Papua New Guinea's first multi-purpose

National Forest Inventory Project

Proceedings of the 2nd National Forest Inventory Research Conference

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Editor: Michael M. Poesi

Conference organizers:

EU-FAO National Forest Inventory Project
PNG Forest Authority Forest Policy Planning Directorate
PNG University of Technology Forestry Department

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 findings of the NFI supported research topics and other related studies to the European Union and FAO funded multi-purpose National Forest Inventory Project

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Contents

Foreword

The European Union and the Food and Agriculture Organization of the United Nations are funding PNG's first multi-purpose National Forest Inventory Project 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.

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 technical 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.

Twenty-nineteen (2019) research conference is the second hosted by the project in collaboration with one of its in-country collaborators, PNG University of Technology. The research conference is designed to provide an avenue for the exchange and sharing of research methods, and the results among project scientists and the project stakeholders. Foremost, the project Master of Philosophy scholars sharing with us the findings of their individual research studies, in the lead up to their graduations at the PNGUoT 51st graduation ceremony on April 5th 2019. It also provided an opportunity for discussing and formulating future research directions, as well as strategize NFI implementation plan for 2019 onwards.

Key speakers that will officiate at the opening of the research conference included the PNG University of Technology acting Vice Chancellor Academic, Dr Ora Renagi, the EU Ambassador to PNG, His Excellency Ioan Giogkarakis-Argyropoulos, Head of FAO PNG, Mr. Ken Shimizu, PNG Forest Authority acting Managing Director, Mr. Goodwill Amos and the PNGFA Forest Planning and Policy Director & NFI Project PNG Country Coordinator, Dr. Ruth Turia.

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

An outline of the multipurpose NFI Project and its 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 forests 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 the two research conferences held in February 2018 and recently in April 2019 that the findings of the first PNG multipurpose NFI were presented and discussed.

Conference Objectives and Outcomes

The main objectives of the second conference were to:

- Review the data management protocols and outcomes of PNG's first multipurpose NFI;
- Build capacity of the PNG researchers and foresters on data analysis, presentation and scientific paper writing;
- Present and publish the findings of PNG's first multipurpose NFI including the research findings of NFI sponsored MPhil students, and
- Publish the second conference proceedings as the annual research report of PNG's first multipurpose NFI.

Welcoming Remarks by PNG University of Technology Acting Vice Chancellor

Dr Ora Renagi

Good morning everyone! The Ambassodor of EU to PNG, His Execellence Ioannis Giogkarakis-Argyropoulos, the head of FAO to PNG Mr. Ken Shimizu, the acting Managing Director of PNGFA Mr. Goodwill Amos, PNGFA Forest Policy & Planning Director Dr Turia, ladies and gentlemen, on behalf of the Council I extend a warm welcome to all of you to this conference. Please let's give ourselves a very warm welcome. Unitech is always delighted to welcome visitors to the university particularly scientists, researchers, engineers who come to the university, our bilateral partners and multilateral partners that come to support us along. Today, we are also witnessing the same and I am very delighted and I welcome you all to the PNG multipurpose national forest inventory project conference.

As the acting head of the University, I am truly delighted to see this event progressing. Because it is an event that is demonstrating what the universities are all about. The support coming from the EU-FAO is giving the opportunity for the university to use its training programs at the university to participate in research and participate in studies. It is what the university should be making and progress made in honour of research capacity, and knowledge capacity at the university. So I really want to thank the EU for its foresight in seeing the need in the country and going ahead with the programs with the PNG Forest Authority. And realizing that we have the universities, the staff and the students, the academics and giving them the opportunity to do research and build the capacity at the university, in terms of developing the knowledge hub in science and technology - that is achieving the main purpose of the university. We are proud to be a partner to achieve that purpose as a university.

So it is a success story for the university that this program is able to engage students that have graduated in the university and give them the opportunity to do their research so they improved their qualifications to Masters and PhD levels – that is the focus of this university. One of the strategies of this university is to build the knowledge hub in science and technology so that our academics continue to gain new knowledge that is required to provide solutions to the industry needs out there, solutions to community needs out there. So that we become relevant to the society – that is my arguments all the time. Universities are knowledge entities, we should be in the forefront of discovering new knowledge and in the forefront of advising the industry, consulting with the government and private industries and whatever problems they have, they should be liaising with us and we as academics who are experts in research and discovering new knowledge to provide solutions to the needs that are out there.

We are all aware of the challenges that we faced through climate change. And our partners are all aware of that - it's a concern around the world. I am glad that with the forest resources that we have, that EU and FAO is able to support this program so that we can contribute effective to the concerns of climate change, the concerns of conserving our forests and other environmental concerns as well.

And so I am deeply thankful for this program. It has given the opportunity to sixteen students to continue their post graduate studies. I hear about the success of the students and I am delighted with this development. Now I'd like to see continuation of this type of program in the future going forward so that we can continue to build capacity in the university.

Some months ago, I was talking about how - for fifty years now we only have about five-six-seven national Professors. Next fifty years, we want to see fifty national professors but they can't' come to reality until we continue to push on research and development like we are now seeing today. So I'd like to encourage those that are graduating with your MPhils through this program – don't stop here. The NFI has lots of data in which academics can continue to do research and publish, a person like Dr Peki who can do his research and publish and become Professor Peki – Amen, Amen. It only means it's true, it can be done. So those are the environments that we want to build up going forward.

And it is not only happening in forestry sector and agriculture sector – agriculture is leading in terms of research. But gradually our engineers and scientists are going into the same field as well.

I am very happy to report today that we have signed a MOU with the Conservation and Environment Protection Authority. They have engaged national scientists at the university to do an independent peer review of the Wafi Goldpu environment impact statement. This is a breakthrough for Unitech. It brings the knowledge capacity of Unitech to international standard. Because previously in the past the international companies have always been doing the independent peer reviews. Now CEPA has realized the capacity we have at Unitech, it is engaging our national scientists. The story is a successful one and we boost about our elevations to the international levels. That's what we want to see more. So the opportunity for our academics to delve into research environment so that they continue publishing to become professors in their knowledge of expertise is what we are looking forward to build up as well.

Ambassodor Giogkarakis-Argyropoulos is a frequent visitor to Unitech now. I told him this morning the more you visit Unitech, the better we will get pronouncing your name correctly. But two or three weeks ago, he was also here to witness the commissioning of two very advance equipment that is donated by EU for NATSAL. The equipment will be used in ensuring that quality of our samples are known for trade purposes but also for our technology, knowledge and research as well. Again, I applauded the EU's support to the university. With the progress that we are making in providing quality training to our students, growing them to be world class technocrats (I forget that there are different between the UPNG graduates and Unitech graduates, they train bureaucrats and we train the technocrats - we build the society with forestry, agriculture & engineering science knowledge and we want to hold to it strongly). But that support is there and we want to continue to build that support. Today, he is back to witness some more donations or equipment that will progress the research in the Forestry Department.

We want to acknowledge the support of the FAO. It is very crucial at this time when the government is focusing to explore the vast potential in developing our agricultural activities, agricultural economies in the nation. The university wants to be part of that development and that is our purpose. Because we know very well that the striving university sector is synonymous with the living standards of its people. This is what we want to make contact with the agriculture industries, supporting them with technological development so the greater rural population out there is receiving the quality of life that we expect to see through the developments that are taking place.

Thank you very much again PNGFA, the Unitech Forestry Department and all our partners from the industries, government and the research institutes that are here. To the students that are committed to this program, we look forward to a stronger development to continue building the knowledge capacity that will serve our government, our people in the years to come. Before I sit down, I'd like to challenge the partners to consider developing the program from here and onwards. I am aware that the funding of this program is easing very soon but we would like to see the research activities and programs continuing in partnership with the relevant agencies, our multi and bilateral partners. So let's keep the communication going and develop on the next stage of the development of the project so that the students keep doing their research, the academics keep doing their research and building on the knowledge capacity for which the universities are established for.

With those few remarks, welcome again and I look forward to the presentations, findings of the students' research in this project.

Speech and Launching of the NFI Soil Manual by PNGFA Acting Managing Director

Mr Goodwill Amos

His Excellency Ioannis Giogkarakis-Argyropoulos, the European Union (EU) Ambassador to PNG; Dr Ora Renagi, the acting Vice Chancellor of PNG University of Technology (Unitech); Ken Shimizu, the head of FAO in PNG; my colleague Steven Mesa who is standing in for acting DAL Secretary; not forgetting Dr Ruth Turia, who is the iron lady behind the multipurpose National Forest Inventory (NFI); students and staff of PNG Forest Authority (PNGFA); distinguished guests; ladies and gentlemen. On behalf of the Minister of Forests and the Chairman of the Forest Board, it gives me a great honour to officiate at the NFI research conference – a project that I have been very much part of at the start of its implementation in December 2014. On this occasion, I will be doing two things today – firstly make a speech and secondly launch the soil manual.

The multipurpose NFI – we always dream of having this initiative implemented here in PNG. Back in 1990, we put in a submission for the government to fund this exercise. Unfortunately the government came back to us saying that there was no money. But good things happen when you wait, and I thank the Lord for his instruction to us to always wait. Because when you wait good things come on your way.

So you will notice now that we are implementing the multipurpose national forest inventory. We will be having sixteen students graduating this year – the first time in history for such numbers here in Unitech. I am grateful that I am also a student here at Unitech, more than twenty years ago I was walking around this campus. I am thankful that with this training, I stand before you and also not only here but in the world and presenting what we have. Like what I always say that I am always passionate about the forest that we have. There are no other forests like what we have in this great nation. There is no forest cover like what we have here in PNG. Nowhere on the planet that have 78 percent of forest cover. Dr Hitofumi Abe has corrected me from last time we have the International Day of Forests that Japan has 70 percent. We are 8 percent above Japan so we are still up there. Brazil has 60 percent, Indonesia 60 percent, Malaysia 50 percent and Europe is going down around 30 or 40 percent. China about 400 years ago it used to have 80 percent or around 78 percent. By 1948, it has gone down to 4 percent so now they are working very hard to ensure that by 2020 they will reach about 20 percent. But note that China's forest cover is man-made, not like ours which is there by probably the time I'm gone.

I am thankful that the Pastor opened the conference this morning with a word of prayer. You know that when a man of God opened the conference with the word of prayer, I know that all is well, this conference will be well, the forest that we are managing will be well and the Unitech will be well. I remember back in 1997 when I attended a conference in Turkey and as usual out there in the world, I speak passionately about our forests here in PNG. Because they fly you there and they give you only 10 minutes to speak, so within those 10 minutes you need to say something. So I always say something passionately about our forests. Data back in 1979 - 1997, our forests cover was 90 percent and I like presenting about our forests. This gentleman from Dominican Republic came up to me and said "*your country must be paradise*? And I said, *off course, my country is paradise*. He said, '' *God must there''* and I said *''off course God is in Papua New Guinea''.* So that is the reason why we still have our forests. God is here and God will ensure that we manage our forests. He will give us the godly wisdom, godly understanding, godly knowledge, godly discernment to ensure we look after our forest - we manage our forest.

You know working with the PNGFA for a very long time – more than 40 years to be exact. I always have this bad thought in me that I am not doing as much as I could - that our forest is being depleted until the multipurpose NFI, until we had support from EU, technical support from FAO and with support from JICA. And one day they mentioned to me, *''Mr. Amos, you have a lot more forests than you think''* and they were smiling. So when somebody is smiling, I know that all is well. So this is the reason why we are here today. We will be having your presentations - I'll be here, I'll be listening to your presentations. I know I am excited to hear of what you have say because you have very important topic to share.

In 1979, I went to Philippines. Like this in a room, I was sitting between three Professors who were 65 years old and I was 19 years old at that time. I was severing to be seated among these great men, and the three men noticed me, noticed that I was severing and they told me '*'Mr Amos, we want to hear from you; we want to listen to what you have to say''*. I was a 19 years old young man straight from the college. So my encouragement to those that will be presenting today, we are here to hear from you. You have something to share with us - you have something valuable to share with us and we are here to listen to you. Thank you for the sleepless nights because if you did not have sleepless nights we won't be here. There are those that are here that are sitting in front or those at the back including myself that have had sleepless nights – that is why we are here, we are here to listen, and we are here to learn. Here on earth every day is a learning exercise, we learn new things every day. The only time we stop learning is when we are in the graves. But while we are alive, it's time to learn, it's time to learn new things and implement new things.

Before I end here, I'd like to share something from the Scriptures - from the Bible. In Genesis Chapter 2 verse 15 after God created the heaven and earth, he gave us a job to do. I always say and we always argued with the agriculturalists and the foresters. The agriculturalists say that the first profession is agriculture and we, the foresters always argued that the first profession is forestry. Because God gave us the instructions - two simple instructions which I will lay with us: (1) to cultivate it and (2) to keep it. So what we have out there we are to use it – the forest resources that we have God has given to us to use it and secondly, we are to keep it. That is why we have the multipurpose national forest inventory to ensure that we know what is out there and to keep it for the future generations. Please note that it happened in Genesis, you read through the scriptures it talks about the forests. In Revelations at the end the forest is there, that is why I encourage us as foresters, agriculturalists, to ensure that we manage this valuable resource that God has given to us.

Before I sit down, I like to launch this field guide for sampling and describing soil in PNG – NFI. I am grateful that I was part of this exercise, actually part of this training when it was first introduced. The coordinator that was taking us through the soil trainings mentioned that PNG soils are as rich and fertile as the soils of the world – soils of Brazil. I know that CSIRO has done some soil tests in the past but it did a small sample and extrapolate the results across the country. I'm thankful that we are going right throughout the country. So far we did six provinces and we've got twelve provinces more to go. Let me assure us here who will be employed, who will go to the twenty-two provinces to do it. We might not get the money now but we will have the money in the future to do it because it is a valuable exercise. Once we complete this, we will know exactly what you have and once we know what we exactly have, we will start putting together the management regimes, all policies and legislations to ensure we protect what we have.

I'm thankful that we have not only look at the timber stock but we also look at the soil as I mentioned here, we looked at the biodiversity, the insect, the birds. I am grateful to be part of the team of young men. They were fast getting to the sites and I was slow but when I was 19, they called me the rocket because I beat everyone getting to anywhere. So with that, I launched the field guide for sampling and describing the soils in Papua New Guinea.

With that thank you all.

Key Note Statement by the Head of the Food & Agriculture Organization PNG

Mr Ken Shimizu

Thank you very much Dr Mex Peki. First of all, I would like to start by acknowledging Dr Ora Renagi, the acting VC of PNG Unitech, also His Excellency Ioannis Giogkarakis-Argyropoulos, the EU Ambassador to PNG, Mr Goodwill Amos, the acting MD for PNG Forest Authority, NFI Project Leader, Dr Ruth Turia, also my good friend Mr Steven Mesa from the Dept. of Agriculture & Live Stock, other senior officials from PNGFA and also PNG Forest Research Institute, my UN colleagues from UNDP, and also the FAO team. A very good morning to you all!

On behalf of FAO, first of all I would like to thank you and congratulate you for a very successful organization of this second NFI research conference. And I would also like to especially thank the PNG University of Technology for not only hosting this event but also for helping the NFI scholars graduate. I understand that the scholars will be graduating this Friday (April 5th 2019) so again a very special thanks to the faculty of Forestry Department from the University of Technology. I would like to again acknowledge the very generous contribution from the European Union. Without the support of the European Union, it would not be possible. Today, we have the privilege to donate some equipment to the University; all of these are coming from the funding from the EU project. I understand that the third year forestry students enrolled at Unitech will be commencing their forest field monitoring exercise soon. I understand that they will be making use of the NFI field manual that was launched last year, and also the soil manual that was launched today. I see also that this is the second year of the NFI research conference. We had a very successful research conference last year with the conference proceeding published on line.

It is very encouraging to see that the young foresters of PNG are being capacitated - they have been trained and they are going out to the field using the equipment, using the methodology and the manuals. So it is very encouraging to see all of that happening. Also, I would like to take this opportunity to commend the PNGFA for their continuous leadership and support and making this project a success. I think without a doubt this project has been one of the successful FAO projects in PNG. As mentioned, when this project was launched about four years ago, I had also my concerns in terms of whether FAO would be able to undertake such a project with extensive field implementation components. As you all are aware, PNG is a very big country, with rugged terrains, and issues of access, transport, security, and land tenure. I had my concerns but the team has proved me wrong. So far the team has been able to conduct NFI assessment of 125 plots in 34 clusters. The research findings have been presented or are being presented today. This year, the conference is being held for the second time, so we are assuming that there will be more advance research findings to be presented.

Also on the International front, the data from NFI has been used to establish the REDD+ Forest Reference Level (FRL). It has also contributed to the PNG government preparing the Biannual Updated Report (BUR) as well as the Technical Annex to the UNFCCC. It has contributed to the National REDD+ Strategy. Also, the project was able to initiate some discussions in finding a way forward for the establishment of a timber legality verification system. We have also started some work on forest policy – so again this is all very encouraging.

But I would also like to echo what the acting Vice Chancellor mentioned earlier. We have started on this work and the capacity has been built, but PNG is a very big country so there are hundred more plots to be assessed. So the work is not complete. But unfortunately we don't have sufficient funding to carry out assessments in all the remaining parts of the country. So I would really like to call on everyone here to echo the fact that capacity has been built, we have results and very good results that we should be proud of. But it is very important that we continue with this initiative and we carry on the good work. And because I think (the acting) Vice Chancellor you mentioned that this is a university that produces technocrats (technical experts). So I think I am at the right university because FAO is also a technical agency – it's a UN agency consisting of technical experts so I feel at home.

I would really like to congratulate all of you again for the great success. Since I am in an academic environment, I would say that all of you – everybody involved in the NFI Project, you deserved a big *A+*; for all your achievements. In a short frame of time, the project has generated remarkable achievements that you should all be proud of. I hope the media reports all of these great achievements. On that note, I would like to thank PNG

Unitech and PNGFA for organizing this event. And I very much look forward to all the research findings that will be presented in the two days research conference.

Thank you all, thank you very much.

Key Note Statement by European Union Ambassador to PNG

His Excellency Ioannis Giogkarakis-Argyropoulos

Actually, I see that you started spelling my name effective well so there is a risk that I am not going to join you again. In deed I say that I am here with friends of Papua New Guinea. I frequent PNG Unitech and actually it is a nice place and personal favour ate. In early 1990s when I first served in the country as a young bureaucrats - big than the technocrats level and working on development preparations at that time in Papua New Guinea. I still remember the glorious days when we were design some of the buildings of Unitech which still stand today like the Europa house which still stands today. I am really pleased to be back to my root days – I should say. It really a great pleasure to be back with the Professor and acting Vice Chancellor of PNG Unitech, Dr Ora Renagi. Actually, I can call you all by your first names - acting Managing Director of PNG Forest Authority, Goodwill Amos; off course Dr Ruth Turia, off course Mr. Ken Shimizu and Mr. Steven Mesa because you are too far and I will be working with you on an agriculture program. I would like to pay tribute also to Dr Hitofumi Abe because he is one of the major players in this project.

So, I am also pleased because my term here in Papua New Guinea started somehow together with this project. With what I would say business, it very difficult when you come to a country and witness whole of – normally you would come in at the beginning, at the middle or at the end of a project and you don't face the whole story of the project. It is really a nice coincidence because I was also - still remember when we launched the project in March 2016 with the presence of the Prime Minister at that time. I am also pleased that I am associated with the prolongation of the project until September where we are going to complete this endeavour. So I am very happy off course to open together with other colleagues and partners this expected intense discussions about the research and the progress that was made with this project. Because in deed it's a discovery – it's an on-going discovery at the end of the day and it’s not at the end. I am very happy that this exchange will really support the exchange of knowledge that the University of Technology is one of the principle mandates. Actually I am really happy to be on this second National Forest Inventory research conference.

It was said that the identification and need to have a National Forest Inventory (NFI) dates back to the 1990s and it was recognised. The designing and planning of this inventory was really attempted on a number of times in the past. It’s now a reality and I am very happy that the European Union, Food & Agriculture Organisation (FAO) and all of us here today are part of these realities. Really a major endeavour and I would like to congratulate you all for this achievement. This project initiative is not part of a usual cooperation, it is extra support. This is thanks to the policy that we (European Union) support the United Nations for reduction of emission from deforestation and degradation which was one of the basic principal drivers. I would like to say that to get the funding, which is quite substantial that the project in the order to get off the ground would need to be 50 million kina so it really a big amount of funding which is also supported by the social component of the European Union. It is a very competitive process – it not really easy to get it. And I would like to congratulate FAO in particular and off course PNG Forest Authority for the cossetted effort to present the proposal that was successful. I am very pleased that we witnessed the success now with results that we going to exchange. I am also very pleased that this project has dedicated approach by supporting the scholarships and congratulation to the students – I would not make it but congratulation. I know it’s very difficult, a hard work and it’s really a moment to celebrate – I still remember my old times that I have to celebrate my graduation. Thank you for inviting me!

I would like to congratulate all partners because indeed it is a partnership. It is really an exemplary partnership. We had in one account the University that provide the venue for the exchanges; we had the PNG Forest Authority that promote and develop the policies, and we FAO that has the expertise and know-how and the team in place. In fact, I would say that we had forty years of partnership – European Union with Papua New Guinea. We prepared a film – this film is not on the screen so I revealed some confidential information now. Because European Union has invested in the country for over forty years - communication, roads, water supply, environmental protection and also the management of the mangroves etc. When we were considering the film – how we are going to make the story, the end part of the film even the very end of the film is this project. Because it relates to the future I think we had the term ‘*’Green Gold*’’. I agreed partially to the term ’’*Green*’’ that’s for sure but I disagreed to the term ‘’*Gold*’’ because it is more precious. First of all, it is renewable and therefore if it is managed properly it can really last forever. Secondly, even with the support of this project, we are yet to discover the wealth of the forests. We are getting there but I am afraid that it will be very hard to reach that knowledge. These are the challenges we faced when we finished this project – how can we explore, exploit the full potential of this initial knowledge brought to us at the surface. This is really the next step - a very challenging step that I am sure all of us will try to work together on different fields of expertise - and I look forward to that.

I am very happy also that European Union is also associated as I said, we partner with Papua New Guinea for forty years (since independence for forty years now). What do we do? It's an investment for better future and better work. The European Union supports financially through grants – it's not a loan (we don't have a return), the return is you. The return is really what you are able to achieve, to delivery with the investment we make through not only the human capital. A lot has been said about the need for infrastructure, facilities etc., but these are essential for development. I am very pleased to note that the government also has launched the mid-term development program. A lot has been said about the infrastructure, facilities – it's expensive of the other. But this is necessary but not sufficient success factor. The success always passes through the human capital, human engagement, and human development. This is what we are trying to develop. And I am very happy that this project develops the knowledge, the research and also some individual, scholars – and again congratulation for that, I am very pleased with that!

Having said all of these, I would also like to repeat that the European Union is going to continue to be engaged with Papua New Guinea. There's another competitive process again and this time it is with the Climate Change Development Authority (CCDA). It's for the large scale management approach of environment - allocating management of land to achieve large scale social economic objectives without tarnishing the environment. It is really an ambitious project that we are trying to set up; it is in the Highlands this time. Again it is a competitive process so we wait to see whether we going to receive it or not. As you understand I am part of the European Union and I am on Papua New Guinea's side, though I will deal with it from the inside here. So we try to see how Papua New Guinea can really strive because of its potential, yet more benefits from it than national developed resources that are competitive.

The bilateral assistance that we have to provide, the programming is more standard but these are extra fund. This is because of the conservative efforts and I would like to encourage the partnership and other partners to really set up in years. Because I will tell you, funding although people complain about the scarcity, it is never a problem at the end. The problem is how can you best utilize it, how can you best use it, how you achieve results and that's why I look forward to see how this project can play a role for development for this country for a better governance. This is what we, at the end of the day want to achieve together, in partners with Papua New Guinea, partners with you, better governance, that why we put forestry in our field at the end. Because of the potential of Papua New Guinea, the potential of the country, the potential of forests under our engagement, in our discussion so we can better support Papua New Guinea realize the abundance for the benefits of the people.

So I wish you a successful conference today and tomorrow and a wonderful ceremony, thank you.

Progress of the National Forest Inventory Project by PNG Country Coordinator

Dr Ruth Turia

Good morning all. Firstly, I think many of you in this room are familiar with the multipurpose National Forest Inventory. So I don't intend to read word for work of what was prepared for me. I must acknowledged that this particular presentation was prepared (for me) by Dr Abe, who is the Chief Technical Advisor for this project. But before I continue, I must say that there are many other people in this room that help the process to where we are at now – it's not just me. I want to acknowledge my PNG colleagues; we had people like Professor Saulei who was then with the PNG Forest Research Institute, my own colleagues at the PNGFA HQ - Gewa Gamoga and Rabbie Lalo to name a few. So when we started this whole work, we had FAO in Rome and we were here in PNG trying to design this multipurpose National Forest Inventory.

When the project was designed, FAO wanted to train 30 undergraduate students at Bulolo – that was one of the objectives of the project. When it came to us we said no - we don't think that was a good idea so we push for the post graduate programs. As a result we have sixteen (16) scholarships – nine (9) have completed their programs, the other four (4) are still continuing their programs and three (3) are yet to do their programs and we are hoping that University of Papua New Guinea (UPNG) will accept them this year. This is how these programs came about. As our good friend, the EU Ambassador to PNG said, all this project that come on because there are certain donor partners that have programs they are working on to assist developing countries of which PNG is one of them. All of this also started with the discussion on climate change and what effects it would have on the countries. So when we designed this project, we were looking at how PNG as a country would assist the debate on climate change.

How many of you in this room have heard or have not heard of the multipurpose NFI Project? My good friend, Dr Mirzohaydar is putting his hand up and Dr Mulung - I don't believe you because you've been involved in some work from the start. So we have already heard of how this project came about and what I'm going to present is just the progress of where we are as of today. As we've heard that the project was supposed to have ended last month (about three days ago). But thank you to UNREDD FCPF, they are supporting the project for the next six months up to September 2019 and after that we have no more funding to continue on the project. But my challenge to my PNG colleagues is that we've got all the manuals developed and we already have knowledge to do what needs to be done. If we don't get any more funding from the donors, maybe we should be doing it ourselves as Papua New Guineans.

So, why are we doing this work? We always say that PNG is third largest tropical rainforests – and I must correct that it's not just PNG but we are talking about the island of New Guinea that includes the western part of West Papua. 90% of the land is customarily owned and we all know that; more than 80% people live in the rural areas and they rely on their forests. PNG forest is well-known for its biological endemism and diversification, and that's what Mr. Amos and Dr Abe were saying that when he/they are out in other countries he/they don't see the kind of forests that we have in PNG. For PNG, the current data that we have it may be saying that we have 15,000 plant species, 200 mammals and 700 bird species. But with all these diversities that we have, we also know that 80% of our population is relying on these forests. There is a lot of disturbance going on the forests. So part of the work under the NFI Project is to understand what is out there so we can manage it well for our generation today and into the future.

So the project itself, the multipurpose NFI Project title is "*Technical Support to the Papua New Guinea Forest Authority to implement a multipurpose National Forest Inventory*''. As I said earlier, the project focus initially was supposed to be with the PNGUoT Forestry Department with the other state agencies and the students. But when it came to us, we had a look at it and my team (and I) in Port Moresby thought that we are really going to undertake this particular project, that wasn't a good way to. So we changed some of the focus of how the project to be implemented. In terms of budget there was a total 7.7 million Euro. The EU funding was 5.8 million and UNREDD initially 1.9 million Euros.

For the output of the project, the overall objective is to contribute to the implementation of PNG's development goals and the climate change policies and measures on mitigation. There were four outputs: (1) NFI designing & capacity building and that's the component I said earlier that my PNGFA colleagues plus the two universities were also involved in trying to designing the methodology; (2) NFI field assessment which have commenced and I will come to our status where we are now; (3) NFI reporting and (4) Policy dialogue.

So if we look at the first output, which is I said was to develop the methodology to implement the NFI. We decided after two workshops that was done prior to all the work that the method that we wanted to use was two phase approaches. One of those was to use remote sensing to identify where all these forests are. The next one was to look at how we want to approach – go out to do the field tests and prepare the manuals which one of them was launched today. In terms of remote sensing, at the moment PNGFA is using the '*'Collect Earth''* – a tool that had been developed by FAO. This is what is showing here using CE to identify where all the forests are and then the next was the workshop. We've identified that in PNG 78% of the country is covered by forests. But I also need to stress that 78%, the previous studies before this study that in PNG about 60% forest cover. We are saying 78% because PNG has now got a forest definition. And the forest definition is that '*'the land area is equal to or more than one hectares, the canopy cover is greater than 10% and the tree height in meter is 3m*''. This is our definition of what forest is. As well as that from our assessment using CE, we noted that 3% of PNG forest is still undisturbed. You are hearing that a lot of PNG forests is being disturbed because of logging but our assessment is saying otherwise. I think you will note that a major deforestation activity that is happening in PNG is agriculture (I am looking at my friend Steven Mesa) and oil palm plantations. So that's the kind of background on what things are using RS to track what is happening/available in PNG.

There are some statistics on that as well. We noted that deforestation in 2011 was the highest, with about 200,000 ha and degradation in 2013 was about 40,000 ha. There is a difference between deforestation and degradation (but I am not going to define that), I'll leave that with the scholar working on it to define it for us. With all these work, I think it also worth mention to the EU Ambassador, we have assisted with the work we have doing as part of this project to develop the FR for PNG, which have already been submitted, accepted and currently on the website for UNFCCC.

So our current estimate at the moment, we are saying that there are about 2050, 9 million tons of carbon is available in PNG. These are some of the work we have been doing as part of this project under the NFI Reporting; the National REDD strategy and the Biannual Updated Report which was submitted in February 2019. The other output of the project is that PNG has a web-portal that is managed under the CCDA.

Still on output one in terms of capacity building, we've had a lot of in-country and overseas trainings for our officers. Unfortunately, it has been only PNGFA officers that have been benefiting from this project. I would like PNGUoT and UPNG to be involved but I think your academic programs doesn't allow you to be involved in some of the trainings. It is one of the issues that we have been facing and that why you have missed out on many of the trainings. As I said, we've had thirteen scholarships (supposed to be sixteen) and many of the students will be graduating this Friday (April 5 2019).

With output 2 which is the NFI field assessment roll-out, the assessment started in the Highlands in May 2017. We have done 124 plots (34 clusters) have been assessed – within a cluster there are four plots. We the PNGFA team that assess the upper plants, non-tree diversity, and the soil including the dead litters and the BRC team that assessed the zoology components – the moths, fruit flies, ants and the birds.

For output three – NFI Reporting, there were 16 research subjects that were determined for the Project scholarship awarded students. I think the opportunity was given to PNGUoT to identify its staff for the scholarship but its quota was awarded to the BRC. Twelve (12) scholars have been submitted their thesis, and few others have yet to compete their studies. The first NFI Research Conference was held in February 2018 of which a total of 29 presentations were made including 16 NFI Project scholarship students. The conference proceeding was published, and available both in hard copies and electronically on the website. We also had two (2) NFI studies that were presented at the Association of Tropical Biology and Conservation conference held in in July 2018 in Sarawak, Malaysia.

For output four – Policy Dialogue, two key areas that the project assisted to addressing include the REDD+ & climate change which the NFI data has been used as the core information for PNG's REDD+ discussions including National REDD+ Strategy. This enables CCDA, the lead state agency to prepare and submit PNG's FRL in January 2017 and the conduction of the Technical Assessment by the UNFCCC. The project assisted also with the PNG's first Biennial Update Report and REDD+ Technical Annex which was prepared in 2018. Secondly, the Timber Legality Verification System (TLVS). PNGFA has been working on establishment of National Timber Legality Standard (TLS) for many years. The NFI Project also supports this activity and TLS is currently at the final stage of endorsement. Additionally, the NFI Project is now supporting the designing of National Timber Legality Standard Verification System (TLVS).

In terms of item procurement, the project had procured many items (e.g. vehicles, boats & outboard motors etc.) with PNGFA and equipment donated to BRC for zoological studies) but on this occasion the list below only highlights the forest inventory tools and equipment that the project had procured for PNG University of Technology (UniTech).

Total Cost including freight:	**USD 177,589.88**
Suppliers:	• Santpoort Project Supplies B.V, Netherlands (USD 107,752.10) • International Procurement Agency, Netherlands (USD 69,837.48)
Number of items:	85 items of varied quantities

Way forward for PNG multipurpose NFI: As I said the project will be ending in September 2019 and the NFI Project will be able to complete the assessment of about 200 plots. It enables us to produce statistically reliable data of PNG's forest carbon stock and biodiversity for international reporting (e.g. revising REDD+ FRL emission factors). However, itt requires about another 3 years to assess all the forest types and the entire country to produce fundamental and comprehensive information. The design of PNG NFI is very comprehensive and thus requires large resources including funding, qualified researchers and time. Constrains including rugged terrain, limited road connections, requirement of extended awareness due to customary land tenure and security issues make the NFI implementation very expensive, challenging and time consuming in PNG. Importantly, the required capacity is built and the most difficult part of NFI has been completed and it is now a matter of continuation. We really need additional funding to continue NFI to cover the all forest type and the entire country.

Estimating number of required samples – Introduction to a new Open Foris application

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Abstract

The National Forest Inventory has completed assessments in 34 clusters by the end of March 2019. For planning of further assessments, the collected data is useful for analysing the required number of sample plots in the NFI forest strata. A new Shiny application '*Sampling Simulator*' developed by FAO was used in estimating the number of plots based of target error sampling errors by strata.

This Shiny application contains two main methods in estimating the required number of sample plots: 1) formula of Cochran (1977) and 2) Bootstrap sampling simulation. Both methods require plot level above-ground biomass (AGB) estimates as input data. Two different targeted accuracy percentages (i.e. sampling error of mean) were examined: 10% and 15%.

For the analysis, *Logged* and *Other human disturbance* strata were combined on *Lowland* and *Uplands* forest types because there were not enough samples in *other human disturbance* category. Because the mean AGBs in *Primary* forest are almost equal in *Lowland forest on plains and fans* and *Low Altitude Forest on Uplands* in the data, these two strata were also combined. For the same reason, *degraded* forest classes were combined.

At the 10% error level, the required number of plots is 416 (equal to 104 clusters). When the sampling error target was set to 15%, the target total number of plots is approximately 200.

The applied Shiny application proves to be an easy and user-friendly tool to use existing sample plot information for estimating the required number of samples. It also shows that to achieve the same accuracy in terms of the mean AGB in primary and degraded forests, the required number of plots is double in degraded compared to primary forest sites.

Introduction

The National Forest Inventory (NFI) has completed assessments in 34 clusters by the end of March 2019. For planning of coming field interventions and assessments to be conducted during a potential NFI extension phase, data collected this far is useful for analysing the required number of sample plots in the NFI forest strata. Previously, there was no representative field data available to determine a sufficient number of clusters to be sampled. Therefore FRI's Permanent Sample Plot (PSP) data was used to estimate the initial number of samples in the NFI design phase (Phase 1).

PNG NFI Phase 1 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 where identified within 15 different forest strata.

PNG NFI is using FAO Open Foris (OF) tools to store and process field data. Data analysis and reporting are done with the help of OF Calc, and R is the programming language currently to run the analysis scripts in OF Calc. Shiny is an R package that makes it easy to build interactive web apps straight from R (https://shiny.rstudio.com/). A new Shiny application '*Sampling Simulator*' has been developed in 2019 by the National Forest Monitoring Team of the FAO Forestry Department, and this tool can easily provide useful information when estimating the updated number of plots based of target error sampling error(s) by strata and collected field data (Fig. 1).

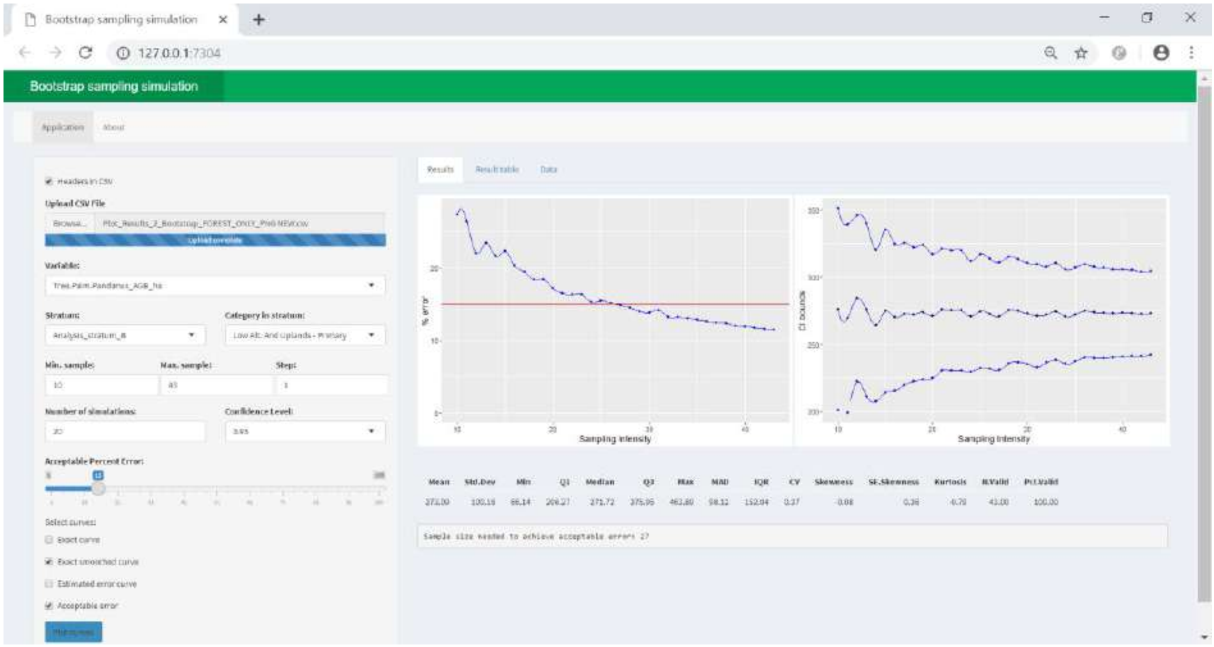

Figure 1. Screenshot of '*Sampling Simulator* 'Shiny tool.

Methods

The analysis was conducted only for strata which have field samples. In addition, the following strata were combined: a) *Lowland forest on plains and fans*, *Logged* and b) *Lowland forest on plains and fans – Other human disturbance* into *Lowland forest on plains and fans – Degraded*. Similarly, the corresponding two strata of *Low Altitude Forest on Uplands* were combined. The reason was that there were not enough samples in "*Other human disturbance*" category.

There are two main methods implemented in estimating the required number of sample plots (n) with the help of a Shiny application:

1) Using formula of Cochran (1977)[1], which is based on the estimated Coefficient of Variation (CV) and the accuracy target (E), as follows;

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

2) Generating the percent error curve as a function of sampling intensity using a bootstrap technique (see e.g. Efron & Tibshirani 1993). Because the accuracy of estimates increases when sampling intensity is increased, this method can be used to determine where the error curve crosses the targeted error level.

Both methods require that plot level AGB were estimated. This was done by using formula by Chave *et al.* (2014) which takes into account tree diameter, height and dry wood density. The plot level AGB estimates were expressed per hectare basis (i.e., tons ha^{-1}) and this was done by taking into account

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

each tree's plot area according to nested plot design. The computing of result variables was implemented in R language within Open Foris Calc and plot results were written into a CSV file (Fig. 2).

cluster_no	plot_id	stratum	accessibility	plot_elev	confirmed_land_use	confirmed_forest_type_label	confirmed_forest_st	Number_ha	BA_ha	volume_stem	volume_bole	AGB_ha	B
108924	C	1	0	0-499m	Forest Land	Low Altitude Forest on Plains	Primary	5603.7	33.2	574.1	205.1	400.7	
108924	E	1	0	0-499m	Forest Land	Low Altitude Forest on Plains	Primary	4224.3	30.9	450.7	149.2	320.8	
108924	W	3	0	0-499m	Forest Land	Low Altitude Forest on Plains	Disturbed other than	3101.6	29.9	293.9	152.3	211.6	
22124812	C	7	0	1000-2999	Forest Land	Lower Montane Forest	Primary	8947.1	36.1	365.7	131.8	262.1	
22124812	E	7	0	1000-2999	Forest Land	Lower Montane Forest	Primary	3176.9	43.5	475.1	136.6	342.3	
22124812	N	-1	0	1000-2999	Forest Land	Lower Montane Forest	Disturbed other than	3889.2	25.2	177.6	30.8	131.8	
22124812	W	8	0	1000-2999	Forest Land	Lower Montane Forest	Disturbed other than	2526.4	31.6	358.5	45.9	262.1	
22130649	C	8	0	1000-2999	Forest Land	Lower Montane Forest	Commercially logged	2852.9	26.1	136.5	10.4	102.4	
22133794	C	14	0	1000-2999	Forest Land	Lower Montane Forest	Primary	4629.4	44.3	479.5	154.5	346.6	
22133794	E	14	0	1000-2999	Forest Land	Lower Montane Forest	Primary	7406.9	56.9	628.7	272.4	448.7	

Figure 2. Input data for the Shiny application.

Two different targeted accuracy percentages (i.e. sampling error of mean) were examined: 10% and 15%. For the Cochran's estimate, the first step was to estimate variability of above-ground biomass (AGB) in different forest strata between the plots. The Shiny application does this and it gives the estimate for the number of plots using Equation 1.

Sampling Simulator creates two plots that show the change of accuracy of estimates of the mean as sampling intensity is increases. This part of the application is a replica of a tool *Plot-GEM* developed by the United States Forest Service (USFS). The first graph (Fig. 3) plots percent error of the estimate of the mean of an above-ground biomass as a function of sampling intensity, i.e. number of samples. The second graph (Fig. 4) shows the confidence interval (lower bound, point estimate, and upper bound) around the estimate of the mean AGB as a function of sampling intensity.

