium amplum.*

Globally the genus is rated 16th out of 52 most species rich genera (Frodin, 2004)[i] and in PNG, it is certainly the first most species rich genus out of more than 2000 tree genera.

Taxonomically the genus is poorly understood that it continues to make identification to specific species very difficult. The Lae Herbarium database has 4,000 records of *Syzygium* specimens which is made up of approximately 150 known species and more than 100 are still unknown (unidentified). The Lae Herbarium staff field expeditions to remote places noted collecting more than one unknown species. The most recent discoveries of some new species included *Syzygium cravenii* and *Syzygium platycarpum* from Vanimo, Sandaun province, *S. pterotum* from Tabubil, Western province and *S. kuiense* and *S. lababiense* from Morobe province (Conn & Damas, 2015)[ii]

The data for this paper was extracted from NFI plots assessed in the Highlands (Eastern and Western highlands) and Morobe provinces. The results are preliminary consisting of data collated from four different clusters within those respective provinces, two from the highlands (high altitude forest) and two others from the lowlands (low altitude) forest at the sea level. The analysis is based on presence and absence of *Syzygium* within clusters and between plots. Presence and absence of *Syzygium* is also assessed within and between clusters. Simpsons species and Shannon Weiner diversity index is used to assess the species diversities and Jaccard similarity index is used to assess the similarities within and between clusters

There is a question of why this tree genus *Syzygium* widely distributed throughout Papua New Guinea so this paper looks at presence and absence, density and diversity of species in different bio-geographical and ecological extremes (Highlands and Lowlands) to see if the wide distribution habit of the genus is influenced by bio-geographical and ecological attributes.

2.0 Methods

The first set of data for this paper was obtained from the Lae Herbarium data base which showed the presence of *Syzygium* in various localities in Papua New Guinea. The herbarium records show almost precise information on where each species was collected from. The latitude and longitudes of the locations where also recorded by the collectors so other environmental variables such as forest types, ecological zonation or geological information can be derived.

The second set of data was collated from the National Forest Inventory (NFI) upper plants and the super plots (10 m radius) components data. Presence of *Syzygium* in each plot was recorded on the upper plants data sheets so for the analysis I extracted only *Syzygium* that were present within each plot (4 x 25 m radius per cluster) and analyzed the species composition and diversity.

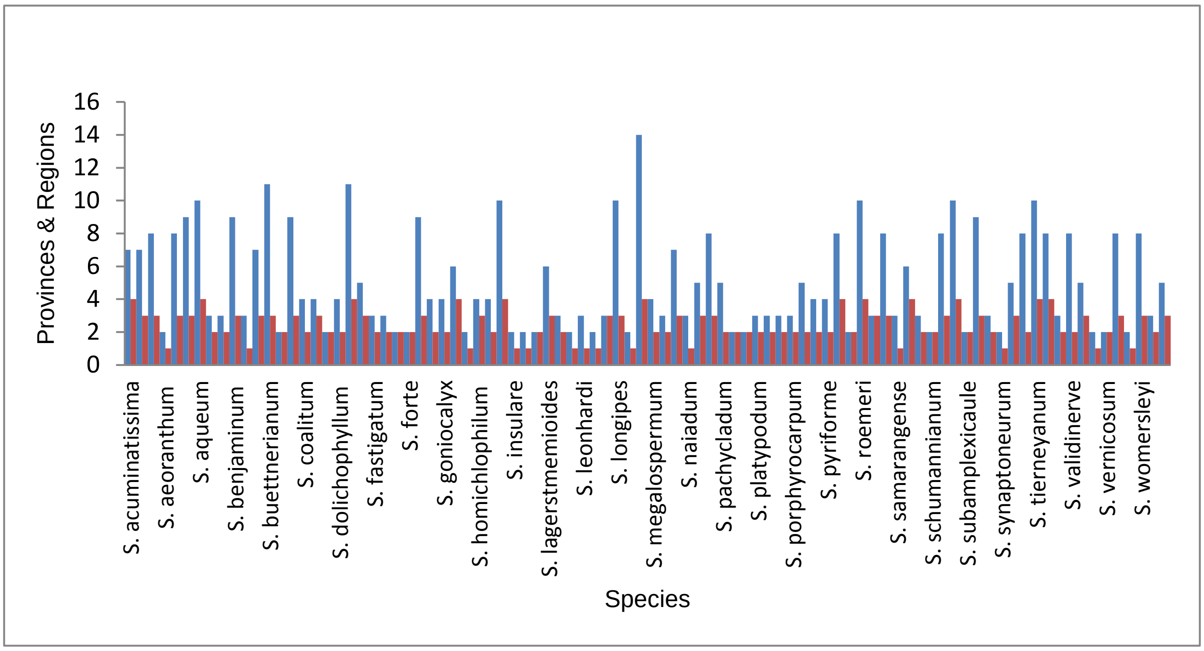
The analysis were made up for the eight NFI clusters, each NFI clusters were made up of 4 x 25 m radius circular plots. Four from the highlands represented by Henganofi and Bena (Eastern Highlands) and Tambul and Baiyer (Western Highlands).The lowlands clusters represented by Yalu, 40 mile, Paiawa, and Kobio all in the Morobe province.

3.0 Results

The results shown in the following bar graphs (fig. 1& 2) show data assessed from the Lae Herbarium data base and from the NFI upper plants tree species data (fig. 3 – 5). Figure 6 show the number of species within the center plots for super plot verses the upper plants categories. The herbarium data assessment was based on 157 species while the NFI data assessment was based on eight clusters (32 plots) within the (UP) upper plants and (SP) super plot categories.

3.1 Herbarium database analysis

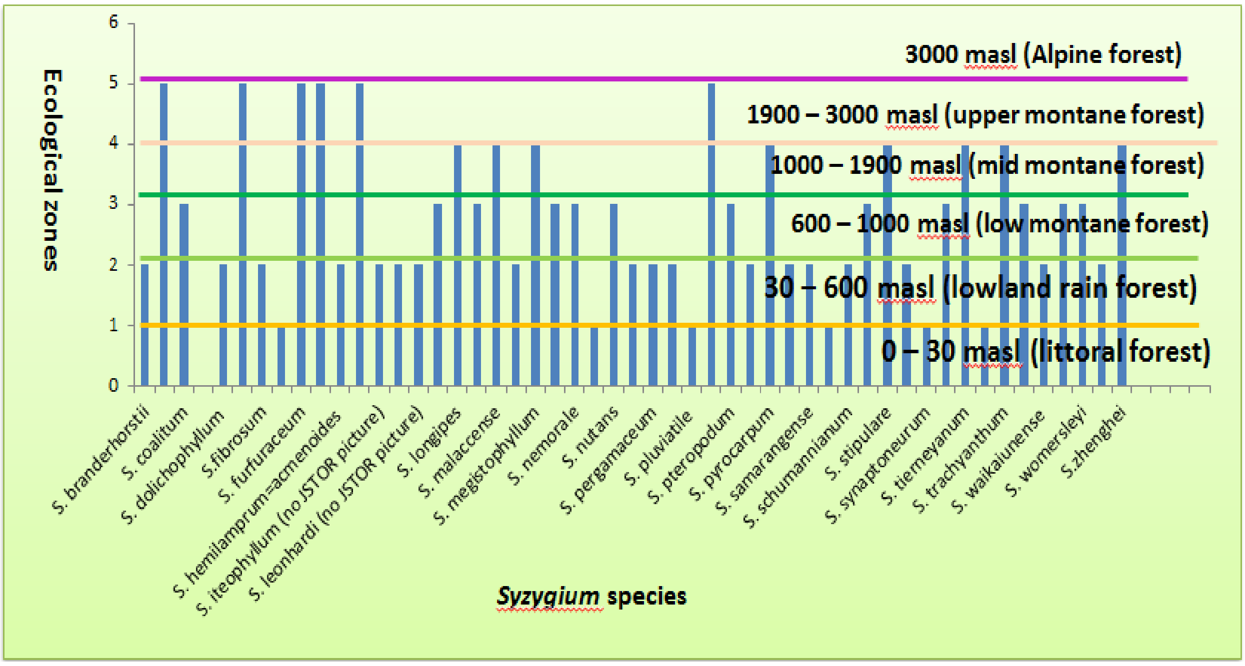
Figure 1 Distribution by province (Blue) and region (red)



The herbarium data above (Figure 1.) show the occurrences of the species in four major various regions and provinces. The graph actually indicates the presence of this genus (*Syzygium*) in all four geographical regions (MOMASE, HIGHLANDS, SOUTHERN, NGI) and the provinces. The graph also shows the distribution by provinces. There are some species that are specific to provinces which the graph above does not show.

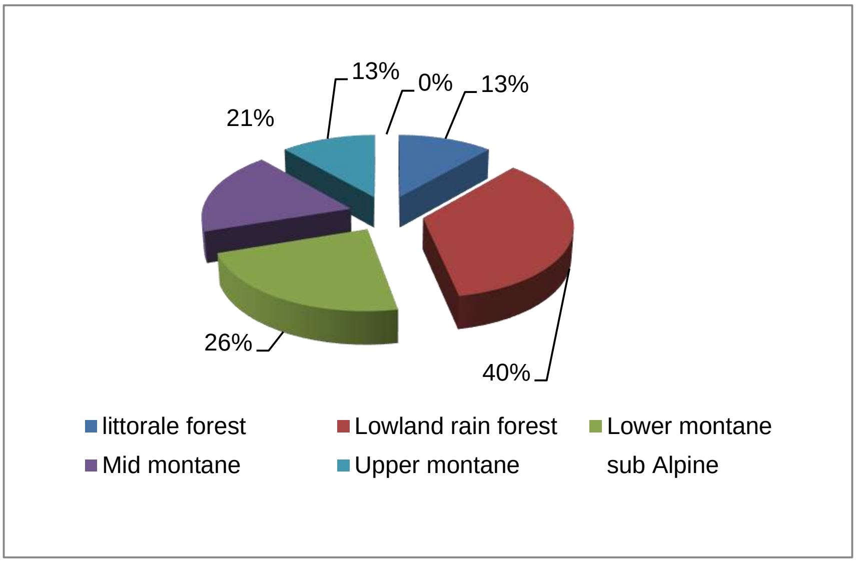
The graph below (Figure 2.) reflects the occurrences of *Syzygium* by vertical ecological zonation in Papua New Guinea by elevation gradients. For this research total of 157 species reported occurring throughout Papua New Guinea by Lae Herbarium was used. The records show that the species composition reduces with elevation vertically (Figure 3.). There some species that is specific to various elevations which this graph does not show.

Figure 2 Distribution by ecological zonation



The ecological zonation classification above based on Whitmore, 1998[iii] and used extensively by Johns, 1977[iv] during his teaching days in the forestry training schools. This has been adopted nicely by ecologist and botanist in Papua New Guinea. Although there is no significant on the ground lines and boundaries that distinguishes or separates one zone from another, the botanist will still maintain that there are several plant species that appear as indicator species to those respective zonations.

Figure 3 Syzygium species composition by elevation



The normal trend of species composition and diversity decreasing by altitudinal gradient is shown by the pie chart above (Figure 3.) Lowland rainforest with 40% and the upper montane 13 % portion as indicated in the pie graph. The sub alpine as always low on the diversity scale, no records of *Syzygium* documented.

3.2 NFI upper plants (UP) Data analysis

Figure 4 Syzygium species in the highlands (High altitude) clusters

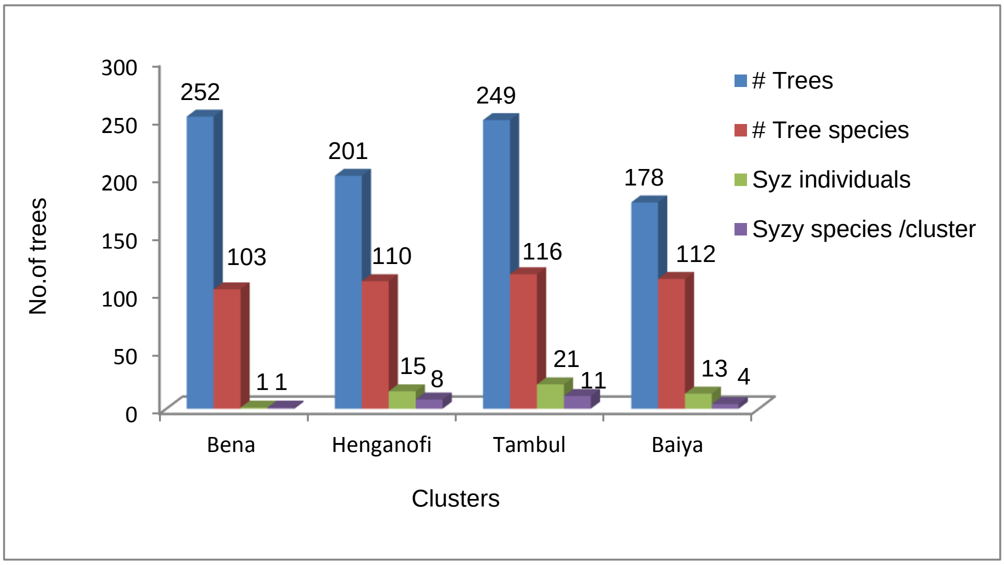
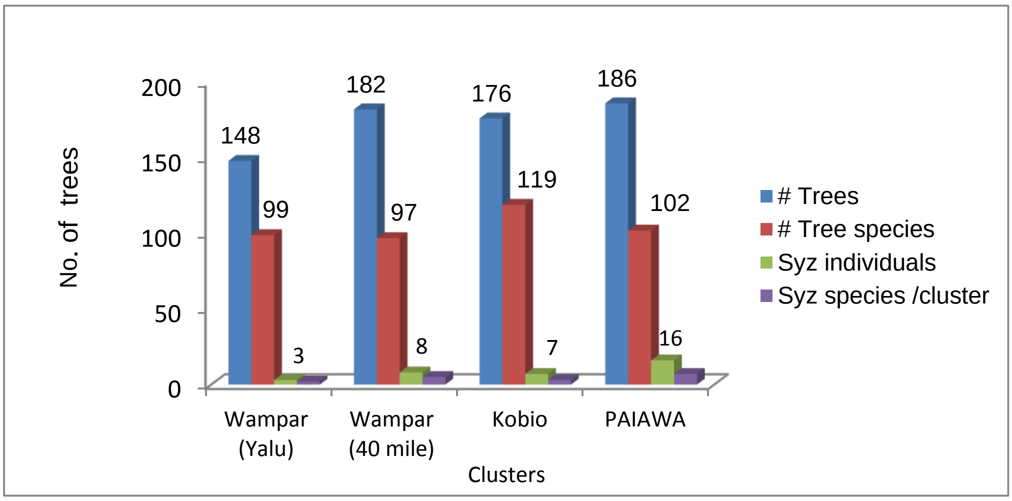


Figure 5 Syzygium species in the lowlands (lower elevation) clusters



3.3 NFI supper plot data analysis

Figure 6 Syzygium species in the lowlands and highlands super plot clusters

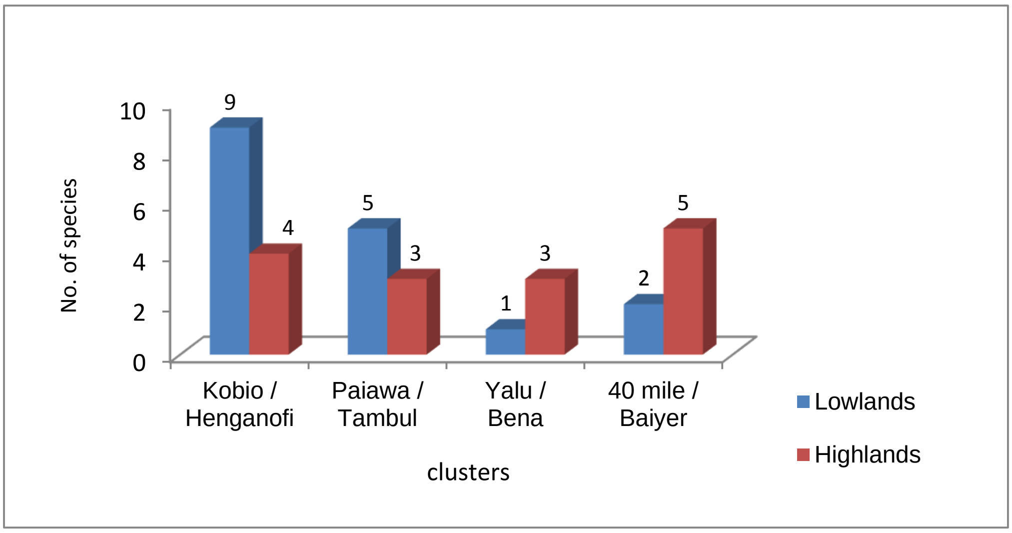
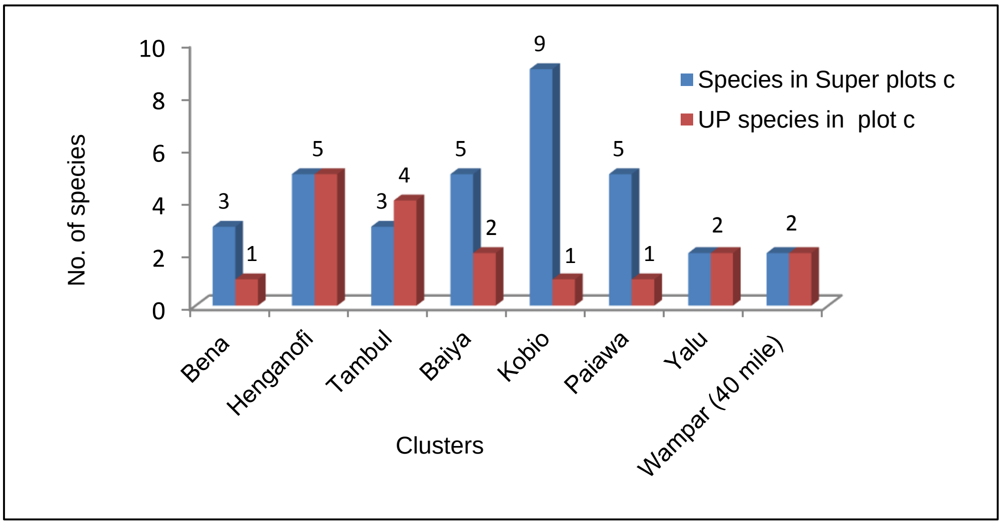


Figure 7 *Sygygium* species in the super plots vs species in the UP's in super plots



The graph above (Figure 7) showing in most center plots known as super plots, the number of large *Syzygium* tree species in the upper plants category is lower than the number of species in the supper plots. The tree sizes in the super plots smaller mostly seedling and sapling sizes compared to those in the upper plants category.

Lowlands clusters

Shannon Weiner: H‘ = - Σ pi/N ln pi/N
H = 2.06
J = 0.86084

Simpsons index: D=1 - (Σn(n-1)/N(N
= 0.59139

Highlands's clusters

Shannon Weiner: H‘ = - Σ pi/N ln pi/N
H = 2.04
J = 0.8209

Simpsons index: D=1 - (Σn(n-1)/N(N
D = 0.841536

Jaccard coefficient: 0.2174 (21%) - Low similarity

The diversity indexes above showing some variations in the species composition within two geographical locations (Highlands and Lowlands). There is low similarity between the two extremes.

4.0 Discussion

The information on the presence of the genus *Syzygium* in Papua New Guinea has only been reported in taxonomic references stating its exact locality where specimens of the respective species were collected. When it is overlaid with other parameters such as elevation, ecology (habitat type), soil types, geology etc., the knowledge and understanding of individual species preference will be known.

At this stage the results provided in graph form indicate densities and diversities present in the plots assessed. The Lae herbarium data gives an overview of the presence of each species in various locations in Papua New Guinea as well as where on the vertical elevation scale the species was collected from.

The graphs from the herbarium data indicated that the Syzygium species are distributed throughout all provinces in all four geographical regions of Papua New Guinea. The diversity according to the collections, the lowlands at 0 to 600 m above sea level was greater and reduces to zero at 3000 meters above sea level (Alpine zone).

The NFI plots assessed and analyzed by Simpsons diversity index was 0.59139 indicating low diversity in the lowlands plots compared to 0.841536 indicating higher diversity in the highlands plots. The comparison of the similarity between highlands and lowlands plots was calculated using Jaccard coefficient of similarity index showed 21% indicating low similarity in the species composition.

The above NFI plot results may contradict the general trend of decreasing diversity and composition on the vertical elevation gradient for most organisms. For *Syzygium,* conclusions cannot be made here as to why it is widely distributed throughout Papua New Guinea until further research be carried out in various other ecological attributes such as soil and rock composition, forest types etc. have been assessed.

Acknowledgements

First of all I want to acknowledge PNGFA/NFI/ FAO coordinators for accepting my request to collect data from NFI survey for my MPhil studies. Secondly to my MPhil studies sponsor Binatang Research for being patient with me all along despite delays in collecting data they continued to maintain my scholarship. Thirdly to all PNGFA/NFI team members who helped in collecting my data throughout the NFI plots. Lastly but not the least to PNGFRI management and Forest Biology program team for providing all the support to me in carrying out my studies using the facilities especially the National Herbarium.

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ii) Barry J. Conn and Kipiro D.Q. Damas (2015) “Notes on Syzygium (Myrtaceae) in Papua New Guinea” Telopea. Journal of Plant Systematics 18:233-241.

[i]iii) Whitmore T. C. (1998) an Introduction to Tropical Rain Forests. Second edition: pg. 10 – 39.

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Forest Recovery Patterns and Species Diversity Dynamics Following Large-scale Forest Disturbance in PNG

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Abstract

Forest recovery following large-scale disturbance either in the tropics or temperate areas normally would follow an orderly pathway of development. The development of the regenerating forests from weeds to secondary trees and later by primary species merging into a climax community followed a generalise pathway. This pathway of succession enables early colonizers to invade disturbed sites become established, grow, reproduce and die and in the process change their environment which is no longer conducive for them but to others that followed. In a PNG lowland rainforest the pattern of recovery following clear-fell logging in Gogol Valley, Madang Province, which was studied from 1983 to 2013 appeared to follow two successional pathways. The first pathway is that of facilitating or obligatory, especially where soils are disturbed such as that on the roads and the log landings. The other pathway is that of competitive hierarchy successional which seemed to occur on sites that have limited soil disturbance.

Species diversity within the plots reached its maximum at the age between 7 and 10 years and thereafter begins to decline. This decline coincides with the high deaths of grasses, weeds and many of the short-lived pioneer trees such as *Macaranga* and *Pipturus* and others, although some remain for some period of time. While at the same time long-lived secondary species such as *Canarium*, *Intsia*, *Anthocephalus* and others together with the primary species (e.g. *Celtis*) become prominent on site; not so much in terms of further recruitment but regrowth from viable vegetative plant parts.

The study also indicated that life-history characteristics of plants are critical for our understanding of how this pattern of forest recovery was progressed. In the cleared forest of the Gogol area it was found that for tree species there were three types of life-history strategies that of early pioneers (short lived), secondary long-lived secondary pioneers and primary species, apart from weeds and grasses.

The modes of regeneration of plants in these disturbed plots were derived from the seed banks, seed rain and form coppices. From these modes seed bank source was more important for early short and long-lived secondary plant species, while the primary species were the main source of the regeneration modes for primary plant species.

The above processes accompanied by the species diversity dynamics will be discussed in the paper.

1. Introduction

Secondary vegetation is today a common feature of humid tropical landscape and is rapidly replacing much of the original or primary forest. In PNG most of the secondary vegetation, apart from natural causes, can be are attributed to anthropogenic activities, especially shifting and commercial agriculture, logging, extractive industries and infrastructure developments. This trend will continue because of economic and population pressures. It is therefore important that the there is an urgent need to start looking at how to manage such forests and mainstreaming them into economic use. However, to do this, we must have a good understanding the processes involved in forming such forests and their dynamics both in space and time.

Forest recovery following man-made large scale forest disturbance has been studied in the tropics and in general found to follow a general pattern leading to the restoration as a climatic climax which is not the same as it origin. In order to achieve the final stage of a climatic climax, the development of recovery generally undergoes a number of changes which can be classified into three phases:

1. First phase. When the forest cover is removed changes at once take place in light intensity, temperature and humidity. The light intensity is increased from that of the deep shade of the forest to that of full daylight. The temperature increases in the range and the humidity is drastically reduced. The array of micro-climatic conditions of the original forest disappears. Owing to the fact that the soil then becomes exposed to rain, wind and rain, soil deterioration sets in leading to erosion, leaching and rapid loss of humus and thus the nutrients.

This first phase of recovery is dominated by weeds and grasses which are often short lived and may go through their life cycle in less than a year.

2. Second phase. Shrubs then enter the area and may succeed in dominating the vegetation, but sooner or later trees take over and form a canopy. These trees are mostly short-lived, fast growing and have mechanisms for wind and/or animal dispersal of their seeds or fruits. These trees cast more shade, in which their own light-demanding seedlings cannot grow.

3. Third phase. In the course of time the more slowly growing, shade-tolerant seedlings of the forest trees enter. The young secondary forest is often even-aged and dominated by a single species which generally lasts a single generation, after which it is replaced by other species. As time progresses, it becomes more mixed in age and species as well as its structure and gradually reach its climax.

Horn (1976) distinguished three models for predicting the direction of succession following forest disturbance which include which will be applied in this study:

1. Invasion of gaps by plant species which are well established in the surrounding forest. Succession in this model is thus achieved in one generation and is particularly found in forest gaps caused by exogenous disturbance (e.g. wind throws or deaths of large trees).
2. Second model generally follows the general process described above which he termed "**obligatory succession**" and involves the replacement of one community by another in a predictable manner until a mature community is established. Each stage in the series of community replacement is assumed to be the prerequisite for the development of the next. This is also known as **Clementsian succession**.

3. Third model involves many species invading the disturbed site simultaneously but only the long-lived species survive into the mature community. Further, the species involved are said to form a "**competitive hierarchy**".

The main objective of this study is to determine the pattern of forest recovery processes with the accompanying issues of regenerative modes of the colonising plants and the species diversity dynamics through the early stages of forest recovery.

2. Methods

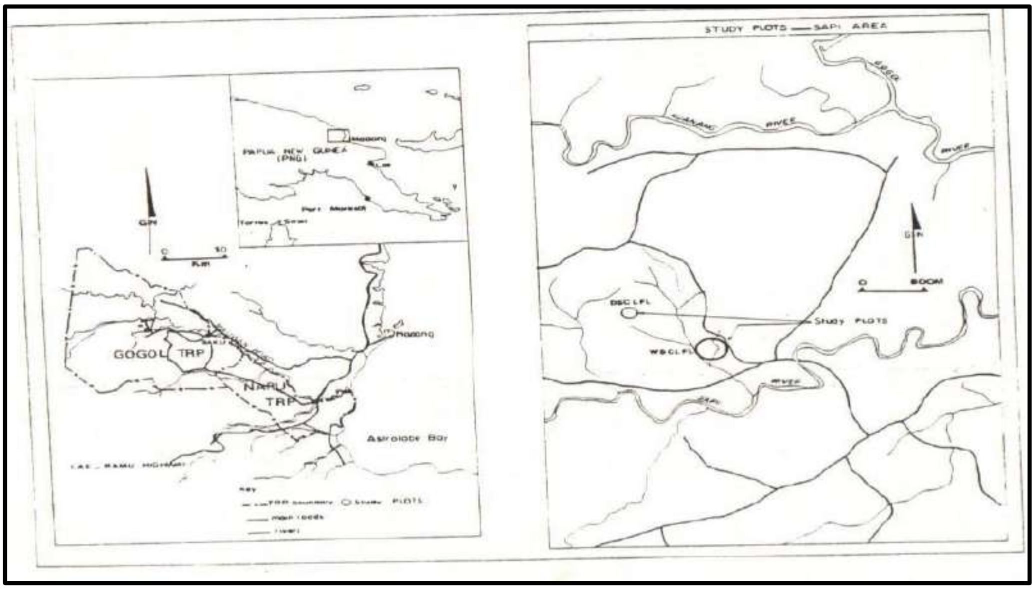
The recovery processes were investigated using a one hectare permanent plot with a series of sub-plots established immediately following clear-felling and burning in 1983 till 2013 in the Gogol Area, Madang Province (Fig1). Within these sub-plots all plants growing in them were enumerated by species, heights and diameters as well as recording their source of origins.

From the onset following the establishment of the plot with its sub-plots enumerations of the regrowth were made every month until year 2 and thereafter at an annual basis until year five when further enumerations were conducted on a 5 year basis until 2013.

Apart from this plot which was established during the wet season logging operation, another plot of same dimension (i.e. 1 ha) was also established in a nearby area that was cleared during the dry season. Similarly, an addition ten (10) plots were also enumerated from the surrounding regenerating secondary forests of serial stages with ages from 3 -12 years old.

To determine the origin sources of colonisation by plants on the disturbed areas, soil samples were collected both from the compacted soils and in undisturbed soils plots at a depth of 5cm and observed and recorded over a year for germinant. At the same time seed traps were also established within the cleared areas to trap any seeds falling into the disturbed area. Likewise, observations were also made on the potential contributions from vegetative plant parts especially that of tree stumps, stems and roots.

Fig.1. The locality map of the Gogol Valley Study area, Madang Province



The details of methods used in this study are provided in number of publications, including Saulei (1984 and 1985).

Prior to discussing the results, it is important that some definitions be made about the terms used in describing the grouping of colonising plants in this study which have been covered by Swaine & Hall (1983) and slightly modified in this study (Saulei,1985):

- **Short-lived pioneers** – those plants that emerged very early on bare areas, become established, reproduce and die over a short period of time (3-10 years). They can only germinate under sunlight and are shade intolerants.

- **Long-lived secondary species** – These comprise species that germinate under limited direct sunlight, (not under shade) become established and persist over longer period forming part of the primary species. Today this group of secondary species comprise between 40-50% of the so called primary forests.

- **Primary species –** Species of trees that are able to germinated under shade (shade tolerants), become established and persist on site forming part of the climax forest community (primary forest).

These definitions of different groups of plants colonizing disturbed forests are based on the **life-history strategies** of these plants.

3. Results and Discussions

3.1 *Pattern of forest recovery or Succession*

In this study of the early stages of forest recovery in Gogol area, two important processes of forest recovery were observed:

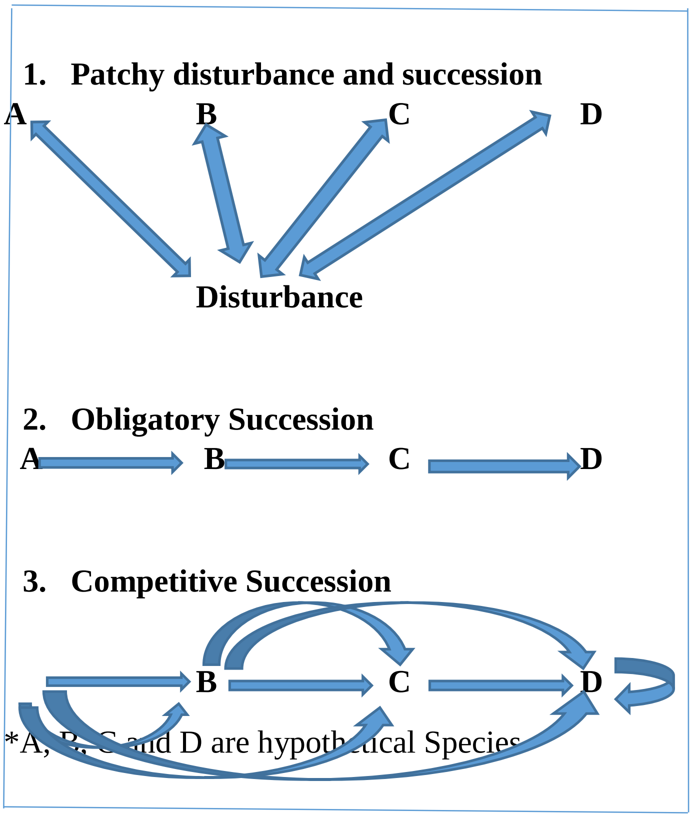
1. Obligatory succession which was observed on severely impacted cleared areas such as those on logging tracts and on log landings. On roads where the soil surface is scrapped leaving behind sub soils as well as being compacted, regeneration processes was observed to be relatively slow and sparse. However, as time progresses the succession proceeds. Likewise, on log landings where soil was compacted recovery was slow.

On these sites, the early colonizers were mostly weeds and grasses which were later followed by short-lived pioneer trees and later by both long-live secondary and primary species.

2. On much of the cleared areas where soils were neither removed nor compacted, it was observed that the recovery process followed the competitive hierarchy model. Here it was found that regeneration almost commenced immediately following clearing and burning by weeds, grasses and short-lived pioneer trees. At the same time a number of long-lived secondary and primary tree species also appeared, originating from either seeds or from vegetative plant parts such as stumps, stems and roots. Of particular interest are the commercial ones such as *Intsia, Anthocephalus, Canarium, Spondias, Myristica, Celtis, Diospyros, Dracontomelum* and *Pterocarpus*.

The first model of forest recovery was applied here as the cleared areas were relatively large. However, such pathway of recovery was observed in a nearby small village reserve adjacent to the clearing area, Here small gaps created by wind throws and fallen matures trees were quickly covered by lateral growth of branches from the surrounding vegetation. On larger gaps, the previously suppressed seedlings and saplings by the original forest cover were able to grow and covered he gaps. A similar observation was also recorded from the intact or closed forest of the Sapi Benckmark Reserve forest. The gaps observed had sizes ranging from small to medium (20 – 40m^2) and larger than that, the other two models can be applied but this will depend very much on the extent of the disturbance.

Fig.2 The three generalised patterns of forest recovery (succession) proposed by Horn (1976)



3.2 Regeneration modes of Colonizers

From both the seed bank and seed trap assessments, it was observed that on large clear-fell logging areas, the colonization process depend very much on the availability of seeds or vegetative regenerations (Saulei & Swain, 1988). Obviously, for the early colonizers, mostly herbs, grasses and short-liver pioneer trees, much of their source of regeneration came from seeds stored in the soil or being dispersed into the area immediately or later from surrounding secondary and primary intact forests. Further, in large-scale clearings the colonising array of plants were derived from three sources; seed bank, seed rain and coppices (Figs. 3a and b). A higher percentage of those regenerating short-lived as well as long-lived secondary species originated from seed banks and to some extent seed rain and coppicing.

On the cleared areas where the soil was not disturbed, regeneration was quite fast and within six months the whole area was already covered by weeds, grasses and early pioneer trees such as *Pipturus*, *Macaranga*, *Leucosyke*, *Homolanthus*, *Trema* and others together with some of the long-lived secondary species such as *Anthocepalus*, *Spondias*, *Vitex*, *Endospermum*, *Dracontomelum*, *Canarium*, *Eleaocarpus*, *Gastoni*a, *Intsia*, *Garuga*, *Cordia* and others.

At the same time the coppicings from vegetative parts of the plants especially the long-lived secondary and primary tree species with particular reference to *Myristica*, S*yzygium*, Glochidion, *Premna*, *Pterocarpu*s, *Intsia* and various species of *Ficus*.

Fig.3a The Seed Bank dynamics in the study area (Saulei, 1985)

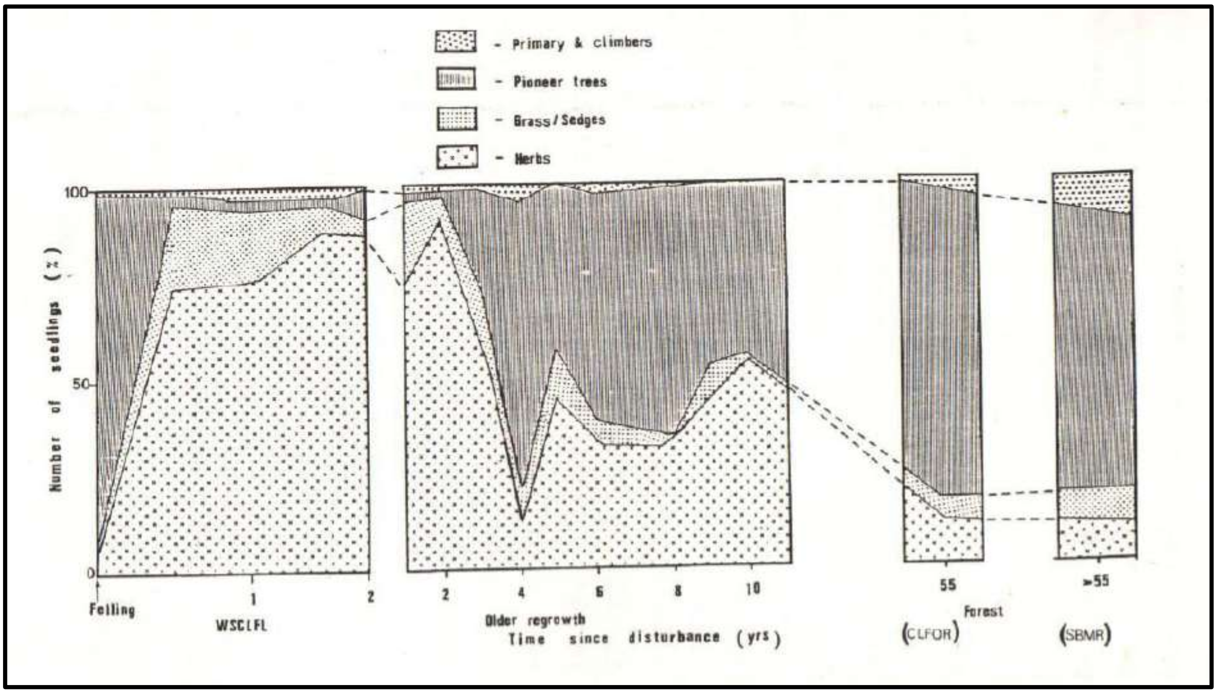
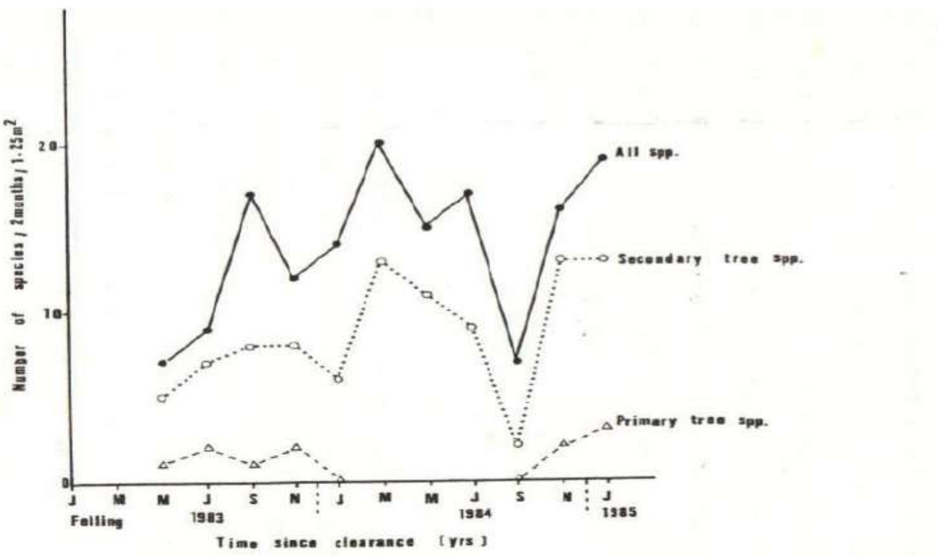


Fig. 3b. The Seed Rain dynamics recorded from the Study area (Saulei, 1985)



3.3 Species Diversity

The species diversity dynamics over the 30 year period is shown below (Fig.4a) in which the apparent increases in the early period of recovery for the pioneer species up to year 10 and gradually declines, especially for the short-lived tree species. While on the other hand the primary species showed a gradual increase. From the serial regenerating secondary forests with ages ranging from 3-12 years old, a similar species trend was also observed (Fig.4b).

Fig. 4a Species diversity for both primary and secondary trees observed on the studied plot

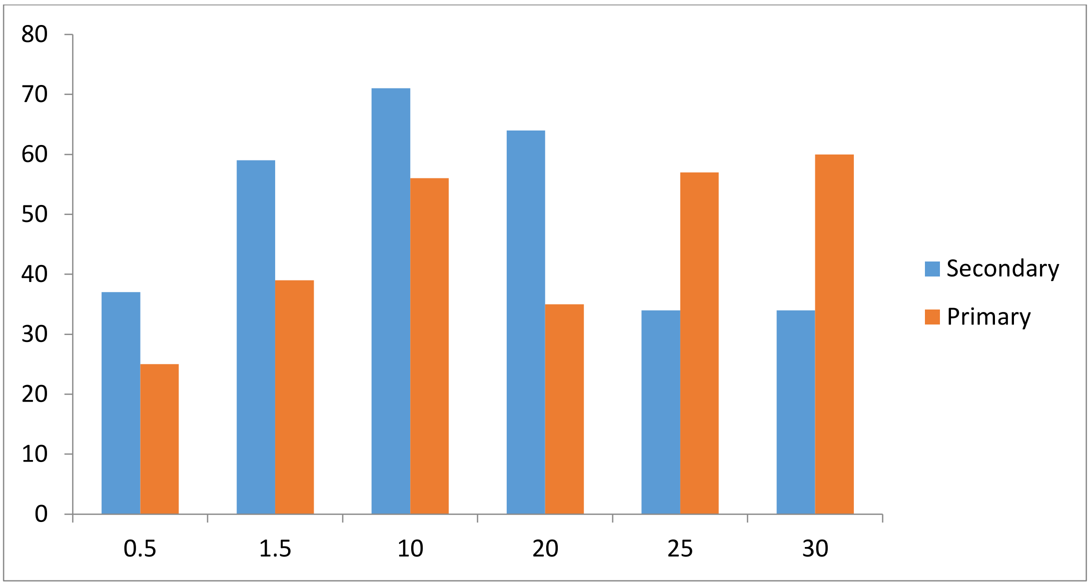
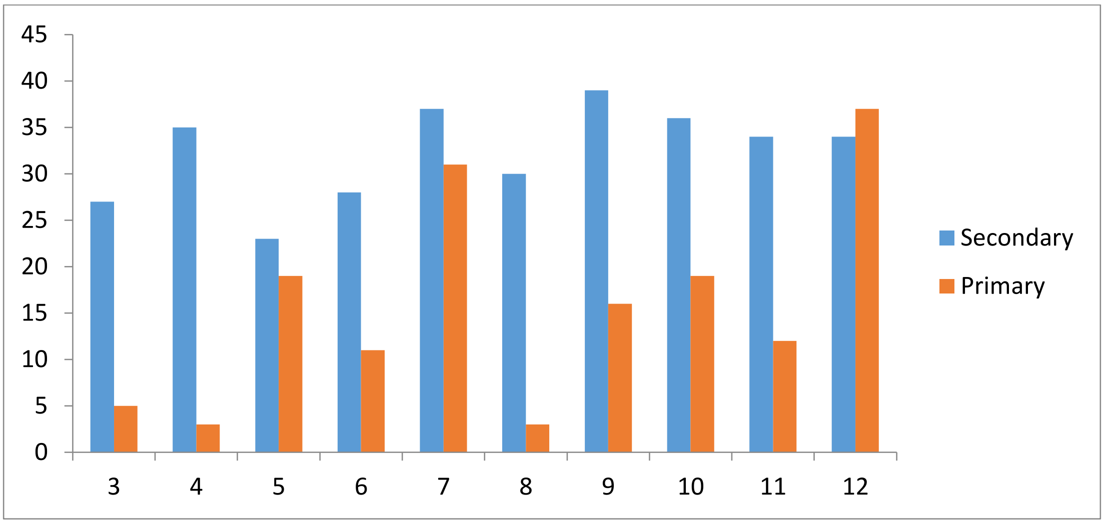


Fig.4b Species diversity for both primary and secondary trees recorded from the older regeneration plots



However, when one looks at the overall species diversity dynamics both for the study area and that from the older plots of serial stages, an interesting trend can be observed. This was the stage in which species diversity seemed to reach maxima. In the study site this maxima was attained by year 10, while for the serial plots this maximum diversity was attained in years 7 and 12 since clearance (figs 5a and 5b). For the study plot this increase in the overall species diversity can be related to the increases in the number of secondary and primary species that were recruited following the El Nino of 1997-1998 periods.