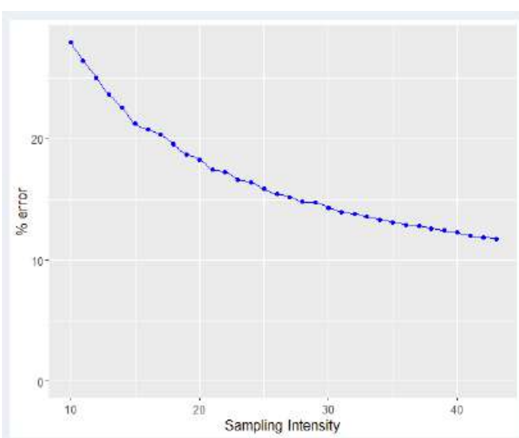

Figure 3. Error curve in Shiny application. Sampling error is presented as a function of number of samples

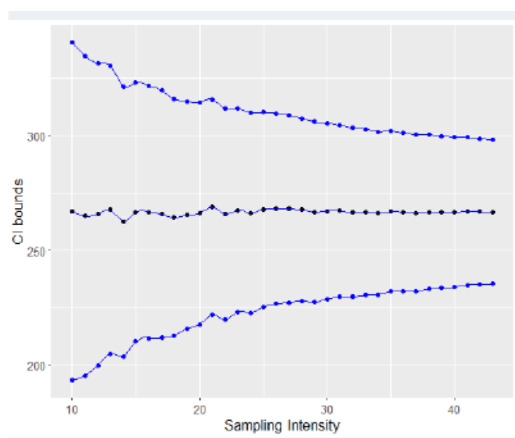

Figure 4. Confidence interval curves in Shiny application

The estimated number of samples is at the point (along X-axis) where the error level crosses the error curve, as shown in Figure 5.

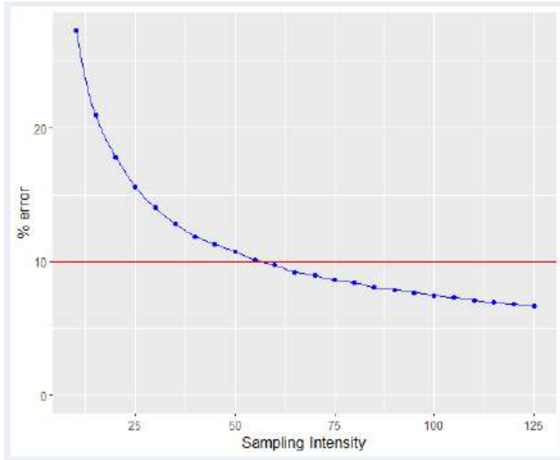

Figure 5. Error curve crossing the targeted error level

Results and Discussion

The NFI project will be closed in September 2019, and only 34 of initially target number of 1 000 clusters has been assessed. So, in short the project will run out of time, and a representative sample of PNG's forests is still yet to be captured. However, currently there is data available to recalculate the coefficient of variation for the number of plots within strata, and get new estimates for the required number of plots and clusters.

There are currently 120 accessible sample recorded in the forest land (Table x). Because the mean AGB estimates in *Primary* forest are almost equal in *Lowland forest on plains and fans* and *Low Altitude Forest on Uplands*, these two strata were combined. Similarly, *Degraded* forest classes were combined (Table X). There are total of 5 strata to examine (when *Forest plantation* excluded).

The sampling simulation was applied for each stratum with more than 10 observations, and this drops down the number of classes to three:

- Low Altitude Forest on Plains and Fans & Uplands, Primary,
- Low Altitude Forest on Plains and Fans & Uplands, Degraded, and
- Lower Montane Forest, Primary.
-

When sampling error target was set to 10%, bootstrap simulation curves did not reach error level. That is marked as "extrapolated" label in Table 1. Due to lack of data, the estimates for *Lower Montane Degraded* (orange) were copied from *Degraded* class estimates above, similarly as *Swamp Forest Primary* from *Primary* class. The Cochran estimate is more applicable in this particular case, and the total number of plots 416 (approximately equal to 104 clusters).

Table 1. Number of sample plots, mean AGB, as estimated numbers of plots with 10% error level and 95% confidence

Stratum	Number of plots	Mean AGB (tons/ha)	Estimated N - Cochran	Estimated N - Bootstrap (extrapolated)
Low Altitude Forest on Plains and Fans - Primary	35	271.7	59	55
Low Altitude Forest on Uplands - Primary	8	279.3		
Low Altitude Forest on Plains and Fans - Degraded	22	203.7	126	109
Low Altitude Forest on Uplands - Degraded	22	206.1		
Lower Montane Forest - Primary	18	325.3	46	41
Lower Montane Forest - Degraded	6	193.5	126	109
Swamp Forest - Primary	8	265.0	59	55
Forest plantation	1	-		
Total	120		416	369

Next, the sampling error target was set to 15% and the bootstrap simulation curves did reach the error level in the lowland primary forest case (Table 2). If the higher estimate is selected, then target number of plots is 183, equal to 46 clusters. However, in lowland primary forest case there are already 43 plots collected, so the real target total number of plots is close to 200.

Table 2. Number of sample plots, mean AGB, as estimated numbers of plots with 15% error level and 95% confidence

Stratum	Number of plots	Mean AGB (tons/ha)	Estimated N - Cochran	Estimated N - Bootstrap
Low Altitude Forest on Plains and Fans - Primary	35	271.7	25	27
Low Altitude Forest on Uplands - Primary	8	279.3		
Low Altitude Forest on Plains and Fans - Degraded	22	203.7	55	54 *
Low Altitude Forest on Uplands - Degraded	22	206.1		
Lower Montane Forest - Primary	18	325.3	21	21 *
Lower Montane Forest - Degraded	6	193.5	55	54
Swamp Forest - Primary	8	265.0	25	27
Forest plantation	1	-		
Total	120		181	183
				** extrapolated*

The applied Shiny application proves to be an easy and user-friendly tool to use existing sample plot information for estimating the required number of samples. The challenge in using the current NFI data is the limited number of observations by original strata and therefore these strata need to be combined. The situation will improve when more plots are recorded. However, it is a 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. In order to achieve the same accuracy in terms of the mean AGB, a rough estimate is that the required number of samples plots is double in degraded forests compared to primary forests sites in NFI.
The disadvantage of these methods are that they do not take into account the reporting required for smaller land areas than for the whole country, as for regions. Secondly, this estimation technique cannot take into account the species diversity aspects. Nevertheless, this new Shiny application will be embedded into FAO SEPAL platform as a part of Open Foris tools in mid-2019 and it will be globally available for planning of forest inventories.

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Above Ground Biomass (AGB) from the Lealea Mangrove Forest Field Protocol Trial, Central Province, Papua New Guinea

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Abstract

Papua New Guinea is made up of different landscapes, vegetation and forest types that house diverse flora and fauna. The multi-purpose National Forest Inventory to be conducted in PNG will be very expensive, time consuming and laborious if similar measurement protocol is used to assess all forest types. It is therefore important that a separate mangrove protocol is develop to achieve the similar NFI outputs in an economical and statistically sound approach owing to its special and harsh environmental conditions.

The mangrove protocol contains similar measurement parameters outlined in the main NFI PNG Field Manual (2016), with few additional modifications from cited literatures. The data to be collected from mangrove forest include (1) lower plants, (2) upper plants, (3) soils, (4) litter, (5) coarse woody debris, (6) dead wood standing, (7) dead wood lying, (8) birds, (9) ants, (10) fruit fly and (11) moths.

This paper only described the above ground biomass attained from preliminary testing of the mangrove protocol. The other results from the zoological component will be available upon laboratory analysis of confirmed species.

Results from this new national level protocol showed that Mangrove forests in Papua New Guinea have been sustainably managed by locals over time due to the important services it provides to them. This work revealed that Lealea Mangrove above ground live biomass (AGLB) with a 95 % confident level, range between 254.7 to 260.3 t / ha (257.5 ± 2.8) thus is higher than the country's latest published mangrove forest average for both live and dead trees' of 235.7 t/ha.

From latest literatures it's proven that PNG is among the top ten countries in the world in terms of its high mangrove forest cover, biomass and soil content. It's too early to draw conclusion to this findings due to the less number of plots assessed, however promising result might pop up once more mangrove forest plots are assessed.

1. Introduction

We conducted the trial of the Mangrove forest protocol from13 to 16 March 2019 in Lealea Village, Central Province. In general the mangrove sites are disturbed and have faced continuous usage by locals and the settlers. The settlers are migrants from the Goaribari speaking people of Kikori in the Gulf Province Papua New Guinea. Logically from field observation the mangrove sites have experienced forest degradation over time and slowly if not managed properly by locals and settlers, we might experience deforestation in the near future.

In brief is an overview of the study, trial protocol and equations used, results and discussion in relation to the above ground biomass content in the Lealea Mangrove forest and its scientifically significance to the local level government, district, province and country.

2. Objective

To test if this national level protocol is suitable using the Above Ground Biomass (AGB) assessment as the *key indicator* so it can be recommended to be used by the NFI/PNGFA project team in assessing different components of Mangrove forest biome in PNG.

3. Protocol

The study was conducted on the pre-assessed NFI Mangrove Forest Cluster number 116407 near Lealea Village, Hiri LLG, of Central Province. The protocols used for collecting the AGB data (Figure 1) are as follows:

- A cluster is a group of 4 sample plots. The coordinates of the center of the clusters correspond to those of the points selected in the sampling frame;
- Plots in a cluster are coded as C (Center), N (North), W (West) and E (East);
- Plot N, W and E are located 100 m from the center plot C;
- Plot N is directly to the North from the center plot C. Angle between Plots N, W and E is at 120 degrees respectively;
- Plots are nested circular shape. Trees with *dbh* ≥ 25 cm are measured in the plot radius of 20m, trees with *dbh* ≥ 15 cm in the radius of 10 m, trees with *dbh* ≥ 5 cm in the radius of 5 m, and trees with *dbh* ≥ 1 cm in the radius of 2.5m, and;
- Stump and fallen deadwood measurements are measured in the circle with radius of 10m.

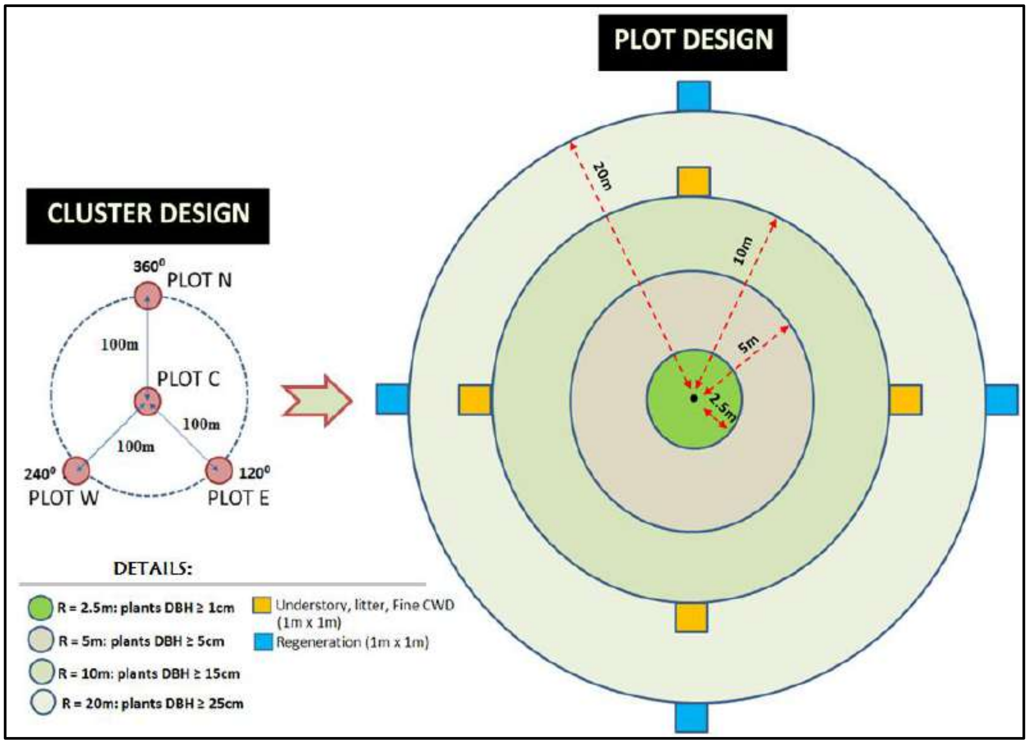

Figure 1. Shows the mangrove cluster and plot designs with different measurements per radius and clip plot

4. Results

Firstly, height equations for each plot were derived using measured height and diameter from the field data using excel spreadsheets. Then the derived equations were used to compute missing heights. Later individual height equation for each plot was derived as shown in Figure 2. These height equations were used with the DBH data in the four plots to generate biomass estimates for the stands.

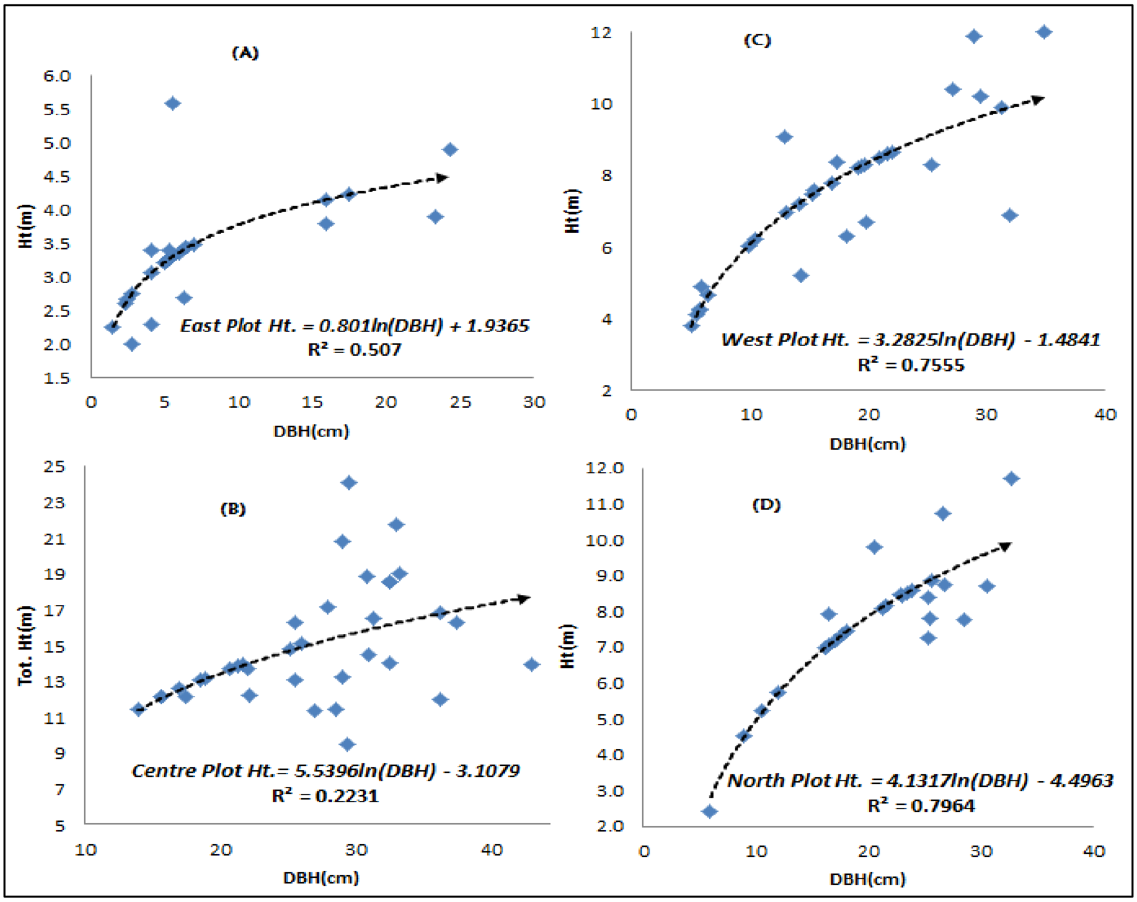

Figure 2. Shows height equations for the Lealea Mangrove Forest (A) East Plot, (B) Centre Plot, (C) West Plot and (D) North Plot

Then the combined above-ground volume (m^3 ha^{-1}) of trees for the four plots were analysed using a paraboloid coefficient as $\boldsymbol{V_t}$=0.56$\boldsymbol{A_t H_t}$, where $\boldsymbol{A_t}$ is the base area of the tree at breast height or point of measure and $\boldsymbol{H_t}$ is the height of every tree. Scaling factor and carbon fraction were used to extrapolate the field measurements taken to a *'per hectare'* basis (Walker *et.al, 2014).* Finally a derived summary of the Lealea Mangrove forest data analysis was computed as shown in Table 1.

Table 1. Summary with a 95% confident level of Lealea Managrove Forest

Summarry	n	*Above Ground Live Tree*		n	*Dead Standing Trees*		n	*Total (live+dead)*	
		Biomass(t/ha)	Carbon (t/ha)		Biomass(t/ha)	Carbon (t/ha)		Biomass(t/ha)	Carbon (t/ha)
East Plot	21	14.6	6.9	5	69.2	32.5	26	83.8	39.4
Centre Plot	35	522.6	245.6	0	0.0	0.0	35	522.6	245.6
West Plot	31	279.6	131.4	0	0.0	0.0	31	279.6	131.4
North Plot	26	213.3	100.2	0	0.0	0.0	26	213.3	100.2
TOTAL(n):	113			5			118		
Average		257.5	121.0		17.3	8.1		274.8	129.2
SD		15.2	7.2		10.6	5.0			
95 % Conf. level		(+ - 2.8)			(+ - 9.3)				

5. Discussions

Height work in the field is quite challenging as compared to girth measurement due to many reasons. One challenging reason is the terrain or sloppiness of where the plots are located especially for the terrestrial NFI field assessment. For Mangrove field assessment the roots of mangrove species and high water level are major challenges. That's why in this work we decided to formulate height equations for each plot so land owners or interested researchers can use to conduct similar studies in the future as shown in Figure 2.

According to Hutchison *et. al., 2014,* Papua New Guinea's average AGB figure for mangrove forest for both live and dead trees' is 235.7 t/ha. Also Tang *et. al, (2018)* stated that the country with the highest aboveground biomass density of mangrove in the top 20 countries worldwide in terms of mangrove area is Papua New Guinea (217.29 Mg ha^{-1}), seconded by Venezuela (199.91 Mg ha^{-1}). Indonesia ranks the third with 193.39 Mg ha^{-1} . High aboveground biomass densities tend to concentrate in countries in Latin America and Southeast Asia (from a range of 98–217 Mg ha^{-1}).

A nearby Mangrove training conducted at Tahire and Motupore Island in Port Moresby PNG by the MARSH-US Aid project in 2014 showed the above ground biomass was 105.9 t. ha^{-1} (2014 training report –unpublished). *This work revealed that Lealea Mangrove above ground live biomass (AGLB) with a 95 % confident level, range between 254.7 to 260.3 t / ha (257.5 ± 2.8) thus is higher than the country's latest published mangrove forest average for both live and dead trees' of 235.7 t/ha* (Table 1).

There aren't many published studies regarding AGB of mangroves in PNG as experienced from this write up.

6. Conclusion

The national level mangrove protocol is capable to conduct all NFI components including AGB except plant species diversity or richness is still problematic due to the variation in the zonation of the mangrove communities. This study indicates that there is more work needed in AGB in PNG thus showing its high result from this trial protocol. Also similar work is needed on other sites in PNG so it can be compared and published hence it can be comparable to global mangrove studies done by researchers from other countries.

To conclude the latest published global figures when compared with the trial work done on AGB in Lealea Mangrove forest area have shown similar findings. This indicates that our local people have sustainably utilized their mangrove forest areas over decades, but there is still room for more awareness to help them really appreciate the scientific role this biome plays locally, domestically, nationally, regionally and at a global scale in terms of carbon sequestration.

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The Extent of Forest in 2015 and the Drivers of Forest Change Between 2000 and 2015 in Papua New Guinea Based on Remote Sensing Point Sampling Approach

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Abstract

Most studies conducted on PNG's forest land use/land cover were based on wall to wall mapping approach. These studies delivered significant results indicating common drivers of forest change but varying rates of forest extent and decline.

In this study, a systematic point based sampling approach was applied and Collect Earth, a free open source software tool including freely available satellite images was used. With the sampling intensity of 0.04 x 0.04 degrees (4.44 x 4.44 km) and 0.02 x 0.02 degrees (2.22 x 2.22 km) for provinces having less than 500,000 hectares of landmass, a total of 25,279 sample points were assessed to determine the extent of PNG's forest and the drivers of forest change based on the PNG's national forest definition.

Furthermore, this study is focusing on the year 2015 where it has established that about 78% of PNG is covered with 12 forest types and the three major ones are low altitude forest on uplands (30.9%), low altitude forest on plains and fans (24.8%) and lower montane forest (22.3%). More than 23% of the total forest has been disturbed or degraded through anthropogenic activities since 2015 and most of these comes from commercial logging (10.7%) gardening (8.3%), fire (3.1%) and others 1.2%. Between 2000 and 2015 about 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 about 6.2% of the total forest area was disturbed or degraded and commercial logging caused most of them (5.7%). Despite the subsistence agriculture and commercial logging been the major driver of the forest change, oil palm development was responsible in the acceleration of both deforestation and forest degradation between 2006 and 2015.

1. Introduction

With escalating concerns on global warming, the role of forest in combating climate change is now becoming increasingly prominent in the climate change debate, e.g. the Paris Climate Change Agreement of the United Nation Framework Convention on Climate Change (UNFCCC).

Papua New Guinea (PNG), as a high forest cover country, is fully committed in identifying appropriate actions that may contribute to combat climate change and adapt to its effects. As a party to UNFCCC, PNG is obligated to report its efforts through Bi-annual Update Reports (BUR), National Communications (NC) and Forest Reference/Emission Level (FRL/FREL). At the domestic front, making informed decisions in managing the forest resources is critical towards balancing environmental conservation, socio-economic development and climate change concerns. To this aim, updated information on PNG's forest and land use change is therefore important.

Collecting such information is challenging over large areas characterized by scarce accessibility such as PNG can be challenging. For this reason Remote Sensing (RS) technology represents a valuable and cost-effective tool which could be particularly useful (Martínez & Mollicone, 2012).

Monitoring land use and change with RS technology has been challenging over the last years due to the cost involved in the satellite imagery acquisition, the use of commercial software (Gibbs, et al., 2007) and the need for high level technical skills to pre-process and analyse imagery (Romijn, et al., 2015). With the significant progress been made in the field of RS over the past decade, assessing forest land use change became cost efficient and technically feasible even for non-remote sensing experts (Bey, et al., 2016). This is due to the reduction in the costs of many types of satellite imageries, the increase in their free accessibility (Hansen, et al., 2013; Ploton, et al., 2012; Montesano, et al., 2009) and the development of several free open source RS software (Bey, et al., 2016). While wall to wall approach has been commonly used, sampling approach has also been used to assess land use and land change (Saebo, 1983). For instance, several national forest inventories (e.g. France, Italy, Swiss, USA) and the European Land Use/Land Cover assessment used multi-phased sampling approach in their land surveys (Romijn, et al., 2015;(PNG Forest Authority, 2013; Matino & Fritz, 2008).

RS technology has proven to be very successful in providing information on PNG’s forest land use/land cover between 1995 and 2014 period (Hammermaster & Saunders, 1995; McAlpine & Quigley, 1998; PNG Forest Authority and JICA, 2012; Shearman, et al., 2008; Bryan & Shearman, 2015). These studies indicate that general decline in the forest occurred. The aim of this study was to determine the extent of forest in 2015 and identify the drivers of forest change between 2000 and 2015 based on the PNG national forest definition. A point sampling approach was used to collect land use data using the Collect Earth (CE) software and medium to high resolution satellite imageries. The assessment was based on the PNG national forest definition and the IPCC land use guidelines.

This study however was focused only on deforestation and forest degradation through anthropogenic means to understand the impacts of human activities on the forest. The results of this study can be used for both international and national reporting such as the REDD+ reporting (BUR, NC and FRL/FREL) and the FAO Forest Resource Assessment (FRA), and to support informed decisions on forest management and conservation.

2. Materials and Methods

2.1 Materials

Collect Earth (CE) is the main software used. It is a user-friendly free open source software 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 Google Earth, Bing Maps, Here Maps and Google Earth Engine Playground Bey, et al. (2016).

The Main satellite images used include Landsat 7 and 8 Annual Greenest Pixel images (composites), Google Earth high resolution images and Bing maps. The supporting information includes Hansen data 2000 -2015, Forest Mapping Inventory System (FIMS) and the Forest Base Map.

2.2 Method

2.2.1 Sampling design and intensity

A probabilistic stratified-systematic sampling design was created in QGIS to facilitate area estimation and proportional land compositions. The sampling intensity is 0.04 x 0.04 degree grid and 0.02 x 0.02 degree grid for the three smaller provinces (Western Highlands, Jiwaka and Manus) having less than 500,000 hectares of landmass. In this way a 25, 279 square sampling plots were generated and overlaid on PNG boundaries.

The each sample plot is size 100m x 100m (1ha), consistent with the minimum mapping area required to the apply PNG’s national forest definition (The Government of Papua New Guinea, 2014). Within each sampling square plots, there are 25 sampling points equivalent to about 4% of the plot. These sampling points help quantify and characterize land use within the sample plot.

These sampling plots are automatically organized by the PNG CE in sub-national units arranged along a 4° grid (WGS 1984 datum).

2.2.2 Land use classification

The assessment of the land was based on the six (6) IPCC Good Practice Guidance (GPG) for Land Use, Land Use Change and Forestry (LULUCF) categories (Penman, et al., 2003) and were used as the main land classes with country specific sub-categories. The IPCC land use categories are Forestland; Settlement; Cropland; Grassland; Wetland and Other land. This study however was focused on Forest and Cropland.

Apart from the 5 IPCC land use categories, 'forest' is already defined for PNG's forest therefore the PNG's national forest definition was used to identify the forestland. The PNG's forest is defined as 'land spanning more than one (1) hectare, with trees higher than three (3) meters and the canopy cover of more than ten (10) percent' (The Government of Papua New Guinea, 2014). This excludes land that is predominantly under agriculture or urban land use. Forest has been classified into subdivision based on the vegetation types and plantations. The classification of vegetation types are based on the structural formation and described in PNGRIS Publication No.4. Full description is available in Hammermaster & Saunders (1995). The cropland category in PNG has been categorized into subsistence and commercial. Where the cropland type was difficult to identified, 'not sure' was recorded.

(i) Subsistence agriculture

The subsistence agriculture is a farming method where a family or a household produce enough food for own consumption. In areas where the market is accessible the surplus is sometimes sold. The subsistence agriculture for the purpose of this study is divided into 'sifting' and 'permanent'.
Shifting refers to a temporary cultivation of land in a rotational basis where the cultivated land is abandoned for a few years then re-cultivated once the land naturally restores its fertility. Permanent on the other hand refers to land cultivated with tree crops such as breadfruits, coconut, and mango and beetle nut trees.

(ii) Commercial agriculture

Commercial agriculture include large scale palm oil, coconut, coffee, cocoa tea, rubber and sugar plantations. They can be either active or abandoned.

2.2.3 Uncertainty analysis

Implementation of statistically valid ground truth survey is not practical considering the fact that most part of PNG is not accessible hence estimation of the uncertainties of activity data is purely statistical with no ground truth. This estimation is based on the the IPCC 2006 guidance (IPCC, 2006), complemented by GFOI Methodological Guidance (GFOI, 2006) on estimating uncertainties of land areas estimated by proportion without verification where the area estimate of each land use category is calculated by multiplying the total area A, for which land categories are to be estimated, by the proportion of sample plots in the specific land category. The percentage uncertainty associated with the area estimate is calculated as ±1.96 times the standard error of A_i divided by A_i.

The standard error of an area estimate is obtained as $A * \sqrt{\frac{p_i(1-p_i)}{n-1}}$

Where:

$\boldsymbol{p_i}$ *is the proportion of points in the particular land-use category (stratum) i;* $p_i = \frac{n_i}{n}$

A *the total area of PNG,*

n *the total number of sample points,*

$\boldsymbol{n_i}$ *is the number of point under a particular land-use category.*

3. Results

3.1 Uncertainty analysis

Below are the results using the spreadsheet developed by FAO for the Land Use Category and Conversion during 2000-2015 based on the above equation. Figure 1 shows the sampling error of area estimate and uncertainties of each land use category of initial land use and current land use, respectively. The results suggest that the assessment work overall was exceptionally performed where the uncertainty is generally low. The higher uncertainty of 'Other land' is quiet high because only a small area was sampled.

Table 1: Initial and Current Land Use

IPCC Land Use Category	Initial Land Use		Current Land Use	
	Plot Count	Area (ha)	Plot Count	Area (ha)
Forestland	19,453	36,225,470	19,314	35,963,273
Cropland	3,061	4,910,816	3,191	5,158,633
Grassland	1,318	2,444,645	1,317	2,442,680
Other land	32	55,352	34	59,277
Wetland	1,108	2,132,460	1,105	2,126,505
Settlement	237	370,120	248	388,495
Total	25,209	46,138,863	25,209	46,138,863

3.2 Land use composition in 2015

Table 2 below shows the land use composition of PNG classified in accordance with the IPCC land use categories.

Table 2: PNG Land Use Composition in 2015

Land Use Category	Area (ha)	%
Forestland	35,963,273	77.97
Cropland	5,158,633	11.18
Grassland	2,442,680	5.27
Wetland	2,126,505	4.61
Settlement	388,495	0.84
Other land	59,277	0.13
	46,138,863	

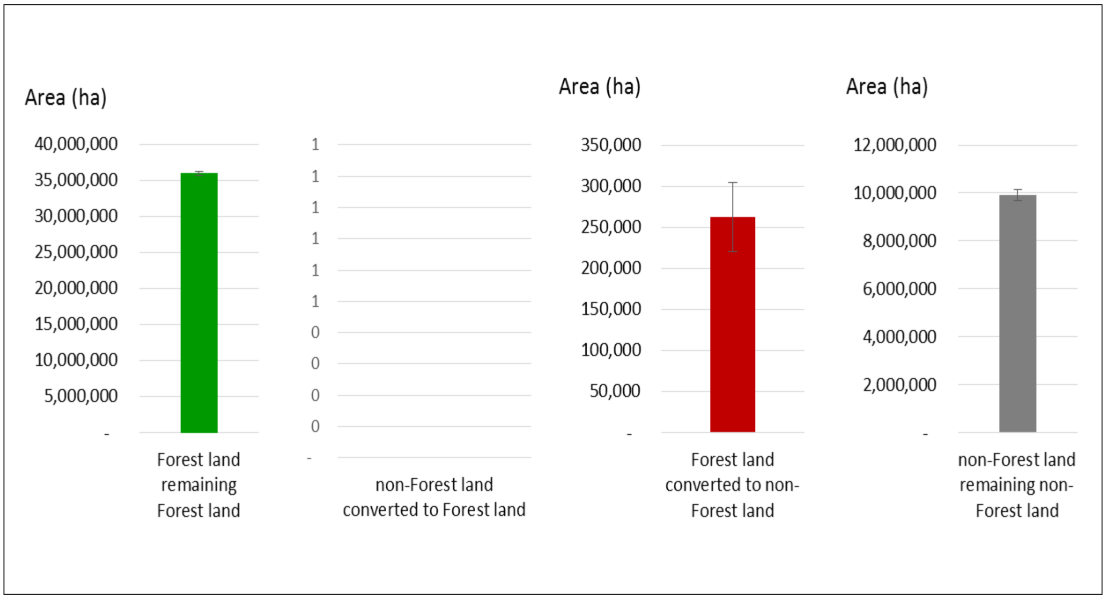

Figure 1: Uncertainty Errors on Land Use and Land Use Change data without verification

3.3 Forest Status in 2015

3.3.1 Forest disturbances/degradation

Table 3 below shows forest degraded or disturbed through anthropogenic activities as at 2015.

Table 3: Types of human impact on the forest types

Forest types	Human Impacts (ha)				None (ha)	Total (ha)
	Logging	Fire	Gardening	Other		
Low altitude forest on plains and fans	2,379,795	160,449	645,816	119,804	5,621,495	8,927,359
Low altitude forest on uplands	1,230,894	88,256	983,856	121,922	8,702,804	11,127,733
Lower montane forest	33,240	128,388	1,126,124	51,318	6,666,762	8,005,831
Montane forest		19,477	10,207		361,131	390,815
Dry seasonal forest	100,097	96,172	31,403	80,471	2,043,166	2,351,310
Littoral forest	3,927	1,957	9,810		130,533	146,226
Seral forest	7,814	5,888	11,761	7,800	287,277	320,540
Swamp forest	77,363	37,320	99,227	49,212	2,199,666	2,462,788
Savanna		276,843	3,905	13,674	329,467	623,889
Woodland	15,681	238,518	46,938	74,560	680,067	1,055,764
Scrub	4,424	29,384	3,918	3,925	178,511	220,161
Mangrove	5,890	1,942	15,628	33,346	225,044	281,850
Plantation	11,821	13,661	1,988	7,828	13,710	49,008
	3,870,945	1,098,253	2,990,581	563,859	27,439,635	35,963,273
	10.8	3.1	8.3	1.6	76.3	

3.4 Forest change between 2000 – 2015

3.4.1 Deforestation

Table 4 and Figure 2 below show the area and percentage of forest types been converted to other land use in 15 years, respectively. Figure 3 indicate forest been converted to cropland types annually. Figure 4 show forest converted to cropland types in Provinces during the same period.

Table 4: Forest types converted to other land use between 2000 - 2015

Forest types	Cropland (ha)							Settlement Large (ha)	Total (ha)
	Permanent	Shifting	Not Sure	Palm Oil	Cocoa	Coconut	Other		
Low altitude forest on plains and fans	5,887	61,050		67,334	1,978	1,957	1,963		140,169
Low altitude forest on uplands		41,526		13,867			1,963		57,356
Lower montane forest	1,479	39,729	1,959						43,167
Dry seasonal forest		1,963							1,963
Swamp forest		5,958							5,958
Savanna								1,315	1,315
Woodland		3,919							3,919
Total	7,366	154,145	1,959	81,201	1,978	1,957	3,925	1,315	253,847

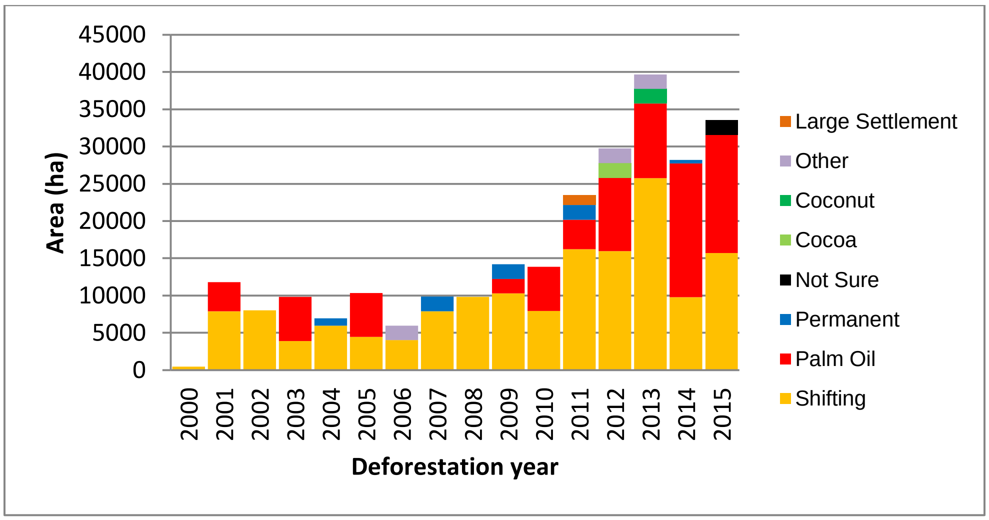

Figure 2: Annual Deforestation

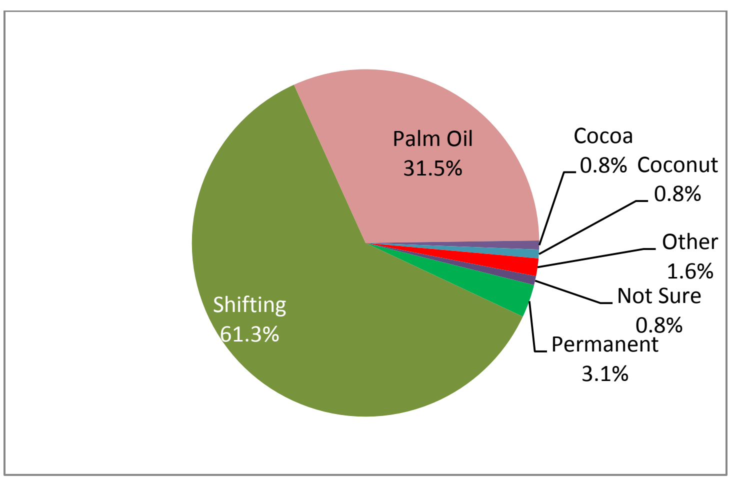

Figure 3: Forest converted to cropland types between 2000 and 2015

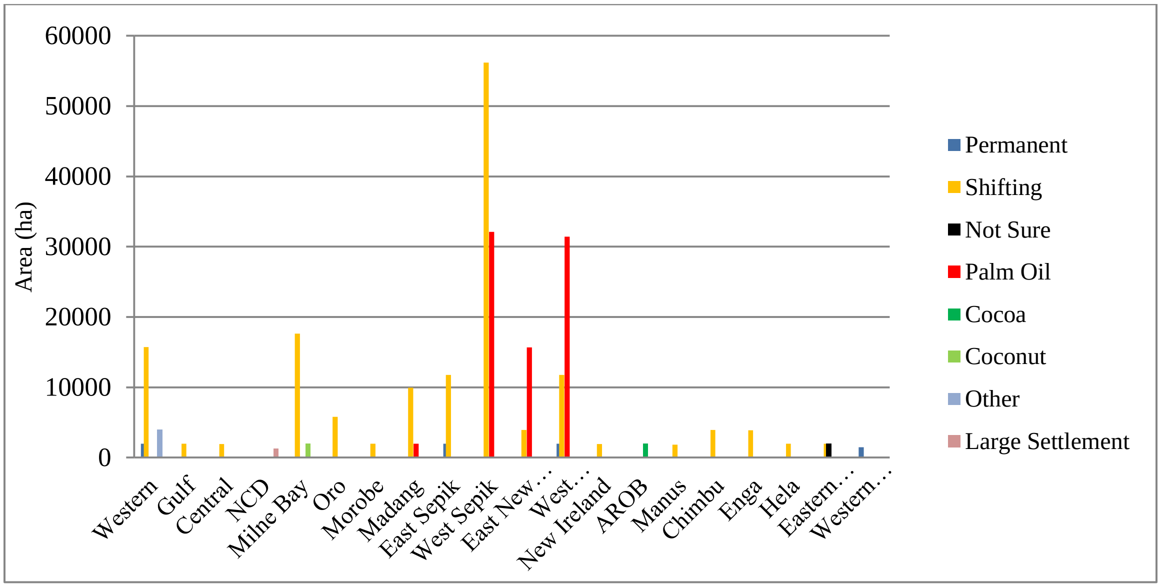

Figure 4: Forest converted to cropland types in Provinces between 2000-2015

3.4.2 Forest disturbance/degradation

Table 5 below show the area of forest types been degraded through anthropogenic activities and annual forest disturbance/degradation.

Table 5: Forest area disturbed or degraded by human activities between 2000 – 2015

Forest types	Area (ha)				
	Logging	Fire	Gardening	Other	Total
Low altitude forest on plains and fans	1,305,586	17,622	53,975	12,709	1,389,891
Low altitude forest on uplands	750,734		43,198	11,251	805,183
Lower montane forest	17,628	1,988	17,794		37,410
Dry seasonal forest	66,732		1,963	3,925	72,620
Littoral forest	1,963		1,963		3,927
Seral forest	3,926			1,939	5,865
Swamp forest	27,567		7,910	3,970	39,447
Woodland	3,925		5,865		9,790
Scrub	3,967				3,967
Mangrove			3,885		3,885
Forest Plantations	9,858	1,953		5,867	17,678
Total	2,191,887	21,562	136,554	39,662	2,389,665
	91.72	0.90	5.71	1.66	

4. Discussions

4.1 Forest definition

Past studies found conflicting information on PNG's forest extent and the forest change rate (Hammermaster & Saunders, 1995; McAlpine & Quigley, 1998; Shearman et al, 2008; PNG Forest Authority and JICA, 2012; PNG Forest Authority, 2013; FRA, 2015; Bryan & Shearman, 2015). This generated much debate among the academics (Filer, et al., 2009; Shearman et al, 2010) and created uncertainty amongst the stakeholders. These differences however are due to technical differences in measuring forest cover and forest cover change (Shearman et al, 2010) and also different forest definitions and classifications used. Forest definitions with high threshold values can exclude some important forest areas that have significant ecological values and carbon stocks. In the context of climate change, these forests have both carbon sink and removal potentials and therefore these potentials can either be under or over estimated. Harmonization of the forest definitions in the country is not only necessary for consistent national and international reporting but its potential to mitigate climate change and its ecological functions. The national forest definition of PNG has low threshold values meaning that some areas of woodland and savanna including degraded forest areas can be accounted for.