While for the two peaks found in the older regenerating plots which were enumerated earlier than the El Nino period were largely due to the disturbance caused by the wild pigs found in these regenerating forests.

Fig.5a The total number of tree species (both secondary and primary) recorded from the study area of Gogol Valley, Madang Province

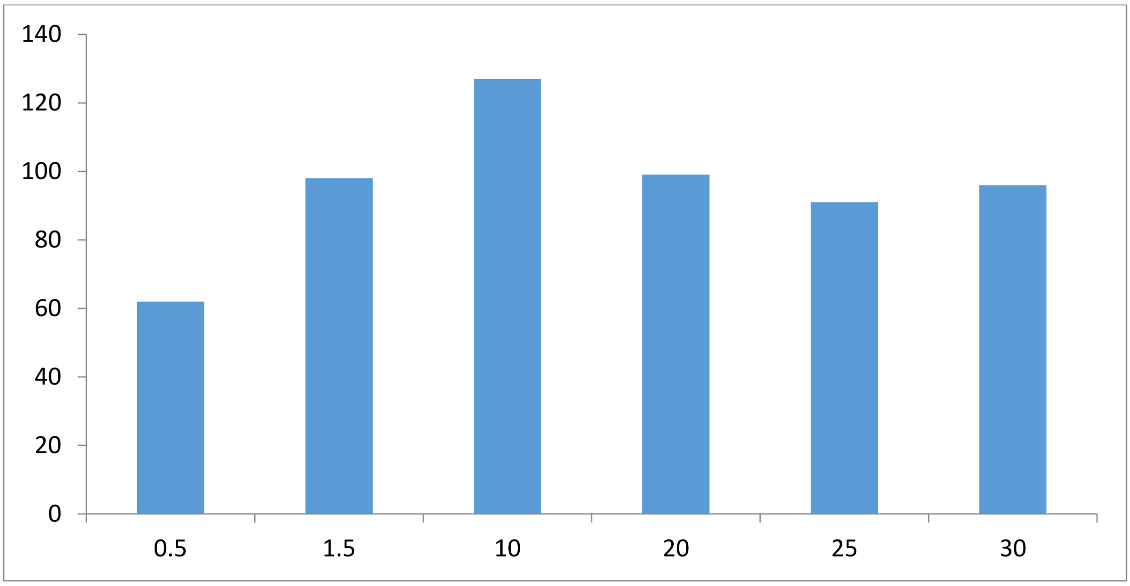
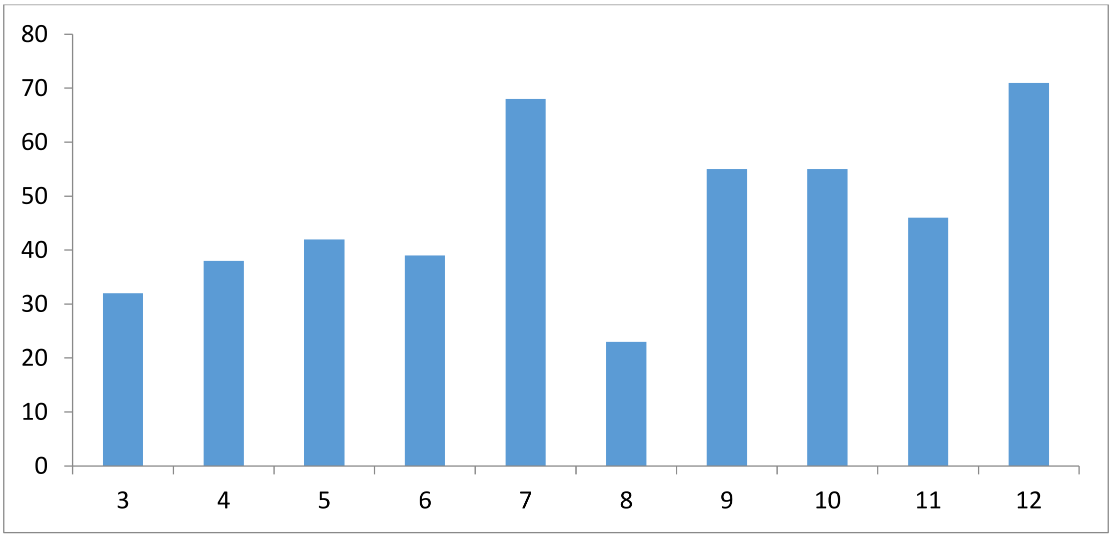
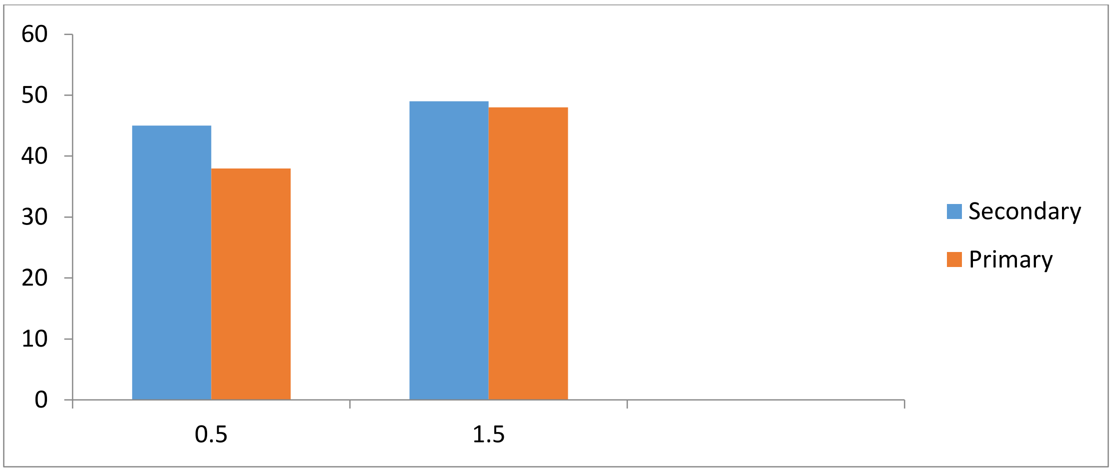


Fig.5b The total number of tree species (both secondary and primary) recorded from the ten (10) serial plots in the Gogol Valley, Madang Province



The tree species diversity recorded from the plot established on the dry season clearing was found to be higher than that on the wet season clearing plot in the first six months of growth for both secondary and primary species (Fig. 6a). However, after 1.5 years the both the secondary and primary tree species showed a lower increase compared to those observed in the wet season plot. Further, most of the increases in primary tree species were derived from coppicing vegetative plant parts unlike those recorded from the wet season clearing where seed bank played a major role.

Fig.6 The regenerative tree species (secondary and primary) on the dry season clearing plot



It could have been interesting to see what happened on this dry season plot after one and a half years of growth if follow up measurements were done. However, this could not be done as the plot was destroyed when the area was cleared and replaced by Kamarere plantation. Nevertheless, the dry season plot showed an interesting aspect of regeneration where it was found that most of the primary species were regenerating from coppices than from seeds as clearing was done at the time when most of the trees from the intact adjacent village reserved forest or from the Sapi Benchmark forest were not fruiting and shedding the seeds.

Conclusions

From the study a number of conclusions can be deduced as follows:

- The observed process of forest recovery (succession) in the Gogol area appeared to follow the two models proposed by Horn (1976) that of (i) obligatory or Clementsian facilitation which were observed on sites which were heavily disturbed such as those on roads and log landings and (ii) the competitive hierarchy model in which all different plant life forms of various life history characteristics invade the cleared areas almost simultaneously;

- In these areas the mode of succession by these various plant life-forms were form seed bank, especially for both short and long-lived secondary species and by coppicing from various viable vegetative plant parts, notably the primary and some long-lived secondary species and to some extent from seed rain. On areas where soils were not disturbed forest recovery was rapid and appeared to follow Horn's competitive hierarchical model of succession.

- Seasonal clearing has an impact on the successional processes with particular reference to growth and the origins of the regenerating plants. It was noted that growth was observed to be slower on dry season disturbance than that of the plot created during the wet season. Further, most of the long-lived secondary and primary tree species originated from coppices and the recovery process appeared to follow the obligatory or facilitating succession.

- Under condition of soil disturbance, both growth and regeneration were found to be slow with the main source of regeneration originating from seeds from seed rain and to some extent seed bank and coppicing from vegetative plant parts. Succession pattern under such conditions was mostly by obligatory or facilitating model of forest recovery.

- Species diversity appeared to be high during the early stages of succession between the ages of 7-12 years old.

Thus, in PNG the forest recovery patterns showed both obligatory and competitive hierarchical models of succession, while under closed intact forests, the gaps created can be filled quickly by lateral extension of the surrounding trees and if large enough, the gaps will be covered by the suppressed saplings and seedling found on the ground floor of the forests.

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Measuring Soil Carbon in the Multi-purpose National Forest Inventory Soil Survey: Summary Report by the NFI Soil Sampling Team

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Abstract

Soil carbon is one of five carbon pools that are being measured in the Multipurpose National Forest Inventory (MNFI) in Papua New Guinea. A total of 1000 sites or clusters were systematically selected for soil survey to cover representative forest types in the country. This report covers the first eleven sites identified for the MNFI and surveyed for soil carbon assessment. The sites are located from lowland to mid-montane forests with elevations ranging from 30 m to 1500 m asl. Sampling design and methodologies followed protocols described in the MNFI Field Manual (FAO-PNGFA, 2018) and the field guide for soil description and sampling (McIntosh et al. 2017).

Preliminary analysis of results obtained from the first eleven profiles described in the survey as well as those obtained from earlier studies indicate soil carbon in the range of 58 to 600 t C/ha. These results confirm that soil carbon to 1 m depth constitutes about 50–75 percent of the country's total forest ecosystem carbon. A 5-category rating system for soil carbon to 1 m depth is proposed to assist comparison between soils

Introduction

Soil carbon C is one of the five forests C pools which need to be reported under UNFCCC. The Multipurpose National Forest Inventory (MNFI) includes soil C assessment so that baseline values of total ecosystem C in PNG forests can be measured at particular sites and extrapolated to the forest estate in general. Once baseline values are known, changes of soil C resulting from land use or natural events can be estimated. Carbon losses can occur through the processes of cultivation, conversion of natural forests to other land uses, run-off, stream erosion and mass movement, among others (Bleeker 1983, table 12.3; Rijkse and Trangmar 1995; Trangmar et al. 1995; McIntosh 2013, p. 47–61). Pre-MNFI results indicated that up to 50–75% of PNG's forest carbon is held in the soil and in some soils a significant proportion of C may is held in subsoils below the topsoil layer (Nimiago et al. 2014). In the MNFI survey a subset of 100 plots was selected for detailed soil C assessment. This report summarises results obtained from the first eleven profiles described in the NFI survey as well as those obtained earlier by other researchers.

Methods

Surface soils to 30 cm depth and 1 m profiles were made within the MNFI plots according to the sampling design described in the MNFI Field Manual (PNGFA-FAO, 2018).To ensure consistency during the MNFI soil survey UN-REDD+ and the Crawford Fund (Australia) funded production of a field guide for soil description and sampling (McIntosh et al. 2017). Soils were sampled to 1 m depth using the methods described in this guide. Soils were classified using the FAO system (IUSS Working Group, 2014). Soil chemical analyses using methods based on those by Blakemore et al. (1987) were done by the Environmental Chemistry Laboratory, New Zealand.

Results

Lowland colluvium from fossiliferous Pliocene and Pleistocene marine sediments

Three soils were described and sampled, at about 120–140 m altitude in the Gogol and Sogeram River catchments of Madang province. One was in alluvium on an imperfectly-drained minor terrace (Paia Mt; cluster 64259), one on disturbed (cultivated and compacted) rolling lowlands (Baisarik; cluster 65768), and another in colluvium on eroding steep lands (Kokun; cluster 67271).

The **135 t C/ha** figure at Paia Mt probably approximates to the C held in undisturbed lowland soils on this parent rock. The Baisarik site cultivated for plantations has lower (**121 t C/ha**) organic matter levels in the topsoil. The Kokun site (**87 t C/ha**) is steep and has been affected by mass movement. The Paia Mt and Baisarik C figures are medium and the Kokun figure is low[4].

Acid-oxalate extractable Fe is in the range 0.5–1.25% in topsoils which is medium to high. Acid-oxalate Al values are mostly in the low range (0.2–0.5%) as are Si values (0.05–0.15%). The higher values of acid-oxalate extractable Fe in the 0–20 cm soils at Paia Mt and Baisarik may be due to recent volcanic ash additions to the surface of these soils. The Kokun soil indicates the strong influence of erosion on soil properties: past landslides at this site have lowered soil C values by about a third with respect to stable soils developed in this parent rock.

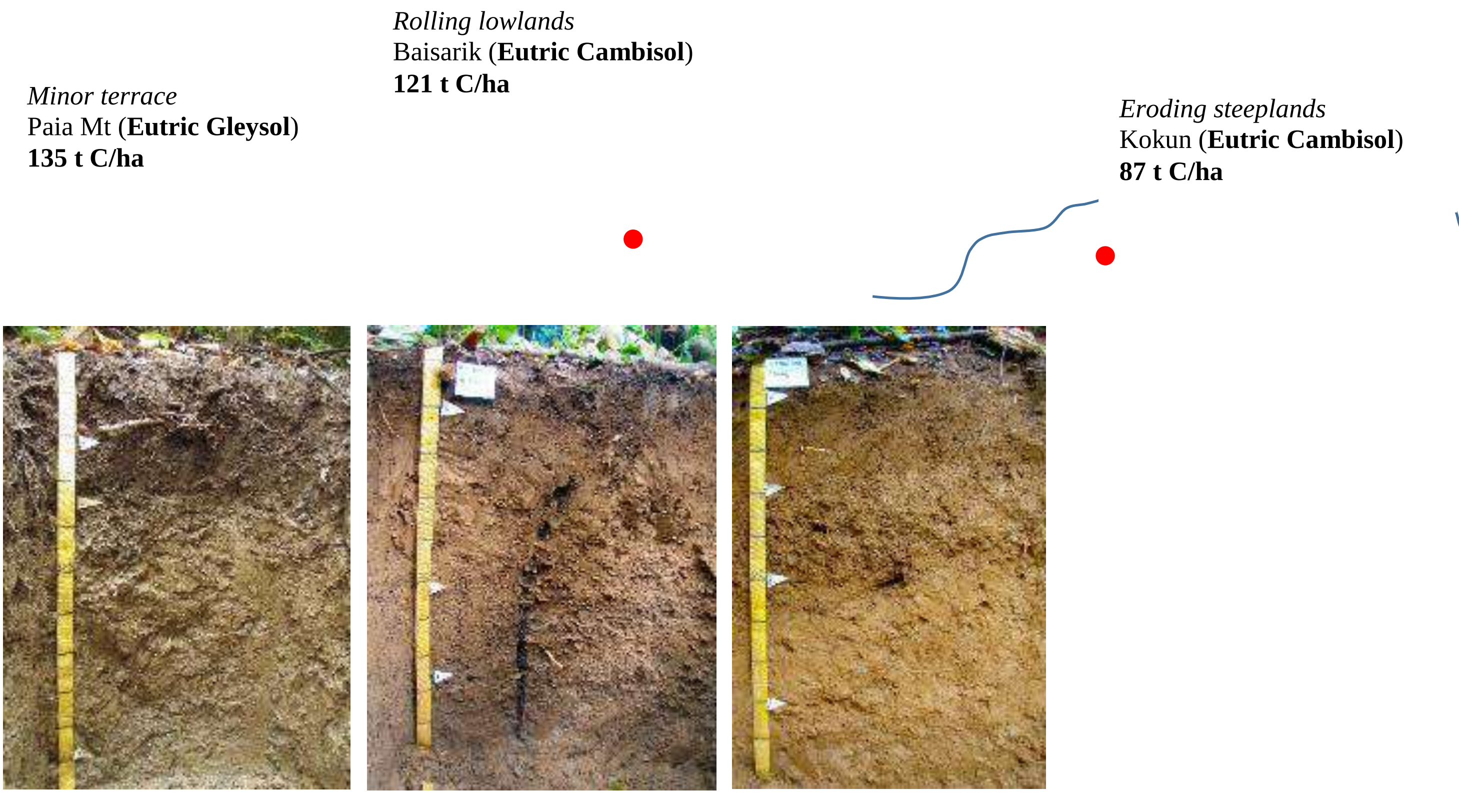

Fig. 1 Diagrammatic representation of soils and landforms in the low-lying parts of Sogeram and Gogol River catchments

Soils of the upper floodplains of major rivers

Two soils were described on the floodplains: one at Manabo in southern Central province, west of the Bomguina River and one at Ngaroyats in Morobe province, south of the Markham River opposite the end of Biomass Road. The Manabo profile (**Fluvic Cambisol**; cluster 126464) contained **196 t C/ha** and the Ngaroyats profile (**Salic Gleysol**; cluster 83331) **113 t C/ha**.

Acid-oxalate extractable Fe is high in the Manabo profile but medium in the Ngaroyats profile. Acid-oxalate-extractable Si values are extremely high (1.2–2.8%) in the Ngaroyats profile and Al values are high.

The Manabo profile contains a palaeosol (buried soil) which is an important repository of extra C: 57% of the C in this profile is held below 30 cm depth. The parent material of this soil is Quaternary alluvium derived from volcanic and sedimentary rocks which outcrop in the foothills of the Owen Stanley Range. It is from the volcanic rocks that the high acid-oxalate extractable Fe values are probably derived. The carbon-complexing iron also contributes to the high carbon in the soil. In contrast the Ngaroyats soil contains no buried soils (although multiple buried soils are visible in the bank of the Markham River nearby – see photograph below) and acid-oxalate extractable Fe values are only medium.

[4] Provisional soil carbon ranges are defined in Appendix 1.

Fig. 2 Manabo profile (left), Ngaroyats profile (centre) and multiple palaeosols on the north bank of the Markham River near Biomass Road (right)

The contrasting properties of the two profiles demonstrate the variability associated with floodplains. What is missing from this survey is a measure of the importance of multiple palaeosols on C storage (see photograph above). Soils with multiple palaeosols are likely to have C contents in the very high range (>271 t/ha) and be an important stock of soil C in PNG.

The Gigioi profile (**Eutric Cambisol**; cluster 126969) comes from a low hill surrounded by the floodplain of the Omado River, a tributary of the Godaguina River which flows into Cloudy Bay. The present-day floodplain may in fact be an uplifted marine bench and the hill, formed in strongly weathered andesite, may originally have been a lava plug. Acid-oxalate-extractable Fe is high in the upper soil layers due to weathering of the iron-rich rock. Soil C levels are only moderate (**118 t/ha**) possibly because of erosion of topsoils as a result of fires or previous disturbance.

Fig. 3 Gigioi profile (left) formed in strongly weathered andesite (right)

Soils of the Sogeri uplands

The Sogeri plateau at about 650–750 m is formed in Tertiary basalt and andesite. The Girinumu profile (**Dystric Cambisol**; cluster 117417) was sampled on a steep slope. Although topsoils are indistinct (see profile photograph) and the hillslope sampled showed evidence of sheet erosion, soil C to 1 m depth (**150 t/ha**) is in the moderate category. Much of the C is probably tightly held in clay-organic complexes. Pyrophosphate extraction would demonstrate whether this was correct. Non-eroded stable soils under forest on this parent material are likely to have C levels in the high category.

Fig. 4 Girinumu site and profile

Soils of eroding steeplands

Two **Eutric Cambisol** profiles were sampled on steeplands north of Lae. One profile (Irom; cluster 82838) was located in the Atzera Range. The other (Kopsasik; cluster 81337) was located near Mt Busu in the Finisterre Range. The two sites are separated by the Busu fault which in this region separates younger sedimentary rocks (Miocene and Pliocene) to the west from older Finisterre volcanics (Oligocene) to the east. Although both profiles were on land which had not experienced recent instability, probably all slopes have experienced mass movement at some time in the past.

The Irom soil has moderate C to 1 m depth (**98 t/ha**) and the Kopsasik soil profile has low C (**68 t/ha**). Low to moderate C levels result partly from erosion and partly from moderate to high percentage of stones in these profiles: the Irom profile had 50% stones in horizons below 58 cm depth and the Kopsasik profile contained 80% stones in subsoils.

The higher acid-oxalate extractable Fe and Al values in the Kopsasik soil compared to the Irom soil are explained by weathering of the volcanic parent rock of the Kopsasik soil.

Fig 5 Irom profile (left) and Kopsasik profile (right)

Soils associated with recent volcanic deposits

Two profiles were sampled on soils developed on recent volcanic deposits of different materials as well as on different landforms. One profile (Ononda; cluster 108924) was sampled in forest on plains in Popondetta on **Gleysol** developed on alluvial deposits and andesitic volcanic ash. The second profile (Hark; – cluster 71396) was sampled in lowland advanced secondary forest in Kimbe on **Andosol** developed on rhyolithic pumice.

The Ononda soil has low C to 1m depth (**58 t C/ha**) as does the Hark soil (**96 t C/ha**). Although both soils are young and therefore would have less carbon (as expected), the low carbon in the Hark soil is also due to the high concentration of pumice gravels throughout the profile.

Fig. 6 Ononda profile (left) and Hark profile (right)

Mainly pumice

Results of other relevant surveys

In their ground-breaking study in montane forest Edwards and Grubb (1977) found that a “humic brown clay” at 2500 m altitude in the Marafunga basin (Chimbu province) east of Mt Kerigomna in the Bismark Range contained soil C to 1 m depth of **600 t/ha** (very high), a value far exceeding the biomass C (155 t/ha) at this site. The soil was on terrace of the River Fatima. The soil parent rock was gabbro and volcanic ash. No soil profile was described but the soil was stated to be free draining “humic brown clay”. In the FAO classification it may be classified as a **Ferralsol**, but this requires confirmation. A notable feature of the soil was the high organic matter content at depth – more than two-thirds of the C in the soil was found below 30 cm depth. The authors remarked that “the richness in organic matter is not always reflected in the soil colour” which suggests that the organic matter was not present as labile humus but as a stable clay-organic matter complex. The soil may be typical of terraces of rivers draining basic and volcanic terrain at high altitude – further measurements on comparable sites would be useful. The surrounding erosion-prone steeplands are likely to have lower soil C accumulation.

The very high soil C at the Edwards and Grubb site emphasises the effect on C stocks of a combination of cool, wet montane climate and weathered parent rocks rich in Fe and Al. More survey sites need to be located in a range of montane environments, covering the topographic variation (steep slopes, hill slopes, stable ridges, terraces and floodplains) as well as the varied geology, to establish how important montane soils are for storing C.

Abe (2007) described four low-altitude well-drained clay-rich (58–86% clay) soils (**Dystric Cambisols** or **Umbrisols**) on slopes of 13–34^{o} in limestone in Mongi-Busiga on the eastern Huon Peninsula. He found that these contained moderate amounts of C (**101–157 t C/ha**) to 1 m depth. The soil with most C was on the steepest slope. The range of values recorded is similar to that measured in stable soils of the Madang lowlands (Paia Mt and Baisarik soils; 121–135 t C/ha) in the NFI survey and supports the proposition that clay-rich non-eroding soils on calcareous rocks of the moist lowlands will mostly have C contents in the moderate range (91–180 t/ha).

Matsuura (1997 and personal communication) measured soil C in two areas: three profiles at 480–1400 m altitude in colluvium in schist steeplands in the Herzog Mountains southwest of Lae in Morobe Province and two profiles in colluvium formed from unspecified sedimentary rocks near Kumil, northern Madang province. All soils are probably classified as **Dystric Cambisols**. In the schist terrain of Morobe Province C to 1 m depth ranged from **86 t/ha** to **132 t/ha** (moderate). The highest altitude site (1400 m) near the Buang River had **97 t C/ha**. The amount of C in subsoils was limited by stoniness: all three profiles analysed had >50% stones in some horizon. In soils in colluvium from sedimentary rock in northern Madang Province C to 1 m depth ranged from **95 t/ha** to **123 t/ha** (moderate). These results confirm that many soils on lowlands in PNG have C contents in the moderate range (91–180 t/ha).

Comparison between the soils

Soil carbon to 1 m depth at the eleven clusters studied is in the range of 58 – 196 t C/ha. Previous studies indicated a range of 86 – 600 t C/ha for PNG. Distribution of carbon down the profile for the eleven sites is variable. Four clusters had < 50% C in the top soil (0-30 cm), 5 of the clusters had equal amounts in the surface and subsoils and 2 clusters had < 50% C in the subsoil (30 – 100 cm). Using a five-category rating system modified from Blackmore et al. (1986) the soils can be rated as low to moderate. Many of the soils surveyed in this study and those of previous studies are classified as Cambisols. These however have varying carbon contents therefore soil classification is not a good predictor of soil carbon.

Table1 Carbon ratings for PNG soils

SOIL	GEOLOGY	CLASSIFICATION	CARBONRATING
Paia Mt	Calcareous siltstone	Eutric Gleysol	Moderate
Baisarik	Calcareous siltstone	Eutric Cambisol	Moderate
Kokun	Calcareous siltstone	Eutric Cambisol	Moderate
Manabo	Alluvium with volcanics	Fluvic Cambisol	High
Ngaroyats	Quartzo-felspathic alluvium	Salic Gleysol	Moderate
Gigioi	Andesite	Eutric Cambisol	Moderate
Girinumu	Basalt and andesite	Dystric Cambisol	Moderate
Irom	Siltstone	Eutric Cambisol	Moderate
Kopsasik	Finisterre volcanics	Eutric Cambisol	Low
Ononda	Alluvium with volcanics?	Gleysol	Low
Hark		Andosol	Moderate
Mt Kerigomna (Edwards and Grubb 1977)	Gabbroic alluvium plus volcanic ash	Ferralsol?	Very high
Mongi-Busiga (Abe 2007) (4 sites)	Limestone	Cambisols or Umbrisols?	Moderate
Oomsis (Matsuura 1997) (3 sites)	Schist	Dystric Cambisols	Moderate
Kumil (Matsuura 1997) (2 sites)	Unspecified sedimentary rocks	Dystric Cambisols	Moderate

Conclusions

The NFI soil survey and previous surveys have shown that forested soils of PNG have soil C in the range 58–600 t/ha. Many soils on PNG lowlands contain moderate amounts of C (91–180 t/ha). Highest C values are found in soils with palaeosols (buried topsoils) or formed in parent materials with high Fe and Al contents, such as gabbroic alluvium or andesitic volcanic ash. Soil classification is not a good predictor of soil carbon.

Acknowledgements

The NFI soil surveys summarised in this paper were carried out by staff of the PNGFA, FRI and UNITECH and funded by UN-REDD+ and the FAO. The cooperation of landowners at each site and their assistance during surveys is gratefully acknowledged.

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APPENDIX 1 RATINGS FOR SOIL CARBON

The NFI survey has established that the lowland and mid-altitude soils of PNG have a wide range of soil C values. To help compare soils, soil C on a tonnes per hectare basis to 1 m depth has been provisionally rated into five categories:

Rating	**C to 1 m depth** (t/ha)
Very high	271+
High	181–270
Moderate	91–180
Low	46–90
Very low	0–45

Soil Carbon Modeling across Forested Landscapes in Morobe Province

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Abstract

In PNG rainforest ecosystems at least 50 % of carbon is held soils; however; variations in landscape properties and vegetation cover affect soil carbon distribution. Geospatial approaches and digital soil mapping techniques using satellite data (digital elevation models and Landsat images) have proved useful for developing predictive models of soil properties in other studies and this study aims to assess the feasibility of creating a predictive soil model for Morobe Province, concentrating on the extent of soil carbon distribution with respect to the impact of topographic features and vegetation cover in tropical rainforest. To establish the appropriate methodology, preliminary analysis was done on soils of Morobe Province, for which National Forest Inventory soil information is already available and historical data from two early surveys. Results indicate negative relationship of soil carbon to elevation (r = - 0.472), slope (r = - 0.168) or aspect (r = - 0.365) but Normalized Difference Vegetative Index was positively correlated to soil carbon (r = 0.088). Regression and sequential multiple linear regression showed that multiple linear regression of all data (elevation slope, aspect, and NDVI) combined explained 40% of the variation in soil carbon at a significant level of $p < 0.5$. Evidently, more data is needed to give a reliable estimate of the model.

Keywords: Tropical rainforest, Soil carbon, soil-landscape model, vegetation cover, Geospatial approach, Digital Elevation Model, Landsat Data, Multiple Linear Regression

Introduction

The role of soil in sequestering atmospheric CO_2 makes storage of carbon in soil an important study. Forest soils, in particular tropical forests, roughly store up to 50% of Carbon in forest ecosystems (IPCC, 2000). In Papua New Guinea (PNG) the amount stored may be greater: McIntosh et al. (2017) noted that about 50–75% (summarizing results of Edwards and Grubb 1977, Matsuura 1997, Abe 2007, and Nimiago 2011) of PNG forest carbon is held in the soil.

Papua New Guinea (PNG) contains a vast amount of tropical rainforest hence it was the first tropical rainforest country tasked to develop a national forest monitoring system to honor its commitment to the REDD+ initiative. The PNG Forest Authority and its stakeholders introduced the first ever Multipurpose National Forest Inventory survey in the world to measure and make an inventory of forest and carbon stocks and soil carbon was identified as one of the carbon pools to be measured. However, given that soil is also dynamic in nature, its physical, chemical and biochemical properties vary in magnitude across landscapes, particularly in those that are topographically and ecologically complex (Kunkel et al., 2011). This makes quantifying soil carbon in tropical forest landscapes very challenging. These variations are often observed with changes in parent material, topography and relief, time, climate and biological activity (Jenny, 1941) at a larger scale. At a local scale, topography (elevation, slope, and aspect), vegetation, land-use activity, parent material, biological activity and local climatic conditions are the driving factors that affect soil carbon distribution.

Recent developments in digital soil mapping (DSM) techniques have proved useful in mapping the spatial distribution of soil carbon as well as improving estimates of soil carbon stocks at local, regional and national scale using geospatial approaches. These techniques range from simple linear models to complex models and can be used to map area of interest from small areas to large areas. With the development of these modeling techniques, soil carbon distribution can be spatially represented over area of interest by modeling measured soil carbon stocks against topographic and land cover attributes derived from digital elevation model (DEM) and Landsat Data. Topographic attributes (elevation, slope, aspect) can be derived from DEM while Land cover attributes (NDVI) can be derived from Landsat Data. Kunkel et al. (2011) noted that these physical characteristic have been used and proved useful by Garcia-Pausas et al. (2007) and Tsui et al. (2004) to predict soil carbon distribution.

However, most of the soil carbon modeling approaches have been tried on agricultural farms (Wang et al, 2008; Huggins and Uberuaga, 2010), semi-arid regions (Tesfa et al., 2009; Wang et al., 2008), tropical fallow vegetation (Attua, 2008), sub-alpine and alpine grasslands (Garcia-Pausas et al., 2007), and desert regions (Zhang and Shao, 2014). Little is known about the extent of soil carbon distribution in tropical rainforest as impacted by topographic features and vegetation cover.

In this study, soil carbon distribution will be spatially represented across the tropical rainforest of Morobe Province. This study will address the extent of soil carbon distribution with respect to the impact of topographic features and vegetation cover. The study will seek to address the following specific question;

1. What are the identified topographic and vegetation drivers of Soil Carbon distribution in tropical rainforest?

2. How are each of these variables correlated to Soil Carbon distribution?

3. What is the level of association between these variables and Soil Carbon Content?

4. How is the relationship between predictors of soil Carbon represented spatially?

Included in this paper are methods that were used in collecting and analyzing soil carbon in the field and laboratory, analysis and modeling approaches, preliminary results, discussions and conclusion.

Methods

Study Area

Morobe Province is situated on the northeast coast of Papua New Guinea (Kaima and Kanasi, 1999) and covers an area of 33,933km^2, accounting for 7% of the total land area in Papua New Guinea (Ningal *et al*., 2008). The Province has nine districts and share borders with Eastern Highlands on the west and Province, Madang Provinces on the north and Oro Province to the south respectively (Kaima and Kanasi, 1999). Major parts of the province are still covered with primary tropical rainforest. The topography ranges from sea level to over 4000m a.s.l. and plate tectonics are active. The vast Markham Valley is dominated by grassland that spans from Lae city westward through Huon to Kaiapit district dividing the Saruwaged, and Finisterre mountains to the north from the Highlands mountain systems to the south. These mountains and hills comprise 77% of the total land area. In the lowlands, the climate is hot and humid with an average temperature of 30ºC and a mean annual rainfall of about 2900 mm/year. Wau, Lae, Siassi, parts of Menyamya, Huon and Finschhafen districts are some of the wettest areas with up to 5000 mm/rain year (Ningal *et al*., 2008).

Field and laboratory analysis methods

Field work was done from 20th October to 17th November 2017 in Morobe Province. A total of seven (7) sites were surveyed – four (4) in coastal areas, two (2) in lowland forests, and one (1) on lower montane forest. Permanent circular sampling clusters were identified following random satellite points generated from the Multipurpose National Forest Inventory Survey map and four (4) circular plots (25m x 25m radius) were established at 300 m radius from the center point. Each plot was established in the center, north, southeast and southwest of the cluster (*fig.1*). Soil sample collection followed Field Guide for Sampling and Describing Soils in the Papua New Guinea National Forest Inventory 3rd Edition by McIntosh et al (2017).

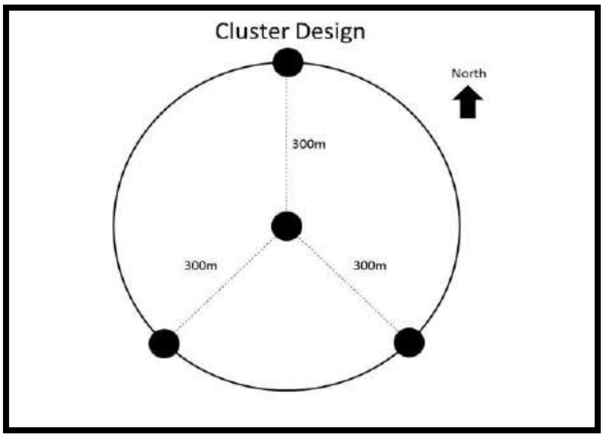


Figure 1 Design of the cluster with circular plots established

Predictor Variables

Terrain Variables

Terrain variables are a representation of the existing physical conditions thus making them useful parameters in assessing carbon distribution across landscapes. Terrain variables (elevation, slope, and aspect) were derived from the DEM (obtained from USGS website https://earthexplorer.usgs.gov/) and field survey while Normalized Difference Vegetative Index (NDVI) was derived from Landsat 8 Image (obtained from USGS website https://earthexplorer.usgs.gov/).

Calculations

Bulk Density and Total Carbon

The Bulk Density is calculated to give an indication of soil's physical condition. It gives a reflection of the soil´s particle arrangement and voids. Soil Bulk density test also gives an indication of soil permeability and root growth in terms of plant – soil system. It is also an essential measurement to make if soil carbon concentrations (usually expressed as a percentage) are to be converted to a weight per unit area figure (usually tons per hectare). After carbon percentage have been obtained from the samples prepared and sent to the laboratory, carbon (in t/ha) is calculated as follows, with a correction being made for slope angle;

$$C(t/ha) = \frac{total\ weight\ of\ oven\ dry\ soil < 2mm\ x\ Carbon\ \%}{100} \qquad (1)$$

Where total dry weight of oven dry soil < 2mm is recorded in tons per hectare and carbon percentage is the percentage of Soil C obtained from the LECO furnace.

Statistical Analysis and Modeling

Statistical Analysis and modeling were performed in excel to examine the relationship between total carbon and the predictor variables aspect, slope, elevation, and NDVI. Descriptive statistics, transformation, correlation test, regression and sequential multiple linear regression statistics and one – way ANOVA tests were performed in excel to assess the relative importance of the predictor variables. The tests reported skewness of the distribution and significance of the normality of the data at *p* – values (0.5, 0.1, and 0.01), correlation coefficient values (r) and coefficient of determination values (R^2) and F and p values.

Results

Soil Carbon

As analyses are not yet available for recent soil survey of Morobe Province, preliminary soil carbon data collected by Matsuura (1997) and Abe (2007) as well as from three NFI sites sampled Morobe Province were analyzed. Results of descriptive statistics showed that elevation, aspect and carbon was positively skewed while slope and NDVI was negatively skewed; however; normality test showed that data was normality distributed for slope at $p < 0.05$, aspect at $p < 0.01$, NDVI at $p < 0.01$ and carbon at $p < 0.05$ while elevation was not (table 1). Transformation performed for elevation did not yield statistically sound results (results not shown). Correlation analysis showed that elevation, slope and aspect were negatively correlated to soil carbon with slope having the lowest correlation coefficient while NDVI was positively correlated to soil carbon at the least (r = 0.084) (results no shown).

Table 1 Results of descriptive statistics performed on each variable

	Mean	Med.	Std. Dev.	Max.	Min.	Skew	W	***p*-value at α**
Elevation	406.1	170	423.66	1400	81	1.7083	0.8669	0.9179
Slope	22.1	23	10.8161	34	0	-0.8077	0.9618	< 0.05
Aspect	63	37.5	67.2144	180	0	1.1786	0.9088	< 0.01
NDVI	0.31	0.5	0.44833	0.7	-0.3	-0.6647	0.9013	< 0.01
Carbon	109.8	106.5	25.8534	157	68	0.3165	0.9829	< 0.05

Predictor Variables of Soil Carbon

Regression of each variable did not yield satisfactory results while sequential multiple linear regression results improved when all variables were combined (elevation, slope, aspect and NDVI); however; only explained 40% of the variation in soil carbon stocks and was significant at $p < 0.5$ (table 3; $R^2 = 0.40$; $p < 0.5$). The developed relationship between all data combined and soil carbon were used to develop the equation;

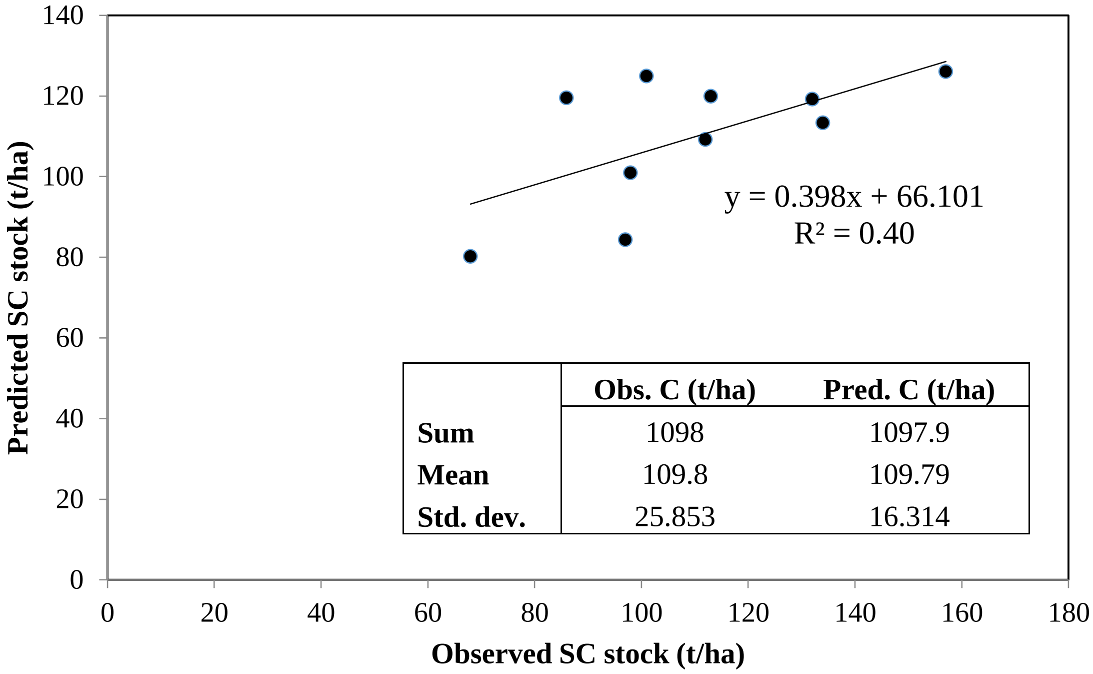
$$C = 121.814 - 0.034(E) + 0.684(S) - 0.197(A) - 2.951(NDVI) \quad (2)$$

Table 2 Regression and sequential multiple linear regression results

Variables	**Regression Statistics**		
Elevation	$R^2 = 0.217$	$F = 2.2176$	$p < 0.5$
Slope	$R^2 = 0.022$	$F = 0.1795$	$p < 0.5$
Aspect	$R^2 = 0.129$	$F = 2.2176$	$p < 0.5$
NDVI	$R^2 = 0.032$	$F = 0.0258$	$p = 0.7768$
Elevation, Slope	$R^2 = 0.217$	$F = 0.9714$	$p < 0.5$
Elevation, Aspect	$R^2 = 0.349$	$F = 1.8731$	$p = 2.11E-05$
Elevation, NDVI	$R^2 = 0.218$	$F = 0.9730$	$p = 4.2E-0.5$
Slope, Aspect	$R^2 = 0.130$	$F = 0.5253$	$p < 0.5$
Slope, NDVI	$R^2 = 0.029$	$F = 0.1058$	$p < 0.5$
Aspect, NDVI	$R^2 = 0.131$	$F = 0.5272$	$p = 0E-05$
Elevation, Slope, Aspect	$R^2 = 0.395$	$F = 1.3080$	$p < 0.5$
Elevation, Slope, NDVI	$R^2 = 0.218$	$F = 0.5570$	$p < 0.5$
Slope, Aspect, NDVI	$R^2 = 0.132$	$F = 0.3041$	$p < 0.5$
Elevation, Slope, Aspect, NDVI	$R^2 = 0.40$	$F = 0.8250$	$p < 0.5$

Modeling the Spatial distribution of Soil Carbon stocks

The developed relationship between soil carbon stocks and predictor variables combined used to model the spatial distribution of carbon stocks again only explained 40% of the variation between observed and predicted soil carbon stocks. While the sum and mean of the soil carbon stocks were the same, standard deviation decreased by 30% in predicted soil carbon stocks than from observed values (fig. 2).