Furthermore the differences can be attributed to the use of the terms ‘land use’ and ‘land cover’. Sometimes they are used interchangeably. Land use is simply how the land is used by the people while land cover is about the physical land type (Coffey, 2013). Therefore the understanding of the context in which the forest definitions are used to determine the land cover/land use in the past studies on PNG’s forest and land cover is necessary to reduce anonymity.

4.2 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 of forest degradation is commercial logging while both subsistence and commercial agriculture activities are responsible for deforestation.

The conversion of forest to other land has been steady until 2009 where annual deforestation increased rapidly (Figure 2). Shifting cultivation was the major driver of deforestation between 1972 and 2002 (Shearman et al, 2008) and continued to be the major driver between 2000 and 2015 (Table 4). The Global Forest Watch (2014) indicate similar pattern. Forest clearance for shifting cultivation is wide spread (Figure 4). This indicates that most people live in rural areas and are dependent on subsistence agriculture. Rural population in PNG is about 86.9% (The World Bank Group, 2019). The population of PNG increased from 5.1 million in 2000 to 7.2 million in 2011 (National Statistics Office, 2015). The increasing trend seems to correlate well with the population increase. The growing population has been projected to double in the next 25 years (Cuthbert, et al., 2016). This will most likely have an impact on the forest.

Over the past decade palm oil has generated about 39% of agricultural export earnings and is the most successful agricultural crop in PNG. (Forestry and Development, n.d.). Between 2004 and 2006 and average of about K420 million was exported per year (Sam, 2015). Between 2000 and 2015 about 31.7% of the total forest cleared was due to oil palm development (Table 4). The issuance of FCAs started from 2007 (PNG Forest Authority, nd) and is responsible for increase deforestation between 2009 and 2015.

Commercial logging was the major driver of forest degradation and was responsible in degrading or disturbing about 10.7% of the total forest in 2015, similar to Shearman *et al*, (2008) (11%) and Bryan and Shearman, (2015) (13%). Most of the logs harvested through commercial logging are exported as round logs (ITTO, 2015) with an average of 3 million cubic meters (m^3) per year (Societe Generale de Surveillance (SGS), n.d) fetching more than US$250 million annually in foreign exchange earnings (Forest and Development Website, 2017).

Commercial logging was responsible for degrading about 6.1% or 2.1 million ha of the total forest between 2000 and 2015. During the same period a total of 50.3 million m^3 of logs were harvested (PNG Forest Authority, nd). Most of the commercial logging activities occurred in Western, Gulf, WNB, ENB and West Sepik and of the total of 4.2 million m^3 of round log exports, 80% came from these provinces (Societe Generale de Surveillance (SGS), n.d).

Issuance of Forest Clearance Authorities (FCAs) for oil palm developments have contributed to acceleration of forest degradation between 2010-2015. Between 2010 and 2015 a total of 5.3 million m^3 of logs were harvested from the FCA areas (PNG Forest Authority, nd). Based on the average stand density of 23 m^3/ha, the total forest degraded FCA areas would be about 230,435 ha or 10.5 % of the total area logged between 2000 and 2015.

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Forest Policy Now & Then

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Abstract

Policy statements are intentions and are implemented whenever circumstances permit and, such is the case with pre and post-independence forest policies of Papua New Guinea (PNG). The 1991 Forest Policy (current) was designed to address forest operational issues and issues relevant to equitable benefits to stakeholders as per the findings of the forest enquiry into aspects of forestry and forest industry sector in the late 1980's. The administrative set up as provided for in the Forest Policy has been implemented adequately but requires strengthening.

While the administrative set up is complied with, the key sustainable forest management (SFM) aspects with regards to landowner participation in industry and equitable benefits, reforestation and domestic processing have remained stagnant for various reasons. Central to all elements of SFM is the land tenure issues where the government may not understand that the land and forest resources are customary owned. Land tenure can be addressed effectively, if landowners participate meaningfully and hence, government needs to take ownership of facilitating their participation which among others include training and developing a pathway. Equitable monetary benefit to landowners is a key factor in ensuring SFM. The insignificant progress in critical aspects of forest management places sustainable benefits from forestry in question.

However, there are success stories such as Open Bay Timbers Ltd (in East New Britain province), Stettin Bay Lumber Company Ltd (in West New Britain province) and PNG Forest Products Ltd (in Morobo province), and using the lessons learnt, progress can be made to ensure a sustainable forest industry. The conclusion of the Multi-Purpose National Forest Inventory (MPNFI) will provide valuable information that would enable the government to rethink its forest management strategies towards a new paradigm shift. Climate change mitigation through Reduced Emissions from Deforestation and Forest Degradation (REDD+) is providing a way forward in the management of the forest sustainably as its components are actually addressing SFM. Development of Timber Legality Standard (TLS) and other relevant standards have the potential of ensuring the diversification of timber markets thus enabling competitive prices for PNG timbers and will further strengthens SFM. The current forest policy though is applicable to addressing the emerging issues, it be reviewed to take a new look to give emphasis to key aspects of SFM. It is appropriate that the forest policy review be undertaken after the conclusion of the MPNFI.

Key words and phrases: sustainable forest management, forest policy, key aspects of forest policy, emerging issues, landowner participation, reforestation, domestic processing, climate change.

1. Introduction

Forest policy like any other sectorial policy, plays a significant role in guiding how forest 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. 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 national budgets year after year, put pressure on the forest resources. Responsible forest management remains the cornerstone for ensuring sustainable benefits and hence forest policy need to be designed to achieve this core objective.

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, p.1) which includes concerns relating to sustainability of forestry operations. The basis of the 1991 Forest policy is the Fourth Goal of the Constitution which is to ensure that the forest resources of the country are used and replenished for the collective benefit of all Papua New Guineans now and for future generations.
In order to ensure sustainable forest management in PNG, key aspects of forest policy require adequate implementation. Some aspects of the 1991 Forest Policy were being implemented adequately particularly, the administrative aspects, while others including landowner participation industry, domestic processing and reforestation have been inadequately implemented due to varying situations.

2. Problem Statement

The implementation of the 1991 National Forest Policy is inadequate even though it has been in existence for the last 25 years; a much longer time than the previous forest policies**.** Forestry issues are fast evolving due largely to increased economic activity, population growth and the emerging issues of climate change and other related issues.

The key aspects of forest policy that are significant to achieving sustainable forest management, have not been adequately implemented which puts sustainable forest management in question. These key aspects are landowner participation and equitable benefits, Increased domestic processing of timber, reforestation. Central to the key aspect is customary landownership and how it operates is not well understood by the government.

Whilst confronted with the non-implementation of the key aspects of the various forest policies of the PNG government, the emerging issues such as climate change are threatening the socio economic and environmental sustainability of the forest. In PNG, logging and shifting cultivation is the major driver of GHG emission. The other emerging issues that are threatening the exportation of PNG timber products are forest certification and international timber regulations where importing countries are increasingly requiring certified and legally verifiable timber, as measures to reducing climate change impacts.

3. Significance of the Study

It is important that forest policy remain relevant to the changing circumstances including addressing emerging issues whilst at the same time maintain contribution towards the development of the country, particularly in the rural areas through SFM. The research focus is on the 1991 Forest Policy; specifically to examine landowner participation and equitable benefits, domestic processing and reforestation. It is equally important to addressing emerging issues namely climate change, timber legality and forest certification without impeding forest management and utilization but complementing each other as the forestry sector is one of the major contributor to the national economy.

4. Aim and Objectives

The aim of the research is to examine the ineffective implementation of the current Forest Policy with more emphasize on its key aspects which are significant to SFM. The key aspects that were examined and investigated are landowner participation in industry, domestic processing and reforestation. Emerging issues such as climate change, forest certification and international timber regulations were assessed and explored on how they can be accommodated in forest policy.

5. Methodology

This thesis write-up is basically through literature research on past and current forest policies and interviewing key personnel involved in the forestry sector as well as making site visits to forestry projects. Field trips were undertaken to various parts of the country where a number of case studies were done. The areas researched on are the key aspects of forest policy which include landowner participation in industry and monetary benefits, domestic processing and reforestation as they are central to sustainable forest management in PNG.

The 1991 Forest Policy was also examined to ascertain the level of its implementation and its relevancy to current socio economic and environmental circumstances**.**

The emerging issues that cut across all aspects of forest management have also been researched. These emerging issues are climate change, international timber regulations and forest certification.

The case studies were used as the basis to dissect the implementation of the key areas of forest policy to assist in drawing conclusions.

The information gathered was discussed, analyzed together with the use of the knowledge and experience of the writer, conclusions were drawn and recommendations made.

6. Review of the 1991 Forest Policy

It is clear that some aspects of the policy have been implemented while others have not been or not fully implemented. In terms of relevancy of the forest policy as a result of the emerging issues, such as climate change, international timber regulations and forest certification, they all can be addressed under the current forest policy as achieving sustainable forest management is addressing emerging as well.

All that is lacking is the effective implementation of the current forest policy on its key aspects such as forest replenishment, domestic processing, landowner participation and community forestry as well as accommodating for emerging issues. The forest policy however needs to be reviewed to clearly articulate and link emerging issues with core aspects of forest policy. The government has forgotten how and why the PNG Forest Authority came into being as it was as a result of the findings of the Barnet Forestry Inquiry that resulted in the current Forestry Act and Policy which gave birth to the PNG Forest Authority. It is important that all actors in the forestry sector including the government remain focus in implementing the forest policy to achieve the government's objective of sustainable forest management.

7. Landowner Participation in Industry

From the findings it can be said that though the government over the years initiated ways for landowners to participate meaningfully in the development of the forest resources, these initiatives have not been adequately developed to attain positive results. There aren't many success stories and hence the government 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. The government tends to think that the foreigners who bid for a timber project are the only people that have the skills and not the landowners or Papua New Guineans for that matter. Usually landowners do not have any skills on forestry business, apart from those operating in small scale workabout sawmills with limited support from the government.

A landowner training center is to be established and scope of training to be broadened to cover skills about logging business. Alternatively, the Forestry and Timber Training College (TFTC) can be tasked to offer forestry related business courses which also include personal viability and financial book keeping amongst others.

Landowners involved in wokabout sawmill to also receive training on business as well as general aspects of logging. Workabout sawmills or any other small scale forestry activities need to operate in a policy and legal environment. 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 the landowners to advance from small to medium to large scale operations. Take the scenario of a baby where he or she grows up to adulthood through stages of development. Currently workabout sawmill operations are categorized under the informal sector.

8. Monetary Benefits to Landowners

Currently, 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 a result of policy change and devaluation of the Kina against the United States Dollar and increase in price of logs.

The two case studies to ascertain the equitable distribution of monetary benefits revealed that, after logging cost, the amount received by the logging company per cubic meter 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). The State is receiving a bigger share through export tax of the two operations of K131m3 (Middle Ramu) and K124/m (Tapila Wipim). Landowners should receive an increased share of the revenue from the sale of logs and that increase should come from a reduction from the State’s share as it is unlikely that loggers share would be reduced. The price used in the two case studies is the average price of logs per cubic meter which is K332/m3 (SGS, 2017).

Usually 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.

In order to be fair and ensuring equitable benefit to key stakeholders, 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 deciding to increase the log export tax and ensuring equitable benefits to landowners.

9. Domestic Processing

The timber processing sector has been at a juvenile stage for the last 65 years as only 20% of the logs harvested are processed in country**.** The forestry sector, particularly the log export sector has been considered as a fast income generating avenue to support the government budget mainly compelled by adverse economic situations of the country over the last 40 years and the trend continues. The logging companies take advantage of the situation and do more log export which is also compelled by the insecurity 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 and under any of the Timber Authority (TA) arrangements.

The government’s expectation for logging companies operating in timber concession areas to provide infrastructure as is the current situation as per timber permit conditions and project agreement is not feasible. It is important that proper feasibility study for projects intended for processing must be done together with the provision of the necessary infrastructure by the government to enable processing in the country to increase.

The two case studies on PNG Forest Product Ltd (PNGFP) and Wawoi Guavi Timber Company (WGTC) are major timber industries in Papua New Guinea. WGTC was previously owned by Strait Marines and PNGFP, previously owned by Commonwealth Timbers, both are now owned by Rimbunan Hijau Group of companies. PNG can learn from these companies to progress in timber processing in the country. The underlying factor regarding PNGFP's success is that the land in which the plantation was established is State land as well as both the State and the company participated in establishing the forest plantations. Further the PNG government has 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 namely; Block 1 in 2021, Block 2 in 2025 and Block 3 in 2029. The PNGFA should consider making plans to reacquire the Wawoi Guavi TRP areas under FMA as per the current Forestry Act as the forest industry operation is the sole economic activity taking place in this sparsely populated part of the country.

10. Reforestation

The success and failures of past and current plantation programs would provide good lessons to set the direction for now and into the future. It is evident that where there is government involvement whether in securing land or having shares, plantation establishment seem to be successful, example 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 have felt comfortable and hence showed serious commitment to plantation development with the aim to sustain these forest industries.

Using the lessons learnt any new sizable natural forest resources allocation should be tied to plantation forest establishment as well as in existing big timber concession the government can renegotiate with the operators to establish forest plantations for the long term sustainability of the operations. The ideal balanced forestry operation should be forest harvest plus tree planting is sustainable.

Wawoi Guavi Timber operation can be renegotiated to undertake forest plantation development as it has two processing plants, a sawmill and a veneer mill. Where there is a stable political, economic and social situation, any decision to undertake forest plantation would be favorable as these factors influence success rates. Wawoi Guavi is better placed to progress into plantation development as there is low population density.

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 participation would enable proper security of land which will be the key to a successful plantation program. The Operation *Panim Graun na Planim Diwai* is a good starting point and with an improved investment climate and adequate financial resources significant progress can be made in plantation development in meeting the government's target of 800,000 hectares by 2050.

Woodlot farming is increasingly being promoted in communities by NGO communities, the PNG Forest Authority and international research organizations such as ACIAR. The initiatives by East New Britain and the Western Highlands Provincial governments in supporting communities to establish woodlots are good initiatives. With good technical advice and awareness woodlot farming will go a long way in providing economic benefits as well as environmental benefits.

11. International Timber Regulations and Forest Certification

The significant thing about the international timber regulations is that, they all respect the national laws as their definitions of illegal timbers is in contravention with the national laws. PNG has adequate forestry laws however implementation is problematic as revealed by the ITTO diagnostic mission.

The insufficient financial appropriation to the PNG Forest Authority by the government will continue to remain the same as was the case for the last twenty years and this has had significant effects on enforcing forestry laws. With the ever increase in the cost of goods and services and increase of 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 thinks reasonably and decides to opt for the first call on the revenue generated from forestry projects will be to support forest management including monitoring of forest operations, then, there will be some improvement in progressing towards effective forest management.

On a positive note it is anticipated that initiatives currently on foot which includes the Decision Support System (DSS) and the PNG Timber Legality Standard (PNGTLS) will improve the enforcement of forestry and related laws and dispel perception of illegal timber from PNG shores as well as attracting potential markets.

Forest Certification schemes or programs must still be promoted as they bring credibility to the timber industry and its timber products originating from certified operations as well as promoting sound forest management. The cost of certification programs need to be subsidized by the government particularly for small scale operators as they have difficulty meeting the costs. Meeting international regulations and forest certification requirements is enhancing sustainable forest management requirements.

12. Climate Change

The impact of climate change is enabling countries to rethink their utilization strategies of the forest resources as many have had uncontrolled logging operations 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. Saulei (1998) highlighted that when forest is harvested or destroyed by fire it not only emits GHG but also removes the source of oxygen production, carbon dioxide conversion and carbon mono oxide sequestration (pp.70-71).

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 aspirations are reliant on the development of forestry and other natural resources. Responsible forest management therefore is the cornerstone for ensuring a win-win situation for both climate change mitigation and adaptation and economic benefits.

Papua New Guinea is a leader in climate change mitigation initiatives as it has initiated the concept of reduced emissions through deforestation and forest degradation (REDD) at the Conference of the Parties meeting 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 sustainable forest management. PNG is having significant challenges in undertaking sustainable forest management practices however REDD+ is presenting a good opportunity for the government to realign its pathway in progressing towards achieving sustainable forest management as well as addressing climate change impacts.

PNG is progressing well in complying adequately with the UNFCCC and the various COP meeting resolutions which will soon enable performance based financing to support sustainable forest management. REDD + relate to sustainable forest management and PNG as a country must embrace and take appropriate actions at the operational level for effective implementation to realize positive outcomes.

13. Conclusion

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 the country enjoy now and in doing so address emerging issues such as the impacts of climate change.
The government therefore needs 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 to fund these key aspects of forestry to enable the sustainability of the forestry sector. It is anticipated that integration of climate change issues into policy and forest legislative framework will change the mentality of business as usual.

Landowner participation is not well understood by the government as implementation is not visible, though provided for in policy. How landowners 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 needs to be regulated to provide for in legislation and supported with training of landowners on forestry business and business principles. Strong coordination between sectorial agencies and integration of sectorial policies with adequate finance and manpower support to effectively implement and monitor forestry projects is the way forward in achieving the desired objectives of sectorial policies.

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Above Ground Biomass (AGB) of Major Forest Types in Papua New Guinea

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Abstract

Tropical forest deforestation in the land-use sector contributes about 20%, which accounts for one fifth of total carbon dioxide emissions to the atmosphere. Hence financial mechanisms to compensate developing countries for conserving their forests have been initiated to reduce emissions from deforestation and forest degradation (REDD+). A requirement for the implementation of REDD+ is the estimation of national level carbon emissions and carbon storage through the collection of country specific biomass and carbon stock baseline data.

In this study the aboveground biomass (AGB) is estimated from 103 plots (0.2 ha) assessed as part of the National Forest Inventory of Papua New Guinea (PNG). These clusters were stratified across three major forest types namely; Low altitude forest on plains and fans (P), Low altitude forest on uplands (H) and Lower montane forest (L). These forest types comprise more than 76 percent of the total forest area in PNG. Most logging operations in the country are concentrated on the two low altitude forest types whilst the Lower montane forest is subjected to degradation though subsistence gardening. We compare values from 60 plots in primary forest against 18 plots in logged and 16 in degraded forest.

The mean AGB for trees ≥ 1 cm for primary forests of forest types P, H and L were estimated to be 277.2 Mg ha^{-1} ± 16.59 SE, 279.0 Mg ha^{-1} ± 34.50 SE and 325.1 Mg ha^{-1} ±24.81 SE respectively. The computed mean AGB values for logged forests in forest type P (143.7 $Mgha^{-1}$) and L (242.1 Mg ha^{-1}) were lower than those in primary forest. The AGB values for primary forest in forest types P and H are among the range of previous studies in PNG but lower than global average values for tropical forests. Trees accounted for approximately 96% of Agb in all forest types with the remaining 4% contributed by lianas, ferns, palms and pandanus.

Introduction

Tropical forest deforestation in the land-use sector contributes about 20%, which accounts for one fifth of total carbon dioxide emissions to the atmosphere. Hence financial mechanisms to compensate developing countries for conserving their forests have been initiated to reduce emissions from deforestation and forest degradation (REDD+). A requirement for the implementation of REDD+ is the estimation of national level carbon emissions and carbon storage through the collection of country specific biomass and carbon stock baseline data.

Papua New Guinea (PNG) has a total land area of 46.9 million hectares, of which about 80% is covered with forest. Sixty percent of this forest cover remains intact, whilst about 14% has undergone disturbance, (Gamoga 2017) especially through commercial logging (Shearman et al. 2008). PNG's forests contain unique biodiversity (Laurance et. al. 2012), yet are vulnerable to continued large-scale exploitation by a corporate logging industry estimated at 1.4% per annum (Shearman et.al. 2008). Protecting the forests is essential to global efforts to mitigate climate change. Schemes like REDD+ present the opportunity to pay for the carbon stored in the forests to be protected (Olander et. al. 2008). To validate these schemes, we need to quantify how much carbon is stored in intact and in disturbed forests. This will enable us to determine our level of carbon dioxide (CO^2) emissions. In this paper, we examine the case of aboveground biomass (AGB) in major forest types in PNG which consists of Low altitude forest on plains and fans, Low altitude forest on uplands, Lower montane forest and Swamp Forest. We present inventory data collected from 103 plots. We analyse differences between the aboveground biomass of intact (primary), logged and disturbed (degraded) forests in these forest types and consider the implications for schemes like REDD+ on a national scale.

Fox *et al*. (2010) reported the average of above ground biomass of primary lowland tropical rainforest in PNG as 222.8 Mg ha^{-1} based on ten (10) one (1) hectare permanent sample plots (PSP) managed by PNG Forest Research Institute. This is lower than any of ten lowland tropical rainforest studies (230 – 597 Mg ha-1) in PNG summarised by Bryan *et al*. (2010a) and also lower than averages for tropical equatorial forest (Gibbs & Brown 2007: 328 Mg ha^{-1}; IPCC 2006: 350 Mg ha-1; Lewis *et al*., 2009: 404 Mg ha^{-1}). Often well-developed large forest are preferred and selected for ecological studies, and consequently, aboveground biomass of study plots may biased toward more productive forest. On the other hand, PSP plots are often located in proximity to roads or villages due to management reasons. They may have been subject to some degree of previous disturbance and it might cause lower carbon stock. However above ground biomass estimated for 50 ha plot at Wanang lowland tropical rainforest in Madang Province is 210.7 Mg ha^{-1} (Vincent *et al*., 2015) and estimated for 3,000 ha lowland tropical rain forest of Makapa concession in Western province is 222.7 Mg ha^{-1} (Bryan *et al*., 2010b), generate estimates in agreement with Fox *et al*. (2010). Consequently, it is considered most appropriate to apply the average above ground biomass provided by Fox *et al*. (2010) to estimate carbon stock of the primary forest of five lowland tropical rainforest type (low altitude forest on plains and fans, low altitude forest on uplands, littoral forest, seral forest and swamp forest) in PNG. For above ground biomass of logged over lowland tropical rainforest in PNG, Fox *et al*. (2010) reported 146.0 Mg ha-1 as the average of 115 1-ha PSP plots across the country. This is also supported by Bryan *et al*. (2010b) reporting 152.9 Mg ha^{-1} at Makapa concession in Western province.

The above ground biomass of a unit of forest area of each forest type under different type of disturbance needs to be estimated to calculate emissions from deforestation and forest degradation. National scale information on aboveground biomass in the diverse forests subject to different disturbances is poorly known. Past studies which have attempted to provide estimates of average biomass stocks in PNG have either been confined to certain forest types or too scattered and the results have usually been contradictory. A major objective of this study is the collection of vital information to estimate AGB across all forest types and between different disturbance statuses.

Methods

A total of 103 plots were assessed. Trees (Upper plants) and Botanical assessment were done within each plot under each plot radius sizes. The following criteria were used to measure trees in each sub plot.

- 3m radius plot: All plants ≥ 1.0cm dbh
- 10m radius plot: All plants ≥ 10cm dbh
- 15m radius plot: All plants ≥ 20cm dbh
- 25m radius plot: All plants ≥ 40cm dbh

Allometric equations in Chave et. al. (2014) was used for biomass estimation of individual trees.

$AGBest = 0:0673 \times pD2\ H^{\mathbf{0:976}}$

(Best – fit pan tropical model)

Where *p* is Basic wood density in (g cm^{-3})

D = tree stem diameter at breast height (1.3m) in centimetres and,

H = is total tree height in meters.

PNG wood density in Eddows (1977) was applied. Where species was not listed, IPCC default 0.47 g cm^{-3} (IPCC 2006) was used.

For estimating required sample size, standard formula in Philip (1994) was used.

$n = CV^2t^2/E^2$

where n is number of samples, CV is the coefficient of variation, t is the Student's t value for a 95% CI, and E is the required precision.

Results

Aboveground biomass in primary forest in different forest type

Aboveground biomass (AGB) of different vegetation type and forest status is summarized in Table 1. For primary forest, *lower montane forest* (LMF) contain the highest biomass (325 Mg ha^{-1}) followed by low altitude forest on upland (LAFU: 279 Mg ha^{-1}), low altitude forest on plains and fans (LAFPF: 277 Mg ha^{-1}) and swamp forest (SF: 243 Mg ha^{-1}). AGB of the two major lowland tropical rainforest types (LAFU and LAFPF) in PNG are identical (Fig. 1).

Table 1 Above ground biomass and the estimation of required number of plots for the 15 strata in PNG National Forest Inventory. The number of plots with * were estimated using the data of other forest strata due to the limited or no data collected. ** - Proportion of the area of the forest strata against the total area of forest in the country. *** - Standard Deviation.

Forest type	Forest status	Proporti-on**	Number of plots	AGB (Mg ha^{-1})	SD***	Target error level and required number of plot					
						Error	Plot	Error	Plot	Error	Plot
Low Altitude Forest on Plains and Fans (below 1000 m alt.)	Primary	11.4%	34	277.2	96.7	5%	187	10%	47	15%	21
	Commercially logged	6.5%	9	143.7	105.0	5%	820	10%	205	15%	91
	Disturbed other than commercial logging	5.4%	9	282.2	116.3	5%	261	10%	65	15%	29
Low Altitude Forest on Uplands (below 1000 m alt.)	Primary	18.7%	8	279.0	97.6	5%	188	10%	47	15%	21
	Commercially logged	6.2%	9	242.1	133.6	5%	468	10%	117	15%	52
	Disturbed other than commercial logging	7.7%	1	287.6		5%	65*	10%	65*	15%	29*
Lower Montane Forest (1000-3000 m alt.)	Primary	17.3%	18	325.1	105.3	5%	161	10%	40	15%	18
	Disturbed	6.8%	6	192.9	85.5	5%	302	10%	75	15%	34
Swamp Forest	Primary	5.6%	9	242.5	136.5	5%	487	10%	122	15%	54
Woodland		4.1%				10%	40*	15%	18*	15%	18*
Dry seasonal forest		3.8%				10%	40*	15%	18*	15%	18*
Savanna and Scrub		3.0%				10%	40*	15%	18*	15%	18*
Littoral and Seral forest		1.4%				20%	10*	20%	10*	20%	10*
Montane forest		1.2%				20%	10*	20%	10*	20%	10*
Mangrove		0.9%				20%	10*	20%	10*	20%	10*
TOTAL		100.0%	103				3089		867		432

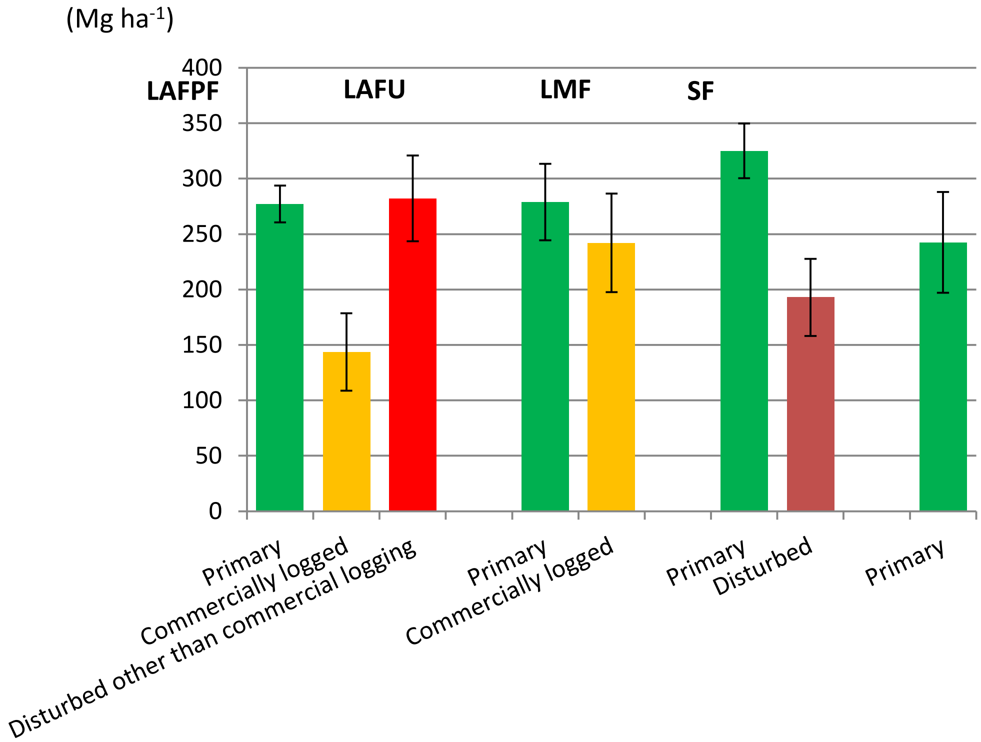

Figure 1 Aboveground biomass of different forest type and forest status in PNG. Green bar indicates primary forest and other colour bars indicate different type of disturbance. The abbreviations for the forest type indicate as follows; LAFPF – low altitude forest on plain and fans, LAFU – low altitude forest on upland, LMF – lower montane forest, SF – swamp forest.

<u>Aboveground biomass in primary forest, logged over forest and forest disturbed other than forest</u>

AGB of logged over forest are lower than primary forest (Fig. 1). Effect of logging on AGB is the most significant at LAFPF, the forest type largely disturbed by logging (PNGFA 2019). AGB of logged over forest (144 Mg ha^{-1}) is 48% smaller than primary forest in LAFPF. AGB of the forest disturbed by other than logging in LAFPF (282 Mg ha-1) is slightly higher than the primary forest. Sample number of this forest strata is small (9 plots) and it requires more sampling of this forest strata. AGB of disturbed forest in LMF (any disturbance including logging but commercial logging is very rare in this forest type) is 193 Mg ha^{-1} and 41% lower than the primary forest.

<u>Number of stems and aboveground biomass in diameter size classes</u>

In general, number of stems decrees as increase of diameter class in any forest type and forest status (Fig. 2). In contrast, total biomass of the diameter class is generally higher in larger diameter class despite smaller number of stems. Presence of higher diameter class trees is the determining factor of forest.

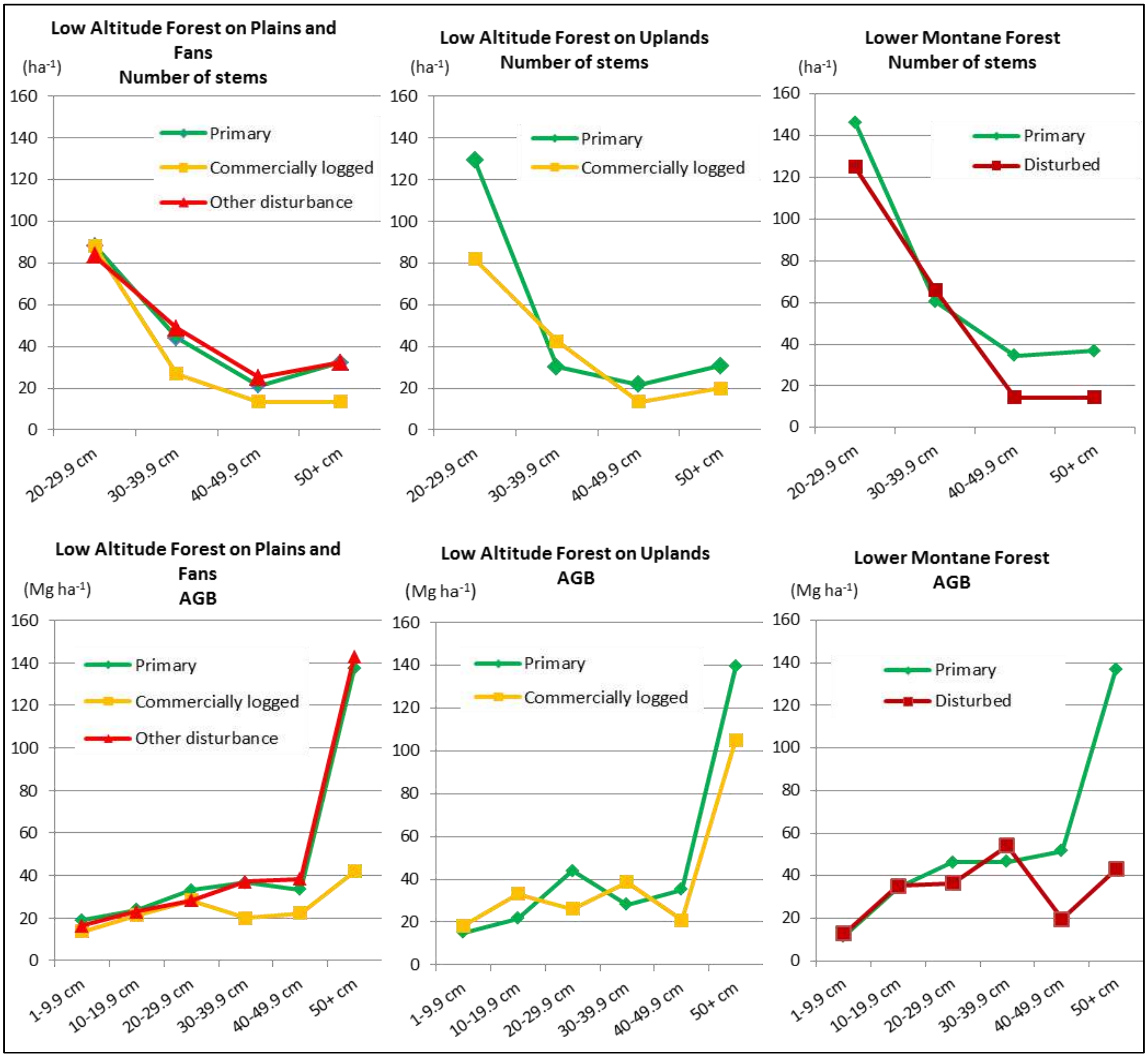

Figure 2 Number of stems (ha^{-1}) and aboveground living biomass in diameter classes of different vegetation type and forest status.

Discussions

<u>Required number of plots for estimating national forest biomass</u>

Required number of plots to estimate AGB of each forest strata in different precision level was estimated using a standard formula (Philip 1994). If we aim 10% error level for the strata with dominancy rate higher than 5% (9 strata, 85.6% of all forest) and apply 15-20% error level to the remaining 6 strata, a total number of plots required is 867 (Table 1). Various combinations of applying different error levels to different occupancy level on forest strata should be considered for determining the final target number of NFI plot. Aggregation of some of the forest strata should also be considered. For example, AGB of LAFPF and LAFU are identical. Combining these forest types may reduce the number of plot to be assessed and improve the accuracy level.

Comparison to other studies in PNG and international default values

AGB of primary forest in LAFPF (277 Mg ha^{-1}) and LAFU (279 Mg ha^{-1}) of this study are significantly higher than the national average AGB for lowland tropical rainforest in PNG (223 Mg ha^{-1}: Fox et al. 2010) but lower than the default value for tropical rainforest in the IPCC Guideline 2006 (300 Mg ha^{-1}). AGB of primary forest in LMF (325 MG ha-1) in this study is more than twice higher than the default value for tropical mountain system in IPCC Guideline 2006 (140 Mg ha^{-1}). Study of Fox et. al. (2010) is generally considered as the most comprehensive national scale study of AGB in the country. The AGB values in the study are commonly used for national reporting. Emission estimation of LULUCF sector in the recent national climate change reporting to UNFCCC such as PNG REDD+ Forest Reference Level (PNG Government 2017) and Biennial Update Report (PNG Government 2019) were conducted using the AGB values in Fox et. al. (2010) for lowland tropical rainforest and IPCC Guideline 2006 default value for LMF. There is possibility of large errors in the emission estimate caused by using these values. It is critical to progress NFI further to define the national values of AGB in all forest strata for more reliable estimation on GHG emission.

Acknowledgements

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Forest Structure and Tree Species Diversity in Major Forest Types in Papua New Guinea

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Abstract

This study assessed forest structure and tree species diversity in 22 NFI clusters comprising 79 plots (15.8 ha) from major forest types from low altitude forest on plains and fans in the lowlands to montane forests 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 where all stems ≥ 1.0cm DBH were measured and identified to genus or species level. Vouchers were collected for further identification and confirmation at the National Herbarium. A total of 3404 stems were measured, and identified 527 species of trees with 274 genera from 102 families.

Statistical and regression analysis were used to analyse the forest structure and composition. Shannon Diversity Index showed significant decrease with increasing elevation whilst Simpsons Index and Evenness showed no difference. Stem density and BA showed significant increase whilst height showed significant decrease with increasing elevation. DBH showed no difference. Furthermore, the study showed that greater diversity, stem density and BA were observed in primary forest than disturbed forests. More data from Low Altitude Forest on Uplands and Lower Montane Forest would provide better comparisons for the forest structure and tree species diversity for PNGs first ever National Forest Inventory.

Key words: forest structure, forest types, tree diversity, shannon-weiner index, Simpson's diversity index and tree evenness

Introduction

Saunders (1995) classified forest in Papua New Guinea (PNG) into 13 forest types (12 natural forest types and forest plantations). The forests range from mangrove forest at sea level, wetlands, swamps, grassland and savannah, low and frequently inundated flood plains, hills and ridges to alpine forest at very high altitudes. Hammermaster et, al, (1995); PNGFA (2017) further categorized the forest types into three major forest types; Low Altitude Forest on Plains and Fans (LAFPF), Low Altitude Forest on Uplands (LAFU) and Lower Montane Forest (LMF).

Forests are one of the most biodiversity-rich habitats on Earth where 60% of all higher plants are located in tropical forests (Koubouana et al., 2015). PNG is a tropical country where forests covers 65 percent of the land mass (Saunders, 1995) and accounts for 1.5 percent of the world's tropical forests, containing a wide range of flora and fauna (United Nations, 2001). Forest resources in PNG has and still being used for traditional purposes by the indigenous people where about 80% of the population in rural areas depend on forests for a wide range of subsistence need, including food, fuel, shelter, medicines and cultural aspects, as well as to supply land that is used in shifting agricultural systems (Blaser et al, 2011). Tropical forest resources are being exploited unsustainably raising worldwide concern (Testolin et al., 2015). In PNG the conversion of land for subsistence agriculture (SPC, 2011; FAO, 2017) and timber harvesting has been identifies as a major contributor to deforestation and forest degradation but its impact on biodiversity is still poorly understood (Testolin et al., 2015). Many biodiversity studies have been conducted in the tropical forests looking at their structure, composition, species diversity and species density. These studies have contributed significantly in the management of the forest resources. Diversity, structure and functioning of tropical rainforests are particularly complex and insufficiently known (Koudouana et al., 2015). This study investigated the status of primary (intact) and disturbed (logged) forests from the National Forest Inventory (NFI) data on forest structure and tree diversity of the different forest types in PNG forests.

Study Sites

This study was conducted in five provinces looking at forest structure and tree diversity in rainforests from Low Altitude Forest on Plains and Fans to Montane Forest at different altitudinal elevations. A total of 79 Plots from 22 Clusters were surveyed; one in Oro Province, seven in Madang Province, seven in Morobe Province, four 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.

Methodology

This study used circular plot of radius 25m (0.2 ha) with tree DBH ≥ 1.0cm (Fig. 1) to assess upper plants for forest structure and tree species diversity. Assessment of upper plants (trees including dead standing trees, tree ferns, liana and pandanus) were assessed in clockwise direction, quadrate by quadrate (NE, SE, SW and NW). Within sub-plot 3m radius, upper plants with DBH ≥ 1.0cm were measured; within sub-plot 10m radius, upper plants with DBH ≥ 10.0cm were measured; within sub-plot 15m, upper plants with DBH ≥ 20.0cm were measured and within sub-plot 25m radius, upper plants ≥ 40.0cm were measured. Every first tree and fifth tree (1, 5, 10, 15, …), dead standing trees, tree ferns, pandanus and liana in the plot assessed; their diameter and heights were measured using pole height or clinometer. Trees with DBH ≥ 40.0cm heights were measured using a clinometer. All upper plants assessed were identified to genus level in the field and recorded onto Field Data Sheet and into the Tablet. Plant specimens were also collected and taken to the National Herbarium, Lae, Morobe Province (PNG Forest Research Institute) for further identification and confirmation. Description of each plot and actual field observations were also noted. In this study dead standing trees, shrubs, tree ferns, pandanus and liana were not considered.

Cluster Design

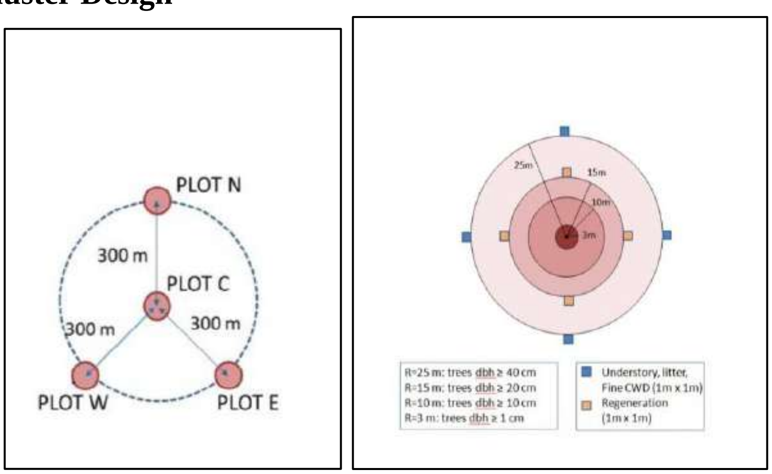

Figure 1 NFI Cluster and Plot design

Statistical Analysis

Excel and Software Saiku (Calc Software in OpenForis) were used to compute forest structure and tree diversity (Shannon-Weiner Index), species richness (Simpson's Diversity Index) and species Evenness based on the number of trees of each species in major forest types in Papua New Guinea and between primary and degraded forests.

Results

Table 1 Number of assessable plots, families, genera and species between Primary and Disturbed Forests in Major Forest Types. Major Forest types acronyms explained: LAFPF=Low Altitude Forest on Plains and Fans, LAFU=Lower Altitude Forest on Uplands, LMF=Lower Montane Forest.