	Obs. C (t/ha)	Pred. C (t/ha)
Sum	1098	1097.9
Mean	109.8	109.79
Std. dev.	25.853	16.314

Figure 2 Observed VS predicted soil carbon (SC) stocks using multiple linear regressions with combined predictors

Discussion

While the model predictions' performance was well below satisfactory, there are a number of points to highlight the model's limitations. The negative correlation between elevation, slope and aspect to soil carbon shows the interrelationships between these variables. Soil carbon tends to increase with altitude because the temperature tends to drop at high altitudes limiting biological activity thus impeding rate of decomposition of organic matter. This trend is also supported by Nimiago (2011). Slope gradient and position also affect soil carbon distribution through erosion and landslides and water runoff where soil particles are distributed downslope thus redistributing soil nutrients while the negative correlation to aspect can be explained by the direction of aspect with 7/10 sites facing north direction while 2/10 face the south and one is flat. North facing aspects were found to have higher carbon stocks compared to south facing aspects and increases with elevation (Kunkel et al. 2011); however; this study contradicts that trend. The likely reason could be related to climatic regime. Kunkel et al. (2011) did their study on semi – arid area. Carbon stocks with regard to aspect reflect in part the physical characteristics of the site. The high carbon stock reflected in flat aspect is related to the site's stability - a flat slope lowland flood plain at an elevation of 81 m. The only likely disturbance to this area would likely be precipitation that will result in flood affecting and altering the soil's physical features. The decrease in carbon in the two south facing sites may reflect slope steepness which alters soil properties through erosion and landslide redistributing soil particles and nutrients downslope. Same applies to the north facing aspect where soil carbon distribution is related to their sites characteristics. NDVI reflects the health and vigor of forests. Positive correlation in NDVI suggests that, as in many ecosystems, soil carbon content is strongly dependent on the rate of carbon input from above ground vegetation, as shown by Kunkel et al. (2011). In this study, the resulting correlation could be the influence of land – use activity that was the limiting factor in reflecting the importance of NDVI. Most of the sites studied were subjected to certain disturbance, mainly subsistence agriculture and to certain degree erosion. Again, the main objective of this study is to map the spatial distribution of carbon stocks in forested landscapes of Morobe Province. The multiple linear regressions is a widely used, simple approach to develop predictive models from soil carbon observation and extrapolate predictions to locations without observations (Kunkel et al., 2011) and it is considered worthwhile making further investigation on applying the model to Morobe Province. However, it is important to note the low number of samples (n = 10) used. Analyses using more comprehensive data coupled with field validation of predictions will be required to evaluate the performance of the model.

Conclusion

Morobe Province is an ideal regional area for developing a soil-landscape model given its geographic location and the range of forest types with elevation ranging from sea level to over 4, 000 meters and average rainfall ranging from 2,900 mm/year to as high as 5,000 mm/year in some remote parts of the province. The preliminary exercise showed that model performance can be improved with the increase in the number of samples.

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Fruit fly species diversity, composition and community distribution across different NFI surveyed forests in Papua New Guinea

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Abstract

This paper describes the fruit fly (Diptera: Tephritidae) community composition and diversity over the different forests of five provinces that has been surveyed by the PNG National Forest Inventory project since the commencement of the exercise. The current knowledge of the forest fruit fly composition within the context of its diversity and distribution nationwide is limited. The ever changing climate scenario and high incidence of exotic invertebrate occurrences and outbreak demands a review of records of this important taxa. The main objective of this study is to establish diversity and distribution of the fruit fly communities in PNG's forests nationwide and identify factors responsible.

This paper defines the research process employed to capture this ecological representation of the taxa basically through pheromone trapping at NFI clusters simultaneously with assessment of other zoology and botany taxa as well. The brief results elicited from this scattered survey indicated that species abundance and richness are higher at lower elevation and decreases with increasing elevation as expected and species distribution between the different elevation and region revealed species with higher adaptation ability while others are confined.

Hosts are considered a major factor in determining distribution from which NFI botany survey provides a sound background. Presented is a preliminary overview of what is expected as the PNG NFI project advances further to other parts of the country.

***Keywords**: pheromone, zoology, frugivorous, faunal, beta diversity, species richness*

Introduction

Papua New Guinea has the greatest diversity of tropical fruit fly species (Diptera: Tephritidae: Dacinae) in the world (Leblanc *et al.*, 2001). Diverse as it is with over 250 species, it is economically important as it includes numerous existing and potential agricultural pest species. Fruit fly pest species prevalence has provoked active agricultural research on fruit flies in PNG with collaborations from Australia in recent years which is ongoing. Frugivorous fruit flies including the agricultural pest species also attack numerous rainforest fruits and are therefore an important component of forest communities (Novotny and Toko, 2015).

In PNG, fruit fly is well known taxonomically, easy to identify and are species-rich. Distributed across different forest types and altitude, they respond to environmental conditions and thus are of high bio-indicative value representing a mix of ecological roles and trophic levels in forest communities.

Assessment of indicator targets of the forest components of floral and faunal communities and the soil condition gives status of the health of the forests (Hughes et al., 1992). Papua New Guinea National Forest Inventory offers a presentable platform for floral assessment in which the faunalistic component can be incorporated which is cost-effective (Novotny and Toko, 2015) for this purpose.

The objective of the study is to establish fruit fly species diversity distribution across different forests, elevations and geography and to relate to plant beta diversity in and across clusters surveyed nationwide.

Methodology

Fruit fly study protocol has been formulated and is part of the ongoing insect protocol that is coordinated with the botany and ornithology survey as proposed for the PNG NFI by the PNG Forest Authority. The methods and focal taxa were justified in the BRC document (Novotny: Methodology for Faunal Biodiversity Assessment: Insects, 2015). The protocol has been designed so that they can be implemented for a cluster during 2 days of field work per site, with one lead researcher and two assistants. The NFI surveyed forests are in the provinces of Madang, Morobe, Eastern Highlands, Western Highlands and West New Britain.

For a survey cluster 10 Steiner traps each baited with a combination of three lures: Cue lure (4-(*p*-acetoxyphenyl)-2-butanone, CAS 3572-06-3), Methyl eugenol ME (4-allyl-1,2-dimethoxybenzene, CAS 95-15-2) and Zingerone (vanillylacetone, CAS 122-48-5) which have insecticide infused and are stationed at ten predetermined locations within and at the periphery of the NFI cluster. The Steiner fruit fly traps containing the three pheromone lures combined are labelled 1-10 and are hung at about 1.5 meter high above the forest floor or ground. Insect glue was been placed on the rope used to attach the trap to prevent ants from entering into the trap.

Collection of trapped fruit flies from the trap is made 24 hours after the time of set up and the samples were carefully collected into vials filled with ethanol (70% not absolute, make dilution) for preservation. The traps are then labelled according to the trap label number. (Each label has the name and coordinates of the site, date, name of the collector, and the code of each trap.)

The preserved samples from the field were brought back to the lab and samples from each trap were examined under normal magnifying lens or microscope. Different species are sorted according to their morphotype and identification done. Each species were then collected into separate vials containing 99% ethanol and labeled while unidentified species were coded and expert assistance sought for its identification and possible recording as new or unnamed species.

Identification codes were given to all species correlating to codes of species already at BRC's fruit fly reference collection and database and new species were given codes beginning from the last code number on the existing reference collection and database codes. Species record of each cluster was updated into Microsoft Office excel for data compilation and analysis.

Assessments were done on the number of fruit flies species at the different elevations, number of fruit flies species at each forest types, fruit flies species beta diversity and the beta diversity of plant species in each cluster (NFI botany survey) and comparison of new fruit flies species in the area to the documented species found in the area.

Analysis tool used was Microsoft Office Excel software, Canoco version 5 and Statistica.

Results and Discussion

Fruit fly data was gathered from the clusters in the five provinces where the survey was conducted. Generally the result provides an overview and comparison of fruit fly species diversity distribution and beta diversity comparison against total plant species of the surveyed clusters and species abundance and richness across different elevations.

Table 1 Fruit fly species abundance and richness from surveyed clusters

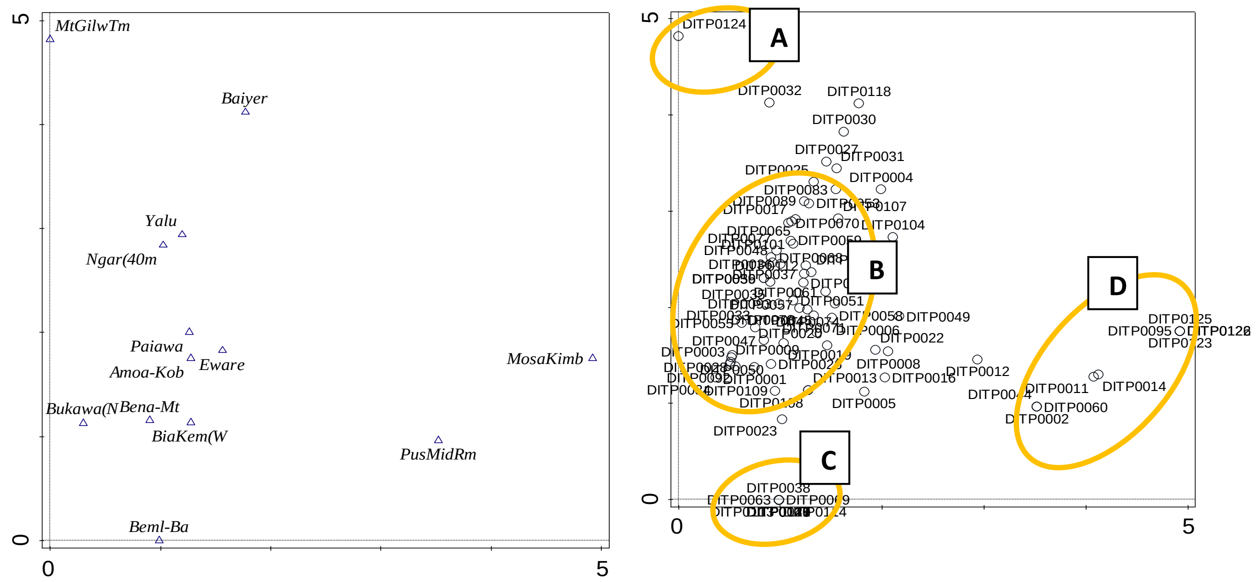
Cluster name	Elevation (masl)	Fruit fly abundance	Total species
Kobio	31	27	17
Eware	70	26	18
Ngaregemo	73	384	44
Bemal	85	654	18
Mdl Ramu	117	301	20
Kimbe	139	33	8
Yalu	147	438	52
Bukawa	356	1220	30
Paiawa	357	31	22
Biaru	1415	60	20
Baiyer	1562	199	14
Bena	2447	19	2
Henganofi	2486	0	0
Tambul	2728	121	2
Grand Total		**3513**	**83**

Table 1 detail the total individual count and species recorded for each cluster site at each elevation respectively. This result shows an abrupt increase of fruit fly abundance and species at low elevation to a steady decline as elevation increases. Irregularity at sampling may cause unusual data from some sites but a general trend is seen. For the 14 sites sampled, a total of 3513 individual were collected of which 83 species were identified. The species number is expected to rise as survey progresses into new areas but alluding to the total captured, most of the species would be common throughout different areas.

Fruit fly species distribution

Distribution of fruit flies species in forests throughout the regions and provinces in the country is interesting information that this survey explores. There are various factors influencing distribution which are altitude, geography, climate and hosts plants. Graph 1 shows each survey sites been grouped according to fruit fly species distribution. Few species are common to several sites while others are specific to their location. More surveys would reveal more shared species and also identify unique species of each area and region.

Graph 1 Distribution chart of fruit fly species at 13 cluster areas

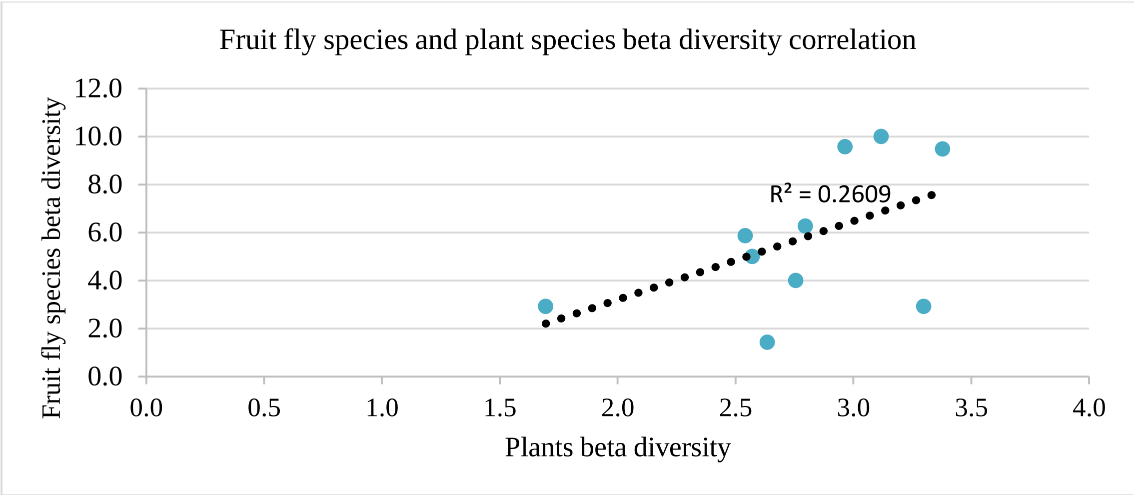


Species that are currently identified as unique are found to be in geographically separated and distant sites such as (D) Kimbe in West New Britain Province, (A) Tambul in Western Highlands Province and (C) Bemal in Madang Province. The rest of the other sites (B) fairly share common number of species between them.

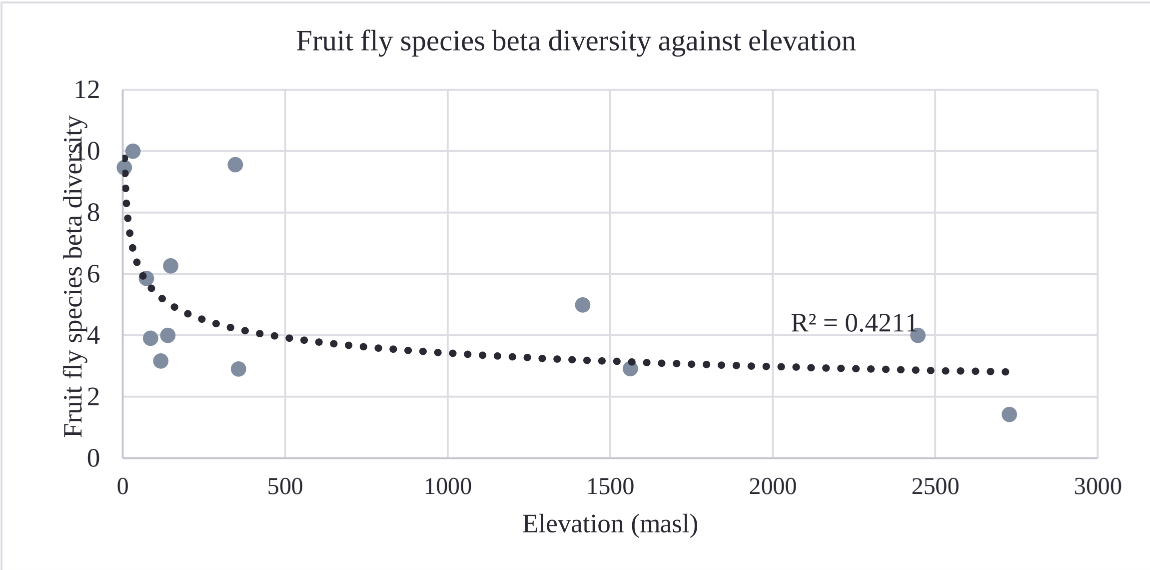
Fruit fly species beta diversity against plants diversity along elevational gradients.

Assessing the status of plant species beta diversity of the cluster to fruit fly species diversity, there is a positive correlation of the two. High beta diversity of plants as surveyed in a cluster area positively correlated to high beta diversity of fruit flies species (Graph 2). This may be explained by the feeding and hosting characteristics of the fruit flies. Some fruit fly species are generalist while others are host specific therefore having a wider species range of plants within an area gives host to a wider species range of fruit flies. On the other hand, beta diversity generally decreases with increasing elevation simply implying that few species are found in a wider area up in the higher altitude areas compared to lower altitude areas where more species are restricted to a certain area and only few common species are scattered over larger area (Graph 3).

Graph 2 Correlation of fruit fly species beta diversity and plants species beta diversity



Graph 3 Fruit fly species beta diversity along elevational gradient



The declining fruit fly species beta diversity along elevational gradients is due to several factors of which are weather and climate pattern of the area, temperature, plant species diversity and geographical boundaries.

Conclusion

This preliminary result and over-view of each short-term fruit fly monitoring for the few forest clusters surveyed have suffices prove of influence of environment that exists on distribution of fruit fly species community and its diversity. Beta diversity of plant species is shown to be positively related to fruit fly species diversity and geographical barriers have a slight effect on species distribution as can be seen by the unique species sampled from West New Britain, Western Highlands Province and Madang Province.

This study is expected to improve as PNG NFI progresses however an interesting trend has developed which will be monitored for further validation. PNG has recorded the highest number of tropical fruit flies species compared to other tropical countries which Drew (2004) believed is due to strong fly-species/host-plant behavioral relationship, the consistent patterns of monophagy and polyphagy across biogeographic regions contributing to high speciation of the Dacine species in PNG which is apparent in the vast number of plant species found here. Outcome of this study will contribute to knowledge on biodiversity impacts by changes in forests which may be artificial or by climate change.

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The Effects of Forest Types on Birds Communities in Different Elevations Across North Eastern New Guinea: Exploration of Diversity and Abundance

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Abstract

New Guinea is the center of bird diversity in Australasia (Australia and NG combined, plus nearby Islands). There are 779 bird species found in New Guinea and of these, 365 species are endemic to the New Guinea region. This study was conducted to investigate the beta-diversity, alpha-diversity and the abundance of bird communities in different habitat types and elevations across Papua New Guinea from sea level to the tree line. The feeding guilds of bird species show that insectivores are more consistent in all the different habitat types than the other three guilds. The other factor that I am interested in is to look at the movement of bird species in terms of their distributions along the elevational gradients in relation to climate change. Field work were carried out in Bena and Henganofi clusters in the Eastern Highlands, Baiyer and Tambul clusters in Western Highlands and Biaru, Bukawa, Kobio, Eware, Paiwa,Yalu and Ngaregemo areas in Morobe province of Papua New Guinea. According to results analysed for the four high elevation clusters there were significant differences in the diversity and abundance of bird species at the different clusters. The forests surveyed were Mid-montane primary forest for the four clusters in the Eastern highlands and Western highlands provinces. Methods used were point counts (7 stations=300m apart from each other/point), Mackinnon list (300m apart from each point), Son meter recorder (stationed at the NE point recording 48 hours non-stop) and species checklist were also made for each of the clusters. Results show that there were significant differences in species diversity and abundance between the clusters surveyed.

Keywords: Diversity, elevation, habitat types, species, clusters, abundance

Introduction

The Food and Agriculture Organization (FAO) together with the Papua New Guinea Forest Authority (PNGFA) in conjunction with other stake holders are conducting a Multi-Purpose National Forest Inventory (MNFI) of plants, soils, Entomology and Ornithology of Papua New Guinea. It is the first ever MNFI survey to be conducted in PNG after so many years of planning. There are about 1000 plus clusters identified and mapped throughout PNG to be surveyed over a period of three years. The first proper MNFI surveys started in May and June of 2017 for the four Highlands clusters (Bena and Henganofi districts in Eastern highlands province and Dei and Tambul districts in the Western highlands province). Biaru, Bukawa, Kopio, Eware, Paiawa and Yalu and Ngaregemo in Morobe province of PNG were surveyed from October 17th–November 17th 2017. Ornithological component studies were conducted to investigate the beta-diversity, alpha-diversity and the abundance of bird communities in different habitat types and elevations across Papua New Guinea. The surveys will continue in 2018 once awareness and reconnaissance are completed for at least two provinces (Madang & Simbu). There were 4669 individual birds recorded in the eleven clusters surveyed so far and out of that 209 bird species were recorded.

Materials and Methods

The study was carried out in nine different clusters/sites which included Eastern Highlands, Western Highlands and Morobe provinces of Papua New Guinea. Methods used to conduct this research were Point counts (seven point count stations located 300m apart from each other in a circular plot (Figure:1). Point counts were conducted starting at 6.00am at point number one at the North plot and ended in the centre plot at 11.00am spending 15 minutes at each of the stations counting birds that were either visually seen or by sound. A short-gun recorder was used during the point count to record bird calls just in-case some species were missed out. Mackinnon list surveys were also conducted (first 10 species of birds were recorded at each point and then moved to the next station 300m apart and process repeated). Song meter recorder was stationed at the NE point and run for 48 hours recording all bird calls. These recordings are then brought back to the lab where they were analysed by listening to the voice calls. Species check-list for all the clusters were also been produced.

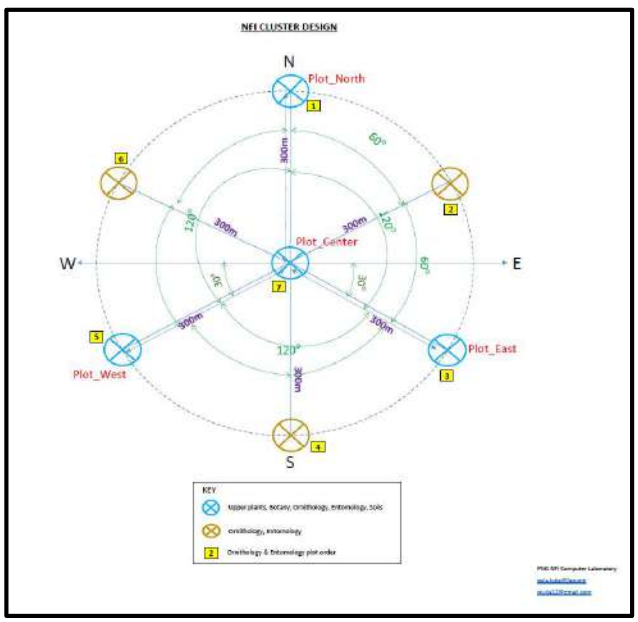

Figure 1 Cluster design for NFI surveys (2016-2017)

Study Sites

There were a total of eleven proper NFI clusters surveyed between 2016 and 2017. Bena and Henganofi clusters in the Eastern Highlands province were surveyed in May and Baiyer and Tambul clusters in June 2016. The Morobe clusters (Biaru, Paiawa, Bukawa, Yalu, Kobio, Ngaregemo and Eware) were surveyed from October to November 2017 (Figure: 2).