Forest Type	**LAFPF**		**LAFU**		**LMF**	
Forest Status	Primary	Disturbed	Primary	Disturbed	Primary	Disturbed
# of Assessable Plots	27	20	4	2	18	8
# of Families	65	67	35	18	62	27
# of Genera	155	140	57	26	113	41
# of Species	272	221	68	28	177	47

Table 2 Mean Tree Species Diversity using Shannon-Weiner Index, Simpson's Diversity Index and Evenness in Major Forest Types and between Primary and Disturbed Forests.

Forest Type	**Forest Status**	**# of Plots**	**Mean_Shannon-Weiner Index (*H'*)**	**Mean_Simpson's Diversity Index (*D*)**	**Mean_Evenness (*J*)**
LAFPF	LAFPF	47	2.30	0.15	0.75
LAFPF	Primary	27	2.36	0.13	0.76
LAFPF	Degraded	20	2.22	0.18	0.75
LAFU	LAFU	6	2.64	0.10	0.78
LAFU	Primary	4	2.56	0.11	0.76
LAFU	Degraded	2	2.78	0.08	0.83
LMF	LMF	26	2.13	0.18	0.73
LMF	Primary	18	2.21	0.17	0.72
LMF	Degraded	8	1.96	0.21	0.75

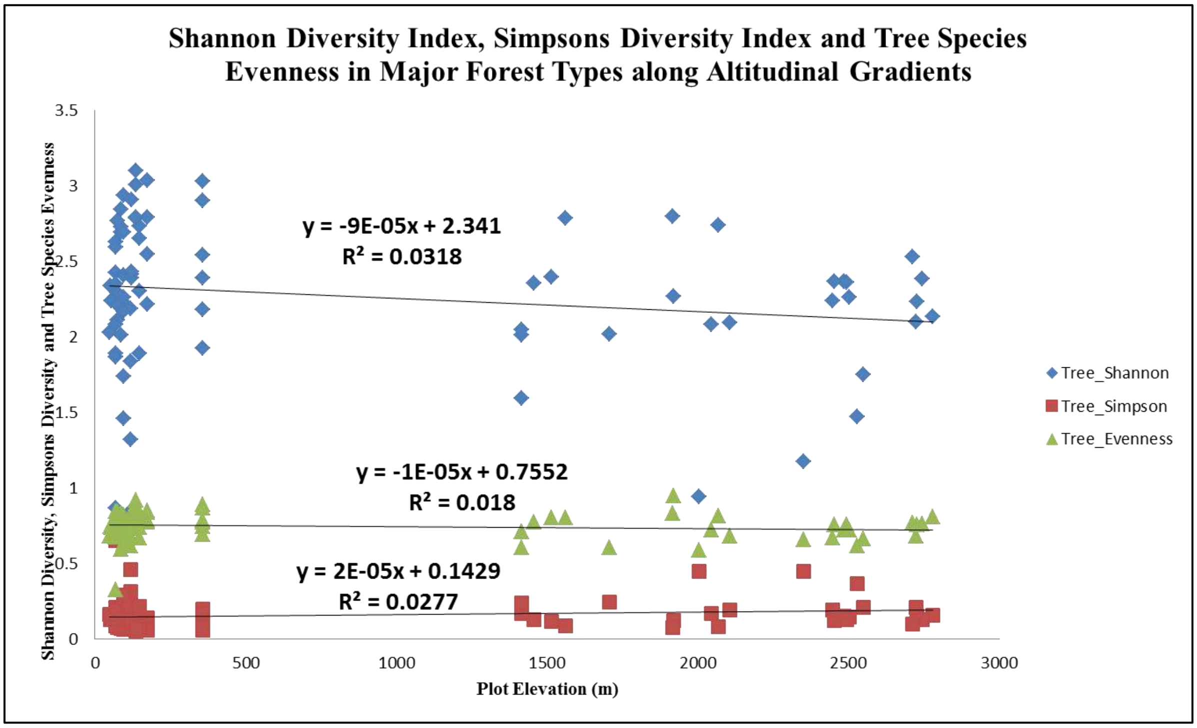

Figure 2 - Shannon Diversity Index, Simpson Diversity Index and Tree Species Evenness between plots at different altitudinal elevations. The graph report 79 plots where linear regression lines are shown. Shannon Diversity Index showed significant decrease with increasing elevation whilst Simpsons Diversity Index and Evenness (J) showed no significance with increasing elevation.

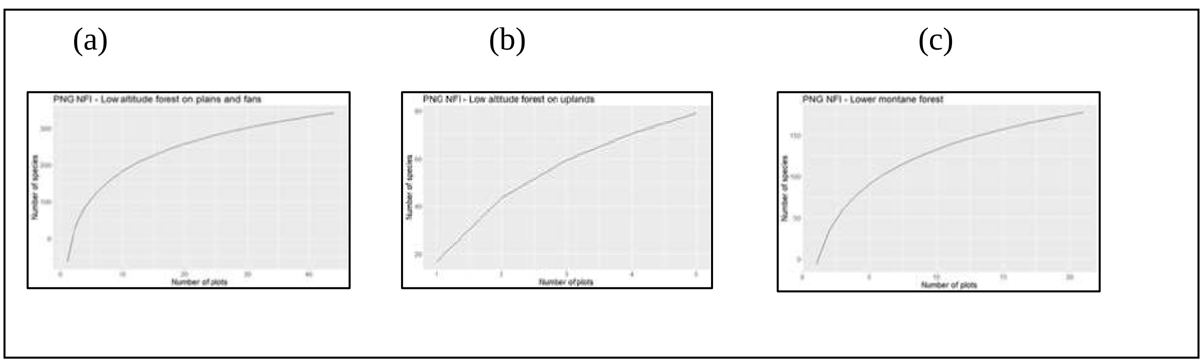

Figure 3 – Graphs showing tree species richness in major forest types; LAFPF (a) LAFU (b) and LMF (c) with increasing number of plots

Table 3 Study by Katovai et al (2015): Acronyms explained; FSF=Riverine Succession Forest, LMF-Lower Montane Forest, HF=Hill Forest and RMF=Riverine Mixed Forest.

Forest Type	Alt (m)	Mean species richness	Shannon Index	Est. Forest density	Tree stand density
RSL	~874	31 ± 2.2^{D}	2.60 ± 0.09^{B}	22.8 ± 0.6^{C}	62.3 ± 4.6^{A}
LMF	~1174	44.8 ± 1.0^{C}	2.73 ± 0.15^{B}	21.2 ± 1.4^{C}	41.3 ± 1.5^{B}
HF	~665	50.3 ± 2.6^{B}	3.07 ± 0.04^{A}	25.9 ± 0.7^{B}	47 ± 1.8^{B}
RMF	~173	55.3 ± 1.9^{A}	3.2 ± 0.009^{A}	31.6 ± 1.4^{A}	41.5 ± 3.1^{B}

Table 4 Summary of Mean Stem ≥ 10.0cm/ha, Stem BA ≥ 1.0cm/ha, Stem DBH ≥ 1.0cm/ha and Stem Height ≥ 1.0cm between Primary and Disturbed forests in Major Forest Types.

Forest Type	**Forest Status**	**No. of Plot**	**Stem/ha ≥ 10.0cm**	**Stem BA/ha ≥ 1.0cm**	**Stem Mean BDH ≥ 1.0cm**	**Stem Mean Height ≥ 1.0cm**
LAFPF	LAFPF	47	451	29.1	37.9	22.5
LAFPF	Primary	27	444	32.0	44.2	24.6
LAFPF	Disturbed	20	460	25.3	29.3	19.6
LAFU	LAFU	6	509	32.9	32.5	20.1
LAFU	Primary	4	567	32.8	32.2	19.1
LAFU	Disturbed	2	392	32.9	33.2	22.3
LMF	LMF	26	611	36.5	36.0	19.2
LMF	Primary	18	653	41.2	40.1	20.6
LMF	Disturbed	8	518	26.1	26.7	16.2
Mean Overall						
LAFPF/ LAFU/ LMF	Primary & Disturbed	79	524	32.8	35.5	20.6
LAFPF/ LAFU/ LMF	Primary	49	555	35.3	38.8	21.4
LAFPF/ LAFU/ LMF	Disturbed	30	457	28.1	29.7	19.4

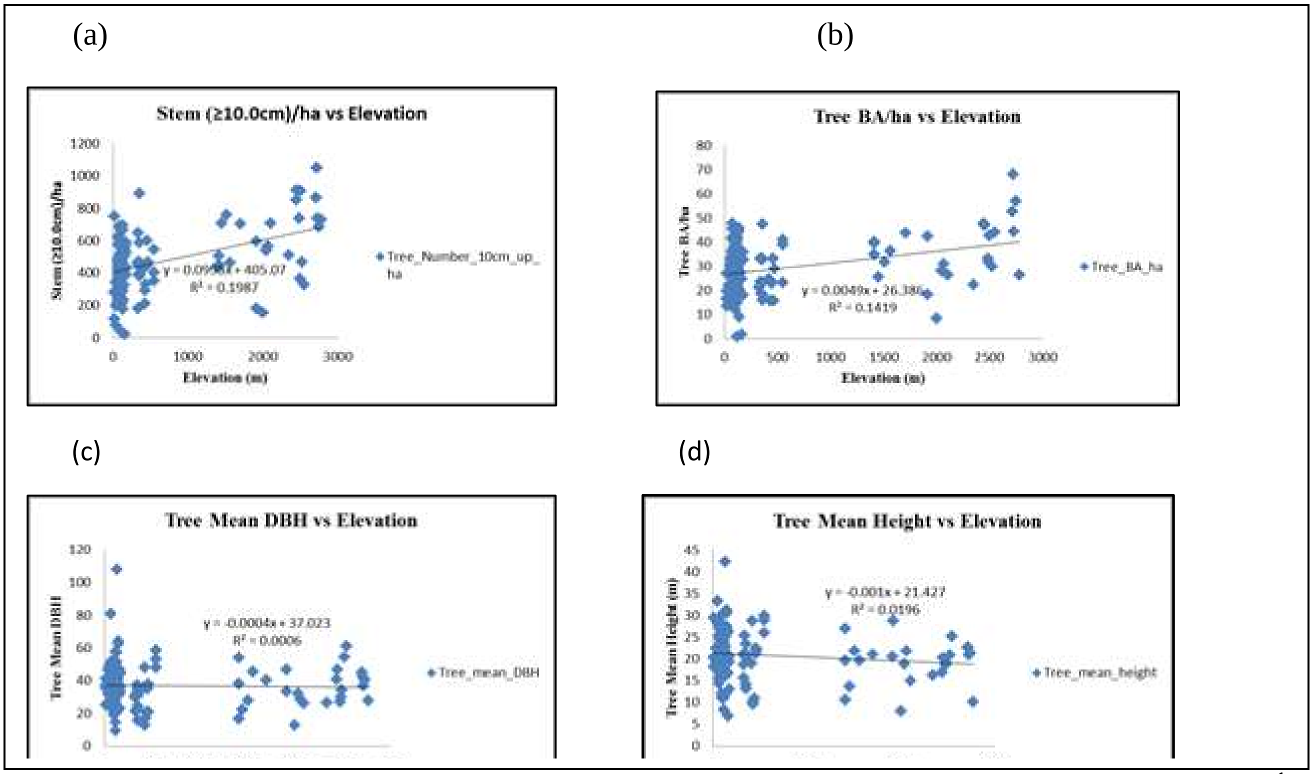

Figure 4 - The graphs report 79 NFI plots along different elevations. Linear regression lines are shown. Tree stem ha^{-1} (a) and BA m^2 ha^{-1} (b) showed significant increase with increasing elevation. Tree mean DBH (c) showed no significance with increasing elevation. Tree mean height (d) showed significant decrease with increasing elevation.

Table 5 Comparisons of diversity and structure to other plots sampled within Papua New Guinea. Bold values represent the highest value in that column.

Country	**Forest**	**Basal Area**	**Stem ha^{-1}**	**Reference**
Papua New Guinea	Lake Hargy Caldera	37.4	554	Lauder (2015)
Papua New Guinea	Crater Mountain	31.5	602	Weiblen (1998)
Papua New Guinea	Crater Mountain 2	37.1	**693**	Wright et al. (1997)
Papua New Guinea	Alowia	40.1	529	Keppel et al. (2010)
Papua New Guinea	Sewa	**46.3**	612	Keppel et al. (2010)

Source: Lauder (2015)

Table 6 Summary from NFI Major Forest Types

Country	**Forest**	**Basal Area**	**Stem ha^{-1}**	**Reference**
Papua New Guinea	LAFPF	29.1	451	This study
Papua New Guinea	LAFU	32.8	509	This study
Papua New Guinea	LMF	36.5	611	This study

Discussion

This study in total conducted assessment on 79 circular plots of radius 25m (0.2ha) in 15.8ha with trees DBH ≥ 1.0cm (Fig. 1). A total of 3403 stems were measured, and identified 527 species of trees within 271 genera from 102 families (Table 1) in the three major forest types and between primary and disturbed forest at different altitudinal elevations. Preliminary results using Shannon-Weiner Index (Table 2 and Fig. 2) indicated significant decrease in tree diversity as elevation increases. Although, tree diversity in LAFU (Table 2) indicated highest diversity, the number of sample size is very small with only 6 plots being assessed in this forest type. Simpsons Diversity and Evenness on the other hand showed no significance with increasing elevations in the major forest types. Disturbed forest with human activity indicated low tree diversity as compared to intact forest with minimal or no disturbance (Table 2). The number of tree (tree species richness) increases as the number of plots is assessed between plots (Fig. 3) in the major forest types. This is expected to increase as more clusters are surveyed.

To determine the variations and relationships in forest structure, tree genera and forest types are often used (Maiguo, 2018). The forest structure is classified into horizontal and vertical dimensions (Bourgeron 1983 and Brun 1983 cited in Maiguo 2018). However, in this study only stand density, basal area, stem DBH and stem height were used for structural analysis (Table 4). The study indicated the LAFPF has stem density of 451 trees/ha and BA of 29.1m^2/ha. LAFU has stem density of 509 trees/ha and BA of 32.8m^2/ha whilst LMF showed 611 tree stem/ha and BA of 36.5m^2/ha. This study revealed that tree stem density/ha and BA m^2/ha significantly increases with increasing elevation (Figure 4). Stem DBH, however, does not indicate any significance whilst the tree height indicated significant decrease with increasing elevation. The study also indicated that the primary forest have higher tree stem density/ha, greater BA m^2/ha, stem DBH and mean height than the disturbed forests.
Current study when compared with a diversity study conducted by Katovai et al (2015) on forest type LMF, results on Shannon-Weiner Index indicated 2.73 (Table 3). This study showed 2.13 (Table 2), indicating that diversity is quite similar within similar forest type. Forest structure also revealed that current study can be compared with similar studies undertaken within the region (Table 5).

This study only assessed 22 clusters (79 accessible plots) of the targeted 1000 clusters to be surveyed. Results of tree species diversity and forest structure indicated interesting results between major forest types. This study recommends that more data is needed with the forest types LAFU and LMF for more reliable findings.

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(1) FAO and EU for financial and technical support to conduct PNGs first ever National Forest Inventory and in doing so collected data for this study; (2) Mr. Lauri Vesa, FAO Forestry Consultant for assistance in the data analysis (Excel and Saiku (Calc Software in OpenForis) and advise; (3) Mr. Kiporo Damas, Senior Botanist, PNG Forest Research Institute for the species identification; (4) All PNGFA Officers and support staff and local assistants in conducting and collecting data for the country's first ever National Forest Inventory; and (5)To all the communities where the NFIs were surveyed. Thank you for your kind hospitality and most importantly for allowing us into your beautiful forests.

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Fern Species Richness and Beta-Diversity in the Forest Ecosystems of Papua New Guinea

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Abstract

This study surveyed quantitatively fern communities at 11 sites spanning undisturbed and disturbed forests from 70 to 2700m above sea level (a.s.l) in northern parts of the New Guinea islands. The analysis revealed high species richness of ferns, with the 76 species from 36 genera and 19 families recorded. Of these, 52 species were terrestrial and 24 species were epiphytes. The study however also highlighted insufficient taxonomic knowledge of this group. The study documented increasing species richness with elevation, both for terrestrial and epiphytic ferns. There are several species with extremely wide elevational distribution, spanning >2000m a.s.l, while a majority of species have narrow elevational ranges. Elevation was also a significant environmental factor determining species composition of ferns. This makes ferns a suitable focal taxon for climate change studies.

In contrast, ferns responded much less to forest disturbance. The disturbance altered fern species composition but not diversity, probably due to the dispersal ability of ferns, being able to rapidly colonize disturbed habitats. Further studies within the National Forest Inventory should bring more detailed understanding of ferns, but even this limited study has shown that ferns are ecologically unique, showing ecological patterns different from trees or seed plants in general.

INTRODUCTION

The tropical rainforest on the island of New Guinea harbors 5-7 % of global biodiversity including Papua New Guinea (PNG) (Shearman et al., 2008). PNG rainforest requires careful assessment to document species richness, alpha and beta diversity along ecological gradients including the elevational gradient (Katovai, Katovai, Edwards, & Laurance, 2015; Shearman et al., 2008). The careful assessments on floral biodiversity in PNG contributes to an in-depth understanding of selected taxa group such as the unexplored species rich taxa from low to high elevation forests. As such, ferns and fern allies (Pteridophytes) are more concentrated at the mid-point elevation (Colwell et al, 2016), often in extremely rough and deep terrains, fringing streams in inaccessible mountain forests. The midpoint diversity maximum suggests fern species prosper most in montane forests while both lowlands and alpine vegetation are less favorable (Colwell et al. 2016).

The ensuing dissimilar distribution pattern of fern species between high and low elevation are determined by factors such as forest types (e.g. cloud forests) topography, microhabitats, land surface slopes, rainfall pattern, temperature, humidity level and moisture content on plant stems. The hypothesized variables have been documented in many other related studies of fern species where they drive distributions, species richness, alpha and beta diversity of ferns in the tropics.

New Guinea is poorly explored for plant diversity, including ferns. At the same time, fern species are suitable indicator taxa to assess species distribution in tropical forests and have been used as a model taxon in tropical forests studies to understand the distribution of plant species (Tuomisto et al. 2003). Study of ferns along elevational gradients has proven to be particularly useful (Kromer et al., 2005, Watkins et al., 2006). Fern species occurrence in response to changing forest structure and climate along elevational gradients has greatly contributed to the understanding of species diversity drivers, and possible response of tropical biodiversity to climate change.

Ferns in Papua New Guinea Rainforest: Research Questions

The main research questions asked in this study were; i) what are the patterns of species alpha and beta diversity in ferns with forest types, including those along elevational gradients, ii) how the fern communities respond to forest disturbance, and iii) what are the differences in diversity and habitat distribution among terrestrial and epiphytic growth forms in ferns?

METHOD

The sampling scheme is based on standard protocol for the Nationwide Forest Inventory. Moreover, reasons for using standard sampling scheme can be used to compare individual sites with respect of their species richness and diversity with other taxonomic and functional groups of plants.

Study Sites

The island of New Guinea is a composite structure of the southern regions that are a part of the Australian craton and were in the past often connected with Australia by a land bridge (the last time it happened was 18,000 years ago during the latest glacial period), and the northern regions that are a series of island terrains that amalgamated with the Australian craton. These collisions have uplifted the Central Range, providing the island with topographic diversity from the lowlands to the permanent ice area above 4,500m a.s.l. Finally, the islands north of New Guinea, including New Britain and New Ireland, are biogeographically separate units that have never been connected with New Guinea and that are slowly floating towards it.

In these biogeographical settings, the present study area extends over the lowlands of the Northern part of New Guinea and the elevational gradient of the Central Range, with study plots spanning elevations from 70 to 2700m a.s.l (Fig. 1). The studied forests include sites from Morobe, Madang, Eastern Highlands and Western highlands Provinces of PNG. They include five high elevation plots (1450, 1562, 2447, 2486 and 2728m a.s.l) and six lowland plots (70, 73, 137, 147, 356 and 357m a.s.l). The location of individual study sites was determined by random selection of geographic coordinates within landscapes to avoid bias. The study area extends on an elevational gradient forest starting from Morobe province to Eastern Highlands and Western Highlands Provinces of PNG (Fig. 1).

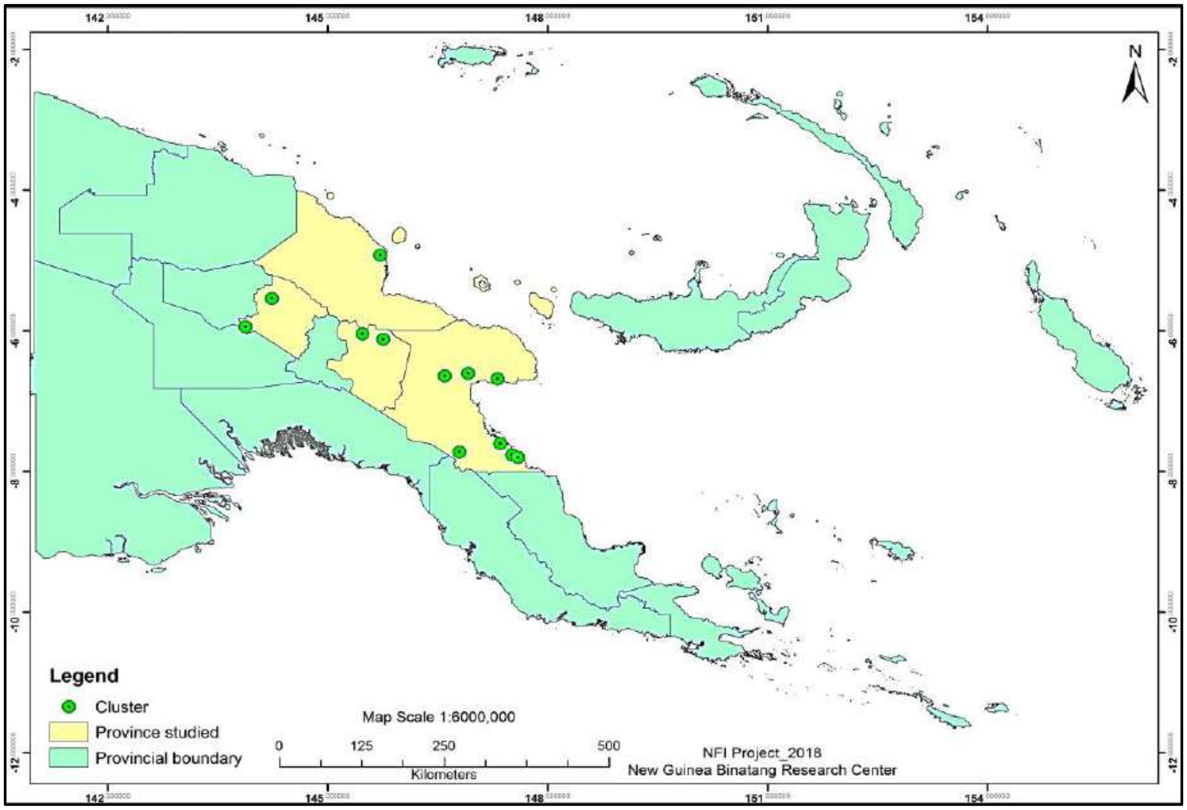

Figure 1 Map of the study area in Madang, Morobe, Eastern Highlands and Western Highlands Provinces with sampling sites indicated with green points

Plot Design and Sampling Approach

The main objective of sampling design was to reach a representative, consistent and realistic design for forest assessment and monitoring in PNG. The major forest types, namely low elevation forest on plains and fans, low elevation on upland and lower montane forest were further divided into disturbed and undisturbed forests. Disturbed forests include logged-over forests, forest recovering after slash and burn agriculture or major land slips areas adapting into mature primary forest. Undisturbed forests have only some small-scale natural disturbance such as tree gaps due to naturally falling trees. All the four plots were nested in circular shape and were surveyed starting from the central plot and onto the other three plots at 100m distance at 120^o angles. Trees with diameter at breast height (dbh), dbh $\geq$ 40cm were measured in the plot radius of 25m, trees with dbh $\geq$ 20cm in the radius of 15m, trees with dbh $\geq$ 10cm in the radius of 10m, and trees with dbh $\geq$ 1cm in the radius of 1m. The dbh measurements and mapping trees in plots is the standardized method used in many botanical research protocols for plant survey and wood biomass calculation (Gentry 1988, Laurance et al. 1997, Wang, 2006).

On the forest floor, the centre radius plot was divided into eight segments to ease the sampling of fern in the plot. This method was replicated in all the 11 plots. Most studies on ferns are done using transect plots and square plots to estimate their abundance and species richness (Kessler, Salazar, Homeier, & Kluge, 2014). Here, we have used circular plots with 10m radius to sample fern species where all terrestrial and epiphytic fern species were sampled from the ground to 10m height, surveying understorey vegetation as well as tree trunks. Ferns were treated and assessed similar to other herbaceous plant species using the standard national forest inventory protocol. All the ferns were collected together with other plants. This protocol was replicated in one plot per site, across all 11 study sites. Fern specimens were preserved in ethanol and taken to Herbarium at National Forest

Research Institute in Lae, Morobe Province. Most ferns were identified to genus level and then to numbered morphospecies since the taxonomic knowledge of ferns in PNG remains limited and the fern herbarium reference collection does not represent well the ferns flora throughout PNG.

Data Analysis

Regression analysis was used to test the relationships between species richness and elevation. Paired *t-test* was used to test the difference between ferns sampled occurring at different ecosystems from high and low elevation forest, ferns in disturbed and undisturbed forest types, species richness inhabiting epiphytic and terrestrial ferns. Jaccard similarity index was used to measure species turnover (beta diversity) among individual study sites. The multivariate analysis implemented by Canoco 5 software was used to test the response of fern species to elevation and disturbance.

The total species diversity was calculated by Chao 2 index based on the ratio of rare to common species in accumulation curves of species with increasing sampling effort across study sites. The species accumulation curves were constructed based on increasing forest area (i.e. number of sites studied) and increasing number of species records (i.e. a particular species recorded at a particular site), since the number of individuals was not recorded. The Estimate*S* software was used for calculations. The external environmental variables used in this study included forest disturbance and elevation.

RESULT

Species Diversity

The ferns were surveyed in plots at 11 sites within the PNG multipurpose national forest inventory. There were 76 fern species from 36 genera and 19 families recorded. Of these, 52 species were terrestrial and 24 species were epiphytes. Five plots were regarded as high elevation forests at >1000 m a.s.l whereas six plots were categorised as low elevation forests below 1,000 m a.s.l. The three highest elevations also showed the highest species diversity of ferns (Fig. 2 left). The fern species diversity ranged from 3 to 32 species per site for sites ranging from 70 to 2728 m a.s.l., and it was significantly correlated with elevation (r=0.6884, P<0.05). Fig. 2 right).

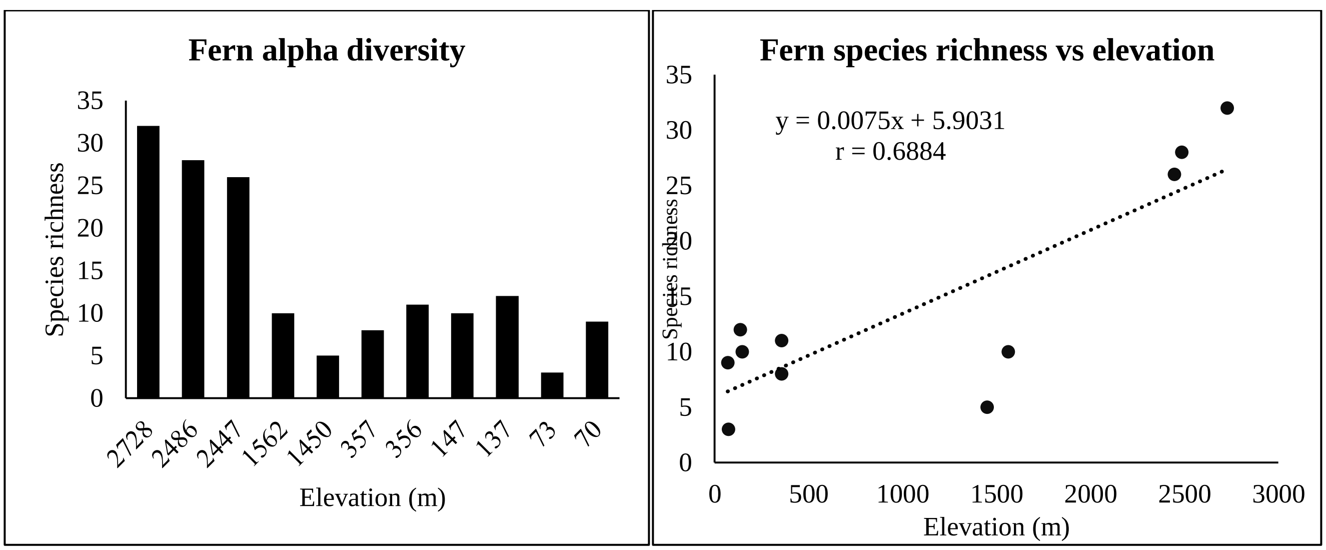

Figure 2 (left) *S*pecies richness of ferns at individual study sites, and **Figure 2** (right) positive correlation between elevation and species richness of ferns graph where the fern species increases with elevation. (r=0.688, P<0.05).

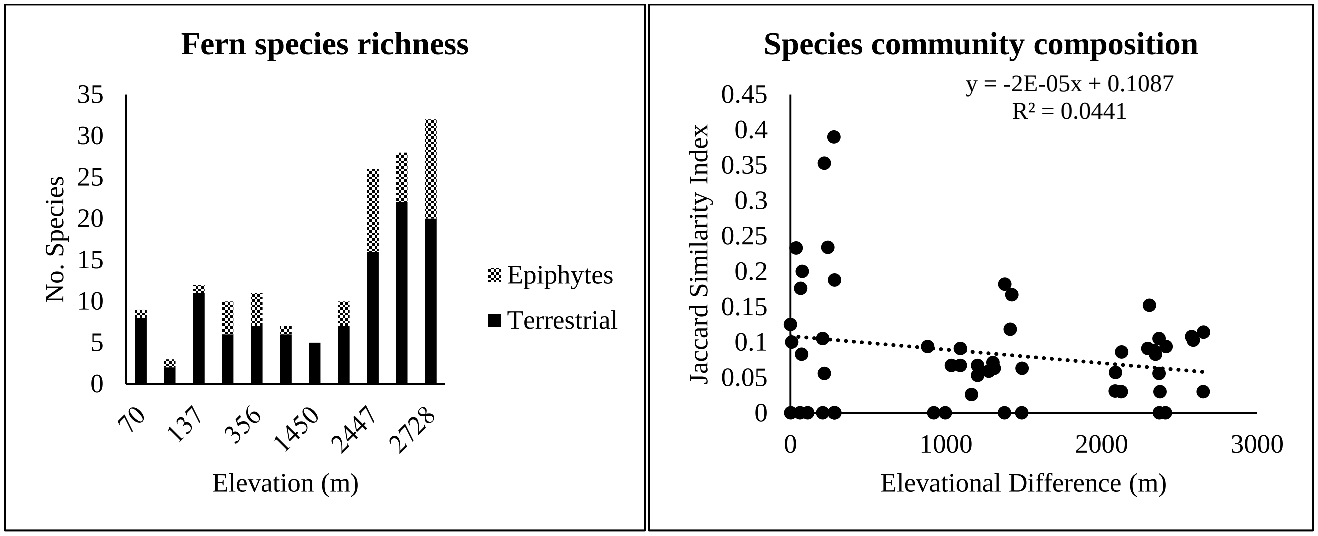

Figure 3 (Left) Species richness of terrestrial and epiphytic ferns and Figure 3 **(Right)** Fern community similarity (Jaccard index) declines with the difference in elevation between the compared fern communities.

Both the epiphytic and terrestrial fern species shows an increase in species richness from low to high elevational forest plots (Fig. 3 left). The species richness of terrestrial ferns is significantly higher than the richness of epiphytic ferns (paired t test, t = 4.8028, P<0.001).

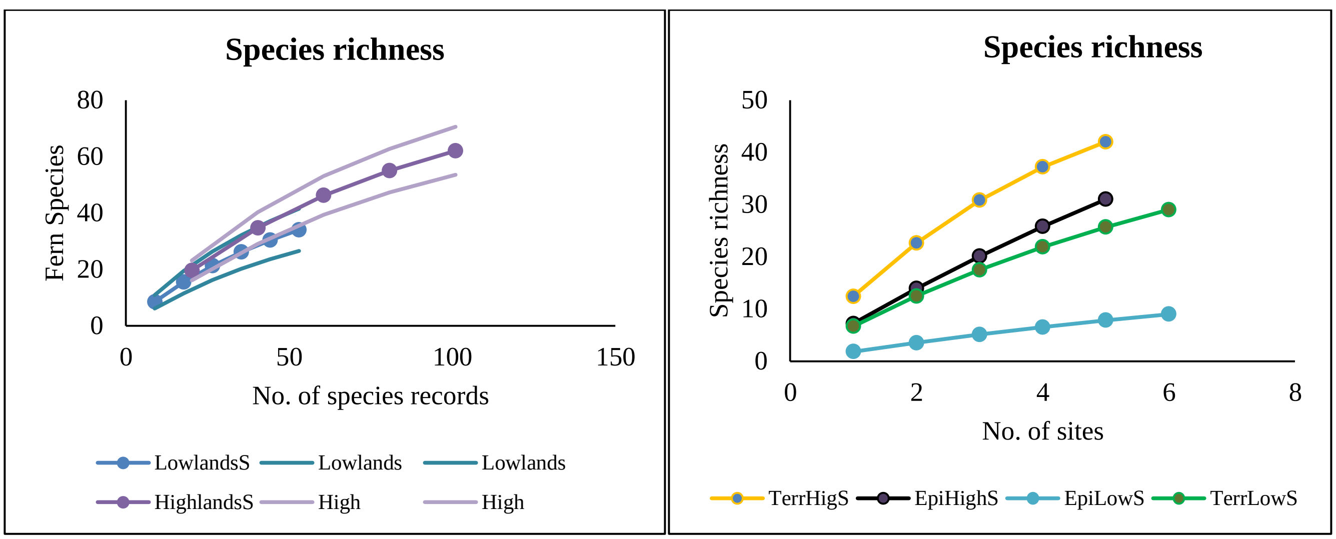

Figure 4 (Left) Species accumulation (with 95% confidence intervals) with increasing number of individuals for lowland and highland ferns communities. **Figure 4** (Right**)** Species accumulation with increasing number of study sites for lowland and highland ferns from terrestrial and epiphytic life forms with the forest area (number of sites).

Based on the Jaccard similarity index (Fig. 4 left), two fern communities from similar elevation share between 0 and 40% of species, and there is a significant (Mantel test, P<0.01) but slow decrease in community similarity with increasing elevation difference towards communities separated by >2000m a.s.l. Lowland species diversity standardized per number of species records was only slightly, and not significantly, lower than that for highland fern communities (Fig. 4 right). The lack of difference was caused by the fact that ferns are both less diverse and abundant in lowland forests. When the species accumulation curve is expressed per forest area, i.e. the number of study sites sampled, the higher species diversity of high and lowland fern communities becomes obvious (Fig. 4 right).

The terrestrial and epiphytic ferns have equal species diversity per number of species records (Fig. 4 right). The comparison of species richness for terrestrial and epiphytic ferns in lowland and highland forests shows the lowest diversity of epiphytes in the lowlands, followed by lowland terrestrial, highland epiphytic and finally highland terrestrial ferns, when expressed per forest area (Fig. 4 right). Species diversity, measured using Shannon and Simpson indices, shows slowing rate of increase with increasing number of sites sampled (Fig.6). The number of observed species continues to increase with increasing sampling effort, but the total number of species as estimated by Chao 1 (using the information on the number of total species, singletons and doubletons) is close to reaching an asymptote and points to only relatively small under-sampling in our system of study sites.

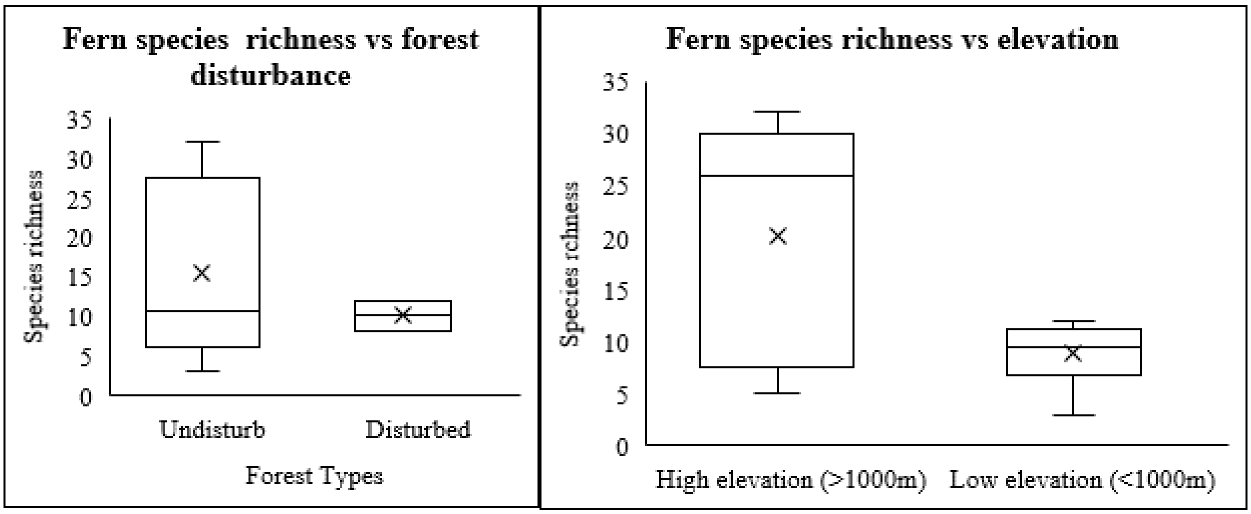

Figure 5 (left) Box & whisker plot showing species richness differences between disturbed and undisturbed forests (3 disturbed and 8 undisturbed forest sites**). Figure 5** (Right) Box & whisker plot showing species richness differences between low elevation (<1000m) and high elevation (>1000m) forests.

There was a significant difference between disturbed and undisturbed forest in the number of fern species (t-test, P <0.001) with disturbed forests having higher fern diversity (Fig. 5 left). The differences in species richness of ferns were also clear when comparing montane high elevation (>1000m a.s.l) and low elevation (<1000m a.s.l) forests (Fig. 5 right, t-test, P<0.05). The elevation range of fern species was narrow in most species, with approximately half of species found only at a single elevation (i.e. single site). This may be underestimation as many rare species could have been under sampled. However, interestingly, 13 species had extremely wide ranges >2000 m a.s.l. (Fig. 14), explaining thus non-zero overlap in species composition between fern communities from very distant elevations (Fig. 5). The wide elevation ranges were observed for both epiphyte and terrestrial ferns (Fig. 6).

The species composition of samples responded to forest elevation and disturbance, as shown in the direct ordination diagrams (Fig. 6). As expected from species diversity data, most of the species have high elevation distribution optimum.

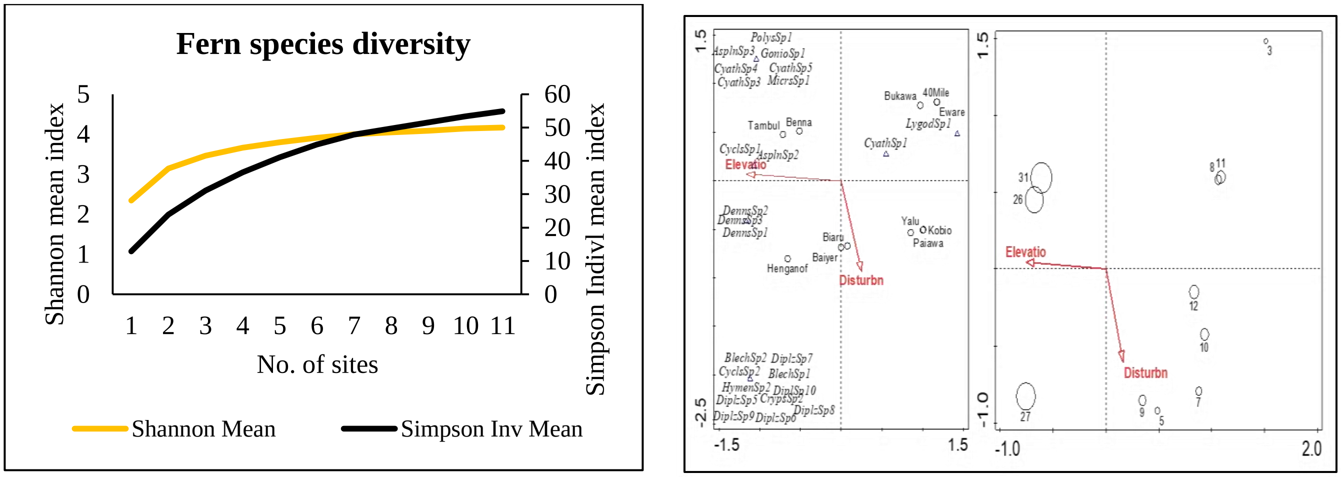

Figure 6 (left) The trends in Shannon and inverse Simpson diversity indices with increasing number of studied sites, based on species records. **Figure 6 (**right) the canonical correspondence analysis (CCA), a direct ordination method, showing species (left) and sample site (right) distribution in response to forest disturbance and elevation. The size of bubbles (right) correspond to species richness per site. The effect of variables on species composition is significant (P <0.05, Monte Carlo analysis).