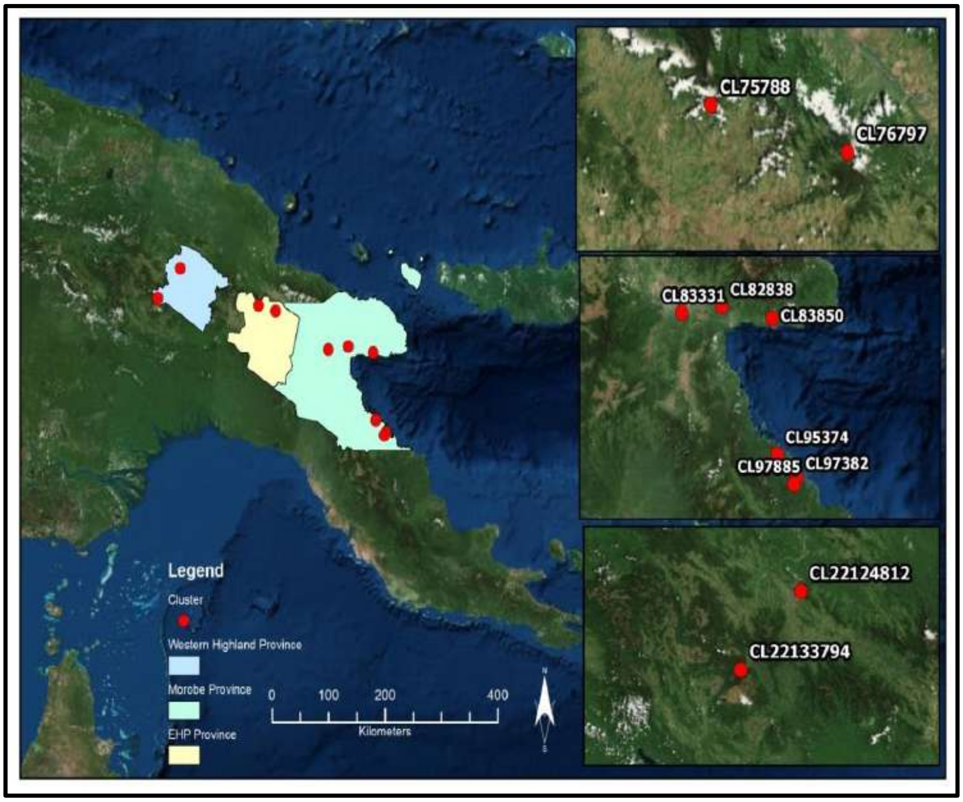

Figure 2 Map of all NFI clusters surveyed from 2016–2017

Results

Species diversity of birds was much lower in the primary forest then the other forest types. Total number of individuals was higher in the degraded forest while the primary forest recorded the lowest number of individuals. When there is an increase in the number of individuals, number of species also increases. Number of individuals hit the peak at the mid-elevation. Number of individuals and species of insectivore birds recorded higher then carnivore birds. Feeding guilds of birds show that insectivores are more consistent in all the different habitat types than the other three guilds. Results show that the species diversity of birds decrease with increasing elevation and the number of individuals are more abundant in the degraded forest while the primary forest had the least number of individuals.

Figure: 3&4 When number of individuals increase in a cluster, number of species increases and species diversity of birds decrease with increasing elevations

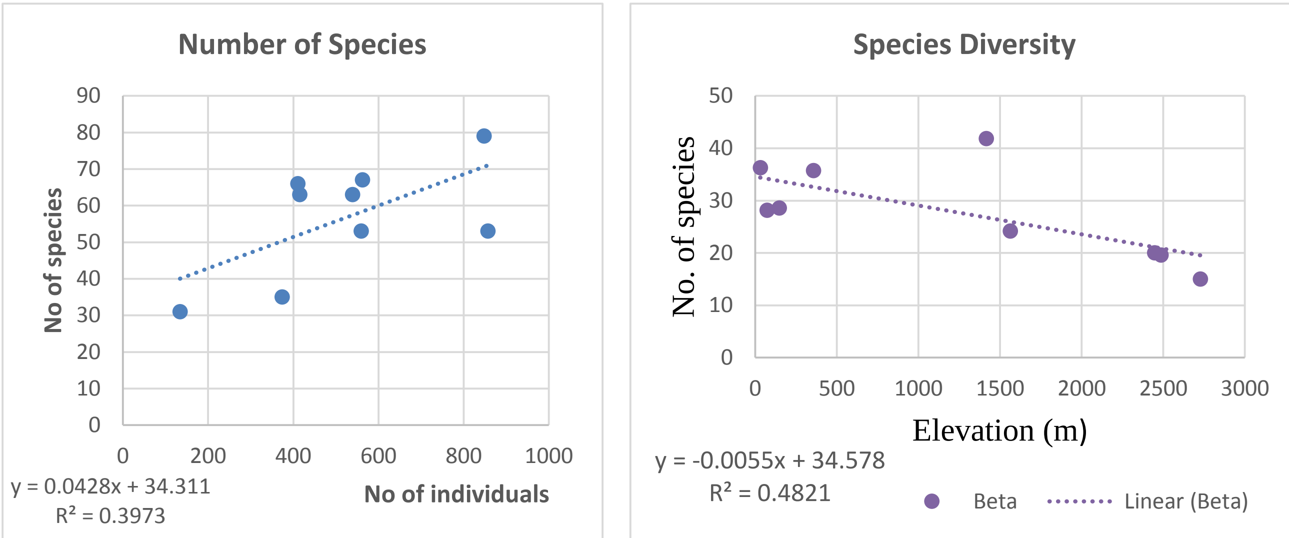

Figure 5&6 Number of individuals and species of insectivorous feeding birds are higher than the other feeding guilds

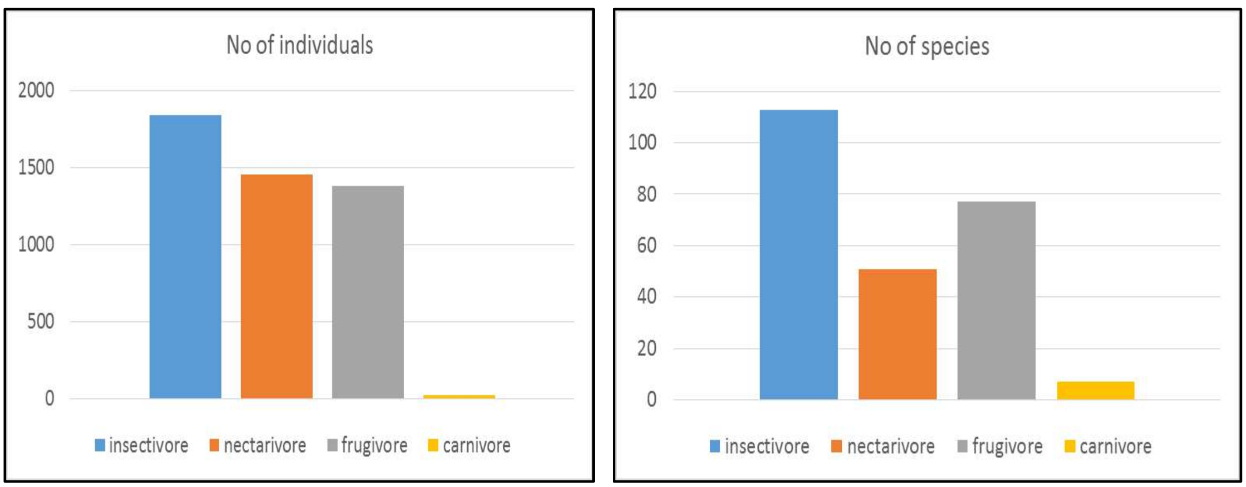

Figure 7 Insectivores are more consistent in all forest types

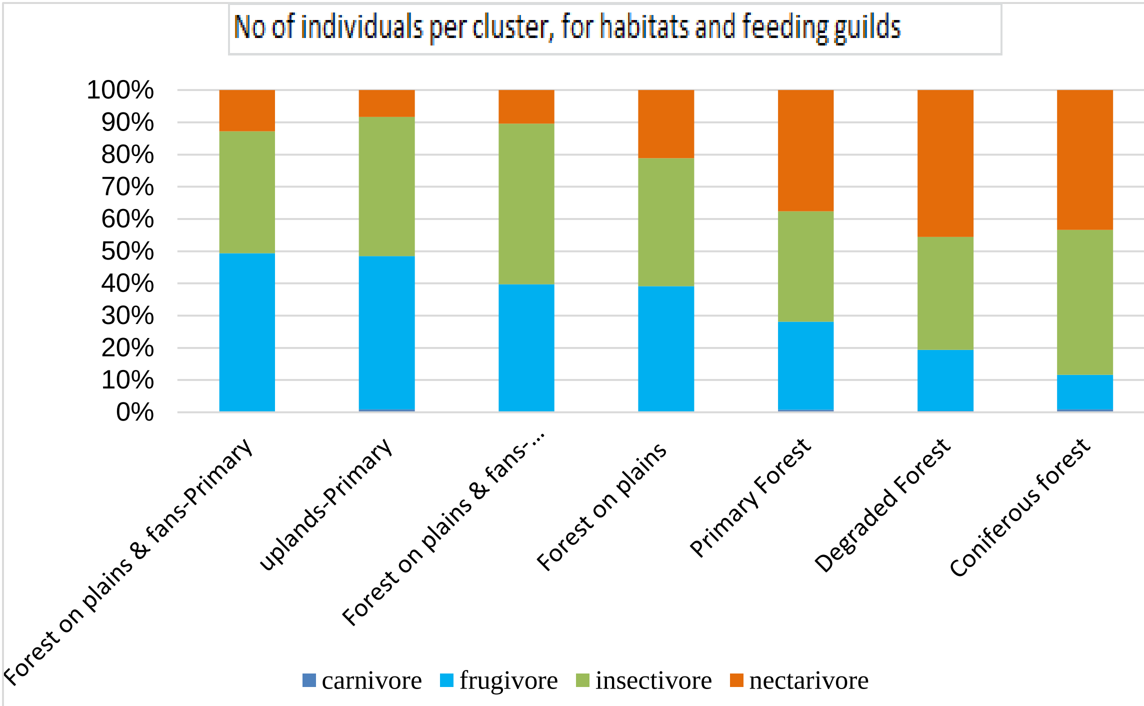

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Figure 8&9 Number of species are lowest in the primary forest while number of individuals are higher in the degraded forest

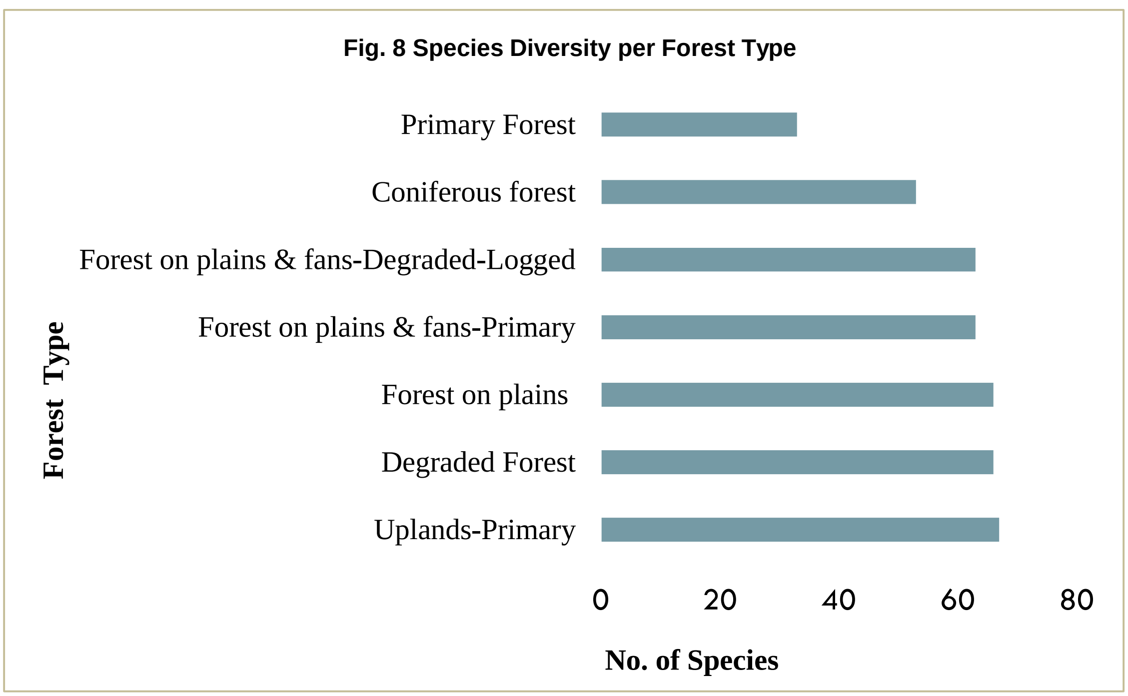

Fig. 9. Total number of individuals per forest types

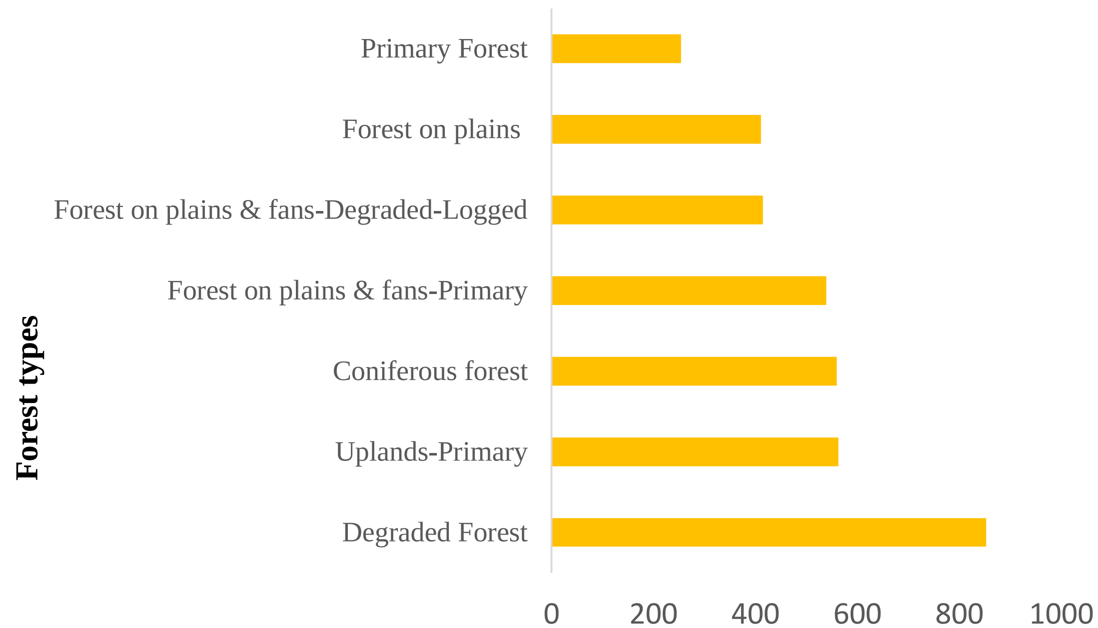

Table 1 This table shows the number of feeding guilds in different forest types

Forest Types	Carnivores	Frugivore	Insectivores	Nectarivore
Forest on plains & fans-Primary	1	265	204	69
Uplands-Primary	5	268	243	47
Forest on plains & fans-Degraded-Logged	0	165	207	43
Forest on plains	1	160	163	87
Primary Forest	2	69.5	87	95.5
Degraded Forest	3	162.5	298.5	388.5
Coniferous forest	5	60	252	243
Grand Total	**22**	**1382**	**1840**	**1457**

Table 2 This table shows the total of species and individuals recorded per NFI cluster

Cluster ID	Total Species	Total Individuals	Mean Species per PC	Taxon	Beta	Forest types	Altitude (M)
EHP-CL:75788	31	134	11.0	birds	20.0	Primary Forest	2447
WHP-CL:22133794	35	374	20.0	birds	15.0	Primary Forest	2728
WHP-CL:22124812	53	857	28.9	birds	24.1	Degraded Forest	1562
MP-CL:97382	66	411	29.7	birds	36.3	Forest on plains	31
MP-CL: 83850	67	563	31.3	birds	35.7	Uplands-Primary	356
EHP-CL:07697	53	560	33.4	birds	19.6	Coniferous forest	2486
MP-CL:82838	63	415	34.4	birds	28.6	Forest on plains & fans-Degrade-Logged	147
MP-CL:83331	63	539	34.9	birds	28.1	Forest on plains & fans-Primary	73
MP-CL:96863	79	848	37.1	birds	41.9	Degraded Forest	1415

Table 3 Species checklist of birds for the 11 clusters (209 total Species)

Common Names	Scientific Names
Azure Kingfisher	*Ceyx azureus*
Beautiful Fruit-Dove	*Ptilinopus pulchellus*
Belford's Melidectes	*Melidectes belfordi*
Black Berrypecker	*Melanocharis nigra*
Black Butcherbird	*Cracticus quoyi*
Black Cicadabird	*Edolisoma melas*
Black Fantail	*Rhipidura atra*
Black Pitohui	*Melanorectes nigrescens*
Black Sicklebill	*Epimachus fastosus*
Black Sitella	*Daphoenositta miranda*
Black Sunbird	*Leptocoma aspasia*
Black-bellied Cicadabird	*Edolisoma montanum*
Black-billed Cuckoo-Dove	*Macropygia nigrirostris*
Black-breasted Boatbill	*Machaerirhynchus nigripectus*
Black-browed Triller	*Lalage atrovirens*
Black-capped Lory	*Lorius lory*
Black-capped Robin	*Heteromyias armti*

Black-eared Catbird	*Ailuroedus melanotis*
Black-headed Whistler	*Pachycephala monacha*
Black-sided Robin	*Poecilodryas hypoleuca*
Black-throated Robin	*Plesiodryas albonotata*
Blue Bird of Paradise	*Paradisornis rudolphi*
Blue-capped Ifrit	*Ifrita kowaldi*
Blue-faced Parrotfinch	*Erythrura trichroa*
Blue-grey Robin	*Peneothello cyanus*
Blyth's Hornbill	*Rhyticeros plicatus*
Boyer's Cuckooshrike	*Coracina boyeri*
Brahminy Kite	*Haliastur indus*
Brehm's Tiger Parrot	*Psittacella brehmii*
Brown Cuckoo-Dove	*Macropygia amboinensis*
Brown Oriole	*Oriolus szalayi*
Brown-backed Whistler	*Pachycephala modesta*
Brown-breasted Gerygone	*Gerygone ruficollis*
Brown-headed Paradise Kingfisher	*Tanysiptera danae*
Brush Cuckoo	*Cacomantis variolosus*
Buff-faced Pygmy Parrot	*Micropsitta pusio*
Buff-faced Scrubwren	*Sericornis perspicillatus*
Channel-billed Cuckoo	*Scythrops novaehollandiae*
Chestnut-backed Jewel-babbler	*Ptilorrhoa castanonota*
Chestnut-bellied Fantail	*Rhipidura hyperythra*
Chestnut-breasted Cuckoo	*Cacomantis castaneiventris*
Cinnamon Ground-Dove	*Gallicolumba rufigula*
Common Paradise-Kingfisher	*Tanysiptera galatea*
Common Smoky Honeyeater	*Melipotes fumigatus*
Coroneted Fruit-Dove	*Ptilinopus coronulatus*
Crinkle-collared Manucode	*Manucodia chalybatus*
Dimorphic Fantail	*Rhipidura brachyrhyncha*
Dimorphic Jewel-babbler	*Ptilorrhoa geislerorum*
Double-eyed Fig-Parrot	*Cyclopsitta diophthalma*
Dusky Lory	*Pseudeos fuscata*
Dwarf Fruit-Dove	*Ptilinopus nainus*
Dwarf Koel	*Microdynamis parva*
Eastern Koel	*Eudynamys orientalis*
Eclectus Parrot	*Eclectus roratus*
Edward's Fig-Parrot	*Psittaculirostris edwardsii*
Fairy Gerygone	*Gerygone palpebrosa*

Fairy Lorikeet	*Charmosyna pulchella*
Fan-tailed Berrypecker	*Melanocharis versteri*
Fantailed Monarch	*Symposiachrus axillaris*
Forbes's Forest-Rail	*Rallicula forbesi*
Friendly Fantail	*Rhipidura albolimbata*
Frilled Monarch	*Arses telescopthalmus*
Garnet Robin	*Eugerygone rubra*
Glossy Swiftlet	*Collocalia esculenta*
Golden Monarch	*Carterornis chrysomela*
Goldie's Lorikeet	*Psitteuteles goldiei*
Great Cuckoo-Dove	*Reinwardtoena reinwardti*
Greater Black Coucal	*Centropus menbeki*
Green-fronted White-eye	*Zosterops minor*
Grey Crow	*Corvus tristis*
Grey Thornbill	*Acanthiza cinerea*
Grey whistler	*Pachycephala simplex*
Grey-green Scrubwren	*Sericornis arfakianus*
Grey-headed Goshawk	*Accipiter poliocephalus*
Grey-streaked Honeyeater	*Ptiloprora perstriata*
Helmeted Friarbird	*Philemon buceroides*
Hooded Butcherbird	*Cracticus cassicus*
Hooded Monarch	*Symposiachrus manadensis*
Hooded Pitohui	*Pitohui dichrous*
Hooded Pitta	*Pitta sordida*
Hook-billed Kingfisher	*Melidora macrorrhina*
Island Leaf-Warbler	*Phylloscopus poliocephalus*
King Bird of Paradise	*Cicinnurus regius*
King of Saxony Bird of Paradise	*Pteridophora alberti*
Large Scrubwren	*Sericornis nouhuysi*
Large-billed Gerygone	*Gerygone magnirostris*
Lawes's Parotia	*Parotia lawesii*
Lesser Bird of Paradise	*Paradisaea minor*
Lesser Ground-Robin	*Amalocichla incerta*
Lesser Melampitta	*Melampitta lugubris*
Little Bronze Cuckoo	*Chalcites minutillus*
Little Shrikethrush	*Colluricincla m. megarhyncha*
Long-billed Cuckoo	*Rhamphomantis megarhynchus*
Long-billed Honeyeater	*Melilestes megarhynchus*
Long-tailed Buzzard	*Henicopernis longicauda*

Loria's Satinbird	*Cnemophilus loriae*
Lowland Peltops	*Peltops blainvillii*
Macgregor's Bowerbird	*Amblyornis macgregoriae*
Madarasz’s Tiger- Parrot	*Psittacella madaraszi*
Magnificent Bird of Paradise	*Diphyllodes magnificus*
Marbled Frogmouth	*Podargus ocellatus*
Marbled Honeyeater	*Pycnopygius cinereus*
Metallic Starling	*Aplonis metallica*
Meyer's Friarbird	*Philemon meyeri*
Mid-Mountain Berrypecker	*Melanocharis longicauda*
Mimic Meliphaga	*Meliphaga analoga*
Mottled Berryhunter	*Rhagologus leucostigma*
Mountain Fruit-Dove	*Ptilinopus bellus*
Mountain Kingfisher	*Syma megarhyncha*
Mountain Meliphaga	*Meliphaga orientalis*
Mountain Mouse-Warbler	*Crateroscelis robusta*
Mountain Owlet- nightjar	*Aegotheles albertisi*
Mountain Peltops	*Peltops montanus*
Mountain Swiftlet	*Aerodramus hirundinaceus*
New Guinea Harpy-Eagle	*Harpyopsis novaeguineae*
New Guinea Scrubfowl	*Megapodius decollatus*
New Guinea Vulturine Parrot	*Psittrichas fulgidus*
New Guinea White-eye	*Zosterops novaeguineae*
New Guinea Woodcock	*Scolopax rosenbergii*
Northern Fantail	*Rhipidura rufiventris*
Ochre-collared Monarch	*Arses insularis*
Olive Flycatcher	*Kempiella flavovirescens*
Olive-backed Sunbird	*Cinnyris jugularis*
Orange-bellied Fruit-Dove	*Ptilinopus iozonus*
Orange-billed Lorikeet	*Neopsittacus pullicauda*
Orange-breasted Fig-Parrot	*Cyclopsitta diophthalma*
Orange-fronted Hanging Parrot	*Loriculus aurantiifrons*
Ornate Fruit-Dove	*Ptilinopus ornatus*
Ornate Melidectes	*Melidectes torquatus*
Painted Tiger Parrot	*Psittacella picta*
Pale-billed Scrubwren	*Sericornis spilodera*
Palm Cockatoo	*Probosciger aterrimus*
Papuan Cicadabird	*Edolisoma incertum*
Papuan Dwarf Kingfisher	*Ceyx solitarius*

Papuan Flycatcher	*Devioeca papuana*
Papuan King-Parrot	*Alisterus chloropterus*
Papuan Mountain-Pigeon	*Gymnophaps albertisii*
Papuan Parrotfinch	*Erythrura papuana*
Papuan Scrubwren	*Sericornis papuensis*
Pink-spotted Fruit-Dove	*Ptilinopus perlatus*
Pinon's Imperial Pigeon	*Ducula pinon*
Plum-faced Lorikeet	*Oreopsittacus arfaki*
Puff-backed Meliphaga	*Meliphaga aruensis*
Purple-tailed Imperial Pigeon	*Ducula rufigaster*
Pygmy Eagle	*Hieraaetus weiskei*
Pygmy Lorikeet	*Charmosyna wilhelminae*
Raggiana Bird of Paradise	*Paradisaea raggiana*
Rainbow Bee-eater	*Merops ornatus*
Rainbow Lorikeet	*Trichoglossus haematodus*
Red-bellied Pitta	*Erythropitta erythrogaster*
Red-breasted Pygmy Parrot	*Micropsitta bruijnii*
Red-capped Flowerpecker	*Dicaeum geelvinkianum*
Red-cheeked Parrot	*Geoffroyus geoffroyi*
Red-collared Myzomela	*Myzomela rosenbergii*
Red-flanked Lorikeet	*Charmosyna placentis*
Red-legged Brushturkey	*Talegalla jobiensis*
Regent Whistler	*Pachycephala schlegelii*
Ribbon-tailed Astrapia	*Astrapia mayeri*
Rufescent Imperial Pigeon	*Ducula chalconota*
Rufous-backed Fantail	*Rhipidura rufidorsa*
Rufous-backed Honeyeater	*Ptiloprora guisei*
Rufous-bellied Kookaburra	*Dacelo gaudichaud*
Rufous-naped Bellbird	*Aleadryas rufinucha*
Rufous-throated Bronze Cuckoo	*Chalcites ruficollis*
Rusty Mouse-Warbler	*Crateroscelis murina*
Rusty Pitohui	*Pseudorectes ferrugineus*
Rusty Whistler	*Pachycephala hyperythra*
Sclater's Whistler	*Pachycephala soror*
Scrub Meliphaga	*Meliphaga albonotata*
Shining Flycatcher	*Myiagra alecto*
Singing Starling	*Aplonis cantoroides*
Slaty-headed Longbill	*Toxorhamphus poliopterus*
Sooty Thicket-Fantail	*Rhipidura threnothorax*

Spangled Drongo	*Dicrurus bracteatus*
Spectacled Longbill	*Oedistoma iliolophus*
Spotted-Jewel Babbler	*Ptilorrhoa leucosticta*
Spot-winged Monarch	*Symposiarchus guttula*
Stella's Lorikeet	*Charmosyna stellae*
Stephanie's Astrapia	*Astrapia stephaniae*
Stephan's Emerald Dove	*Chalcophaps stephani*
Stout-billed Cuckooshrike	*Coracina caeruleogrisea*
Streak-headed Honeyeater	*Pycnopygius stictocephalus*
Streak-headed Mannikin	*Lonchura tristissima*
Sulphur-crested Cockatoo	*Cacatua galerita*
Superb Bird of Paradise	*Lophorina superba*
Superb Fruit-Dove	*Ptilinopus superbus*
Tawny-breasted Honeyeater	*Xanthotis flaviventer*
Torrent Lark	*Grallina bruijnii*
Torresian Crow	*Corvus orru*
Varied Triller	*Lalage leucomela*
Wattled Brushturkey	*Aepypodius arfakianus*
Wattled Ploughbill	*Eulacestoma nigropectus*
White-bellied Cuckooshrike	*Coracina papuensis*
White-bellied Thicket-Fantail	*Rhipidura leucothorax*
White-crowned Cuckoo	*Caliechthrus leucolophus*
White-eyed Robin	*Pachycephalopsis poliosoma*
White-faced Robin	*Tregellasia leucops*
White-shouldered Fairywren	*Malurus alboscapulatus*
White-throated Pigeon	*Columba vitiensis*
White-winged Robin	*Peneothello sigillata*
Wompoo Fruit-Dove	*Ptilinopus magnificus*
Yellow-bellied Gerygone	*Gerygone chrysogaster*
Yellow-bellied Longbill	*Toxorhamphus novaeguineae*
Yellow-billed Kingfisher	*Syma torotoro*
Yellow-billed Lorikeet	*Neopsittacus musschenbroekii*
Yellow-breasted Boatbill	*Machaerirhynchus flaviventer*
Yellow-faced Myna	*Mino dumontii*
Yellow-legged Flycatcher	*Kempiella griseoceps*
Zoe's Imperial Pigeon	*Ducula zoeae*

Discussion

This study was conducted to see if the forest types were having some effect on the bird communities. The preliminary results are showing some trend in where the bird species occur (Table2). The results analyzed now are for nine clusters out of the eleven proper NFI surveys conducted in 2016-2017. Species diversity of birds decreases with increasing elevation while the abundance of birds peak at the mid elevation. Primary and coniferous forests were poor in species while there were more individuals recorded in the degraded forest than in the primary forest. Insectivorous birds are more consistent in all forest types than the other feeding guilds. There were 4669 individual birds recorded in the eleven clusters surveyed so far and out of that, 209 species were recorded.

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Diversity and community composition of ants in the forests of Papua New Guinea

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Abstract

Ants are an ecologically important component of insect communities in most terrestrial ecosystems, in the tropics they have the highest species diversity and abundance. Their ecological roles as predators, and sensitive to habitat disturbance, makes them an ideal taxon to be studied in biodiversity projects. We used tuna bait and hand collection methods to collect 121 individuals from 67 species of which 17 are unknown, 43 % (29 spp.) of the species were common in both methods, 20% were captured in bait whilst 35% species were recorded in hand collection. As expected, ant species diversity and composition strongly changes with increasing elevation. More species were found in primary forests than disturbed or secondary. The changes in species diversity with increasing elevation was expected. However, it was not so quickly at Mt Hagen which we expected it be of few species. This particular site has disturbed forest which may act as main factor influencing our preliminary result here. We need more data to be confidently saying that forest types also influence ant community composition at higher elevations. Using more than one sampling methods is important in biodiversity surveys as it able to capture cryptic species missed out from baiting.

Key words: Diversity, Community composition, Ants, Elevation, Biodiversity

1.Introduction

The impact of climate change and disturbances on animals and how they will respond to such changes is a hotly debated topic. There is a pressing issue to know how important focal taxa turn to respond to such detrimental changes in their communities (Yusah, 2011). Studies revealed that ants are good indicator to both abiotic and ecological changes (Diamond *et al*., 2012). Their smaller size and robust sensitivity to changes within their communities has reported to be an ideal taxon to be studied in biodiversity monitoring programs(Alonso, 2000).

Ants (Hymenoptera: Fomicidae) are an ecologically important component of insect communities in most terrestrial ecosystems, especially in the tropics they have the highest species diversity and abundance(Klimes et al., 2012). Their ecological roles as predators and scavengers, competitors(Davidson, 1989, Boulay, 2005), and secondary herbivores through mutualistic relationships with sap-sucking hemipteran (Höolldobler, B., Wilson 1990), makes them important player in ecosystems maintenance and functions.

The island of New Guinea (NG) is one of the most important tropical hot spots of ant diversity (Wilson, 1959) in the world. Yet our understanding and knowledge of species diversity and composition is limited (Lucky, 2011), simply because discovery and species description is progressing at a snail pace. We are yet to understand the roles of the 900 plus species we discovered so far. It's important to know this community information about ants because they provide conservational information about stability of the ecological processes. Data collected from these surveys will provide important information on ant spatial distribution and document the presence of any ecologically important species. Such as invasive or tramps, rare, threaten or endanger which will provide baseline data on the health of ecological processes and functioning and indicate the presence of the other organisms as numerous ant species have obligate interactions with flora and other fauna in their community. This study aims to investigate ant communities across different forest ecosystems in Papua New Guinea and identify the main drivers of ant community composition and diversity patterns.

2.Methods

We exposed 140 baits and hand searched 42,2x2m plots across seven clusters in various ant communities. Two sampling methods were used, tuna bait and hand collection to sample ant communities in seven of the 11 NFI clusters surveyed. We exposed 10 baits along 300m transects, from East-Center plot & Center-North plot (Fig 1). Each bait trap was spaced 30m apart along the 600m transect. Tuna bait is made from tinned fish with cordial (5spoons of tuna to 1spoon of cordial). Tuna provide protein and cordial offer energy for foraging ants. After 1hour of bait exposer, recruited ants were collected into vials containing absolute (100% undiluted) insect ethanol.

Hand collection was done in the same day following baits (approx. 2 hours after bait removal), or on the next day if not enough time left. We hand searched 6, 2x2m plots spacing 90m apart per cluster. Ants were collected by 2persons from the ground to the height of 2m above ground level within 15 minutes. We searched on soil, understory vegetation, tree trunks, leaf litter and nesting sites-cavities, dead wood and under stones.

2.1 Statistical analysis

We converted the dataset into presence-absence data and used unconstrained ordination to see if there is relationship between elevation (as supplementary) and the species composition and diversity for statistics interpretation. Since its presence – absent data we used canonical correspondence analysis (CCA) to test the relationship between elevation and species composition in Canaco5. The size of the circles represent species abundance and proximity denote relationship between species occurring at the baits or plots. Statistica was also used to test the strength of the relationship (Fig 2) between the ant species composition and elevation. Two highlands clusters were excluded from this analysis because we didn't collect any ants. The rank abundance curve (Fig 5) was constructed in Excel 2016.

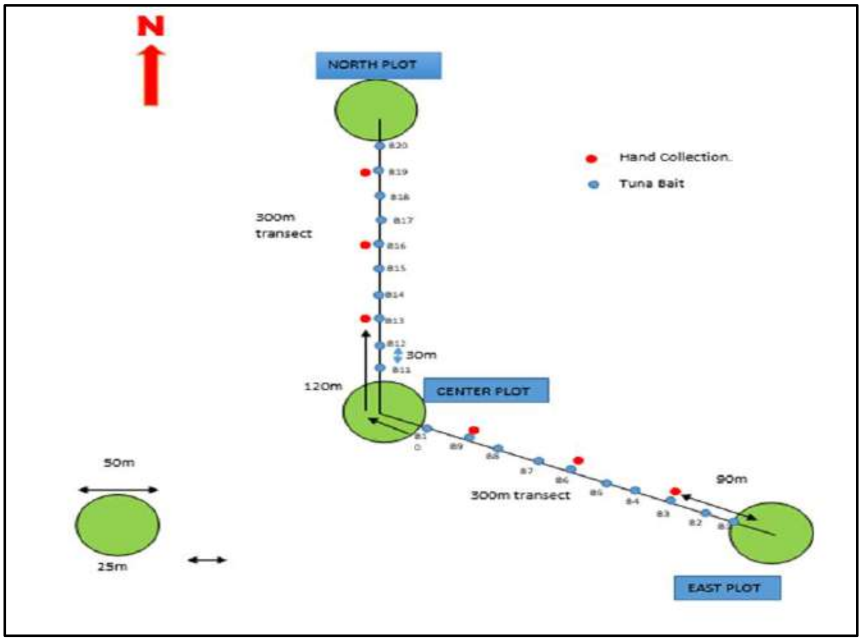

Figure 1 Ant transect for tuna bait & hand collection

4. Results

We collected 121 individuals from 67 species, 17 of them are unknown. We found 78% of the total species in Hand collection and 63% were captured in bait, with 43%) of ants were common in both methods or overlapping. But rarer species were found in the hand collection than baiting. As expected our results show that species diversity and composition changes significantly with increasing elevation, which are demonstrated by both sampling methods (Fig 2,3,4).

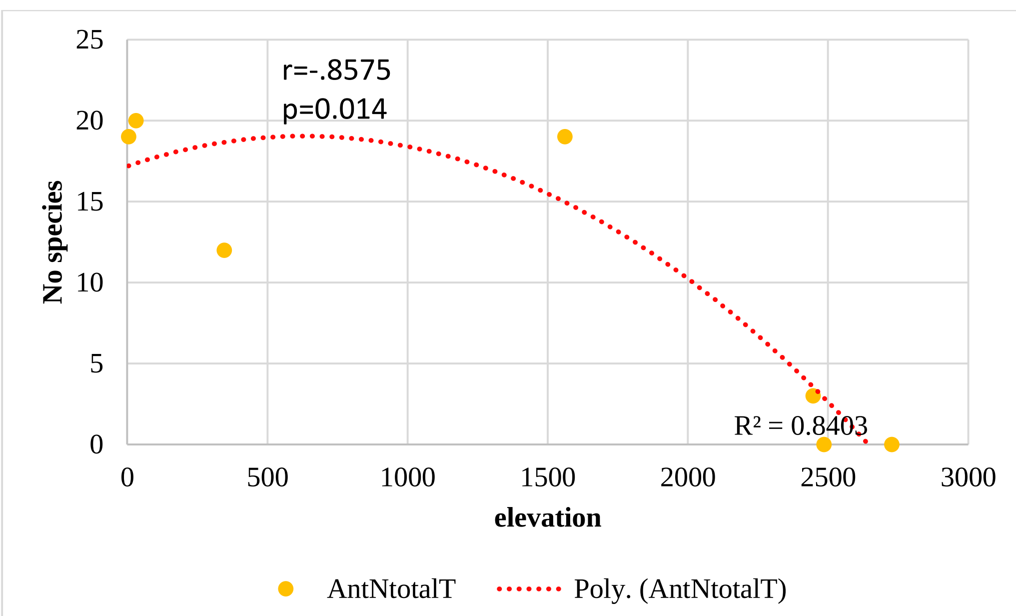

Figure 2 The black dots denote ant abundance at each cluster. Ant species diversity and abundance decreases with increasing elevation. There is slow decreasing of species abundance and diversity along the elevation.

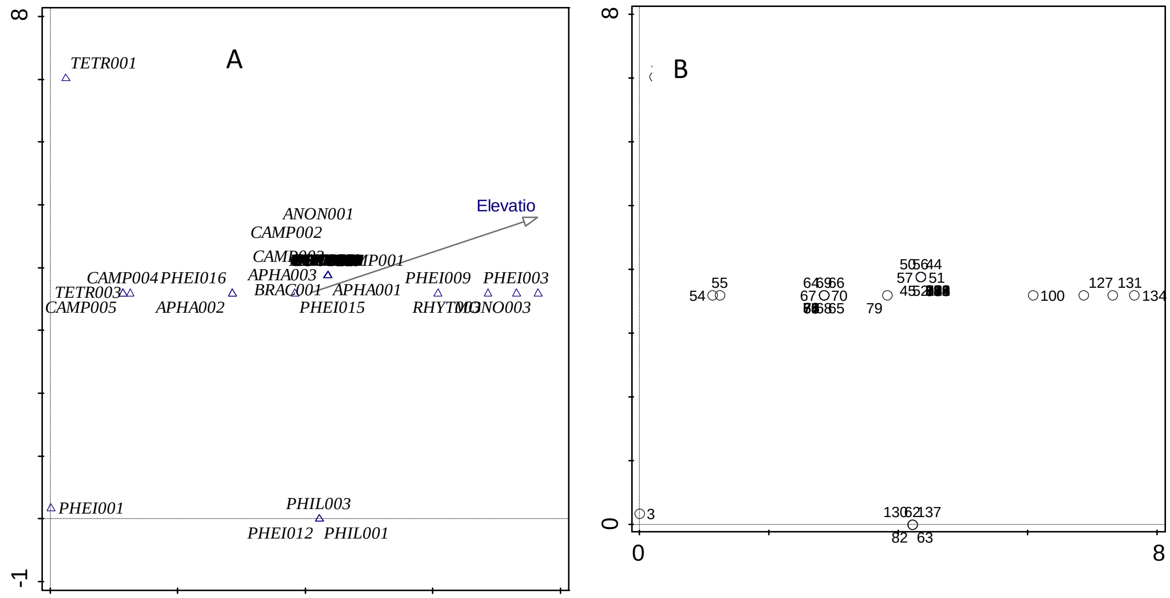

Figure 3 Canonical correspondence analysis showing the relationship between ants and elevation for baits with ants only. The numbers in graph B represents trap No. and sizes of circles denote abundance. The proximity of the circles depict relationships between ant species (see A) and abundance found along the elevations, increasing from left to right

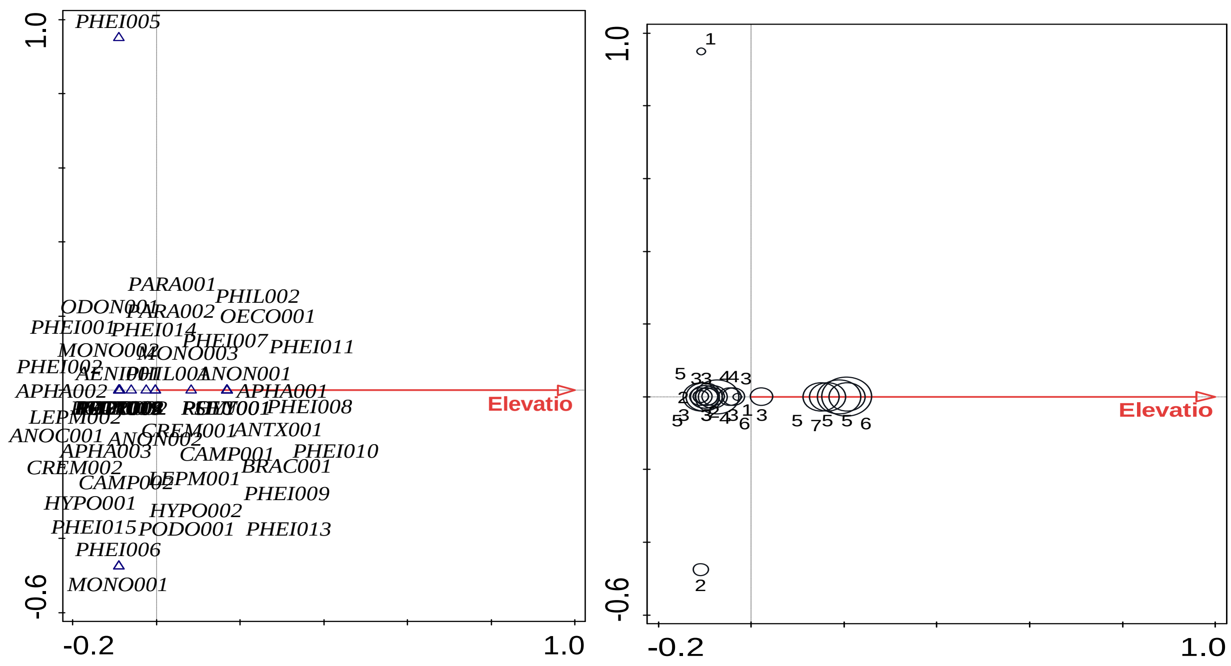

Figure 4 Canonical Correspondence Analysis of ants from hand collection, the closer the circles are, it depicts close relationship with ant species and the elevation. Sizes of the circles represent species abundance and composition at each plot. The bigger the circles, the abundant each species captured at each cluster. Again as we move from left (lower altitude) to right (higher altitude) the species composition and diversity decreases

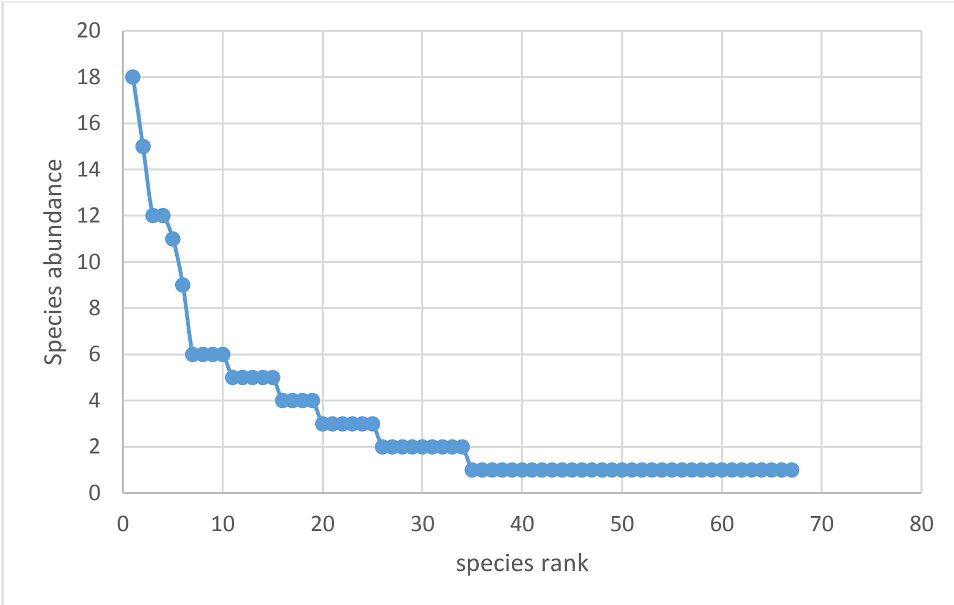

Figure 5 Species rank curve, from the most common species to the least common or rare species encountered in both methods

5.Discussion and Conclusion

Elevation has a negative influence on species diversity and community composition for the data processed from the 7 clusters. The species diversity and richness starts to decrease as we move up the altitudes, but not so quickly. the bell shaped graph (fig 2) illustrates an interesting story here but we are not confident that such trend in higher elevations may continue. This particular cluster was located in Lower Montane to disturbed forest in Mt Hagen which possibly provide a conducive habitat for species to establish nesting sites over time. Such habitats are potential for introduced species to established quickly and thus have negative impact on native ant communities as well as other animals.