DISCUSSION

The present study captured only a small proportion of the estimated 1,300 species of ferns in New Guinea (Hassler 2018). Not surprisingly, the national forest inventory sampling, optimized for the surveys of trees, has not provided complete sample of local fern diversity, as also shown by the Chao estimates. Further, 11 study sites are insufficient coverage for regional diversity estimates. Despite incomplete sampling, the study documented interesting ecological trends. The present study also indicates the potential of ferns as a focal taxon for the study of the impacts of climate change. We have documented several fern species with extremely wide distribution along elevational gradient. These species could serve as models to observe how the herbivore and other dependent species change along the elevational gradient in response to climate. Further, ferns are distributed along the entire studied gradient from 70 to 2700m a.s.l, but many species have relatively narrow distribution. These species could be observed and their elevational shifts in response to climate examined.

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Herbaceous Cover and Composition on Different Forest Types of Papua New Guinea

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Abstract

A total of 51 forest plots representing different forest types across Papua New Guinea were assessed using circular nested plots. Herbaceous total cover, total number of individuals of each species and number of species were recorded. The analysis included herbaceous species richness, diversity and composition. Results from Generalized linear models (GLM) revealed that relative elevation, had no significant influence on herbaceous species diversity amongst all the plots while displaying a similarity in diversity trends along the elevation gradient from the different forest types. Although, some of the plots are impacted by logging and forest canopies are severely damaged, results prove that damages to forest canopy does not affect the herbaceous cover. However, result from relative canopy cover analysis which was considered here as an environmental predictor to terrestrial herbaceous diversity presented a significant value of $p= 0.01$. Thus, the species richness of most the plots was significantly proportional to increase with relative cover from the different forest types signifying the importance of tree canopy cover having on the terrestrial herbaceous plant species within the different forest types. Furthermore, Non-Metric Multidimensional Scaling (NMDS) ordination method using Bray-Curtis index of species composition indicated that species composition amongst the plots in the logged and unlogged primary forest are homogenous with the presence of dominant herbaceous species like *Elatostema beccarii, Elatostema latifolium, Glechnia sp, Hydirastele costata,* are evident.

Introduction

Tropical forest hosts the world's species richest plant communities from different forest ecosystems. Herbaceous plant communities apart from trees contribute significantly to plant biodiversity and generally, it is believed that ground herbaceous plants contribute little to the total richness of the rainforest (Hartshorn, 1983). Besides, herbaceous plants are known to represent 8 to 29% of total plant species richness in moist to wet forests, 53% in dry forests and up to 6% in forests on white sandy soils (Hall and Swaine, 1976). Even with this scarce body of information, it is clear that the ground herbs are a rich group, comprising 14 to 40% of the species found in total species counts in tropical forests (Costa, 2004). Similarly, it was accepted that herbaceous plants are important component of total plant species richness in tropical forests (Sukri, 2014) and ecological studies along altitudinal zonation on South East Asian Mountains have concentrated on trees at the expense of herbs even though they may be a major component of the biodiversity of these forests (reviewed Whitmore, 1984).

However, in Papua New Guinea (PNG), there is very slim information available on herbaceous plant communities. Generally, most studies conducted towards plant diversity in PNG are more concentrated on tree species (Katovai et al., 2015, Gebia, 2001, Marsden and Pilgrim, 2003, Fibich et al., 2016, Whitfeld et al., 2014, Paul, 2011, Kiapranis, 1992, Testolin et al., 2016, Yosi et al., 2011, Wright et al., 1997, Inaho, 2012). Although there are descriptive information on herbaceous communities in the tropics (Poulsen and Balslev, 1991, Poulsen, 1994) and New Guinea (Paijman, 1976, Paijmans, 1982), this assertion is weak and the notion leaves a greater knowledge gap on herbaceous plants in PNG.

With the lack of statistically proven data on herbaceous plant richness, abundance and composition, this unique diversity rich group is now being threatened by disturbances resulting from logging impacts in PNG. Studies have indicated that herbaceous species richness was lower in logged forest, with several rarer species recorded in unlogged forest absent from logged forest (Cleary, 2017). Similar study by Brown and Gurevitch (2004) in tropical Madagascar also showed that even after 150 years of forest recovery, invasive plant species have prevented native herbaceous species to be established thus altering composition and structure while anthropogenic disturbances like logging has encouraged invasion of non-native species encroaching into dominance and affecting recovery of native species diversity.

Nonetheless, studies stated otherwise that there was no loss of native forest herb species from the logged plots and logging did not result in a significant change in the herb community composition at the scale of 4-ha plots (Costa and Magnusson, 2002) while others concluded that low to medium harvesting intensity used in logging may be an appropriate approach to retain biodiversity (Behjou and Mollabashi, 2016). Costa and Magnusson (2002) also proved in their study in Manaus, Brazil that overall, their results indicate that the ground herb community is not severely affected by selective logging at the intensities used in their experiment,

Essentially, the diversity disturbance imbalance needs more or further research to quantify the disturbance specifically into herbaceous plant species diversity and composition. Therefore, the first multipurpose National Forest Inventory project in PNG has provided the opportunity to capture a vast array of data from the different forest types across PNG on trees for Above Ground Biomass and Carbon calculation, Tree diversity and Non-Tree Plant Diversity (NTPD) as biodiversity indicator and it is where most of the herbaceous data have been extracted and used in this research study.

Significantly, this research expectation may increase the knowledge into logging disturbances and is necessary to determine levels of log extraction compatible with multiple uses of forests (Costa and Magnusson, 2002), while limiting damages to retained trees, soil and regeneration and trees in smaller classes of commercially important species that are more vital ineffective management and implementation of harvesting activities (Yosi et al., 2011).

Hence, the main objective now is to quantify the disturbance from logging activities in PNG backed up by scientific knowledge and understanding of the impacts affecting herbaceous cover, diversity, density and composition. Consequently, information about recovery time, impacts of different management practices, and logging intensities on non-commercial species are necessary to adjust the requirements of management plans for conservation purposes (Costa and Magnusson, 2002). More so, it would be very interesting to know the density, richness and composition of these unknown plant communities which are very vulnerable to disappear to deforestation and forest degradation caused by logging.

Study Site

The research study was carried out in 14 clusters located particularly in Eastern Highlands, Madang and West New Britain Provinces of Papua New Guinea (Table 1). A total of 51 forest plots were assessed representing Low Altitude Forest on Plains and Fans, Low Altitude Forest on Uplands, Lower Montane Forest and Montane Forest. The study sites were selected through a randomly stratified classification of the different forest types using remote sensing tools like Google Earth and Collect Earth. The randomly selected NFI clusters are part of the 1000 clusters distributed around PNG which the project is anticipating to assess.

Forest Type	Clusters	Plots	Province
Low Altitude Forest On Plains and Fans	52724	4	Madang
	55742	3	Madang
	62250	4	Madang
	65255	4	Madang
	67263	3	Madang
	67763	4	Madang
	68265	4	Madang
	70274	4	Madang
Low Altitude Forest On Uplands	57765	3	Madang
	70386	4	West New Britain
	71383	4	West New Britain
	72909	4	West New Britain
Lower Montane Forest	81299	4	Eastern Highlands
Montane Forest	82805	2	Eastern Highlands
Total	**51**		

Table 1 Showing Total Number of Study Sites

Data and Methodology

This study collected data from all measured NFI clusters around PNG. As such, the study integrated its data collection inform the NFI methodology (Kuroh et al., 2018) and the Non-tree Plant Diversity methodology (De Sanctis et al., 2016). NTPD is mainly collecting data on three biodiversity indicators which include structure-based indicators (stand and landscape-level features such as stand structural complexity, connectivity, heterogeneity), taxon-based indicators and indicators of functional diversity. However, this study focused more on sampling terrestrial or mostly ground herbaceous plant species across all different forest types as biodiversity indicator for lower plants stand structural based indicator as well as a taxon-based indicator.

Poulsen and Balslev (1991) descriptive definition of herbaceous plants will not be considered in this studybecause their study included those “obligate and facultative” terrestrial herbs which their roots may have some climbing part or epiphytic individuals. Rather, this study strictly collected herbaceous plants which have their rooting system impeded into the soil and those climbers, epiphytes, creepers were excluded. Thus, the study in-cooperated the definition by De Sanctis et al. (2016).

Furthermore, other terrestrial herbaceous plants which were particularly tall and covered most of the areas in the plot, for example, those in Araceae, Arecaceae, Zingiberagceae, and some tree ferns like *Cyathia sp* were categorized as giant terrestrial herbs. They were also sampled usingthe NTPD protocol for assessment. Voucher specimens were collected for some species but bigger specimens, photographs identification was used. Because of the limitation on NTPD data collected, the study obtained data from percentage cover, abundance from all terrestrial herbaceous plants and collections of all unidentified herbaceous species vouchers for taxon-based diversity.

Data

This studycollected data from both the disturbed and undisturbed forest from NFI clusters across different forest types in PNG. Data collection was based on the different types of disturbance regimes made particularly by man but more data from logging sites were used to compare cover, composition and diversity to the natural undisturbed primary forest (Cleary, 2017). Other field data sources like soil nutrients and chemical properties, canopy closures and mean elevation were also included.

Method

This study incorporated its methodology especially the plot design from the NFI Field Manual (Kuroh et al., 2018). Established plots are nested circular plots with sub-plots from 3-meter radius, 10-meter radius, 15-meter radius and 25-meter radius (Figure 1). The 10-meter radius sub-plot was used here as the main sample plot for data collection. Within the 10-meter radius sub-plot, all individual terrestrial herbaceous plant species were identified, visual estimation of its cover was recorded and abundances of individual species were counted and recorded. Data collection and assessment within all 10-meter sub-plots followed a directional bearing sequence starting from the North to East, East to South, South to West and West to North and was applied for all four plots in a cluster Figure 2, (De Sanctis et al., 2016).

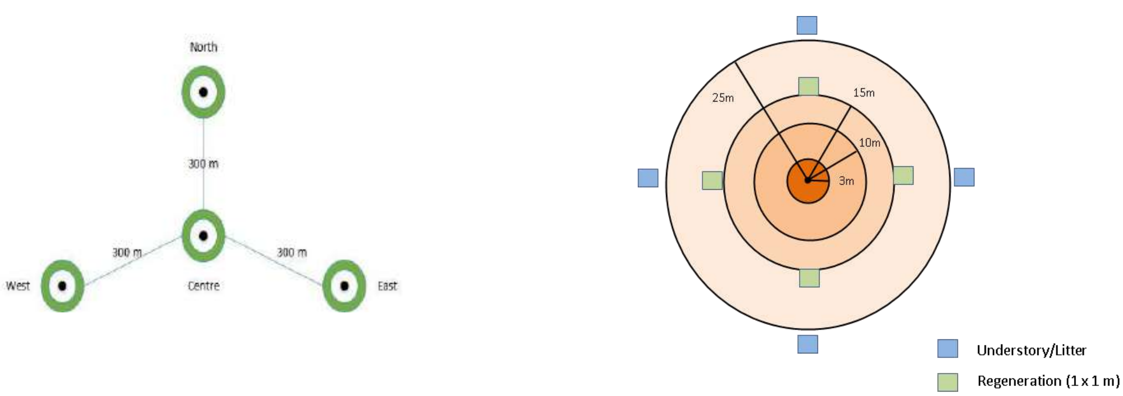

Figure 1: Plot Layout

Each of the plots within a cluster will be treated as individual plots having three nested sub-plots.

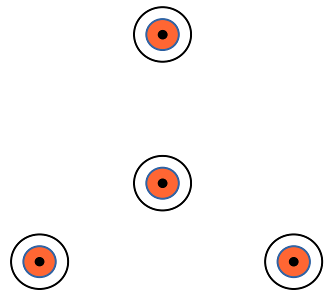

Figure 2: Assessment are located in all 10-meter radius of each Plot in the Cluster

Botanical Method

The collection techniques described by Womersley (1976) was used in this study. Hence, in the field, voucher specimens were collected, allocated with vouchers numbers, pressed and preserved with 75% Ethanol and taken to the PNG National Herbarium for laboratory identification. Most of the plant species names were confirmed using online plant databases search engine. For instance, the Plant List (www.thepalntlist.org), Global Plant on JSTOR (https://plants.jtor.org), Global Biodiversity Information Facility (http://www.gbif.org), ECAT Name Parser (http://tools.gbif.org/nameparser/parser.do), Taxonomic Name Resolution Service (http://tnrs.iplantcollaborative.org/index.html) and Global Names Resolver (http://resolver.globalnames.org).

Data Analysis

Essentially, the study used *R* for all data analysis. *R* has been used widely to generate results which are comparable to the different forest types, disturbed and undisturbed forest areas and correlating these results. The use of *R* software has made it possible to develop General Linear Models (GLM) models especially, calculating the species diversity using the commonly used Shannon–Weaver Diversity index (Shannon and Weaver, 1949), richness, evenness (Pielou, 1969) and rarefaction analysis based on individual species for this study.

Relative density

Relative density is the study of the numerical strength of a species in relation to the total number of individuals of all the species and can be calculated as:

$$\text{Relative density} = \frac{\text{Number of individual of the species}}{\text{Number of individuals of all the species}} \times 100$$

Relative frequency

The degree of dispersion of individual species in an area in relation to the number of all the species occurred.

$$\text{Relative frequency} = \frac{\text{Number of occurrence of the species}}{\text{Number of occurrence of all the species}} \times 100$$

Similarity and dissimilarity indices

Indices of similarity and dissimilarity were calculated by using formulae as per (Sorenson, 1948) as follows:

Index of similarity (S) = 2C/A+B

Where,

A = Number of species in the community A
B = Number of species in the community B
C = Number of common species in both the communities

Index of dissimilarity = 1-S

Species richness, diversity and dominance indices

The species richness of the vascular plants was calculated by using the method 'Margalef's index of richness' (Dmg) (Magurran, 1988),

$$Dmg = (S-1)/ \ln N$$

Where, S = Total number of species.
N = Total number of individuals.

Shannon's diversity index and Simpson's index of dominance will be calculated using the important value index (IVI) of species.

(a) Shannon–Weaver (Shannon and Weaver, 1949) index of diversity:
The formula for calculating the Shannon diversity index is:

$$H' = -\sum pi \ln pi$$

Where,

H' = Shannon index of diversity
pi = the proportion of the important value of the ith species (pi = ni / N, ni is the important value index of ith species and N is the important value index of all the species).

Multivariate Analysis

This study used ordination and clustering methods in its analysis. This analysis is essentially critical to predicting the relationship of each study sites and or habitats and their variables showing similarity and dissimilarity among plots. These methods searched for multivariate patterns datasets of communities, particularly relates the species to their environment, spatial relationship and species interaction. Data was analysed using *R* software.

Results

The results were mainly based on the preliminary data collected from 60 plots around Papua New Guinea. These data contain few herbaceous species which were already identified to species however, once all the herbaceous plant species are completely identified and data from new plots are added, the results are expected to be updated. Therefore, discussions were based on the species diversity and composition preliminary results from the different forest types.

Herbaceous Cover and Canopy Closure

The herbaceous cover was measured from 60 plots from Lowland Forest on Plains and Fans, Lowland Forest Uplands and Montane Forest were analysed using General Linear Model (GLM) to establish a correlation between the herbaceous species cover and canopy closure. It was anticipated at the beginning of this study that relative canopy closure within the 10-15m radius would affect the herbaceous cover layer however, GLM (Figure 3) displayed an insignificant p-value of 0.48. Although it was expected that herbaceous cover layers would be affected due the different disturbance impacts, across the different forest types, the model has predicted otherwise and even the logged forest plots were not affected and the relative canopy density has not altered the terrestrial herbaceous cover layer.

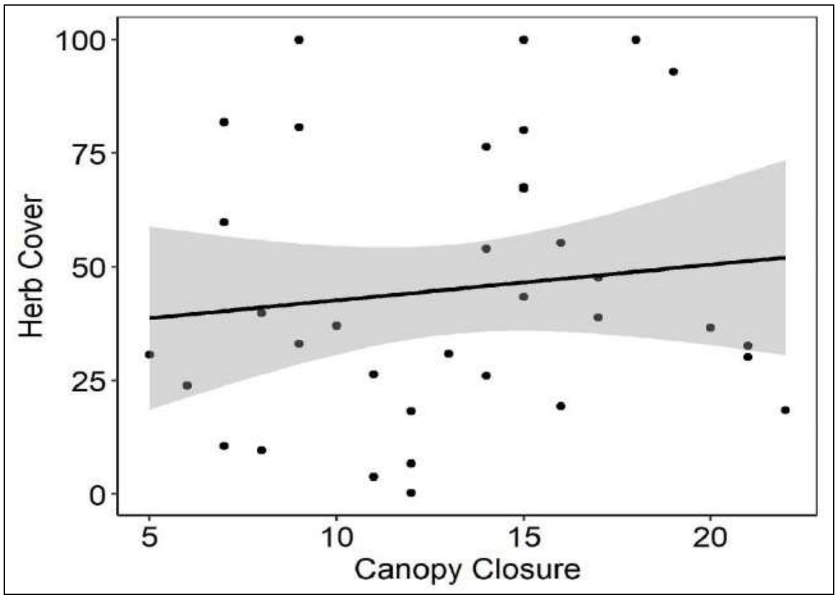

Figure 3: Showing Herbaceous Cover and Canopy Closure

Diversity and Canopy Closure

The GLM (Figure 4) showed a substantial result when correlating the effects of relative canopy cover with the herbaceous species diversity. The model predicted a significant *p*-value of 0.01 which is less than <0.05. The model now suggests that canopy closure across the different forest types plays a major role in determining herbaceous species diversity. Essentially, this models alludes that relative canopy closure from stands especially within the 10-15m radius plays a vital ecosystem function to maintain species diversity apart from other environmental variables, for instance, soil, mean annual rainfall, etc.

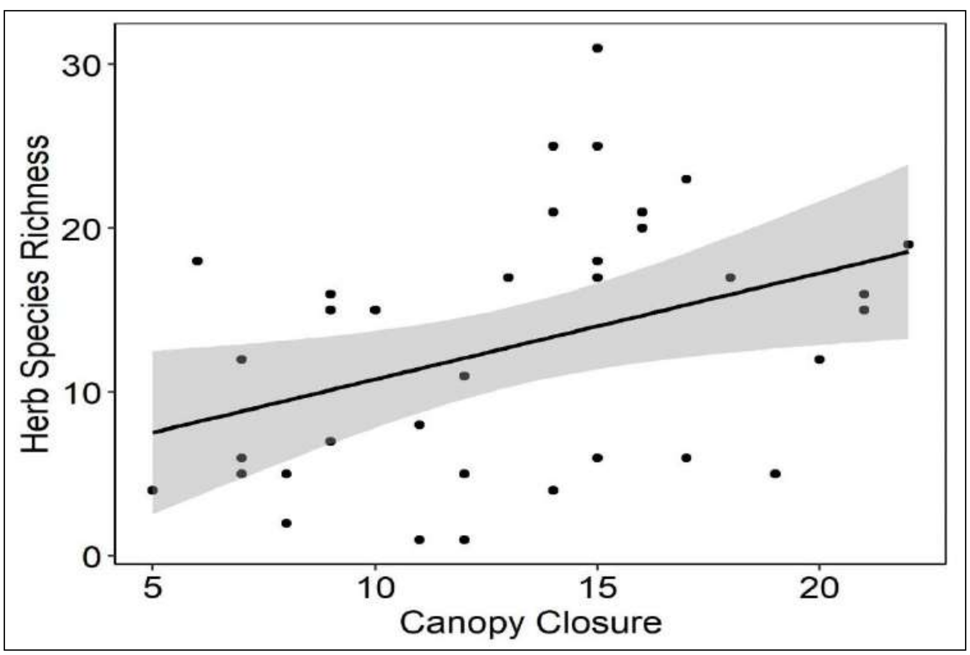

Figure 4: Showing Species Diversity and Canopy Cover

Diversity and Elevation Gradient

Furthermore, GLM (Figure 5) shows an insignificant *p*-value of 0.06 which is more than the expected *p*-value (0.05) when considering the mean elevation of the different forest types as a species richness indicator. Higher herbaceous species richness along an elevation gradient across the different forest types is less expected when moving from the lowlands to the highlands. However, the model also suggests that most plots detected between the mean elevation of 0-500m are found to be more species-rich. Although some of the lowland forest plots were disturbed and severely impacted from logging, herbaceous species richness showed a higher species richness trend within the Lowland Forest on Plains and Fans and Lowland Forest on Uplands.

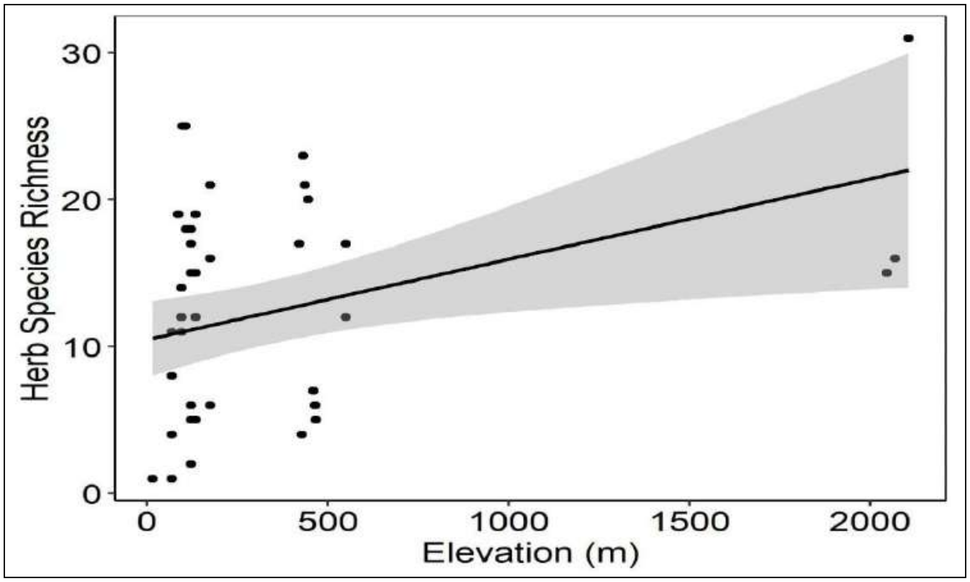

Figure 5: Species Diversity and Elevation

Species Area Curve

Species Area Curve (Figure 6) showed differences with herbaceous species diversity and the number of samples collected when comparing the disturbed logged forest and the undisturbed primary forest. Higher herbaceous plant diversity was expected in primary forest plots however, the rarefaction curve interestingly, indicated a significant change in the diversity of logged forest higher than the primary forest.

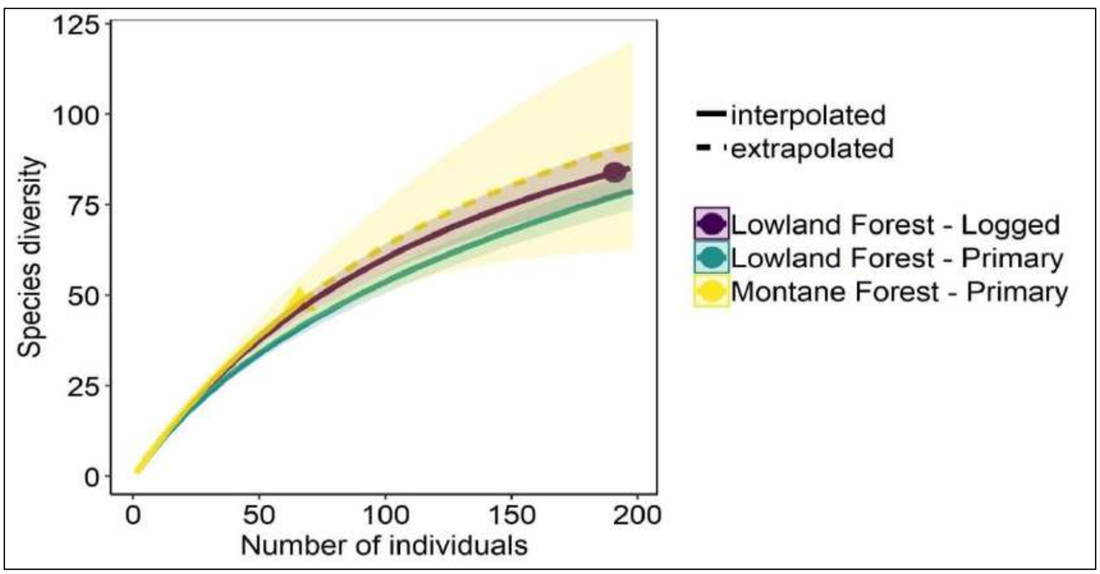

Figure 6: Species Area Curve

Herbaceous Species Composition

Analysis using the Non-Metric Multidimensional Scaling (NMDS) ordination method, based on Bray-Curtis index show similarity in species composition from logged and unlogged primary forest. Most of the plots showed a similar species composition regardless of being severely disturbed by logging even shifting from to higher elevation forest plots (Figure 7).

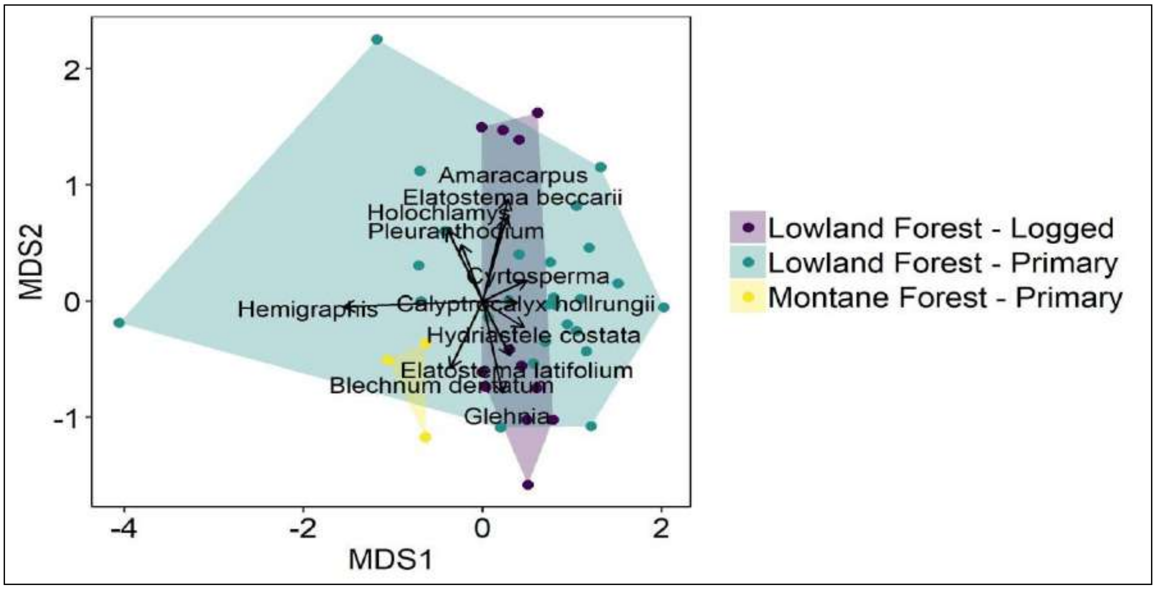

Figure 7: Herbaceous Species Composition

Discussion

The study attempted to quantify the terrestrial herbaceous plant species diversity and the cover of the different forest types furthermore comparing the herbaceous composition of the logged and unlogged primary forest. Studies have indicated that species diversity amongst the herbaceous communities is directly proportional to the increase in soil and precipitation increase (Gentry, 1988, Amani, 2018, Singh et al., 2017). A study by Gentry (1988) suggests otherwise stating that herbaceous species diversity varies at a different elevation. While these studies seemed inevitably with their results, the discussion from this study will be based on relative elevation and canopy cover and how they affect species diversity, cover and species composition in the different forest types of PNG.

Species Diversity Along Elevation Gradients

Preliminary results from this study show that relative elevation, had no significant influence on herbaceous species diversity amongst all the plots while displaying a similarity in diversity trends along the elevation gradient from the different forest types. Although as expected, species richness would alter from lower to a higher elevation, the result indicated otherwise that herbaceous species richness can be homogenous along elevation gradients.

Herbaceous Cover and Relative Canopy Cover

Forest canopy cover is an essential environmental variable playing a crucial role while influencing light and moisture availability to the seedlings and herbaceous layers under a closed forest (Anderson et al., 1969). While it was hypothesized that relative canopy cover from mostly larger stands within the plots would affect the herbaceous cover in different forest types, the results now reject the hypothesis based on the insignificant *p*-value of 0.48 and accept the null hypothesis that there is no relationship with relative canopy cover and herbaceous cover. Although, some of the plots are impacted by logging and forest canopies are severely damaged, results prove that damages to forest canopy do not affect the herbaceous cover.

Species Diversity and Relative Canopy Cover

While studies indicating forest soil, mean annual precipitation and shifting from lower to higher elevation shows great variability in terrestrial herbaceous diversity, however, analysis from this study shows that relative canopy cover which was considered here as an environmental predictor to terrestrial herbaceous diversity presented a significant value of $p= 0.01$. Thus, the species richness of most the plots was significantly proportional to increase with relative cover from the different forest types signifying the importance of tree canopy cover having on the terrestrial herbaceous plant species within the different forest types.

Species Area Curve

Analysis to determine species diversity with total number of species collected was compelling when logged and primary forest are compared. The increase in herbaceous species diversity seemed inevitably to respond to the disturbance initiated from logging. Significantly, disturbances from logging has inclined to increase species diversity with the total number of individuas collected in mostly the lowland forest where logging activities are more concentrated. Also, exprapolated species diversity trends in Montance forest are expected to increase with the total number of individuals enumerated however, more sampled plots are required to compare the richness from the different forest types.

Species Composition

The similarity using Bray-Curtis index of species composition suggests that species composition amongst the plots in the logged and unlogged primary forest are homogenous with the presence of dominant herbaceous species like *Elatostema beccarii*, *Elatostema latifolium, Glechnia sp, Hydirastele costata*, are evident. The preliminary results now support the notion by Costa and Magnusson (2002) that logging did not result in a significant change in the herb community composition. It is now obvious that the relative abundance of species is shared amongst the different forest types reflecting no variation in species presence within understory herbaceous community.

Conclusion

Analysis from the preliminary results shows that there is no significant correlation of herbaceous cover and canopy cover across all the measured forest plots. Similarly, there is no correlation between herbaceous species richness along the elevation gradient from all forest plots. Consequently, the results show a similarity of herbaceous species composition distributed along the elevation gradients and logged and primary forest plots. This now implies a homogenous species composition dominated by certain herbaceous species like *Elatostema*, *Hemigraphis, Hydriastele*, *Blechnum*, etc. Furthermore, results now ascertain that logged forest is more abundant and species-rich when compared to primary forest. However, this study has proven that canopy closure can influence herbaceous species richness and is considered as an essential environmental factor influencing species diversity.

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Biogeographical and Ecological Aspects of Syzygium Genus (Myrtaceae) in Papua New Guinea

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Abstract

Influence of the biogeographical and ecological aspects on the wider distribution of *Syzygium* genus in Papua New Guinea is yet to be understood. Analyzing the available data from the Lae Herbarium, the NFI plot data, the seedling and the wood density, we interpret the influence of the biogeographical and ecological aspects on the genus *Syzygium*.

The herbarium data/collections indicate the presence of *Syzygium* at all elevation zones. However, the Chao-Jaccard similarity index shows that the composition vary between lower and higher elevations. *Syzygium s*pecies composition at 100m elevation zones decreases with increasing elevation difference. Digitalizing and Geo Referencing analyses for species preference in relation to the climatic conditions indicate that many of the species in the genus prefer areas with low temperatures and less rainfall conditions.

1. Introduction

Syzygium is a tree genus in the family Myrtaceae and is known to be one of the tree genera that have greater number species globally having between 500 and 1000 species. The genus was rated 16th out of the 57 mega-diverse genera with >500 species (Frodin 2004).The global distribution of the genus extends from the African continent and through Malaysia, Australia and the Pacific. In Papua New Guinea it widely distributed from the lowlands at sea level to the higher elevations up to 3000 m above sea level.

The genus is a predominant rainforest trees occupying much of the humid Old World tropics and subtropics, Australian and South Pacific. Taxonomically, it is known to have more vexing problems that continues to create unsettled situations in terms of specific species identifications. It is characterized by an opposite leaf arrangement, and leaf blades have distinct intra marginal venation and oily dots. Flowers have numerous stamens and the calyx often fused to form a calyptra. Ovary are ± inferior, 2-locular (rarely 3) with several ovules on an axile placenta. Style is about as long as or slightly exceeding the stamens, and the stigma is small. The fleshy fruit (recalcitrant) is usually one seeded, but it can be rarely 2-5 per fruit according to Hyland (1983). Pericarp is usually thick and fleshy sometimes spongy, leathery or brittle. The different species included in *Syzygium* reach maturity at different growth sizes. In the framework of this research we can mention, at the extremes, flowering trees of *Syzygium iteophyllum* 2 m tall with 3 cm of dbh, while the largest trees reach more than 60 cm dbh and 40 m tall.

In Malaysia particularly in Papua New Guinea, the genus is commonly encountered almost everywhere and discoveries of new species or new records are always possible. The Lae National Herbarium in PNG records 145 species. However, this number continues to increase as new species are discovered. A recent manuscript on Papuasian *Syzygium* by Craven and Damas 2010 (unpublished) included work on 40 species, 28 of which are new to science.

1.1 Economic Importance

In PNG logging is one of the major renewable resources that continue to generate several millions of kina (K1.3 billion) each year (PNG National newspaper *https://www.thenational.com.pg/forestry-encouraged-to-come-up-with-a-plan/*). Hammermaster & Saunders (1995) reported that several species of *Syzygium* were among the 10 most common species harvested.

1.2 Problem Statement

The knowledge of the genus is limited and the foresters and the loggers continue to group different *Syzygium* species they logged under a single name, more often just under a generic trade name "*water gum*". The monetary values of timbers do depend on the wood qualities in different genera and their respective species. There may be a certain species of *Syzygium* that has the best wood qualities that can fetch a good monetary value but this is overlooked since all species are lumped under a common name "*water gum*"

The specific objective of this research is to establish base line information on the diversity and composition of the genus in various bio geographical regions and in relationship to various ecological parameters: forest structure and disturbance level, soil type, and elevation in Papua New Guinea. This should give us some understanding on why this genus is widely distributed throughout Papua New Guinea. The seedling and regeneration assessment was also carried out on some species to find out if the genus' wide spread habit was due to its capability to regenerate successfully.

2. Materials and Methods

The data for this study have been obtained from two major components, herbarium and the NFI data sets. The other two minor components included seedling and regeneration study and wood density The NFI plots were the circular plots of 25 m radius and were divided into a 3 m radius from the centre then to 10 m, 15 m and 25 m. The protocols required assessment of trees sizes ranging from ≥1 cm dbh above to be assessed within 3 m radius, ≥ 10 cm within 10 m radius, ≥ 20 cm within 15m and ≥40 cm within 25 m radius. All *Syzygiums* assessed and recorded within those plots were captured in this study. The total number of plots assessed was 32 comprised of 16 from the lowlands and 16 from the highlands.

The herbarium component involved extractions of data from PNG Plants database that holds more than 2000 records. The specific data collected from each specimens included altitude, species, collection date, precise locality, altitude, latitude longitude, habit and habitat. The seedling component data total of 20 mother trees comprising of 9 species were assessed outside NFI plots. The protocols for seedlings included establishment of series of plots (2 x 2m, 2 x 3m and 3 x 4m) along 10 m strips established in all four different directions (North, South, East and West) under a mature *Syzygium* tree. The seedling of *Syzygium* and all other tree species with dbh ≤ 1 cm were assessed and recorded. Samples of unknown species were taken to the herbarium and were identified.

The samples for wood density data was collected from trees assessed for the seedling component. Several samples (5 – 10) approximately 10 mm by 10 cm were collected for each species. These samples were taken to the laboratory and the outer bark was removed from all the samples. Then a sample of 10 mm x 10 cm was selected and cut into 3 equal pieces then split into two halves and the pith were removed. These were then weighed to get their wet weight then were placed in the oven to dry for 48 hours. The sample was reweighed after 24 hours to see if there was some loss of weight. The samples were re weighed after 48 hours and the readings were compared with the weights taken at 24 hours. If the weight readings were consistent with the readings at 24 hours, the sample has reached the zero moisture content level and they are now ready for analysis.

3. Study Area

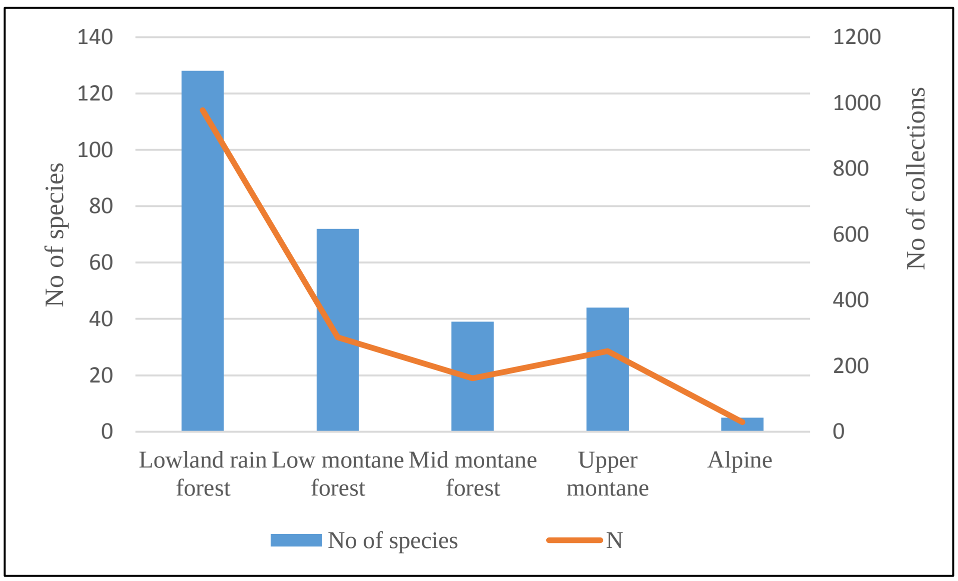
The herbarium component of the study was carried out in the Lae National Herbarium in Lae using the herbarium collections. The NFI data for this study was collected from the Morobe province and Highlands's province (Eastern Highlands and Western Highlands) clusters. The seedlings and some wood sample data was collected from Wanang Conservation in the Madang province while some of the wood sample data came from the trees assessed in the NFI plots.

4. Results and Discussions

4.1 Herbarium Data Analysis

The result from 32 NFI (16 lowlands and 16 montane forests) plots assessed and the species richness test carried out by clusters, regions, ecological zones and forest types all indicated lower highly insignificant. Likewise the wood density analysis performed using 20 samples comprised of 9 known species also indicated low correlation when comparing wood density against elevation. This could be due to less number of samples collected and from where the samples were collected from. In this case, all the samples were collected from the lowlands. The Herbarium data confirmed the presence of the genus in all ecological zones and geographically the genus was present in all the provinces of Papua New Guinea. It was also noted that the number of species collected at the lowlands was higher than the number of samples collected at the higher elevations (Figure 1).

Figure 1. Lae herbarium *Syzygium* collection records



The Chao-Jaccard similarity (Figure 2.) between *Syzygium* species composition within 100m elevation zones decreased with increasing elevation difference. Example the species composition between 1500 m and 3000 m elevation were not common. The species accumulation curve in figure 3 indicates that more species are expected when more collections are made.

Figure 2. Chao-Jaccard similarity between *Syzygium s*pecies composition within 100m elevation zones related to the elevational distance between these zones.

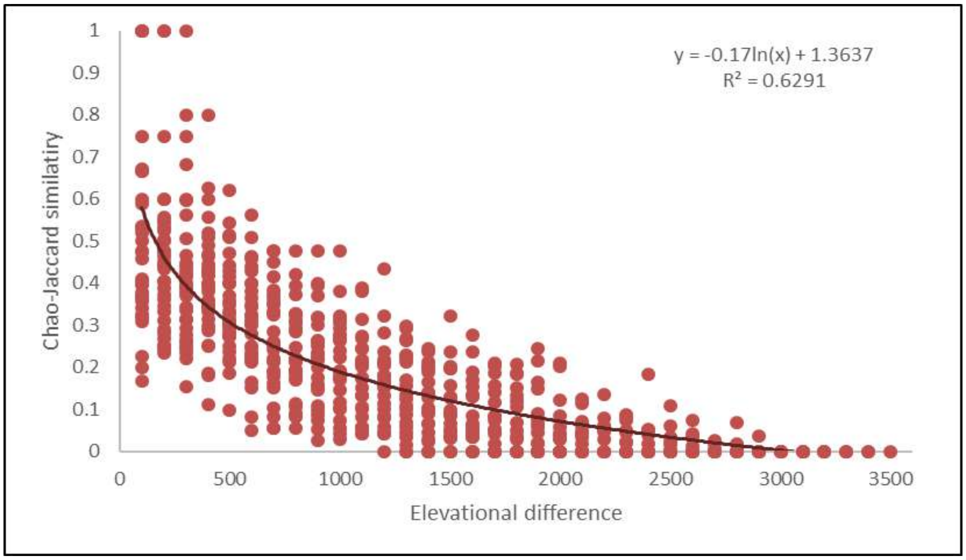
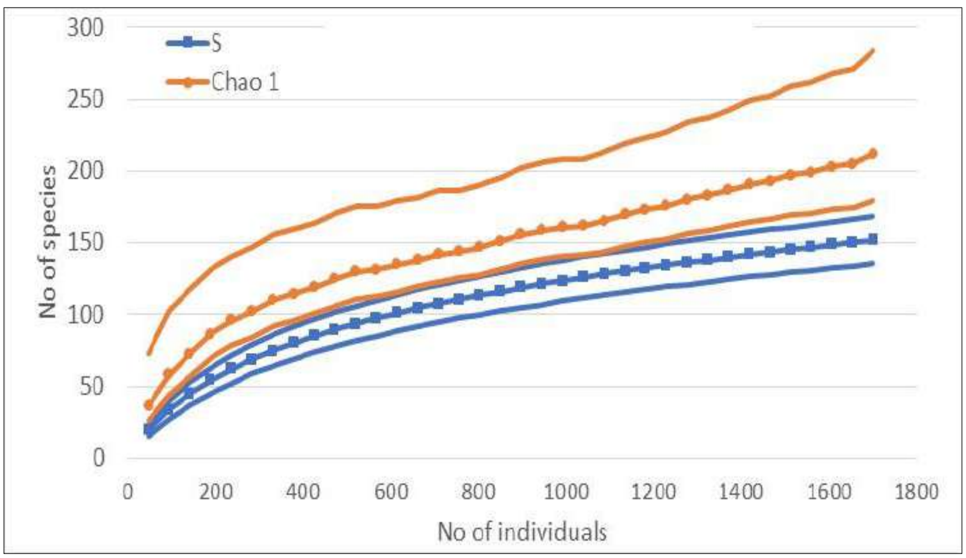


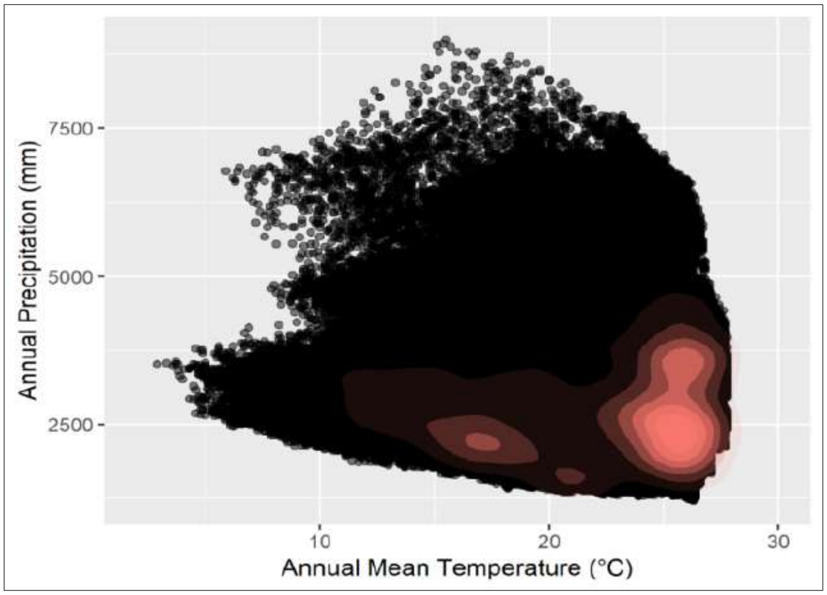
Figure 3. Species accumulation curve with increasing number of herbarium specimens



4.2 Digitalizing and Geo Referencing

When looking at the environmental space of Papua New Guinea represented here by temperature and elevation, the niche preferences by the *Sygyzium* spp. emerged (Fig. 4), pointing to optimum low rainfall and high mean temperatures.

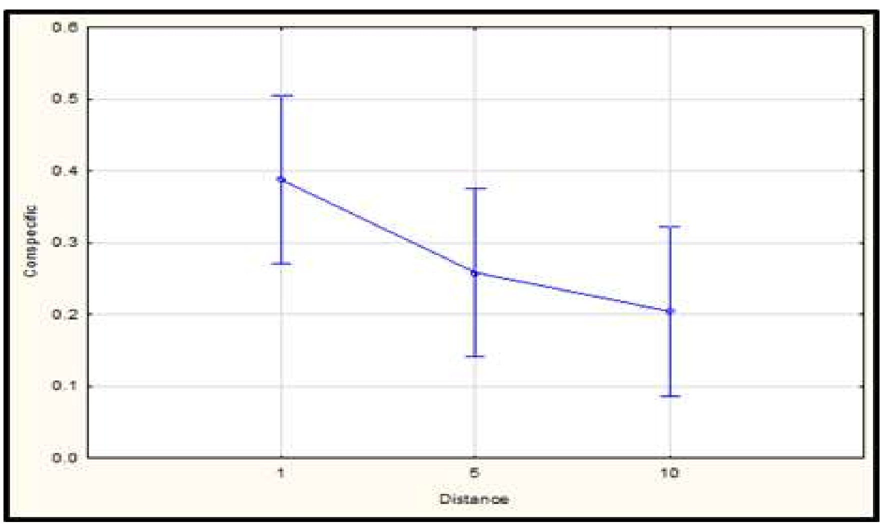
Figure 4. Bidimensional kernel density plots of Papua New Guinea (black) and *Syzygium* sp. (red).



4.3 Seedling Community Analysis

The data on seedling plots also allowed the analysis of general seedling communities (excluding conspecific seedlings from the mother tree), although somewhat biased by the fact that we only placed the plots under *Syzygium* mother trees.

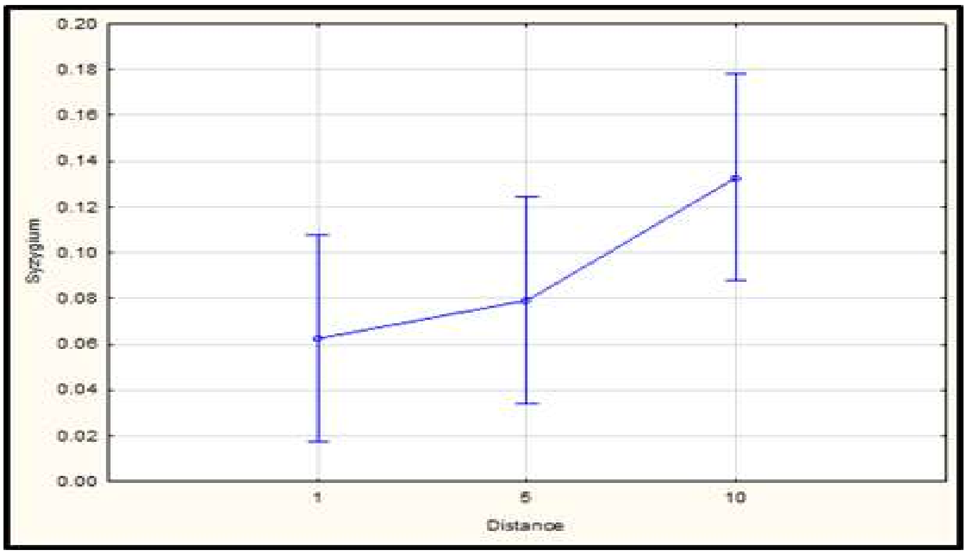
Figure 5. Density of conspecific seedlings with increasing distance from the mother tree (GLM analysis, $P<0.05$, mother tree species as random factor).



The general objective of this research was to understand the distribution pattern of *Syzygium* in the Myrtaceae family in Papua New Guinea and answer question of why the genus is widely distributed throughout PNG. Is the distribution of that measure influenced by some ecological attributes, namely altitude, forest types, soil types, temperature, precipitation etc.?

To understand the genus and to achieve my objectives relating to the questions above, I collated the taxonomical, distributional and ecological knowledge of the genus by integrating the Lae Herbarium records with data from Permanent Sample Plots and plots from the National Forest Inventory conducted within the framework of the UNREDD+ initiative. Other literatures were also sought for information on the vast distribution habit of the genus. One such literature sought was Hammermaster & Saunders (1995) compilation of Provincial reports of National Forest Authority inventory and log harvest data. The genus (*Syzygium*) is recorded as one of those major top ten tree species harvested from various forest types throughout Papua New Guinea. The unpublished data from Permanent Sample Plots (PSP) data established by PNG Forest Research Institute throughout PNG also recorded *Syzygium* as one of those ten most important tree species in almost all the plots established

Figure 6. Density of *Syzygium* seedlings other than conspecifics with increasing distance from the mother tree (GLM analysis, P<0.05, mother tree species as random factor).



4.4 NFI Plot Analysis

The NFI plot analysis documented different *Syzygium* abundance among individual clusters, but failed to explain it by the effects of elevation or ecological zone. These results thus demonstrate difficulties in genus-oriented analyses in limited data sets that are designed for the assessment of the entire vegetation, rather than single genus. The NFI protocol was designed for the analysis of the whole vegetation and since it wanted to maximize the number of study sites, the sampling effort at each individual site was kept relatively low and therefore feasible to complete over short period of time

4.5 Herbarium Data Analysis

The herbarium data proved to be quite informative for testing several ecological patterns. The historical analysis of the specimens' accumulation showed that we have not reached historical colonial-time sampling rates, presenting thus challenge to modern botany to improve the collection rate for better knowledge of PNG flora. Fortunately, this is likely to happen with the NFI project that is ongoing and therefore not included in this analysis. The intensity of sampling, measured by the number of herbarium specimens per species, was surprisingly even across all altitudes, making the observed species diversity patterns comparable along altitudinal gradient, except for the 0-100 m altitude that was sampled much more intensely than the rest.

The analysis of herbarium specimens showed key importance of mainland New Guinea area for the diversity of *Syzygium*, as only a minority of species were shared with, or endemic to, the Islands region. Further, the endemism was high also in the Islands region, as only six species (15%) were shared with the mainland. This can be expected considering that the New Britain and New Ireland Islands are relatively large so that they can develop their own endemic flora, and also have never been connected with the New Guinea island by a land bridge that would have facilitated dispersal of *Syzygium*.

The altitude has proved to be the key environmental variable that determined the species composition as well as the species diversity of *Syzygium* species. The highest number of species was recorded in the lowlands, with monotonous decline with elevation. This can be explained by favorable climatic conditions in the lowlands as well as the large land area, particularly within 0-100m altitude. Other large genera of woody plants in PNG, such as *Ficus, Psychotria* and *Macaranga*, all display similar maximum of species diversity in the lowlands. However, in contrast to *Syzygium*, their elevation range tends to be more restricted. For instance, there are no *Ficus* species above 2700 m asl in PNG.

A large diversity of a plant genus along elevational gradient can be achieved in two ways: either by rapid species turnover with elevation, where most species have narrow altitudinal ranges, or by a very large diversity reached at a particular elevation. Our analysis of altitudinal ranges show that the latter option was the case, as most of the *Syzygium* species has at least part of their distribution in the lowlands, below 200 m asl. For instance, this was the case for 61 of the 67 species that had at least 5 specimens per species in the collections. A large part of species turnover with elevation is generated by loss of these lowland species with increasing elevation, replaced only partially with a small pool of high elevation species. That is why we found decreasing geographic range size of *Syzygium* species with increasing elevation. An example of such lowland species is *S. corymbosum* (Figure 4.5).

The question of how many species of *Syzygium* are there in PNG, including yet undescribed species, is interesting but also hard to answer. Our Chao1 estimate is relatively optimistic, suggesting that we are missing only 50 species in the Lae Herbarium, but this estimate must be treated with caution as the Chao1 values themselves have not stabilized with the increasing number of individuals analyzed so that we can expect its value is an underestimate.

4.6 Seedling Data Analysis

We used General Linear Modelling (GLM) analysis with the mother tree species as random factor to assess the capacity of mother trees seedling to regenerate under it. It is assumed that a successful regeration will suggest that the species has fair chance of survival and that would link to its dispersal The expectation was twofold, the seedling density is expected to decreases with increasing distance from the mother tree due to dispersal limitation, as the most seeds are dispersed close to the mother tree. Alternately, Janzen-Connell hypothesis postulates that the mortality of seeds and seedlings increases close to the mother tree as the seeds and seedlings get increasingly infected by pathogenic fungi and colonized by herbivores from the mother tree (Comita et al. 2014). This process would lead to an increase in seedling density with distance from the mother tree.

The conspecific *Syzygium* species density decreased with distance from the mother trees, suggesting dispersal limitation being more important than Janzen-Connell effects. The density of allo-specific *Syzyzgium* showed an opposite trend, increasing with distance from the mother tree, probably in response to high density of conspecifics close to the mother tree.

Rather suprisingly, the density of all seedlings other than *Syzygium* decreased with the distance from the mother Syzygium tree so that the seeedlings had higher densitites at 1m than 10m from the mother tree The decrease in other species away from the *Syzygium* mother tree caused by several factors including natural gaps, topography of site where the mother tree was standing (Tree standing on the ridge) and the assessment plots were set upwards or downwards. Trees standing on the flood plane were also affected.

Other species besides other *Syzygium spp*. and the conspecifics were also assessed. This analysis can be considered biased since the plots were only set under the *Syzygium* tree species. Despite this a large number (219) of seedling species from adjacent trees were recorded under the *Syzygium* mother trees, a large fraction of the total 274 species represented by seedlings in the community as estimated by Chao1. This illustrates highly diverse mixed-species nature of seedling communities in the lowland rainforest understories, including below *Syzygium* species investigated here.

4.7 Geo Referencing

The analysis of herbarium specimens combined with country-wide data on climate available from remote sensing allowed the analysis of environmental preferences of *Syzygium* species. Our analysis demonstrated wide range of potential distribution of individual *Syzygium* species, from 3 to 77% of the PNG area being suitable for a particular species. Such analyses show great potential for the assessment of potential distribution as defined by climatic variables, but have to be verified by field sampling. This is particularly the case in PNG where dispersal limitation in combination with complicated geological history creates a uniquely complex environment for the distribution of species.

5. Conclusion

In summary, the study used extensive *Syzygium* collections in the PNG National Herbarium to extract interesting patterns of species distribution, including species diversity and species composition trends with altitude. There is an extensive species pool of lowland species that diminishes with increasing elevation, only partially replaced by much smaller pool of high altitude species. This process leads to monotonous decrease in species diversity with altitude, and also decreasing mean geographic range of species with altitude. The latitudinal pattern in *Syzygium* is similar to that found in other large tree genera including *Ficus*, *Psychotria* or *Macaranga*, but *Syzygium* is exceptional in the wide altitudinal range of its distribution.

The herbarium data are also highly useful in combination with remote sensing data on climate variables, and this study demonstrates how the two data sources can be combined into predictions of potential species ranges in PNG. These vary from very limited distribution in <5% of land area to widespread species found on 80% of land area. However, these predictions must be verified by field studies as they do not take into account complicated geological history and dispersal limitation of species. Finally, our herbarium data analysis indicated approximately 50 *Syzygium* species undescribed from PNG, but this may be an underestimate.

The local studies showed highly diverse seedling community developing under the canopy of *Syzygium* mother trees. Within *Syzygium*, the density of conspecific seedlings decreased and that of allo-specific seedlings increased with distance from the mother tree, demonstrating the importance of dispersal over the density-dependent effects of natural enemies postulated by the Janzen-Connell hypothesis.

The analysis of plots from NFI did not reveal any useful clues as to the *Syzygium* distribution as the data proved to be too limited for the analysis of a single genus. This is not surprising as the survey is designed for the analysis of entire vegetation rather than a single genus. In conclusion, this analysis points to further studies of *Syzygium* distribution, particularly in geographically complex regions poorly modelled by geo-referencing, and in connection with ecological factors such as elevation.

Acknowledgments

We would like to acknowledge the botany staff at PNG Forest Research Institute especially Mr. Dubie Damas for his effort in getting all the *Syzygium* specimens into the PNG Plants data base which made it easier for us to extract all the necessary information for this study. We also thank all NFI Botany component staff who willingly collected *Syzgium* specimens and the stems for wood density study during the NFI surveys. Our special thanks to the Binatang Research Centre (BRC) Staff and assistants at Wanang conservation area led by Mr. Albert Mansa for their tireless effort in collecting the seedling data.

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Trend in Wood Density Functional Trait Among Five Hyper-Diverse Mangrove Communities in Papua New Guinea

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Abstract

The study investigated the trends in wood density trait (P_{wood}, g.cm^{-3}) amongst five ecologically distinct mangrove communities in Papua New Guinea. In this research an investigation was carried out to determine, and communicate the variation in P_{wood} amongst ecologically distinct communities, taxa, tidal zonation, and ontogeny.

Wood density is a measure of the amount of cell wall substance per unit volume of wood. It is expressed in terms of mass over volume units (g. cm^{-3}, kg. m^{-3}) and is a key wood functional trait influencing tree rate of photosynthesis, carbon gain, hydraulic, growth rate, mechanical strength, and survival.

Mean wood density (P_{wood}, g.cm^{-3}) trait varied significantly among different mangrove communities ($Fs_{(4, 36)}$ = 21.849, P<0.001), species ($Fs_{(14, 36)}$ = 4.85, P<0.001) and tidal zones $Fs_{(1, 29)}$ = 68.29, P<0.001.

Wood density was positively correlated to tidal zonation and salinity gradient, i.e. P_{wood} increase with salinity gradient (R = 0.838, R^2 = 0.702, Adj R^2 = 0.692) conforming to a linear equation model `Y = 0.144X + 0.283'.

Mean wood density (P_{wood}, g.cm^{-3}) trait among different age groups (ontogenetic variation) was not significant ($Fs_{(2, 32)}$ = 0.261, P>0.05).

Key words; mangrove, wood density, functional trait, tidal zonation, ontogenetic variation

Introduction

Wood density (P_{wood}, g. cm^{-3}) trait defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume (wood specific gravity, or WSG) is increasingly appreciated as strong correlate of ecosystem productivity and carbon sequestration (Bouriaud *et al.* 2005, Donato *et al*. 2011, Walker *et al*. 2012, Chave *et al*. 2014, Yeboah *et al*. 2014, Pompa-Garcia & Venegas-Gonzallez 2016, Das *et al*. 2017). For example; P_{wood} traits is positively correlated to strength, safety, productivity, carbon stock, survival and negatively correlated to hydraulic conductivity, photosynthesis, and growth. (Kobe *et al*. 1995, Poorter and Bongers 2006, Brodribb *et al.* 2007, Feild and Balun 2007, Robert *et al*. 2009, Hudson *et al*. 2010, Poorter *et al*. 2010, Balun 2011, Donato *et al*. 2011, Siikamäki *et al*. 2012, Walker *et al*. 2012, Yeboah *et al*. 2014, Pompa-Garcia & Venegas-Gonzallez 2016, Das *et al*. 2017).

P_{wood} is a key variable in the assessment of forest biomass and carbon stock using the allometric equation (Walker *et al*. 2012, Chave *et al*.2005). Species specific P_{wood} data is highly preferable value under International Panel on Climate Change (IPCC 2006, 2007) for measurement of biomass and carbon stock on country level. The amount of biomass and carbon stock of a forest type is strongly correlated to the P_{wood} trait of trees (Mazda *et al.* 2006, Swenson & Enquist 2007, Mcleod *et al*. 2011, Walker *et al*. 2012, Benson *et al*. 2017).

The coupling effect of interaction of P_{wood} trait and the abiotic environment is recently viewed as a key driver shaping the tropical rainforest community structure and composition (McLeod *et al*. 2012, Moles *et al*. 2014, Ibanez *et al*. 2017). These few studies on interaction between P_{wood} trait and abiotic environment showed the coupling effect of mean annual precipitation (MAP) and mean annual temperature (MAT) has strong affinities on phylogenetic, community structure and composition. These studies argued that the interaction of MAP and MAT (i.e. aridity) is a conceptually and analytically superior abiotic axis for understanding community variation in wood density.

Forest biomass and carbon storage is considered to vary markedly between successional stages (Nyirambangutse *et al.* 2017), between geomorphological stages (Adame *et al.* 2015, along environmental gradient (Ibanez *et al*. 2017), and between communities (McLeod *et al*. 2011, Swenson & Zambrano 2017).

Mangroves also provide plethora of ecosystem services (Mazda *et al.* 2006) including their role in carbon sequestration (Mcleod *et al*. 2011, Walker *et al*. 2012). Mangrove is appreciably the most highly productive and carbon rich ecosystem amongst the diversity of terrestrial biomes (Donato *et al*. 2011, Benson *et al*. 2017).

The fore mentioned few data on P_{wood} trait across environmental gradients indicated marked variation in P_{wood} at taxa (species) and community level but lack sufficiency in empirical data. These few studies are mostly based on tropical rainforest communities and there is negligible effort placed in understanding the distribution of P_{wood} trait at taxa and community level for mangrove despite their increasing appreciation as the most productive and carbon rich ecosystem amongst the diversity of terrestrial biomes. Our study thus, focuses on determining the trend in P_{wood} trait across different mangrove species and communities.

Study Site

The study was conducted in five ecologically distinct mangrove communities in Papua New Guinea, namely; Motupore Island, Bootless Bay, Tamonau in Milne Bay Province, and Liba in New Ireland province from August 2017 to August 2018 (Table 1). All mangrove communities besides the Motupore Island mangrove are river delta communities and receive regular tidal inundation from river. The MAP and MAT for the five mangrove communities are provided in table 1. We established two 0.2 ha rectangular (100 m × 20 m) temporary plots in each study sites (mangrove communities). All plots were set out in perpendicular direction from coastline and datum point established in the mean low tide zone.

Table 6. GPS location of the five study sites (mangrove communities) and their corresponding mean annual temperature (MAT) in degree celsius (^{o}C) and mean annual precipitation (MAP) in millimeters (mm) and mangrove type (riverine or atoll).

Study Site	**Latitude (South)**	**Longitude (East)**	**Altitude (m)**	**MAP (mm)**	**MAT (^{o}C)**	**Riverine/ Atoll**	**Source(s) for Climate Data**
Motupore Island, Central Province	09^{o}31.02	147^{o}17.50	1	1214	31.5	Atoll	McAlpine *et al*. 1983
Bootless Bay, Central Province	09^{o}30.01	147^{o}16.21	1	1214	31.5	Riverine	McAlpine *et al*. 1983
Kore, Central Province						Riverine	McAlpine *et al*. 1983
Tamonau, Milne Bay Province	10^{o}44.91	150^{o}14.17	6.5	2541	26.6	Riverine	McAlpine *et al*. 1983
Liba, New Ireland Province	03^{o}02.46	151^{o}58.36	4	3500	28.5	Riverine	McAlpine *et al*. 1983

Methodology

The 0.2 ha rectangular plot design was adopted from Mueller-Dombois and Ellenberge (1974) and served as models for past numerous biodiversity survey conducted in PNG (Balun 1995, Balun *et al.* 1993, Saulei S M & Kiapranis R 1996, Balun *et al.* 2000). Ten temporary 0.2 ha plots were established at pre-selected sites across the different mangrove communities in PNG. Each 0.2 ha linear transect was established along a central reference baseline perpendicular to the coastline with datum point established in the mean low tide (MLT) zone of the mangrove forested area. Ten sub-plots (10 m x 20 m) were set out along the baseline. Each 20 m wide (10 m each side of the baseline) by 10 m long were enumerated progressively along the transect using the baseline as a central axis. Within each sub-plot plant voucher specimen were collected for all the plant species occurring inside the sub-plot.

All individual plants positioned on the perimeter of the sub-plot with more than half of their stem inside the plot were included in the sub-plot assessment. Plants with rest of the aerial parts inside the sub-plot but roots established outside were excluded in the enumeration. Girth measurements for all trees > 5 cm DBH (Diameter at Breast Height) were measured using a pre-calibrated fiber DBH tape measure. Preliminary identification of plant species were done in the field for all observed plant species. Photographs of plant twigs, leaf, flower, fruit, bark color, and root type were taken for all species.

All individual plants, including epiphytes up to 10 m above ground level were progressively enumerated within the transect to determine Total Species Richness (TSR) for the mangrove community. For wood density (P_{wood}) measurement, 3 x (~6-10 cm length) segments of the branches and stems from the 47 sampled species were cut and placed in Ziploc plastic bags and transported to the field laboratory. All wood samples were taken from branches that were exposed to 100% open sky. An assumption of this method is that field observation of light environment reflects the light environment that stem development occurred in. The stem segments were then recut in the laboratory into ~2-3 cm length segments and debarked. The debarked segments were then split in the center and the pith tissue scrapped off with a stainless steel, sharp pointed screwdriver. We then pinned the split pieces one by one using a syringe and needle and recorded the weight of the fresh stem by inserting the split segments inside a beaker of water on an electronic balance. The displacement weight, which is equivalent in volume to the segment (= cm), was then recorded for 10 segments of each species. Stems segments were then labeled and placed inside a small brown envelope; oven dried for 48 hours at 60-70^{o}C; and measured the dry weight.

The P_{wood} was then calculated using the following equation: P_{wood} = Dry weight (DW, g)/Volume (cm^3) (Aiba and Nakashizuka 2009, Hudson *et al.* 2010, Poorter *et al.* 2010).

Result

Table 7. Two Way ANOVA test of variance in P_{wood} (g.cm^{-3}) among five different mangrove communities (Motupore Island, Bootless Bay in Bootless Bay, Kore in the Rigo District, New Ireland Province, and Milne Bay Province). P_{wood} density varied significantly among the different mangrove communities ($Fs_{(4, 36)}$ = 21.849, P<0.001) and species ($Fs_{(14, 36)}$ = 4.85, P<0.001.

Source of Variation	DF	SS	MS	F	P
Communities	4	0.587	0.147	21.849	<0.001
Species	14	0.456	0.0326	4.85	<0.001
Residual	36	0.242	0.00671		
Total	54	1.508	0.0279		

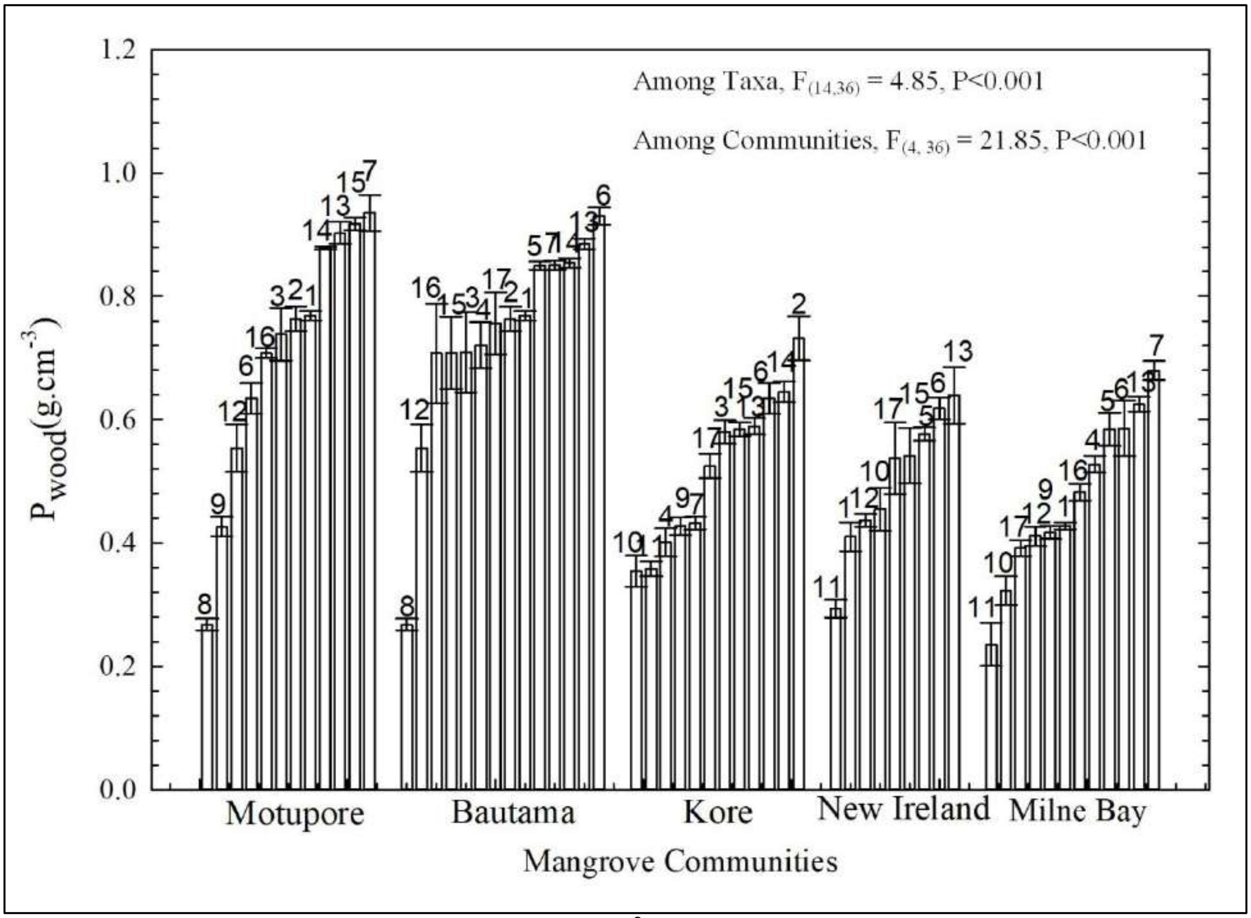

Figure 5. Show the variation in wood density trait (P_{wood}, g.cm^{-3}) among the five ecologically distinct mangrove communities and 17 species in Papua New Guinea. Variation in the P_{wood} amongst the different mangrove communities and species were highly significant ($P<0.001$). The 17 species are; *1=Aegiceras corniculatum, 2=Avicennia alba, 3=Avicennia marina, 4=Avicennia rumphii, 5=Bruguiera parviflora, 6=Bruguiera sexangula, 7=Ceriops tagal, 8=Cordia subcordata, 9=Excoecaria agollocha, 10=Heritiera littorals, 11=Hibicus tiliaceus, 12=Pongamia pinnata, 13=Rhizophora apiculate, 14=Rhizophora mucronata, 15=Rhizophora stylosa, 16=Sonneratia alba, 17=Xylocarpus granatum.*

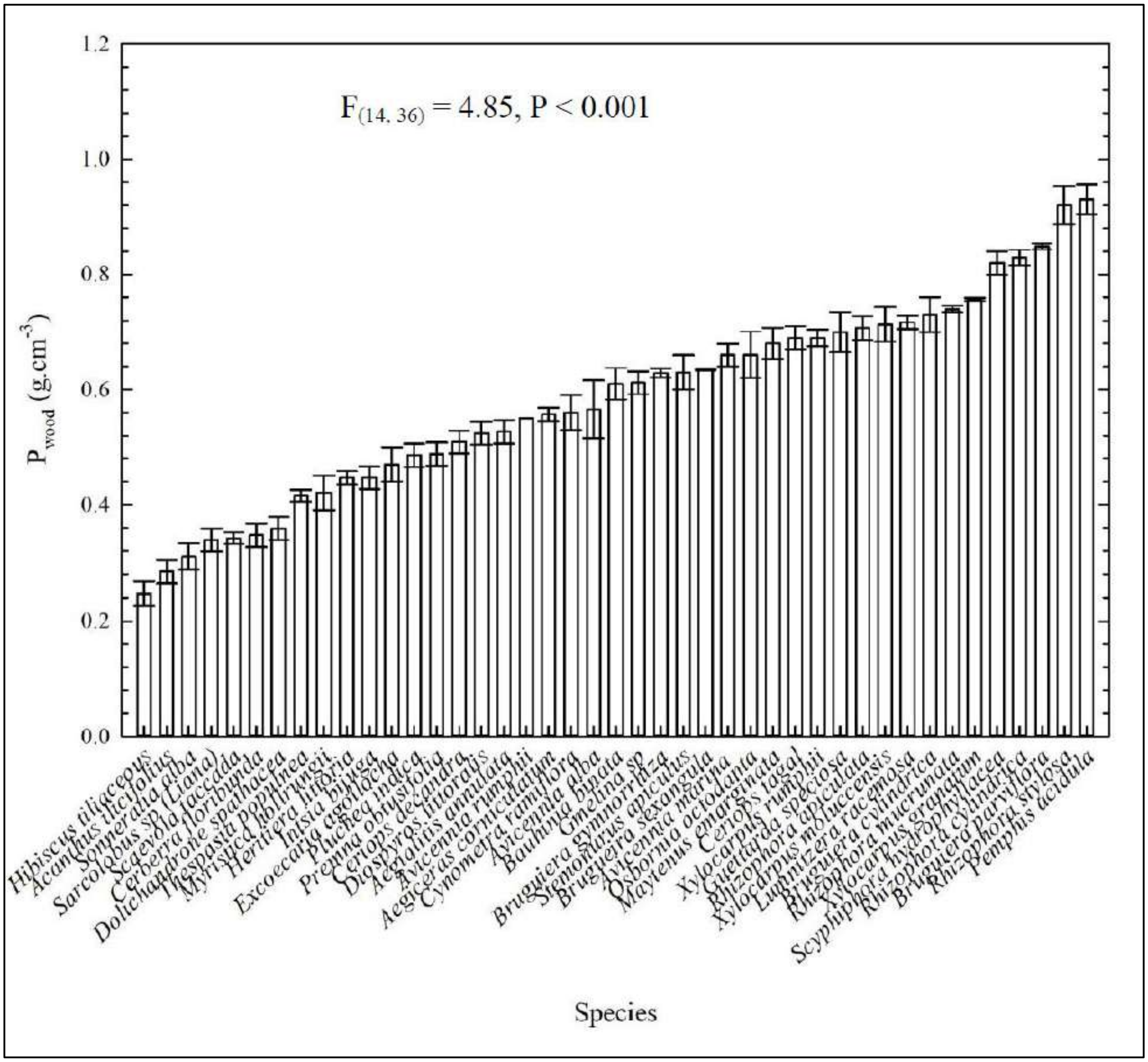

Figure 6. Interspecific variation in wood density (P_{wood}, g.cm^{-3}) among the 43 woody mangrove species varied by three-fold. The variation in P_{wood} ranged from a minimum of 0.28 ± 0.02 SD g.cm^{-3} in *Hibiscus tiliaceous* to a maximum of 0.953 ± 0.27 SD g.cm^{-3} in *Pemphis acidula*.

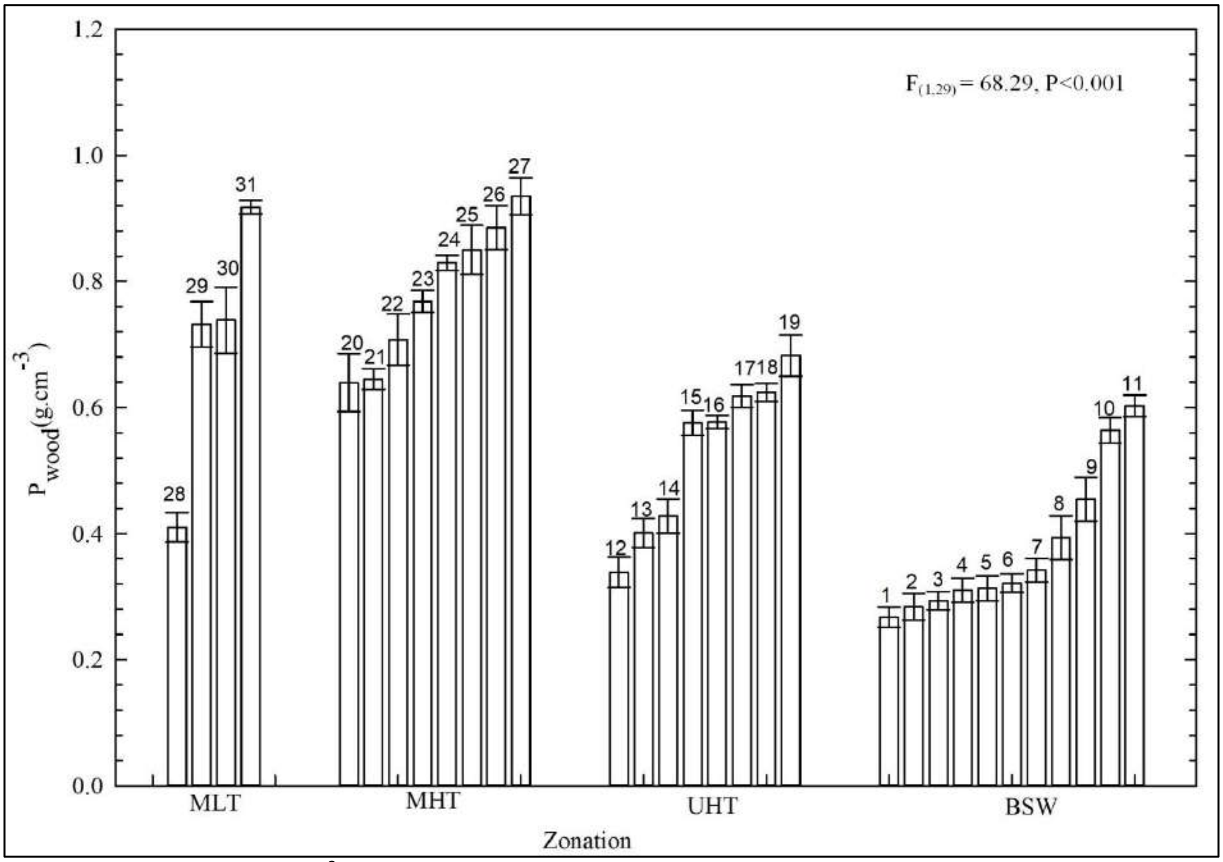

Figure 7. Variation in P_{wood} ($g.cm^{-3}$) of 31 species of New Guinea mangroves along the tidal zonation. Where BSW=Back Swamp zone, UHT=Upper High Tide zone, MHT=Mid High Tide zone, and MLT=Mean Low Tide zone. Each bar and number at the upper end of error bar represent wood density and taxa or species respectively. Data points are means of 10 samples with error bars denoting the standard deviation around the mean. The numbers next to each bar refer to species listed as follows: *1 = Hibiscus tiliaceous*, *2 =*, *Acanthus ilicifolius,3 = Heritiera littoralis , 4 = Sonneratia alba, 5= Myristica hollrungii , 6 = Stemoneurus apicalis, 7 = Cordia subcordata, 8 = Dolichandrone spathacea, 9 = Osbornia octodonta, 10 = Aegiceras corniculatum, 11 = Pongamia pinnata, 12 = Excoecaria agallocha, 13 = Cynometra ramiflora, 14 =Xylocarpus granatum, 15= Avicennia rumphii, 16 = Ceriops tagal, 17 = Ceriops decandra, 18 = Rhizophora mucronata, 19 = Bruguiera gymnorhiza, 20 = Rhizophora apiculata, 21= Xylocarpus australasicus, 22 = Xylocarpus rumphii, 23 = Avicennia officinalis, 24 = Avicennia alba, 25 = Bruguiera parviflora, 26 = Bruguiera sexangula, 27 = Luminitzera racemosa, 28 = Aegilitis annulata, 29 = Avicennia marina, 30 = Rhizophora stylosa, 31 = Pemphis acidula.*

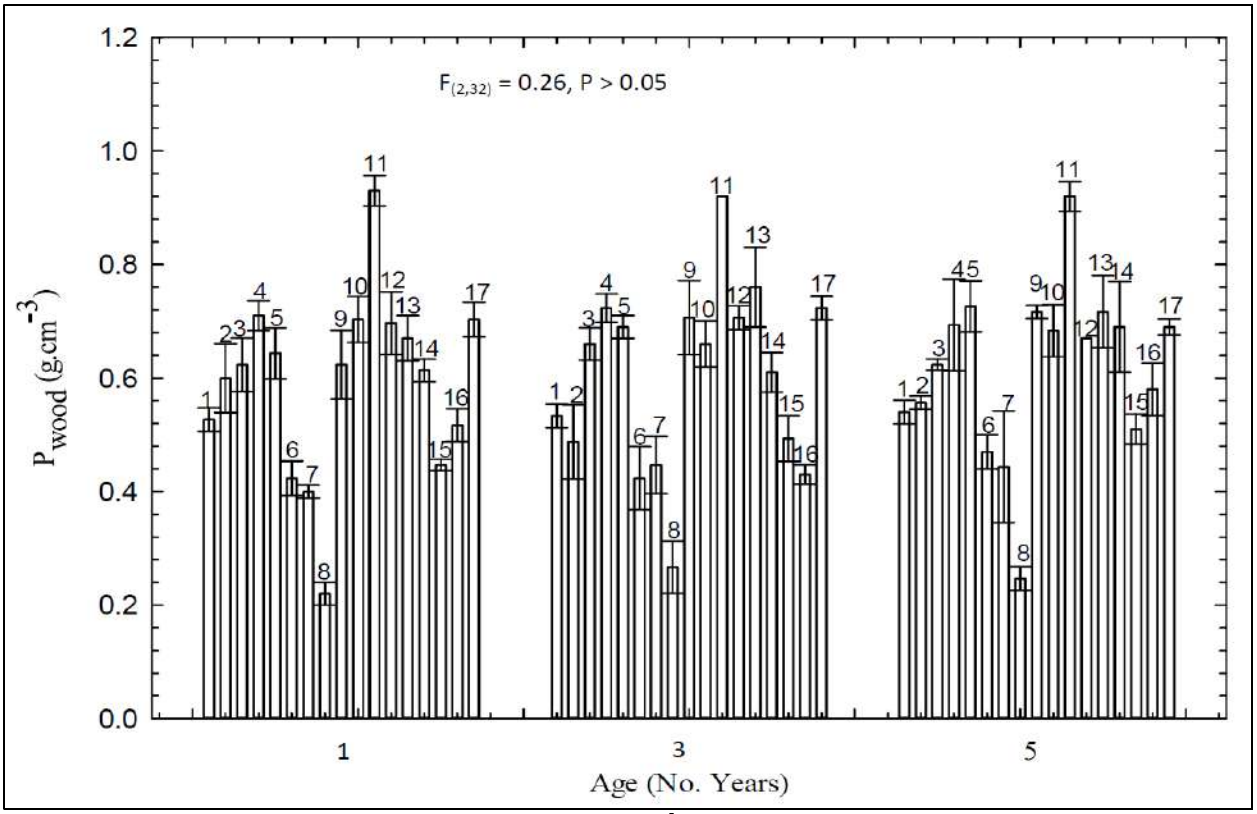

Figure 8. Ontogenetic variation in mangrove P_{wood} (g.cm^{-3}) among different age classes (one year old, three years old, five years old). One way ANOVA showed no significant variation ($P > 0.05$) in P_{wood} within species from different age classes.