Therefore, in conclusion we confirmed that elevation is one of the factor influencing ant species diversity and degraded habitats may possible become a suitable place where introduced species will have established and negatively affecting local ant communities. Using couple of methods is important in biodiversity surveys as it able to capture cryptic species missed out from baiting.

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5. PNG University of Technology

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Species Turnover in Moth (Geometridae: Lepidoptera) Communities in the Forest of Papua New Guinea

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Abstract

Aim: This study is conducted in collaboration with PNG Multipurpose NFI to investigate species turnover in herbivorous insect family (Geometridae moths) communities in the forest of Papua New Guinea.

Location: The study is currently underway throughout different forest types and elevation in Papua New Guinea. So far a total of 11 clusters (Eastern Highlands Province – 2 clusters, Western Highlands Province – 2 clusters and Morobe Province – 7 clusters) were completed within a wide range of habitats between 70m and 2700m elevation.

Method: Geometrid moths were collected manually using light trap method. A total of four light traps were set up within each cluster running simultaneously for two nights. CCA and relative correlation analysis were used to explore how species turnover of geometrid moth are related to different elevation, plant species composition and disturbance.

Results: A total of 2268 individuals were recorded from 558 species for six clusters (Eastern Highland x 2 clusters, Western Highlands x 2 clusters and Morobe x 2 clusters). Geometrid moth species was significantly correlated to plant species ($p = 0.045$) and shows positive relationship with increase disturbance. Plant species and habitat disturbance were better predictors of species turnover of geometrid moths.

Discussion: There is no relationship between elevation and number of individuals and species. However, there was relationship between plant species and geometrid species with p-value 0.045. The CCA analysis between Geometrid and variables; elevation, plant and disturbances shows that the diversity of moths increases with number of plant diversity and disturbance . Hence, CCA analysis shows that the most dominant species are found in primary lowland forest.

Key words: Geometrid, Species turnover, diversity, elevation, habitat type, PNG Multipurpose NFI

Introduction

Herbivorous insects account for a major fraction of global biodiversity (Novotny, *et al.,* 2006; Lewinsohn & Roslin, 2008). Geometrid moths have high potential to use as model system to study the effects of environmental gradients in habitat conditions on different forest types. With more than 21,000 known species (Scoble, 1999), they are one of the three most species-rich families of Lepidoptera. Their potential as 'biodiversity indicators' has been explored through studies in South East Asia (Holloway, 1985; Chey *et al.,* 1997; Intachet *et al;* 1997,1999ab; Willott, 1999; Beck et al., 2002), South and Central America (Brehm *et al*., 2003b, 2007; Hilt *et al.,* 2006), Australia (Kitching *et al.*,2000) and Africa (Axmacher *et al*.,2004ab). However, many environmental factors such as mean annual temperature, levels of radiation or precipitation change along elevational gradients (Kessler *et al*., 2001; Lomolino, 2001). The change in habitat types or land-use changes also vary considerably for different taxa, as particular species traits interact differently with the disturbed environment (Koh *et al.*, 2004). The species turnover or beta-diversity is recognised in investigating patterns of wide range of taxa and environment, thus it is much less understanding than gradients in species richness or within habitat (alpha-) diversity (Beck & Khen, 2006). This study is aim to investigate the species turnover of geometrid moth community in the forest of Papua New Guinea based on different habitat types and elevations.

Method

Sampling was conducted in 11 clusters, however, we have analysed data from six clusters (2 x Eastern Highlands Province, 2 x Western Highlands Province and 2 x Morobe Province) (See figure 1). The elevations of these clusters range from 70m to 2700m above sea level. The forest types were lowland forest, mid-montane forest, lower montane forest and upper montane forest.

To sample moths we used a 3 x 3-m white sheet and mercury light bulb powered by Honda generators to attract moths. We used the NFI cluster design to sample moths. There were two light traps set-up per night for two days sampling. The light traps were set up within the 150m radius of the cluster and were 100m apart. Traps were operated from 1800hours to 2200hours.

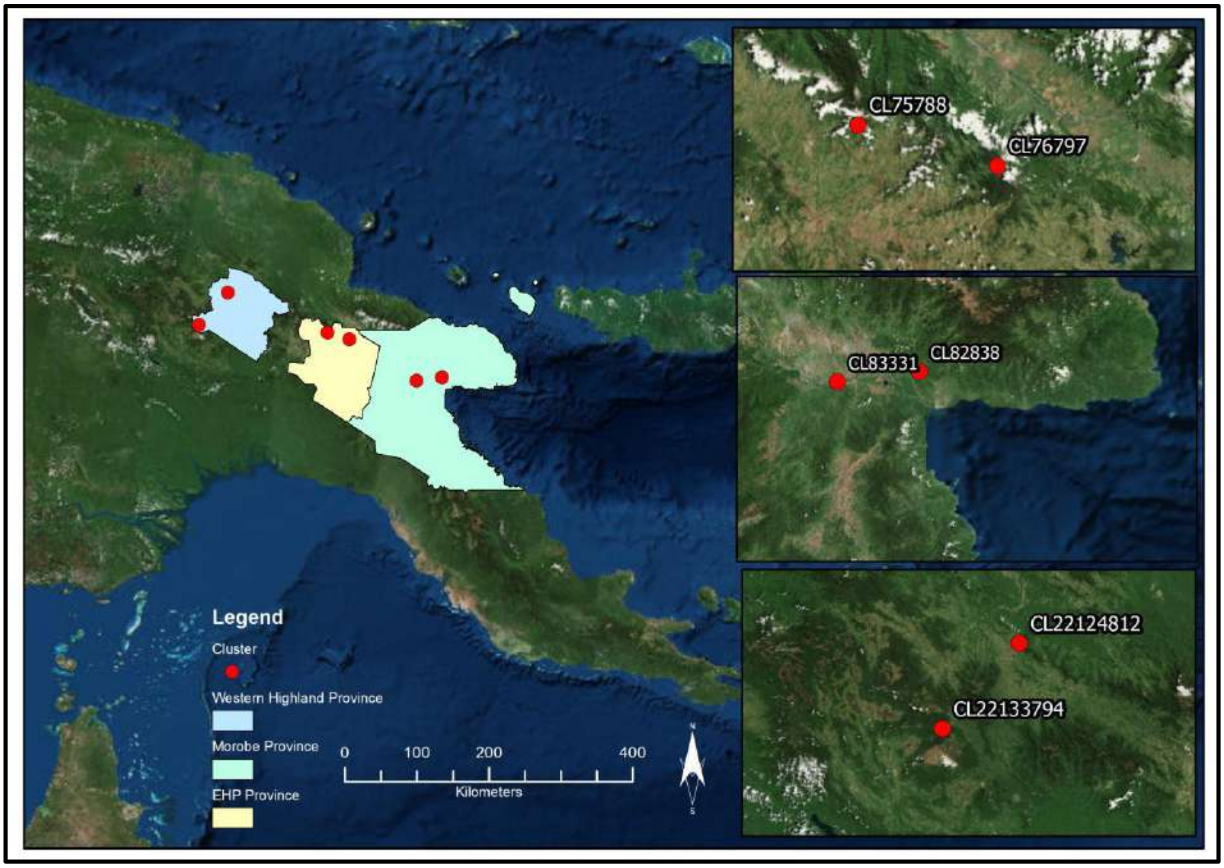

Figure 1 Map of clusters sampled

Result

A total of 2275 individuals from 588 species were collected from a total of 24 lights traps at six clusters. The sample sizes in this short-term study are relatively small and five clusters are still under sorting and identification in the laboratory. Total abundance of geometrid moths ranged from 166 to 725 individuals per cluster. Plant species data was also collected and analysed in this study. A total of 449 plant species were collected in the 6 clusters studied.

According to the results, there is a significant relationship (Figure 2. r = .82184, p=.045) with the increase in plant species at different clusters. In addition, the species composition and diversity of geometrid moth increases with disturbance and plant species (Figure 3ab. CCA analysis). Thus, species turnover of geometrid moth has a positive link with plants species and disturbance at different clusters.

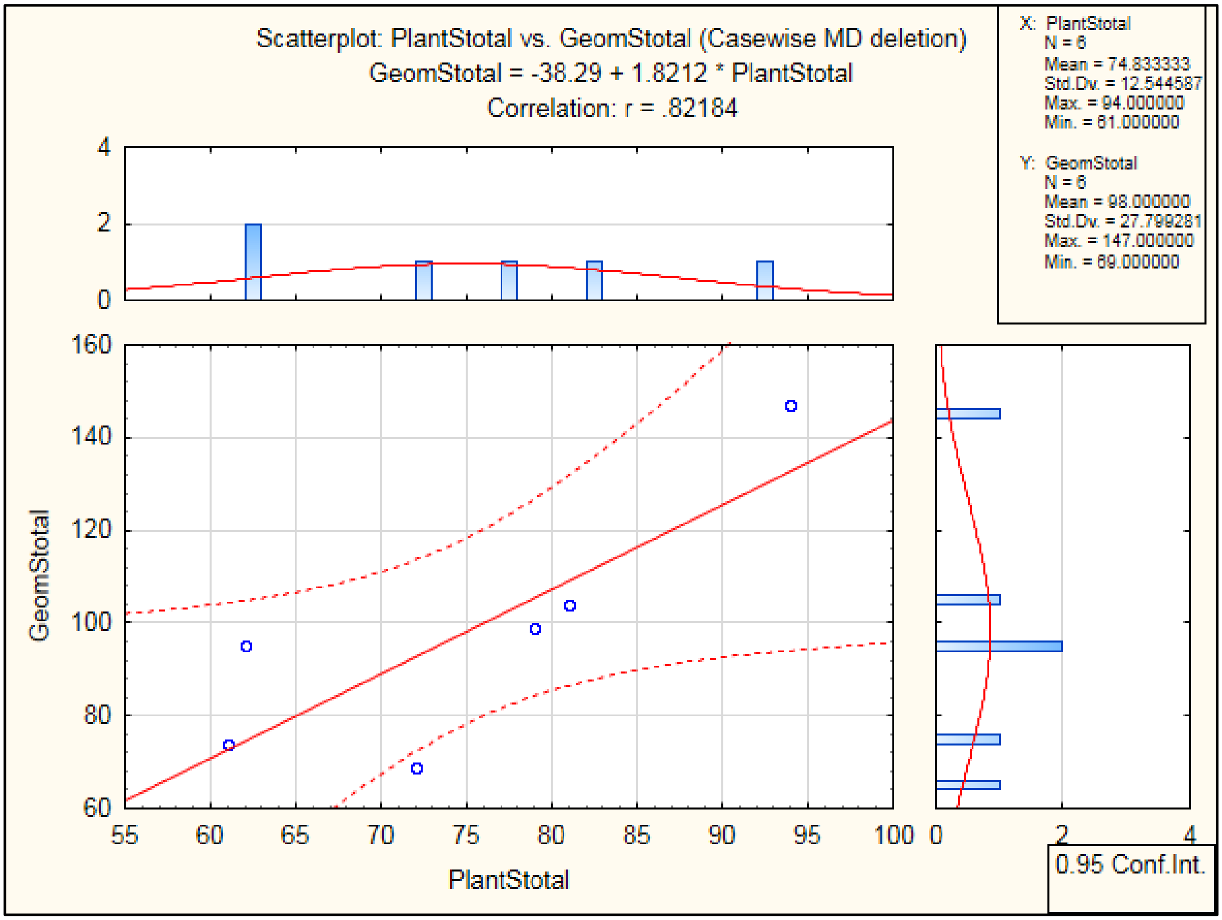

Figure 2 Correlation between Geometrid moth species and plant species for 6 clusters

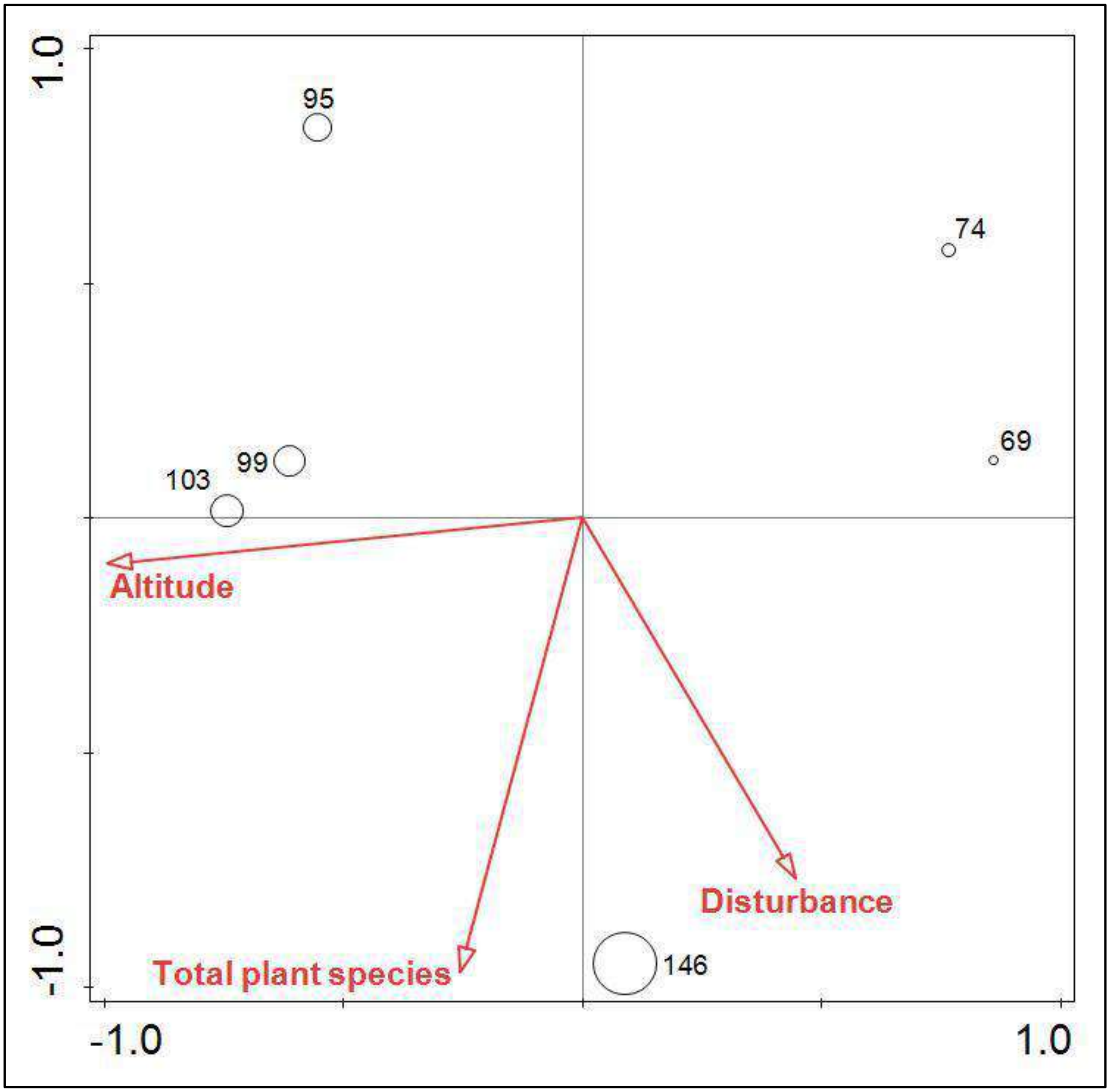

Figure 3a CCA Analysis – Geometrid species composition

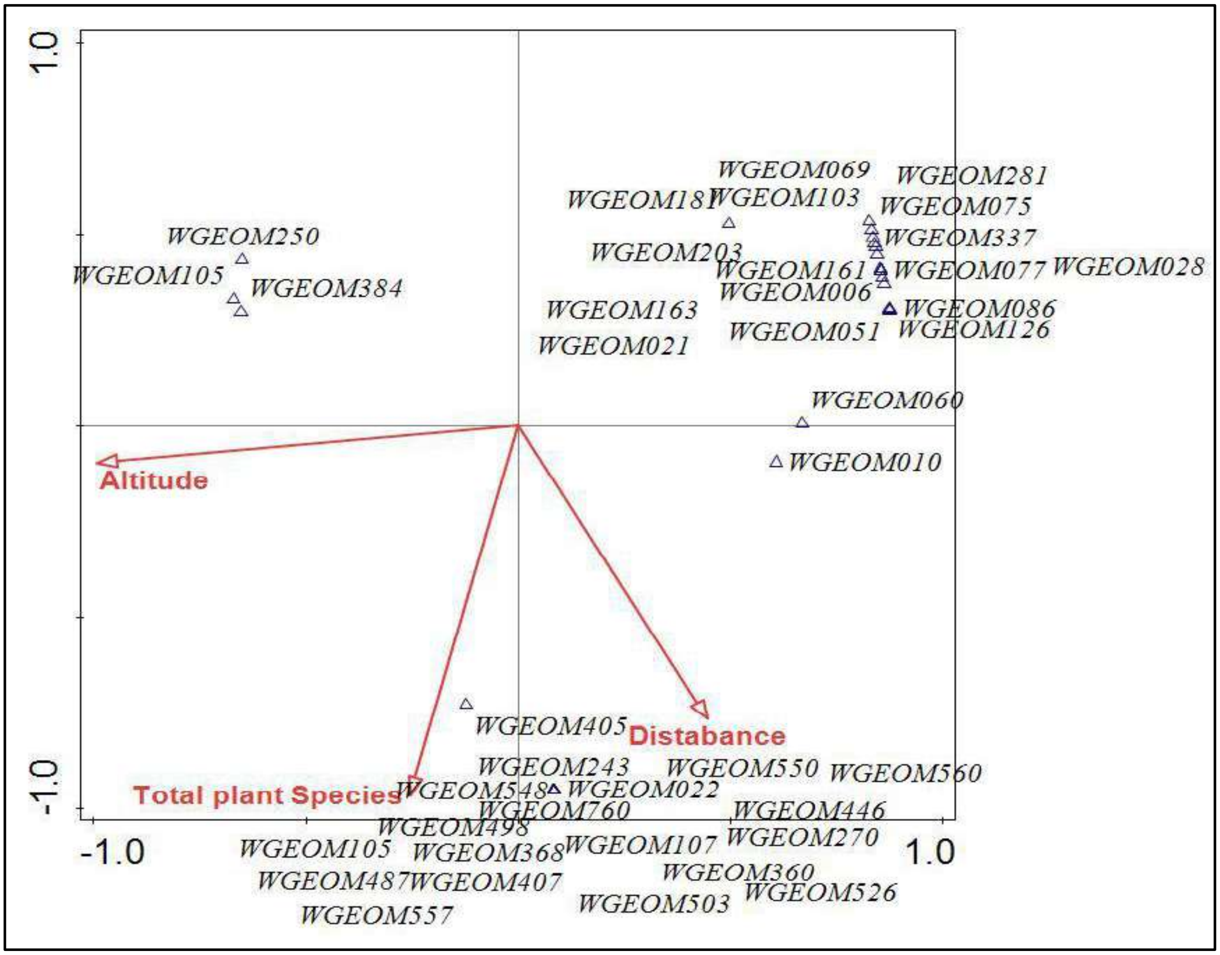

Figure 3b CCA Analysis – Geometrid species composition

Discussion

In this study three variables were used to test the result; elevation, plant species and disturbance. There is no relationship between elevation and number of individuals and species. However, there was relationship between plant species and geometrid species with p-value 0.045.

The CCA analysis between Geometrid and variables; elevation, plant species and disturbances shows that the diversity of moths increases with number of plant diversity and disturbance. Hence, CCA analysis shows that the most dominant species are found in primary lowland forest.

In the future more sampling is needed for better analysis of data and other environmental parameters such as vegetation cover, rainfall, temperature, etc. are also needed for further study. Otherwise, there is a positive link between the two environmental variables.

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