DISCUSSION

Variation in wood density (P_{wood}; g.cm^{-3}) among mangrove communities

Data on intraspecific and interspecific variation in P_{wood} amongst ecologically distinct mangrove communities showed highly significant differences ($P<0.001$, Table1, Figure 5). The trend in P_{wood} functional trait at vegetation community level observed in this study suggested similar mangrove species from ecologically distinct communities exhibited significant differences in their functional performance. The P_{wood} data suggest that mangroves despite occupying a narrow habitat range and pronounced morphological convergence have evolved functional and structural traits that enable functional diversity in performance. Our results further suggest that related mangrove taxa from different communities differ significantly in their wood properties. Our data disagree with the widely held paradigm that considers mangroves as having narrow functional performance (Ball and Farquhar 1984, Ball *et al.* 1988, Ball 1996).

Our P_{wood} values of the five observed mangrove communities are well above the IPCC default value (0.47 g.cm^{-3}). Which suggest that any estimates of mangrove above ground biomass and carbon stock should not be based on the IPCC default value, rather all future estimates of mangrove above ground biomass and carbon stock should be based on site specific P_{wood} value. The data from this study also imply estimates of biomass and carbon stock for any terrestrial vegetation communities based on IPCC default P_{wood} value (0.47 g.cm^{-3}) or from one forest types would be highly erroneous.

Variation in wood density (P_{wood}; g.cm^{-3}) among species

Intraspecific variation in P_{wood} amongst the woody mangrove species showed highly significant differences ($P<0.001$, Table 7, Figure 6). The trends in species specific P_{wood} suggest mangrove despite exhibiting high morphological convergence vary markedly in their functional performance among different taxa. The data from this study show that individuals from similar genus but different species vary in their wood properties significantly. Therefore estimations of tree biomass and carbon stock of a given forest based on generic level P_{wood} can be highly misleading.

Variation in wood density (P_{wood}; g.cm^{-3}) among species

Data on P_{wood} trait amongst ecologically distinct mangrove communities in Papua New Guinea showed P_{wood} trait varied significantly among the tidal zones (Table 1, Fig. 3 & Fig. 4; $Fs_{(1, 29)} = 68.29$, $P<0.001$) and was positively correlated to tidal zonation and salinity gradient, i.e. P_{wood} increase with salinity gradient ($R^2 = 0.702$, Adj $R^2 = 0.692$) conforming to a linear equation model `$Y = 0.144X + 0.283$'. The data indicated P_{wood} varied significantly among different tidal zones (Fig. 1, 2, 3) suggesting that the observed differences in the P_{wood} are linked to the local biogeochemical gradient (zonation). The highest mean P_{wood} (0.918 ± 0.01 SD g m^{-3}) was observed in *Rhizophora stylosa* in the mean low tide (MLT) zone, followed by the mid high tide (MHT) zone (0.850± 0.07 SD g m^{-3}, *Ceriops tagal*), the UHT zone (0.708± 0.08 SD g m^{-3}, *Avicenna alba*), and the lowest in the upper high tide (UHT) zone (0.268± 0.03 SD g m^{-3}, *Cordia subcordata*). The data indicated P_{wood} is moderated by biogeochemical factors, in particular tidal duration, which led to a coordinated increase in P_{wood} with increasing tidal duration. This explanation is consistent with previous studies' findings (Sobrado & Ball 1999, Verheyden *et al.* 2005, Sobrado 2006).

Comparison in wood density (P_{wood}; g.cm^{-3}) between mangrove forest and other terrestrial forest types

The P_{wood} in mangrove community is remarkably high in contrast to tropical and temperate forest communities. For example, mean P_{wood} from 17 dipterocarp species of 0.54 g cm^{-3} (Zhang and Chao 2009), 0.58 g m^{-3} from 42 rainforest tree species (Poorter *et al.* 2010), and 0.54 g cm^{-3} from 30 temperate tree species (Aiba and Nakashizuka 2009) are all lower than mean of mangrove (0.68 g m^{-3}). This suggests that mangrove species are among the worlds' most high density wood. Our data showed that mangrove on community and taxa scale exhibited a higher mean P_{wood} than the terrestrial rainforest communities. The higher P_{wood} in mangrove species is associated with the anatomical wood construction strategies of mangrove species. For example, higher mean P_{wood} is linked to reductions in xylem vessel diameter, pith size, and increase in fiber wall thickness (Nock *et al.*, 2009; Sungpalee *et al.*, 2009; Hashim & Khairuddin, 2014). These relationships between P_{wood} and anatomical traits in mangrove stems are speculated as trade-off strategies between mechanical support and hydraulic functions, both of which are linked to tree growth and survival (Swenson & Enquist, 2007; Larjavaara & Muller-Landau 2010, Balun 2011). The higher P_{wood} across mangrove communities observed in this study is indicative of a highly efficient carbon sequestration strategy. This view is congruent with numerous earlier studies which claimed that mangrove have an efficient ecophysiological mechanisms in harvesting global carbon dioxide (CO_2) than terrestrial rainforest communities (Iftekhar & Saenger, 2008; Nock, *et al.*,2009; López-Medellín & Ezcurra, 2012; Kauffman *et al.* 2014; Hashim & Khairuddin, 2014).

Conclusion

The significant variation in P_{wood} trait among communities and species ($P<0.05$) imply that reliable estimation of carbon stock for terrestrial ecosystem must be based on community specific P_{wood} values.

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Soil Carbon Modeling across Forested Landscapes in Morobe Province

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Abstract

This study was conducted to develop a best-fitting model using environmental variables to estimate and map soil carbon distribution to 1 meter depth in PNG's Morobe province using Multiple Linear Regression (MLR) technique. Descriptive, Correlation and MLR analysis were used to test variables elevation, slope, and aspect derived from digital elevation model (DEM). Normalized Difference Vegetative Index (NDVI) derived from Landsat 8 Imagery data, and raster data for mean annual temperature (MAT) and mean annual precipitation (MAP) downloaded from worldclim website. Statistical software used was SPSS software and ArcGIS 10.

Kolmorov –Smirnov test and Shapiro – Wilk test revealed that elevation and MAT were skewed. Pearson's correlation test revealed that slope was significantly negatively correlated to soil carbon distribution (R = - 0.725 at $p< 0.05$). Spearman's Rank Order correlation test revealed the same for elevation (R = - 0.862 at $p< 0.01$) while MAT was significantly positively correlated to soil carbon distribution (R= 0.906 at $p< 0.01$). Backward selection MLR resulted in three models developed. Model 1 was not significant (adjust. $R^2 = 0.975$ at $p> 0.05$); however; model 2 (adjust. $R^2 = 0.987$ at $p< 0.05$) and model 3 (adjust. $R^2 = 0.990$ at $p< 0.05$) were both significant. Model 2 thus created equation 1 while model 3 created equation 2. Prediction accuracy of the two model show that model 1 (equation 1) (RMSE = 2.597) performed better that model 2 (equation 2) (RMSE = 2.764) hence model 1 (equation 1) was used to predict soil carbon distribution (predicted 271 t/ha).

This study therefore concluded that environmental variables can be used to predict soil carbon distribution However, the limited number of sample data (n = 8) may have greatly affected the model development exercise (e.g. the surprising positive correlation of soil carbon with MAT), and consequently the accuracy of the prediction map.

Keywords: Digital Soil Mapping, Soil Carbon, Digital Elevation Models, Environmental Variables, Correlation Analysis, Multiple Linear Regression, Root Mean Square Error

1. Introduction

Soils acts as a sink and reservoir for atmospheric carbon dioxide and regulates global climate. Globally, the amount of carbon stored in soils is similar to carbon stored in the atmosphere and the above ground biomass together (Schimel 1995). Furthermore, the amount of carbon stored in soils is higher than in the above-ground biomass in most ecosystems (Post and Kwon 2000). This makes soil the largest terrestrial carbon sink. Forest soil, particularly in tropical rainforests, store up to 50% of carbon in forest ecosystems (IPCC 2000) and the amount is higher in Papua New Guinea's forest soil (50 – 75%) (McIntosh *et al* 2017). However, soil is also heterogeneous and dynamic in nature and changes in relation to the surrounding environment.

Apart from soil's physical and chemical properties; physiographic factors, vegetation cover and climatic conditions have a great influence on soil dynamics across and along altitudinal gradients consequently affecting soil carbon distribution. Previous studies have observed variations in soil carbon to have been associated with changing elevation, slope and aspect (Garcia – Pausas *et al*. 2007; Mishra *et al*. 2010; Kunkel *et al*. 2011; Peng *et al*. 2013; Liu *et al*. 2015; Wang *et al*. 2018), vegetation cover

(Mishra *et al*. 2010; Kunkel *et al*. 2011; Peng *et al*. 2013; Wang *et al*. 2018) and climatic conditions (Garcia–Pausas *et al*. 2007 and Mishra *et al*. 2010).To understand soil carbon complexes, there is a need to develop soil carbon models to monitor, evaluate and report soil carbon stock changes.

Papua New Guinea's rainforests are one of the highly complex and diverse ecosystem of a mix composition and a wide diversity of plant species and community characterized by some of the most rugged terrain and profound landscapes and unpredictable climatic conditions. While soil carbon modeling has been intensively studied in temperate regions at various scales, it is poorly researched and represented in tropical rainforests. Hence this study attempts to develop a predictive model using Multiple Linear Regression (MLR) technique for tropical forests based on environmental variables for soil carbon monitoring and evaluation purposes in PNG. In doing so, the underlying influence of soil carbon dynamics in tropical rainforest can be projected.

Apart from that, this study will assist in developing a soil carbon model – based system for soil carbon budgeting purpose in PNG and contribute towards PNG Forest Authority's overall objective of developing PNG´s national forest monitoring system and contribute towards the implementation of PNG´s climate change policies and measures on mitigation and also serve as baseline research for further soil carbon model development in Papua New Guinea to develop and refine a conventional model which can be used for soil carbon prediction and extrapolation. The main objective of this study is therefore attempting to develop a best fitting model using environmental variables to estimate and map soil carbon distribution to 1 meter depth in PNG's Morobe province using the Multiple Linear Regression specifically: (1) to analyse the relationship between environmental variables and soil carbon; (2) to find the best fitting model to predict soil carbon distribution, and (3) to map soil carbon distribution using developed models.

2. Methodology

2.1 Study Site

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 shares borders with Eastern Highlands in the west, Madang Province in the north and Oro Province to the south. Most of the province is 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 ranging from Lae city westward through Huon to Kaiapit district, dividing the Saruwaget, 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 2900mm/year. Wau, Lae, Siassi, parts of Menyamya, Huon and Finschhafen districts are some of the wettest areas with rainfall up to 5000mm/ year (Ningal *et al*. 2008).

2.2 Soil Sampling and Analysis Methods

Field work was done from 20th October to 17th November 2017 in Morobe province. A total of eight (8) sites were surveyed – four (4) in coastal areas, three (3) in lowland forests, and one (1) in 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 radius) were established along the300 m radius from the center point. Each plot was established in the center, north, southeast and southwest of the cluster (Fig.3). Soil sample collection followed Field Guide for Sampling and Describing Soils in the Papua New Guinea National Forest Inventory 3rd Edition (McIntosh *et al.* 2017).

2.3 Bulk Density and Soil Carbon Calculations

Bulk density gives an indication of soil's physical condition, particularly soil 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). Effective Bulk Density as calculated is a relatively simple measurement allowing chemical data measured on <2 mm soils to be expressed on a t/ha basis. 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 because topsoil carbon samples were taken at right angles to slope:

C (t/ha) = total weight of <2mm soil for the depth sampled x C% (1)

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

2.4 Predictor Variables

Topographic variables (elevation, slope and aspect) were derived from GPS readings of each site as well as Digital Elevation Model (DEM) obtained from USGS website (https://earthexplorer.usgs.gov/) whereas Normalized Difference Vegetative Index (NDVI) (an approximation of vegetation cover) was derived from Landsat 8 imagery also obtained from USGS website and Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) was derived from Worldclim website (www.worldclim.org/version 2). Worldclim website is a global climate database available online.

2.5 Statistical Analysis and Multiple Linear Regression Models

SPSS was used to explore and examine the distribution and relationship between soil carbon and the predictor variables elevation, slope, aspect, NDVI, mean annual temperature and mean annual precipitation through normality tests, correlation tests and linear regression tests. Normality test analyzed the data using Kolmorov – Smirnov and Shapiro – Wilk test. *P* – Values of both tests were used to interpret the distribution of soil carbon and predictor variables. Both parametric and non-parametric correlation tests were used to analyze the correlation between soil carbon and predictor variables. Pearson's correlation test was used to analyze correlations between log – transformed soil carbon value to log – transformed predictor variables whereas the Spearman's Rank Order Correlation test was used to analyze the correlations between soil carbon and predictor variables using normal (raw) data. Both tests were used to report the correlation value (R) at $p< 0.05$ and $p< 0.01$. R square and adjusted R square values were reported for the predictive models developed through linear regression and ANOVA was used to analyze the significance of the developed model. Prediction accuracy of the developed model were analyzed and Mean Error (ME), Root Mean Square Error (RMSE), Mean Standardized Error (MSE), Root Mean Square Standardized Error (RMSSE) and Average Standard Error (ASE) were used as evaluation indexes to analyze the prediction accuracy of the prediction maps of soil carbon distribution. Predicted soil carbon distribution maps were developed using raster calculator in ArcGIS 10.

3. Results and Discussion

3.1 Descriptive Statistics for Data Distribution and Correlations of Soil Carbon with Environmental Variables

Kolmorov – Smirnov test and the Shapiro – Wilk test both revealed that elevation and MAT were not normally distributed at *p* value of 0.05. Elevation was skewed to the left whereas MAT was skewed to the right (histogram results not shown). Hence the data was log – transformed and both log – transformed and raw data were tested for correlation using both parametric test (Pearson's Correlation test) and nonparametric test (Spearman's Rank Order Correlation Test). Pearson's correlation test of normal and log - transformed data revealed similar results showing significant negative correlations between soil carbon and slope (r = - 0.725, $p < 0.05$) (results not shown) implying that soil carbon are trans located from steeper sloping areas to flat areas. Significant negative correlations were also observed between MAT to elevation (r = - 0.987, $p < 0.01$) (results not shown), which is the expected trend. Results from Spearman's Rank order correlation indicated a significant negative correlation between elevation and soil carbon (r = - 0.862, $p < 0.01$) while MAT showed a significant positive correlation to soil carbon (r = 0.906, $p < 0.01$) (table 1) implying that soil carbon decreases when elevation increases and soil carbon stock increases when temperature increases which is contrary to many studies because on stable sites soil carbon increases as elevation increases and the climate becomes cooler (e.g. McIntosh *et al*. 2000; Fig. 3) and the correlation observed is almost certainly an artefact caused by the small number of sites included in the statistical analysis. A significant negative correlation was also observed between MAT and elevation (r = - 0.932, $p < 0.01$) as well as between MAT and slope (r = - 0. 817, $p < 0.05$) (table 1). It is therefore possible to say that other factors may have affected the results and ultimately influenced the end result. According to McGrath *et al*. (2004), a normal distribution is desirable in both linear geostatistics and conventional statistics for a studied variable as excessive skewness can impair variogram structure and consequently the predicted results and this was observed with elevation and MAT. Other possible reasons could be related to the soil's physical properties. The negative correlation observed between slope and soil carbon demonstrates in part the general landform of the sites, the physical properties of the soils, the vegetation cover and hydrological process. Tsui *et al*. (2004) argued that in a forest ecosystem the soil properties are also influenced by vegetation composition contributing to the spatial difference of soil properties where at high steep slopes of high altitudes where plant community and diversity decreases, the vegetation could not maintain soil structure hence the area experiences erosion and landslips resulting in loss of soil particles and consequently soil carbon. Furthermore, precipitation is the major force acting on the soil movement from upslope downwards. This moves rich top soils from soil surfaces downslope. All the sites have high mean annual precipitations thus the role of precipitation in slope – soil carbon relationship is unavoidable in this study.

Table 1: Statistical results of Spearman's Rank Order correlation test using normal (raw) data

	Elevation (m a.s.l)	**Slope (deg.)**	**Aspect (dec. deg.)**	**NDVI**	**MAT (deg. C)**	**MAP (mm)**	**Soil C (t/ha)**
Elevation (m)	1.000	0.643	0.228	-0.452	-0.932**	0.024	-0.862**
Slope (deg.)	0.643	1.000	0.323	0.000	-0.817*	0.119	-0.623
Aspect (dec. deg.)	0.228	0.323	1.000	-0.120	-0.289	-0.012	-0.042
NDVI	-0.452	0.000	-0.120	1.000	0.409	0.262	0.347
MAT (deg. C)	-0.932**	-0.817*	-0.289	0.409	1.000	-0.013	0.906**
MAP (mm)	0.024	0.119	-0.012	0.262	-0.013	1.000	-0.072
Soil Carbon (t/ha)	-0.862**	-0.623	-0.042	0.347	0.906**	-0.072	1.000

** Correlation is significant at the 0.01 level (2 - tailed)

* Correlation is significant at the 0.05 level (2 - tailed

3.2 Effects of Environmental Variables on Soil Carbon Distribution

Each model developed through backward selection method was able to explain approximately 100% of the variation in soil carbon ($R^2 = 0.996$) with an increase in performance increased as each variable was removed (table 2, adjusted R^2 values). While R^2 measured the proportion of the variation in soil carbon, adjusted R^2 adjusted the statistics based on the 8 number of independent variables in this study. ANOVA analysis of the 3 models developed indicated that models 2 and 3 were significant (Table 2). Hence, soil carbon predictions were tested as a function of the predictors in models 2 and 3. Model coefficients of the predictive model developed were;

Equation 1

Soil Carbon (t/ha) = 1143.877 – 0.224 (Elevation) – 2.358 (Slope) + 0.214 (Aspect) – 33.318 (NDVI) – 39.542(MAT) ($R^2 = 0.996$, Adjusted $R^2 = 0.987$, $p < 0.05$)

Equation 2

Soil Carbon (t/ha) = 1132.712 – 0.222 (Elevation) + 2.309 (Slope) + 0.216 (Aspect) – 38.555 (MAT) ($R^2 = 0.996$, Adjusted $R^2 = 0.990$, $p < 0.05$)

The developed equations using multiple linear regressions in this study again show the importance of physiographic properties and climatic conditions to soil carbon distribution. Furthermore, the models developed show the essence of the interrelations among the variables where the effect of one affects another and collectively affect soil carbon distribution. For instance, vegetation cover represents total ecosystem productivity and is directly proportional to net carbon input to the soil; however; the rate of decomposition of litter and other wood debris by biological activity is largely dependent on temperature and humidity. Landscape attributes on the other hand influence soil carbon through run-off and run-on processes, condition of natural drainage, and exposure of soil to wind and precipitation (Dianwei *et al.* 2006). The inclusion of aspect and NDVI in the MLR exercise in this study suggests that either their effects may be controlled by other factors or they affect other variables thus having an indirect effect to soil carbon distribution. According to Dorji *et al.* (2014), vegetation cover have significant impact on soil carbon dynamics through organic carbon (OC) inputs, decomposition and stabilization while the relationship of slope aspect with soil carbon is by controlling the microclimatic factors such as soil temperature, moisture, vegetation and microorganisms by affecting the solar radiation and evapotranspiration. Also, different Eco-regions have differing environment hence displaying the importance of local – scale microenvironment and microclimate.

Table 2: Summary statistics of Multiple Linear Regression using environmental variables using backward selection method

Model Summary						
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**F**	**Sig.**
1	0.998[a]	0.996	0.975	7.348	46.263	0.112
2	0.998[b]	0.996	0.987	5.249	108.794	0.009
3	0.998[c]	0.996	0.990	4.548	181.030	0.001

a. Predictors: (Constant), MAP, Aspect, Slope, NDVI, Elevation, MAT

b. Predictors: (Constant), Aspect, Slope, NDVI, Elevation, MAT

c. Predictors: (Constant), Aspect, Slope, Elevation, MAT

3.3 Model Development and Accuracy

Results of the prediction accuracies of model 1 (equation 1) and model 2 (equation 2) presented in table 3 indicate that both predictions were unbiased (ME equals to zero) and accurate (RMSSE close to 1). Root Mean Square Error (RMSE) for model 1 was 2.597 while for model 2 was 2.764 respectively indicating that model 1 performed better than model 2 hence model 1 was used to map soil carbon distribution. Soil carbon stocks to 1 meter depth from previous studies ranged from 86 t/ha (Matsuura 1997) to 157 t/ha (Abe 2007) in Morobe Province whereas the highest measured was 600 t/ha in Eastern Highlands Province (Edwards and Grubb 1977). Soil carbon estimates from the model is even higher than what was actually measured showing again the importance of local – scale variability. In geostatistics, models developed should follow three assumptions in order for the output predicted map to be considered valid and accurate. These three assumptions are; (1) mean prediction error should be close to zero for that predictions to be considered unbiased; (2) the standard error are accurate, indicated by a root – mean – square standardized prediction error close to 1; and (3) the prediction do not deviate much from the measured values, indicated by root mean square error and average standard error that are as small as possible. Both models conformed to the three assumptions. RMSE for both models were a bit higher than other studies which is probably due to the low number of samples ($n = 8$) and could be in part related to other variables not being tested (e.g. soil properties) (Table 3).

Table 3: Comparison of prediction accuracy between model 1 and model 2

	Model 1 (Equation1)	Model 2 (Equation 2)
Samples	8 of 8	8 of 8
Mean Error	0	0
Root Mean Square Error	2.597	2.764
Mean Standardized Error	0	0
Root Mean Square Stand. Error	0.935	0.935
Average Standard Error	0	0

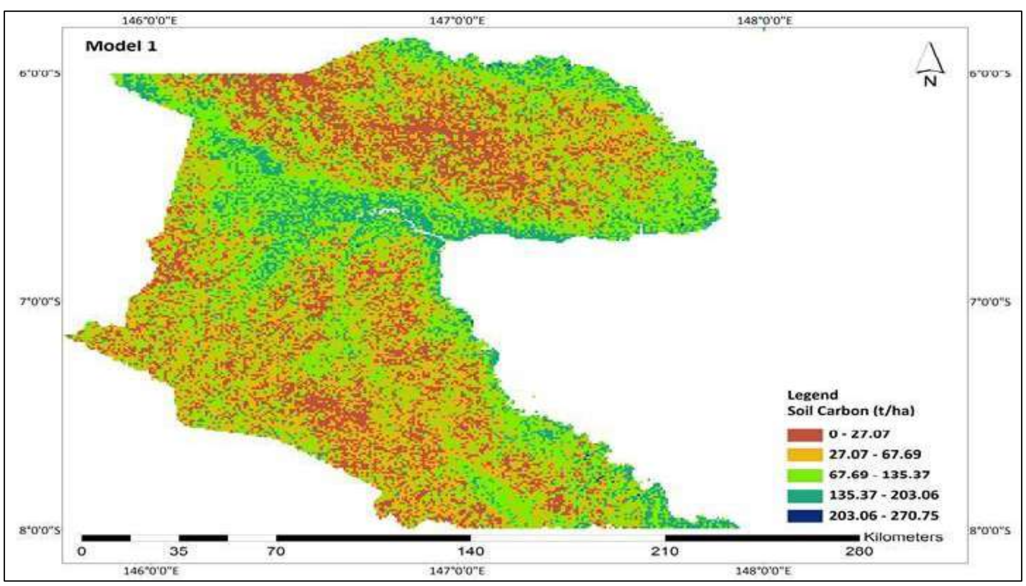

Figure 1: Prediction map of soil carbon distribution in Morobe using developed prediction model 1 (Equation 1)

4. Conclusion

This study was able to reveal the importance of physiographic properties, vegetation cover and climatic conditions to soil carbon dynamics. The models developed using MLR technique has the potential to reliably predict soil carbon distribution over large areas. The models developed were based on very limited sample size and were not actually field-tested in the field to validate its reliability and accuracy due to logistics and time constrains. Therefore models developed can be regarded as preliminary findings until more data becomes available to carry out actual test to ascertain its accuracy. It is strongly recommended that future soil carbon modelling studies in Morobe be continued to collect more data on areas not covered in this study. This will then allow more accurate estimates of landscape carbon in the province.

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Measuring Carbon from Soil, Understory Vegetation, Litter and Coarse Woody Debris in National Forest Inventory

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ABSTRACT

Measuring carbon from soil, understory vegetation, litter and coarse woody debris in the National Forest Inventory (NFI) provided basic data for evaluating forest carbon stocks in PNG for environmental assessment, GHG and REDD+ developments. The NFI program commenced in 2016 with preliminary soil surveys in easy accessible cluster plots, then full surveys in selected clusters in 2017. Field survey and laboratory results for 16 areas indicated very high soil carbon at 1m depth, 408 C(t/ha) in Tambul in Highlands is very high while Yalu in the lowland coastal area had 69 C(t/ha), lowest value in the low C category in the PNG rating scale.

Estimated carbon for the litter, coarse woody debris and under story vegetation varied across surveyed plots of the 15 clusters. Average estimated C for 15 sites; litter, ranged 0.5-3.5 t/ha, coarse woody debris, ranged 0.8-3.2 t/ha, understory vegetation, ranged 0.3-.6 t/ha. The high altitude, cool and moist forest in Bena, Henganofi, and Tambul in the PNG Highlands had higher values compared to lowland forests of Yalu and Bukawa in Morobe province. Carbon from all pools compares well with the prescribed IPCC default values for similar soils, forest and climate zone.

INTRODUCTION

Forest soils contain significant organic carbon in terrestrial ecosystem. Estimated to be 700 billion tons of C globally in soils (IPCC 2006). Soil organic carbon (SOC) of mineral soils varies between 20 and 300 t/ha to depths of one (1) m. About 50% SOC is represented within the surface layer of 30cm. Highest input of organic carbon is from decomposed ground litter soil organic matter (SOM) tends to be more concentrated in upper soil horizons. Carbon stored in the upper horizons is most unstable; usually chemically decomposable; dissolved, leached and eroded. Natural and anthropogenic factors influences SOM and the balances of SOC. Soil carbon are lost through cultivation, runoff, stream erosion, mass movement, deforestation, and fires. How much carbon in soils in changing landscapes? Where is low and high carbon distributed relating to soil, rock, and forest types? What may be done to management systems to ensure carbon stock changes remain healthy for the soils and climate change objectives?

There is very little documentation on the status and changes of carbon in the soils and forests of Papua New Guinea (PNG). Litter and deadwoods is established pathway for the cycling of organic matter and chemical nutrients in forest ecosystems. Studies on nutrient cycling and litter production have been undertaken in many different tropical forests around the world (Sundarapandian and Swamy 1999). In PNG such studies were undertaken by Edwards (1977), Edwards and Grubb (1977) and Grubb and Edwards (1982) in the high-altitude forest of New Guinea. There has been some work on estimating C in soils Edwards and Grubb 1977, Abe 2007, Nimiago 2011, carbon in above-ground live biomass (Fox et al. 2010). However, there is information gap on forest carbon pools such as litter, deadwood and understory. Values for these pools for tropical forests were notably lacking in the IPCC 2006 thus collection of country specific data for in the PNG is obligatory.

The Papua New Guinea Forest Authority (PNGFA) with the support of European Union (EU) and UN-REDD attempted the first ever multi-purpose National Forest Inventory (NFI) for PNG commencing in 2016. The goals for the PNG Multipurpose NFI are firstly to develop appropriate methodologies and technical capacity to readily assess and evaluate the forest resource for economic, social and environmental benefits. Secondly to undertake scientific research then share inventory information among collaborators and stakeholders for use in policy and management decisions in broad spectrum of sustainable environment. The NFI will be one of the main national data sources for the PNG greenhouse gas (GHG) inventory that will enrich country specific data thus reduce reliance on default values from the Inter-governmental Panel on Climate Change (IPCC).

This paper will describe a preliminary assessment of carbon(C) in soils and forest floor biomass and C for minor above ground pools; litter, coarse woody debris and understory living plants of selected forests in PNG under the NFI in the surveyed clusters. This work for PNG is a component of a larger body of work, estimating the entire forest C stock, undertaken in joint collaboration with the Food and Agriculture Organization (FAO) of Rome during 2016 to 2018. The specific objectives of the NFI were to generate initial data on PNG forest C stocks to support the REDD+ development in PNG, and to provide capacity building of national scientists to enable them to undertake surveys and provide internationally accepted results.

METHODOLOGY

The general procedures for site selection, sampling design, equipment used, and calculations and estimation of C in soils and litter are as prescribed by the 2006 IPCC guidelines. The field sampling and laboratory procedures are similar to accepted standard procedures by Pearson et al. (2007) and the BioCarbon Fund (2008). The NFI employs a stratified random sampling strategy covering the entire land mass of PNG. Sampling units are plots arranged into clusters, each representing a particular forest type and distributed systematically in geographical map grids as specified in the National Forest Inventory Field Manual Field Guide (Kuroh et al 2019). The sampling protocols have been defined and outlined in the above mentioned Field guide.

Plot design and field sampling

Sampling in the field covered selected NFI clusters in Madang, Morobe, Eastern Highlands, Western Highlands, and West New Britain, Central provinces. Sampling of a cluster was concentrated in each of the four separate 25m radius circular plots, laid out systematically.

Soil profile was one close to the plot, surface soil for carbon were randomly extracted in 30cm depth. Meanwhile, sampling of litter, coarse woody debris and understory were done in the shaded 1mx1m clip plots at each of the four ends of the main plot (Figure 1).

Figure1. From left to right, NFI Plot design in a cluster, a soil profile at cluster 60748, taking fresh weights of and samples of litter in clip plots and preparation of soils in FRI laboratory for chemical analyses.

Within the NFI survey a subset of 100 sites was selected for detailed topsoil sampling and carbon measurement to 1 m depth (or to a rock contact if this was shallower than 1. m).

To capture variation in the stop soils, composite sampling was done to obtain an accurate estimate of carbon at any one site. Ten replicates per topsoil depth increment from 0 to 30 cm were done in a plot (Figure 2) at each of the surveyed NFI cluster. Topsoils were sampled in three 10 cm increments; 0–10 cm, 10–20 cm and 20–30 cm, using a split-tube (Eijkelkamp sampler) as described in the NFI *Field Guide* (Soil Survey Team, PNG NFI 2019). Bulked samples were thoroughly mixed, and then 10 sub samples were separated for each sampling depth for bulk density (BD) determination and soil chemical analysis.

Profiles were dug at a representative location of the site. Single samples for bulk density for sub surface soils were taken using 10 cm long aluminium tubes contained in a custom made steel sampler, hammered into horizontal benches cut at 40 cm and 75 cm depth, as described in the *Field Guide*. In very stony soils subsoils were sampled by excavating a 10x10x10 cm volume of soil from benches cut at 40 cm and 75 cm depth.

Soil treatment

Soils were dried, sieved and prepared for chemical analysis at the PNGFRI in Lae (Figure2). All mineral and organic material were air dried or oven dried at 40 °C, homogenized, sieved and stored in airtight seal bags and prepared for chemical analysis. Samples for bulk-density determination were weighed and sieved to isolate the fine earth for bulk density then oven dried at 105 °C for 24 hours. Chemical analysis of air-dry <2 mm soil fractions was done by the Landcare Research Environmental Chemistry Laboratory in, New Zealand using methods and ratings for chemical properties based on those described by Blakemore et al. (1987).

Measurement of soil carbon

Carbon was measured using a LECO CN analyser by Landcare Research Laboratory in New Zealand. Moisture content was determined for the samples and then used in correcting the actual C content by dry weight. Soil sample density was determined from the dry weight and again corrected using subsample dry weight. The organic C data obtained from the CN analyzer were converted to C (mg) on the basis of sample weight, and then converted to C content percentage (C %) based on the corrected dry weight of samples. Carbon % is then converted to C content (g/kg). Carbon stock (t/ha) was determined as C content (g/kg) multiplied by the corrected dry soil density (kg/m3) by soil depth. Using the BD values, carbon values were converted to t/ha figures, with values being adjusted for slope. A provisional scale covering the observed range of values for PNG soils was used to rate carbon values (Table1).

Table 1: Rating of soil carbon in PNG Soils.

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

Litter, Coarse Woody Debris and Understory

Total fresh weights of Litter, Coarse Woody Debris and Understory were taken within the 1mx1m clip plots located at four ends of each circular plot (Figure1). Subsample weighing between

200-250 g, and where there was less representation of a component were oven dried at 70 °C to constant weight. No records were done when a component was not present at sampling time.

- Litter refers to dead leaves, twigs and small sticks <2cm diameter.
- CWD refers to deadwood having diameter between 2cm to 9.9 cm.
- Understory are any live plant with diameter up to <1cm
- Where grass is dominant in a plot all are collected kept separate.

Estimation of Biomass and Carbon

Dry weights of sub samples were used to determine the total dry weight of total sample. The sample area of 1m^2 was converted to hectares (ha) while total dry weight in gram (g) was converted to tones (t). Estimation of total biomass and carbon were calculate from the ratios of sample fresh and dry weights for sample area and then expanded for plot area. Carbon values were determined as proximately halved biomass values.

RESULTS

The NFI surveys covered the generally accessible low coastal to inland areas, and selected high altitude areas representing major forest types of PNG. The results indicated that the lowland to mid-altitude soils of PNG have a wide range of soil carbon values on a tons per hectare basis to 1 m depth, therefore a provisional rating from very high to very low category has been done (Table 2). Very high C, 408 t/ha came from Tambul in the Highlands region, Manabo in the coastal lowland had high, 196 C (t/h). The lowest C in the low category, 69 was from Yalu. The results from 16 clusters presented in Table 2 and Table 3 indicated variation of carbon in soils from different NFI areas and within the soil profile depths.

The C distribution within soil depths (Table 3) at selected NFI sites has indicated a very high C at the sub surface soil below 30 cm in Tambul by comparison with other four surveyed sites (Figure 2). Carbon content for surface soil layer of, 0-30 cm, at Bena, Biaru and Bukawa were more than double the amount in the below 30 cm while Yalu had amount similar C distribution in the surface and subsurface soils to depth of 1m (Figure2).

Table 2. Soil carbon from first NFI surveyed sites with indicative carbon rating

NFI Surveyed Site	**Carbon (t /ha)**	**Soil Carbon Rating**	**Geology**	**Soil Group**
Baisarek-Madang	121	Moderate	Calcareous siltstone	Cambisol
Kokun-Madang	87	Low	Calcareous siltstone	Cambisol
Paia-Madang	135	Moderate	Calcareous siltstone	Gleysol
Irom-Morobe	98	Moderate	Siltstone	Cambisol
Kopsasik-Morobe	68	Low	Finisterre volcanics	Cambisol
Ngaroyats-Morobe	113	Moderate	Quartzo-felspathic alluvium	Gleysol
Ononda- Oro	90	Low	Alluvium with volcanics	Gleysol
Hark- West New Britain	108	Very Low	Rhyolitic Ash	Andosol
Gigioi-Central	118	Moderate	Andesite	Cambisol
Girinumu-Central	150	Moderate	Basalt and andesite	Cambisol
Manabo-Central	196	High	Alluvium with volcanics	Cambisol

Yalu –Opo- Morobe	69	Low	Siltstone	Cambisol
Bena- Eastern Highlands	124	Moderate	Andesite	Andosol
Tambul-Western Highlands	408	Very High	Andesite	Andosol
Biaru- Morobe	129	Moderate	Chrorite Schist	Phaeozem
Bukawa-Morobe	79	Low	Alluvium and Andesite	Cambisol

The measured biomass and estimated carbon for the forest floor litter, coarse woody debris and understory plants for first NFI clusters were presented as averages for surveyed sites (Table 4). The averages were based 16 subplots (clip-plots), some clusters had less than 16 at the time field measurements were undertaken. No measurements were done on the understory component of Eware. The forest floor litter component biomass ranged from 1.0 t/ha at Vanigado to 7.0 t/ha at Henganofi, the coarse woody debris biomass ranged from 1.7t/ha at Bukawa to 6.4 t/ha at Yalu, while understorey biomass ranged from 0.5t/ha at Mare to 3.3t/ha at Henganofi. Carbon has been determined as half fraction of biomass litter; coarse woody debris and understory respectively for each cluster and low to high values are similar. Average estimated C for 15 sites; litter, ranged 0.5-3.5 t/ha, coarse woody debris, ranged 0.8-3.2 t/ha, understory vegetation, ranged 0.3-.6 t/ha

Table 3. Distribution of soil organic carbon by soil depth for the selected NFI clusters as example

Cluster ID and Location		**Soil Depth Layer (cm)**	**BD (t/m^3)**	**Organic C %**	**C t/ha**
Name	**Altitude**				
Bena	High	0-10	0.26	11.81	39.9
Bena	High	10-20	0.45	7.62	44.2
Bena	High	20-30	0.55	3.61	25.6
Bena	High	30-60	0.71	0.64	13.7
Bena	High	60-80	0.14	0.13	0.36
Tambul	High	0-10	0.21	23.1	49.1
Tambul	High	10-20	0.32	15.2	49.3
Tambul	High	20-30	0.33	17.2	57.5
Tambul	High	30-60	0.40	12.9	153.6
Tambul	High	60-100	0.59	4.1	98.0
Biaru	High	0-10	0.24	11.74	39.3
Biaru	High	10-20	0.42	5.66	33.7
Biaru	High	20-30	0.71	2.79	27.8
Biaru	High	30-60	0.65	1.13	22.2
Biaru	High	60-85	0.57	0.41	5.8
Bukawa	Low	0-10	0.24	5.20	29.3
Bukawa	Low	10-20	0.42	1.78	17.8
Bukawa	Low	20-30	0.70	0.84	14.1
Bukawa	Low	30-60	0.57	0.75	12.7

Bukawa	Low	60-100	0.65	0.19	5.1
Yalu	Low	0-10	0.34	4.14	14.0
Yalu	Low	10-20	0.47	1.87	8.8
Yalu	Low	20-30	0.46	1.51	7.0
Yalu	Low	30-60	1.09	0.65	21.3
Yalu	Low	60-100	1.27	0.35	17.6

Table 4. Average biomass and carbon from the forest floor litter, coarse woody debris and understory vegetation for first NFI clusters.

NFI Cluster location with Province Index	Cluster Number	Litter			Coarse Woody Debris			Understory Plants		
		N	Biomass t/ha	Ct/ha	N	Biomass t/ha	C t/ha	N	Biomass t/ha	Ct/ha
Bena- EHP	75788	16	6.7	3.4	16	3.5	1.8	16	1.8	0.9
Henganofi-EHP	76797	16	7.0	3.5	16	4.6	2.3	16	3.3	1.6
Tambul-WHP	22133794	16	5.9	2.9	16	1.8	0.9	16	1.5	0.7
Yagana-EHP	81299	12	4.1	2.1	7	2.3	1.2	11	1.2	0.6
Vanigado-EHP	82805	8	1.0	0.5	8	2.9	1.4	8	0.6	0.3
Baiyer-WHP	22124812	16	3.5	1.8	12	2.5	1.2	16	1.3	0.6
Biaru-MORP	96863	12	3.6	1.8	12	1.8	0.9	12	1.6	0.8
Bukawa-MORP	83850	8	3.2	1.6	8	1.7	0.8	8	0.7	0.3
Yalu-MORP	82838	16	4.2	2.1	15	6.4	3.2	15	1.2	0.6
Kobio-MORP	97382	16	2.0	1.0	16	2.9	1.4	16	0.8	0.4
Eware-MORP	97885	16	2.8	1.4	16	2.3	1.1			
Mare-MORP	83331	16	6.6	3.3	16	5.4	2.7	15	0.5	0.3
Paiawa-MORP	95374	15	1.8	0.9	9	1.9	1.0	15	1.1	0.5
Yoidig-MADP	61766	15	4.7	2.4	13	2.1	1.0	15	1.0	0.5
Sarantu-WNBP	70869	14	5.2	2.6	14	3.9	1.9	14	0.7	0.4

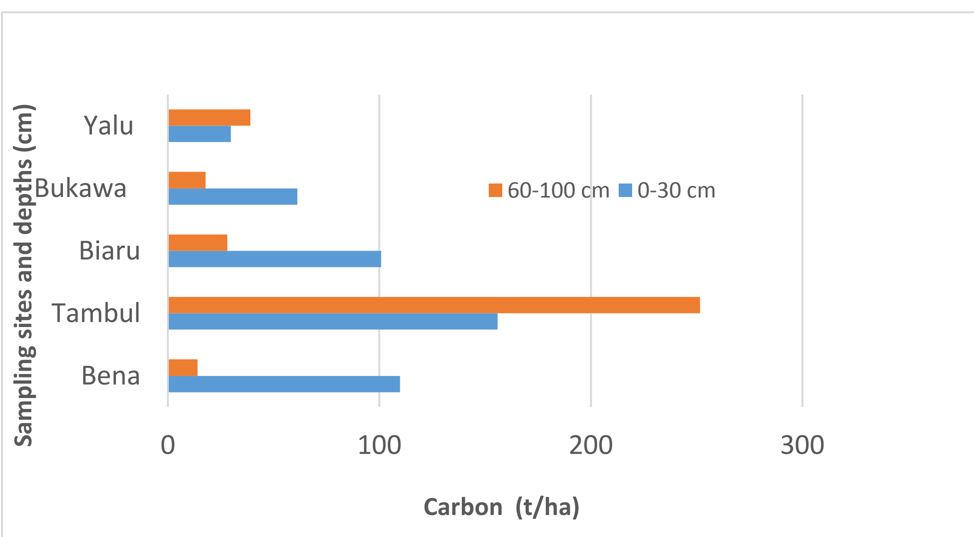

Figure 2: Indicative carbon content by soil depth at selected NFI sites

DISCUSSION

Soil C varied greatly among the surveyed NFI clusters. Tambul had 408Ct/ha which was the highest for the clusters surveyed so far. The soil parent material and land form influences High C was noted in Tambul, Yangana, and Bena are associated andesite and volcanic derived soils. High C at Manabo, 196 C (t/ha) reflects accumulated organic carbon from the alluvial plain. The soils of Yalu had 69 C (t/ha), the lowest compared to other sites, soil derived from siltstone and located active flood plans. Carbon storage capacity of the high-altitude, cool montane forest conditions of PNG were also observed at Kerigomma by Edwards and Grubb (1977), 600 C (t/ha) to 100cm and in Watut, 113 C (t/ha) for 30 cm depth by Nimiago (2011). The studies by Matsuura (1997) and Abe (2007) show that the very high total soil carbon content studied by Edwards and Grubb (1977) are indicative of varying distribution of C in PNG soils on lowlands and mid-altitude sites. Soils in cool areas such as the high altitude forest of PNG has potential for longer storage of C compared with the lowland and coastal warm areas (Table 2).

The clusters at Bena and Tambul in the Highlands has similar terrain, geology, climate, vegetation, forest type and little evidence of natural and human disturbances. However the marked difference in the very high C in Tambul compared to Bena and the other surveyed sites the high and low lands is an area requiring further investigations. Half of the surveyed sites (Table 2) had C with the moderate rating, 91-180 c (t/ha). The sites included both, the low and high altitude areas and good representation of the geology, parent material and land form.

It is generally assumed that over 50% of C in soil is usually within the first 30 cm for undisturbed sites (IPCC 2006). The bulk of SOC is generally concentrated in the 0–15cm soil layer, although this may vary in forest soils (Lal 2005). An analysis on five selected clusters showed, Bena, Biaru, and Bukawa with up to more than half C can be stored in the first 30 cm layer of soil (Figure2). In the soil's upper zone the C input is mainly from decayed organic material. Soils which are derived from the alluvial mudstones and siltstones typical of the area and provide the reservoir of nutrients. Chemical analysis will be interesting to compare the status of C for the broad more areas, Sogeram and Ramu in Madang and other similar areas in Morobe and central province. This is also regarded as the top soil layer, where C content is vulnerable to changes by natural agents or human activities.

Average quantity of litter, coarse woody debris and understory are regarded as preliminary findings of the NFI. Litter biomass and C in Henganofi was higher compared to other forest. However Vanigado had very low litter values which were uncommon. Coarse woody debris biomass was very high at Yalu due to lowland forest with many tree fallen trees at the time of sampling while low values at Bukawa was due to disturbance by floods. Mare forest were seasonally inundated and subjected to floods from the Markham therefore had very low understory plants. Henganofi had the highest understory biomass compared to other sites. This is attributed to cool conditions thus low rate of decomposition under a much closed canopy forest as noted in the field. Apart from rainfall and temperature, forest type with species composition, type and level of disturbances in the forest often influence quantity of litter and coarse woody material and amount of understory plant. There have been few studies on biomass and C estimation only for the litter for some forests of PNG. The initial work described in this paper is foundation for further work within the country for continue national inventory of forest C pools.

Intensive human disturbances and settlement is evidently expanding from the movement of people to establish new hamlets. Subsistence gardening remains mains source to sustain the livelihood of the local population of the area. Carbon pools are being threatened by clearings of forests for growing agriculture cash crops like, coffee, cocoa, coconut, rubber, and beetle nut.

CONCLUSION AND RECOMMENDATION

The NFI soil survey and previous surveys have shown that forest soils of PNG have soil carbon in the range 69–600 t/ha. Many soils on PNG lowlands contain moderate amounts of carbon (91–180 t/ha). Highest carbon values were 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. It is recommended that further work is concentrated in three ecosystems: montane forests, forests of floodplains of major rivers and forested swamps, as the contribution of the soils of these ecosystems to PNG's carbon stocks is relatively not well documented, and is likely to be high. Soil carbon has to be understood and accepted as an important carbon reservoir that will supply this essential element to support any food or tree crop or forest in a site. It is hoped that soil survey is understood, correct procedures with complete description of site and soils enable proper analyses, documentation, referencing, and reporting. Soil has potential to accumulate carbon from the decayed organic matter and if nutrient cycling process is protected and sustained overtime carbon storage is stable and valued under carbon credit business.

Forests of the six surveyed NFI cluster are typical evergreen forests shedding leaves through senescence processes but differ in age, structure and local climatic conditions. Very high accumulation of coarse woody debris recorded at Henganofi reflected prevailing cool and moist forest floor conditions of high attitude montane forest. Understory biomass are comparatively smaller in size compared other two components of above ground biomass measured for the forest floor. Estimates of C stock from understory, litter and coarse woody debris, as a component of the dynamic forest C pool, are valuable as they are indicative of C temporarily held in the forest floor of the surveyed forest types of PNG. The forests of PNG are typically heterogonous in species composition, climate, elevation, and land use and disturbance history. This study provides input for decision-making on areas to sample, and which C pools to evaluate, considering the availability of funding.

With this NFI in PNG, the sampling procedures have been standardized for consistency with IPCC guidelines. Qualified surveyors have been trained and successfully undertake fieldwork. Sampling strategies have been standardized nationwide thus there is greater consistency and accurate field measurements and laboratory results coming in. FAO has really enhanced the NFI capacity with responsible and careful sampling strategies in place.

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Fruit Fly Species Diversity, Distribution and Community Composition in Response to Elevation and Forest Types in Papua New Guinea

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Abstract

Fruit flies (Diptera: Tephritidae) are ecologically important insects in New Guinean rainforest infesting fruits of various forest plant species. They are also of economic importance as fruit fly species attack fruit crops. Adult fruit flies can be efficiently sampled by lure traps where they are attracted by sexual pheromone analogues. These traits make fruit flies an important indicator group that can be used to assess forest ecosystems. Here we study fruit fly abundance, species richness, diversity and community composition in response to forest type and disturbance. The study is a part of the zoological component of the Papua New Guinea Multipurpose National Forest Inventory and includes quantitative samples from 19 sites. Elevation, as a factor, significantly affected fruit fly abundance, richness, diversity and distribution, while forest type and disturbance level showed some to none effect. Highest abundance, richness and diversity were observed in lowland forests and diversity of fruit flies was high in disturbed forest of the highland slightly having resemblance to lowlands undisturbed forests. Many fruit fly species have specific habitats and narrow distribution while a few others are distributed across wider ecological and geographical area. The sampling has captured a large proportion of existing species, demonstrating the feasibility of rapid quantitative biodiversity surveys in rainforest ecosystems.

Key words: diversity, pheromone, lures, frugivorous, community composition, taxa, fauna

Introduction

Dacinae tribe of fruit flies are endemic to subtropical and tropical regions from the Sub-Saharan Africa to Indian subcontinent and across to the Oceania. There are 932 described species of which 461 belong to the genus *Bactrocera*, 196 belongs to genus *Zeugodacus*, 273 to the genus Dacus and 2 to the genus *Monacrostichus* (Drew, 1989, Doorenweerd *et al.*, 2018). Of these, at least 80 are known to infest commercial and/or edible host fruits and fleshy vegetables, causing direct damage to fruit and frequently resulting in trade restrictions (Leblanc *et al.*, 2013). In the tropics, the tribe reaches its greatest diversity in Papua New Guinea with 181 described species (Drew, 2004) and as many as 70 undescribed species still under identification and these including agricultural pests also attack numerous rainforest fruits and are therefore an important component of forest communities (Novotny and Toko, unpublished). Fruit fly is one taxa studied in the zoology component of the PNG Multi-purpose National Forest Inventory project as their presence and role in forest areas can proxy as an indicator of forest health because fruit flies qualify in respect of their large population size, a short life-span, fast reproduction with multiple overlapping generations and rapid reaction to environmental change (Meffe and Carroll, 1997). Novotny *et.al* (2005) studied frugivorous fruit flies in lowlands tropical forest of Papua New Guinea to determine the host specificity, abundance and the number of species attacking various plant species. They looked at plant-fruit fly food web including 30 plants and a total of 29 fruit fly species feeding on them. Forty percent of all taxonomically described species known from PNG were collected from this study. This study looks at fruit fly abundance and species richness, diversity, distribution and community composition in response to forest types and elevation in PNG and also provides much-needed update to fruit fly database information for current and future use.

Materials and Methods

Study Area

The samples for the study were collected from 19 sites from the provinces of Madang, Morobe, Eastern Highlands, West New Britain and Western Highlands Province respectively from which the PNG NFI were conducted commencing in 2016 to current 2018. The selection of forest survey sites (called here clusters) was done by placing random coordinates to satellite maps using *Collect Earth* which is one of the Open Foris software. The sites cover a wide range of the forest types, geographic areas, land-use and climates.

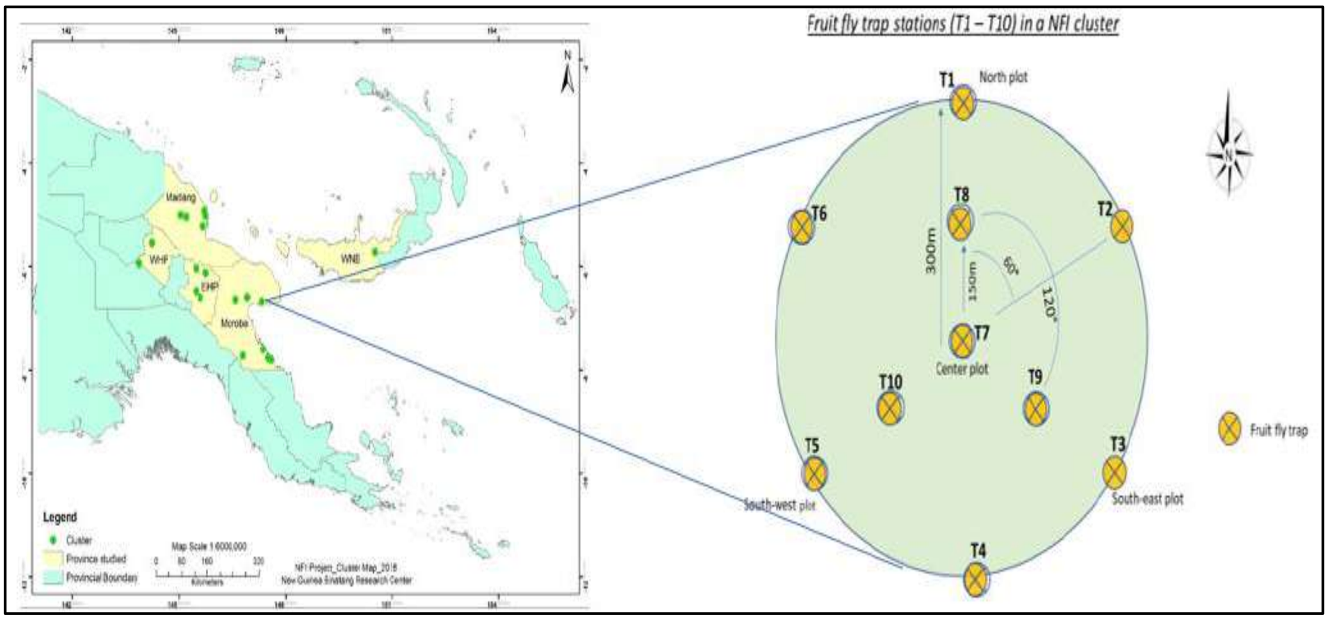

Figure 1 Sites of the 19 NFI clusters sites in PNG from which fruit fly samples were used for this study and the NFI cluster map containing the 10 fruit fly trap stations

Trap Setup and Bait Lures, Specimen Sorting and Identification

For each survey, a cluster contains 10 Steiner traps, each baited with a combination of three lures: Cue lure, Methyl eugenol (ME) lure and Zingerone infused with insecticide, was placed at predetermined locations at 1.5 meters above forest floor within the periphery of the cluster. The lures are mimicking sexual pheromones of fruit flies, attracting approximately 70% of all species (Leblanc *et al.*, 2001). Each lure attracts different species. The advantage of the method is active attraction of fruit flies and also a clean sample of fruit flies only as other taxa do not respond to these cues. Sampling is done at 48 hours intervals. Sorting and identification of specimen is done at the lab and unknown species are given species code and referred for specialist confirmation.

Analysis used Microsoft Office Excel software, Canoco version 5 and Statistica 10, EstimateS version 9.1.0 and R version 3.4.

Results

A total of 4609 fruit flies were collected from the 19 clusters under study and 96 species were identified from the total samples. Each cluster used 10 traps each therefore amounting to 190 traps used in this survey. The seven highlands (>1000 meters above sea level) clusters had a cumulative fruit fly abundance of 403 individuals and 34 species, while the 12 lowlands (<1000masl) clusters had a cumulative abundance of 4206 from which 91 species were identified.

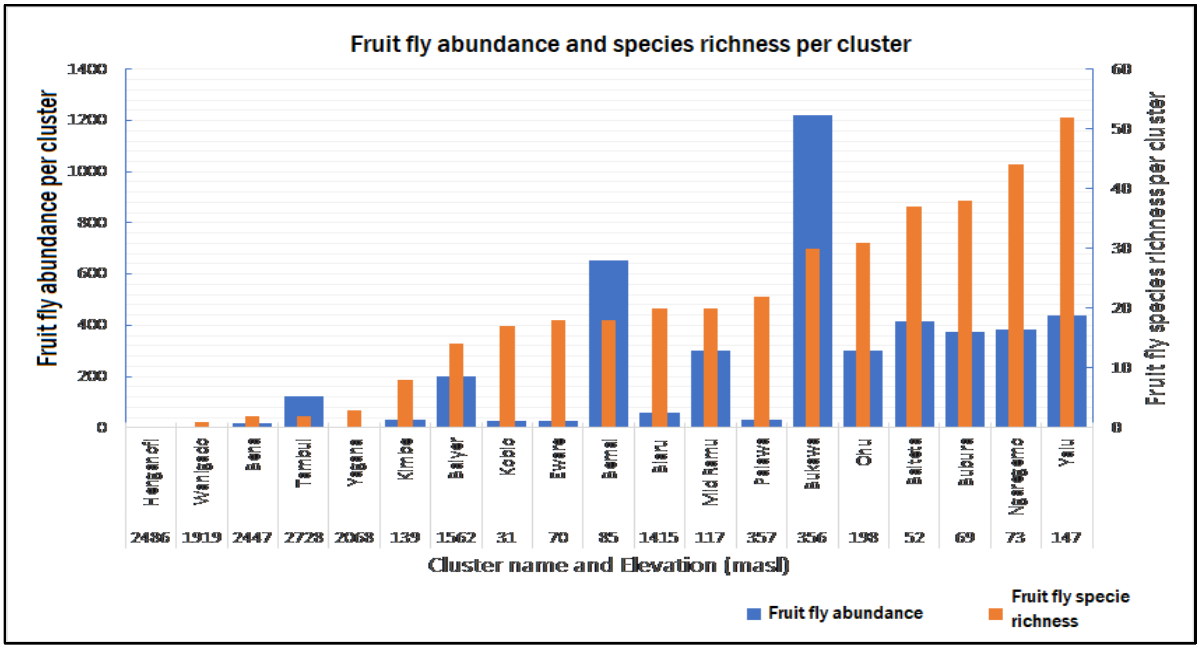

Figure 2 Fruit fly abundance and species richness across elevation

Clusters in low elevation areas below 400 masl of Morobe province (Bukawa, Yalu, and Ngaregemo) and Madang (Bemal, Ohu and Baiteta) had high abundance of fruit flies (Fig. 2). Also, high fruit fly species richness was observed in these clusters. High elevation clusters above 1000 masl retrospect these observations with low abundance of fruit flies including low species richness.

Fruit fly species diversity (Fig. 3) was observed to be high for the low elevation forests while it is quite low for high elevation forests ($F_{1,186}$=94.69, $p<0.001$). Diversity showed no clear response in comparison of the disturbed and undisturbed forests in both elevations ($F_{1, 186}$=0.08, p=ns).

Fruit fly species diversity therefore has a negative correlation (r=-0.6; $p<0.001$) to elevation. Interaction of the factors disturbance and elevation was significant ($F_{1,186}$=9.27, $p<0.01$). Fig. 3 shows a possibility of fruit fly species diversity increase in the highlands disturbed forests to equate diversity of the lowlands undisturbed forests.

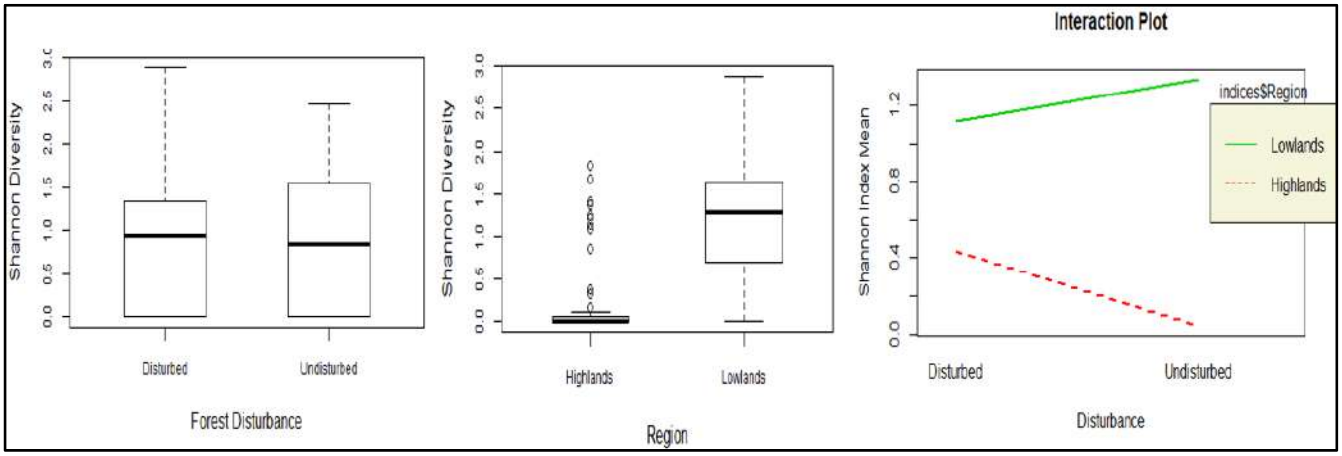

Figure 3 Fruit fly species diversity response to forest disturbance, elevation and interaction observation

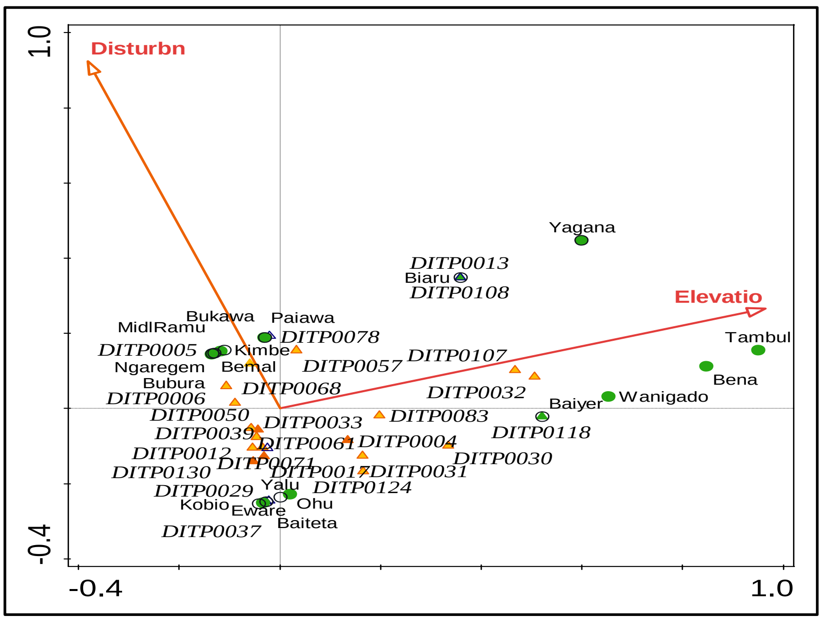

Figure 4 Distribution of fruit fly species in response to elevation and forest disturbance

The ordination diagram (Fig. 4) positions species and clusters according to their optimum distribution from lowlands (center) to highlands (upper right), and from undisturbed (center) to disturbed (upper left). Elevation and disturbance as the two main variables significantly account for 14.8% of the variation (p=0.04).

Discussion

Fruit Fly Species Abundance, Richness and Diversity

The effective response of fruit fly abundance, richness and diversity (Fig.2 and 3) in different sites, across elevations and in different forest types reaffirms its high presence in Papua New Guinea (Drew, 1989; Fletcher, 1998) and the general observation establishes that low elevation forest clusters contain higher fruit fly abundance, species richness and diversity and these decreases as elevation increases. Abundance affects richness and diversity but does not necessarily imply a forest area of high abundance comprises higher species richness and diversity then forest area with lower abundance.

Forest Disturbance Effect on Fruit Fly Species Abundance, Richness, Diversity, Distribution and Community Composition

Forest disturbance was shown to have no effect on fruit fly abundance and richness but fruit fly species diversity for the highlands disturbed forests showed expected interaction to lowlands forest (Fig. 3) in the near future and is a remarkable contrast to note in the light of climate variability, ecological composition and anthropogenic activities. Some biological interactions that are thought to increase diversity, like habitat heterogeneity, predict positive relationships (McCain and Grytness, 2010) supports the observation that disturbed forests of the high-altitude areas shared fruit fly species diversity likely to lowlands forests. Although the response to forest disturbance or loss and fragmentation of native vegetation varies across species, a consistent pattern commonly emerges from empirical studies. The high fruit fly species diversity in the disturbed forests of the highlands having semblance to lowlands forests follows the observation that forest disturbance causes. Species that are negatively affected are usually habitat specialists or endemic to the native vegetation type under consideration, while those unaffected or positively affected are widespread, habitat generalist species, or open area specialists that expand their distribution as ecological adaptation happens (Pardini *et al.*, 2010; Estavillo *et al.*, 2013; Banks-Leite *et al.*, 2014). Undeniably, species responses to the loss and fragmentation of native vegetation have been shown to depend on habitat necessity traits such as niche-breath (Filippi-Codaccioni *et al.*, 2010). Consequently, the loss and fragmentation of native vegetation contributes to what has been termed biotic homogenization (Solar *et al.*, 2015): an increase in the similarity of biological communities across patches, landscapes, and regions (Pardini *et al.,* 2018) from which the fruit fly species diversity of disturbed forests of the highlands has portrayed.

Distribution and Community Composition of Fruit Fly Species

Again, elevation and forest disturbance are two common factors that effects fruit fly species distribution and community composition. This study demonstrates that there are dominant species of certain elevation, species that are fairly distributed and species that are only common to certain region irrespective of factors under observation. For example, *B. abdominingra (DITEPH 0032), Z. alampetus (DITEPH 0030)* and *D. discors (DITEPH 0013)* are species that are common in the highlands surveyed forest areas whereas *B. dapsiles (DITEPH 0083), B. musae (DITEPH 0005), B. papuaensis (DITEPH 0012) and Z. abdopallescens (DITEPH 0038)* are fairly distributed across most part of the elevation (Fig. 4). Other species, such as *B. furvensis (DITEPH 0037), Z. fallacis (DITEPH 0029), B. balagawi (DITEPH 0068), B. rhabdota (0017), B. trifaria (DITEPH 0050), B. aurantiaca (DITEPH 0061), B. frauenfeldi (DITEPH 0071), B. tryoni (DITEPH 0033)* and *B. abdonigella (DITEPH 0006)* are more common species of the lowland forests. Forest disturbance had low effect on the distribution and community composition of fruit fly species and this may be due to close resemblance of fruit fly species diversity of highlands disturbed forest and lowland forests.

Host Plant Distribution

The distribution of host plants in the terrestrial areas of lowlands, islands and highlands also importantly determine fruit fly species diversity, distribution and composition. Novotny *et al.*, (2004) indicated a total of 53 plant species as hosts of fruit flies in the lowland forests of which the common plant families are *Ochrosia*, *Garcinia*, *Syzyzium, Gnetum, Anacardiaceae, Apocynaceae, Rubiaceae and Myristicaceaei*. This confirms the high number of fruit fly species sampled in this NFI study in the lowlands area while for highlands, very little data is available on rainforest fruit fly host study. The low number of fruit fly species sampled in this study implies fewer host plants in the higher elevation forests and also the climatic effect at higher elevations.

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Effects of Habitat Type and Elevation on Bird Communities in Papua New Guinea: Exploration of Beta-Diversity, aApha-Diversity and Abundance

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Abstract

Aim: This study was conducted to investigate the effects of habitat type and elevation on bird communities across Papua New Guinea and to assess trends in their beta-diversity, alpha diversity and abundance in response to environmental factors. The analysis also focused on individual feeding guilds.

Location: The study was carried out in 13 study sites in Papua New Guinea which included Bena, Henganofi and Okapa districts in Eastern Highlands, Dei and Tambul districts in Western Highlands, Huon Gulf, Bulolo and Nawae districts in Morobe Province and Sumkar district in Madang province.

Methods: The research relied on Point count methods (Seven-point count stations per site where 15 minutes was spent recording birds within 50m radius at each point); supplemented by Mackinnon lists and Song meter recorder run for 48 hours per site.

Main conclusions: We have recorded 231 bird species and have 6,835 bird individual records from 7 point-counts at each of the 13 study sites. The number of species was rising rapidly for the first 40-point counts, and then slowed down but continued increase for the entire sampling. Species diversity of birds decreased with increasing elevation. Individual species have shown preferences in their distribution for specific elevations, but less so for a particular disturbance intensity. The species accumulation curves within each study site showed also steady by slow increase in species diversity, with observed species numbers close to those predicted by Chao 1. The point counts were able to record significant proportion of local bird communities and regional species pools even within limited sampling protocol completed in three days per site. The bird communities were dominated by insectivores, closely followed by frugivorous, with nectarivores and especially carnivores low.

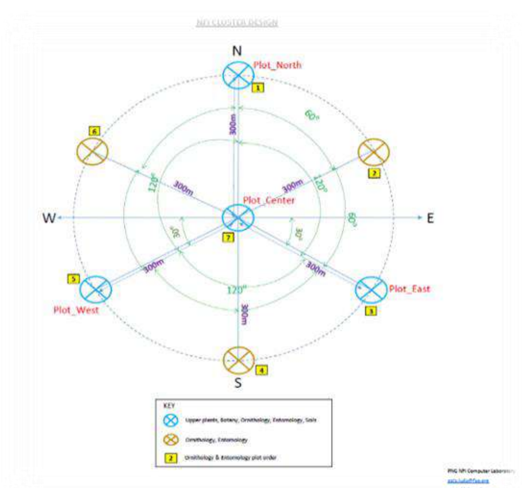
Keywords: Diversity, elevation, habitat types, species, clusters, abundance.

Introduction

This is Papua New Guinea's first and biggest ever National Forest Inventory (PNGNFI) surveys conducted focusing on flora and fauna. The Island of New Guinea is home to 780 species of birds (Pratt & Beehler, 2015). Among them, approximately 740 are present in Papua New Guinea (PNG) (Coates *et al.*, 1985) and 365 are endemic to the New Guinea region (Coates *et al.*, 1985). PNG is home to one of the world's four great tropical avi-faunas, separated in its history and evolution from those of Asia, Africa, and the Americas (Pratt & Beehler, 2015). The region is noted for being home to a rich and distinctive humid forest avifauna characterized by cassowaries, megapodes, pigeons, parrots, cuckoos, kingfishers, owlet-nightjars, (Pratt & Beehler, 2015). The latter include hundreds of small insectivores belonging to numerous families and most renowned of all, the birds of Paradise and Bowerbirds (Pratt & Beehler, 2015). The National Forest Inventory (NFI) surveys were conducted at various elevations, habitat types investigating beta and alpha diversity and abundance of birds but few papers have looked at species diversity across intact and disturbed forests at different elevations. This article seeks to address that gap in the literature by analysing data collected through PNG's first National Forest Inventory (NFI). In this paper we present data collected from 13 clusters of survey plots in the Eastern Highlands, Western Highlands, Morobe and Madang provinces in Papua New Guinea. We analyse this data from disturbed and undisturbed habitat types and different forest types in Papua New Guinea. We recorded 231 species of birds from 6,835 individuals. We discuss the implications of our results for better forest conservation in PNG.

Materials and methods

This study is part of the Papua New Guinea National Forest Inventory (PNG NFI) project. PNG NFI aims to establish plant plots throughout the country to collect empirical biological data to inventory PNG biodiversity. These biological data include plant and animal taxa. Animal taxa include arthropods and birds. This thesis reports the biodiversity inventory of the bird component for a portion of the whole inventory. The plots were selected randomly across the country with random number generator, but here we analyse the study sites from four provinces only (Eastern Highlands, Western Highlands, Morobe and Madang, (Figure 2). The studies were carried out in 13 sites in Papua New Guinea. The sites ranged in altitude from 69masl to 2728masl. The surveys were conducted from May 26th 2017 to 25th June 2018, equally distributed between wet and dry seasons. To survey bird communities, we used point-counts, MacKinnon lists and acoustic recordings (Song Meter Acoustic SM3), but the present analysis is based on point counts only. At each study site, seven-point counts were located 300m apart from each other in a circular plot (Figure 1). Each point was surveyed for 15 minutes, and to survey all 7 points thus took 105 minutes. All birds detected visually or based on call were recorded. We started the point count at 6.00am at point number one (Figure 1) at the North plot and ended in the centre plot (point 7) at 11.00 am. A shot-gun recorder was also used during the point count to record bird calls for potential further call identification or confirmation. The birds were recoded within 50m radius from the observer. Mackinnon list surveys were carried out by walking along cut trails and when the first 10 species are recorded, we move on and repeat the same process. Song meter recorder was placed at the NE point and run non-stop for 48 hours. At the end of each survey day, species checklist for each site was made, and all birds detected during the day and between the standardized surveys were recorded there.



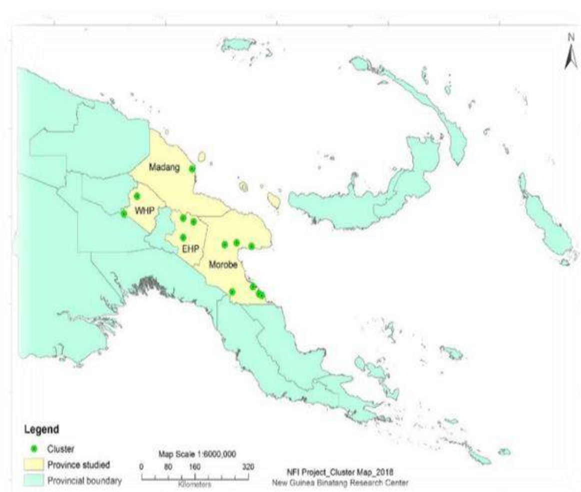


Figure 1 & 2. Sampling design for the NFI surveys and Map of all NFI clusters surveyed from 2017-2018.

Statistical Analysis

We used parametric *t* test to examine the differences between forest categories, including forest types and disturbance categories. The relationships with continuous variables, particularly elevation, were examined by Pearson correlation. The total number of expected species in the samples was calculated using Chao 1 index, based on the ration of common to rare species (singletons and doubletons) in the samples. This index is defined in EstimateS software that was also used for its calculation. The EstimateS was also used to generate randomised species accumulation curves where the increase in the number of species was related to the number of point counts. The bird diversity was estimated by simple count of species and by the Shannon index of diversity, taking into account also abundance of individual species. The Shannon index was calculated using EstimateS. The beta diversity of bird communities was quantified by Jaccard index of similarity, calculating the proportion of shared species between two samples. The relationships between similarity index and altitudinal differences between pairs of samples was tested using Mantel test rather than standard Person correlation since the pairwise comparisons are not independent data points (78 pair-wise comparisons were generated from 13 independent study sites). The Mantel test was calculated using R script. Change in species composition of birds in response to environmental variables was analysed using multivariate methods, particularly direct Canonical Constrained Analysis (CCA) that assumes unimodal distribution of species along environmental gradients tested (such as elevation or disturbance) and extracts variability in species composition that can be explained by these gradients. The significance of environmental gradients was tested by Monte Carlo tests that randomly re-shuffled the environmental values assigned to individual samples. The CCA ordination allowed examining also the preferred position of individual species along the gradients examined, such as the optimum elevation for each species. The ordination was performed in Canoco 5 software. The altitudinal distribution of each bird species was described by (i) minimum elevation, (ii) maximum elevation, (iii) elevation range: max–min elevation, and (iv) mean elevation, i.e. the average elevation for all individuals of the species. Standard statistical tests were performed using the Statistica 13.3 software. Graphs were generated in MS Excel.

Results

We have recorded 231 bird species and have 6,835 bird individual records from 7 point-counts at each of the 13 study sites. This represents 740 PNG bird species known from the main island (Pratt & Beehler, 2015). The number of species was rising rapidly for the first 40-point counts, then slowed down but continued increase for the entire sampling (Figure 3). This trend suggests that we have not sampled the entire bird diversity. However, the Chao 1 estimate of the total number of species has almost reached an asymptote and 250 species, suggesting that we are only missing approximately 20 species from the species pool including our study sites (Figure 3). The bird communities were dominated by insectivores, closely followed by frugivorous, with nectarivores and especially carnivores low. The order of importance of individual guilds was the same whether we considered number of species or individuals (Figure 5). However, while the dominant insectivores were sampled by approximately 20 individuals per species and the frugivorous reached 25 individuals per species, the nectarivores had highest abundance per species, almost 40 individuals. It therefore appears that for the three most abundant guilds, high species diversity is accompanied by low abundance per species. The importance of individual guilds also changed between forest types. The species diversity at each site is related to the abundance of birds, as there is a significant relationship between the number of individuals and species that across the sites. The results show that the species diversity of birds decreases (Figure 10) with increasing elevation, although this decrease is a very slow one. The linear regression between elevation and number of species was significant, although a quadratic function indicating very slight increase in bird diversity at mid-elevation provided slightly better fit than linear function. I have also examined whether the small-scale change in bird community composition, from one-point count to another within the same site, changed with elevation. In other words, I tested whether beta diversity at each site depended on its elevation. This was done by calculating Jaccard similarity for all pairs of seven-point counts at each site and relating the mean value to the elevation of the site. The abundance of birds is closely related with the number of species recorded per site (Figure 9). The relationships between mean elevation and elevation range was characterized by quadratic function, with mid-elevation species having widest elevation ranges distribution between mean elevation and altitudinal range for bird species. The species with mid elevation distribution had wider altitudinal ranges than lowland or high montane species (Figure 13). Shannon diversity index for disturbed and undisturbed forests showed no difference in species diversity between the two habitats (Figure 14).

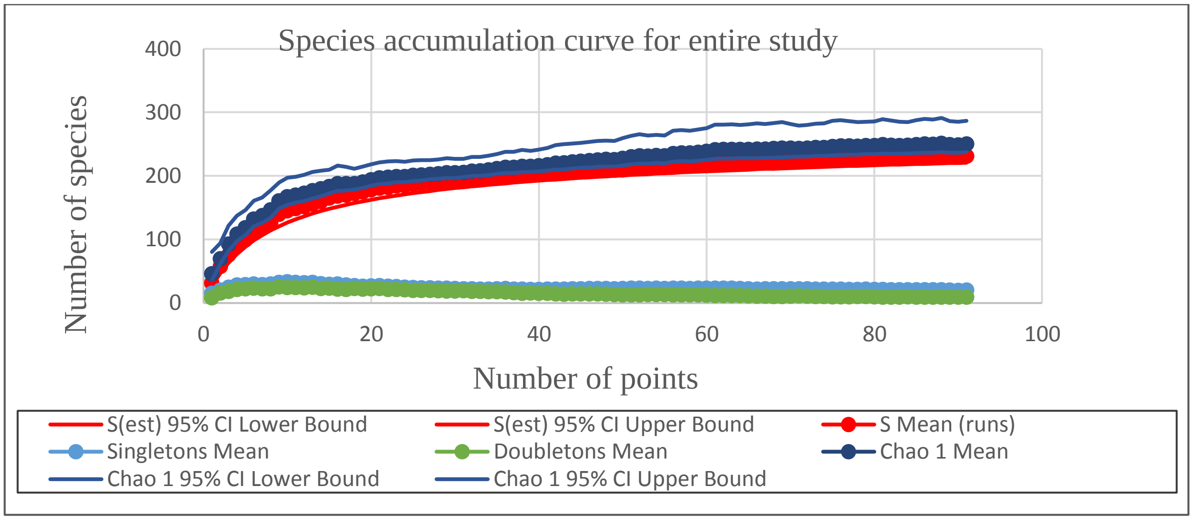
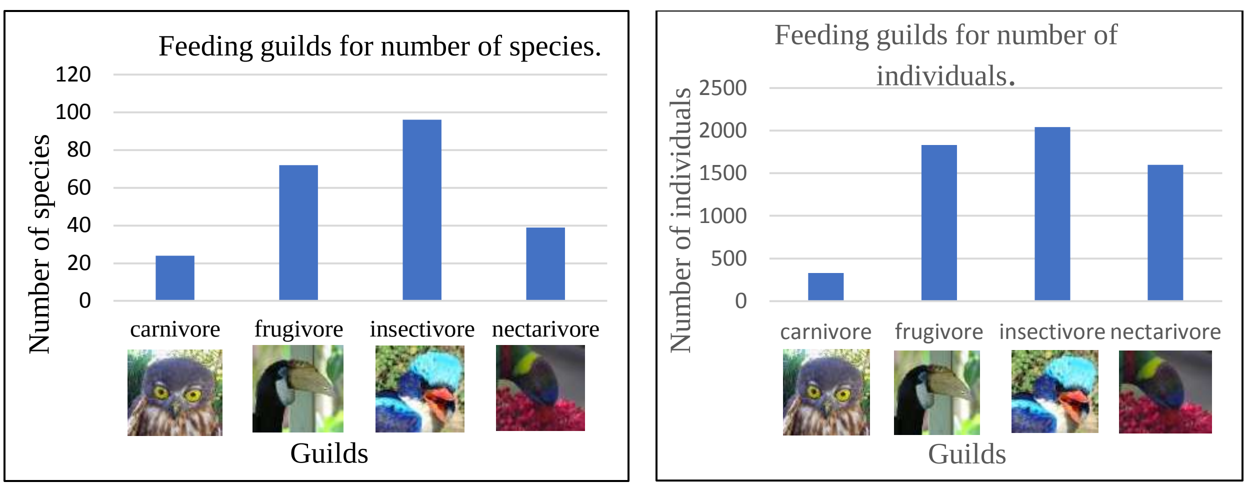


Figure 3: The species accumulation curve with increasing number of point counts across the entire study area shows the number of observed species (with 95% confidence intervals), the total number of species estimated by Chao 1 (with 95% confidence intervals), and the numbers of singleton and doubleton records.



Figures 5 & 6. Number of bird species and individuals from individual feeding guilds represented in the overall data.

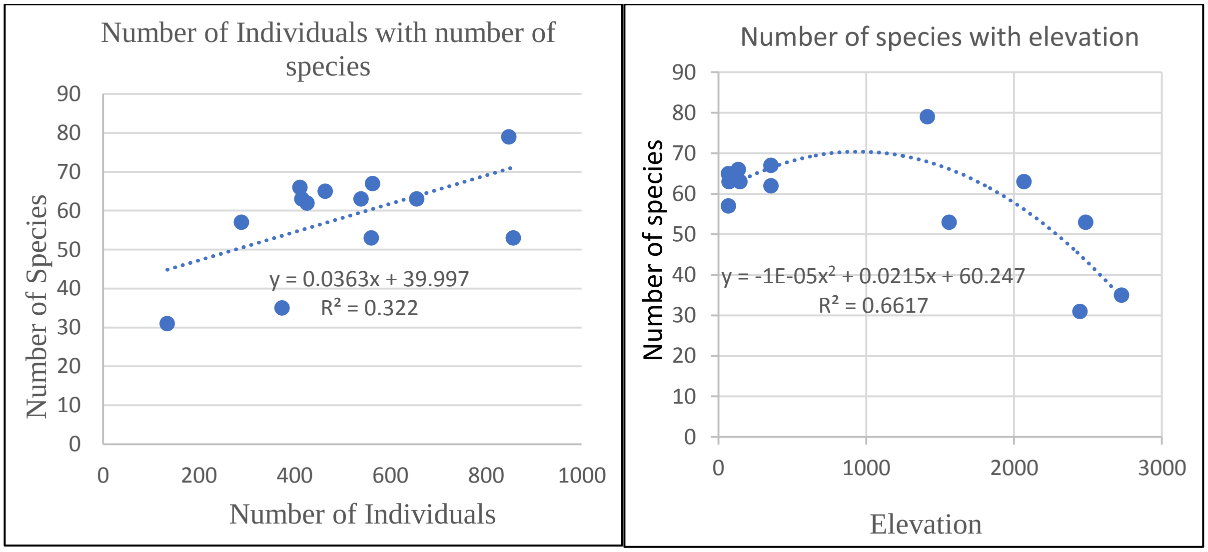


Figure 9 & 10. The abundance of birds is closely related with the number of species recorded per site (r=0.56, r2=0.32, N=13, P=0.043) while number of species decreases with increasing elevation.

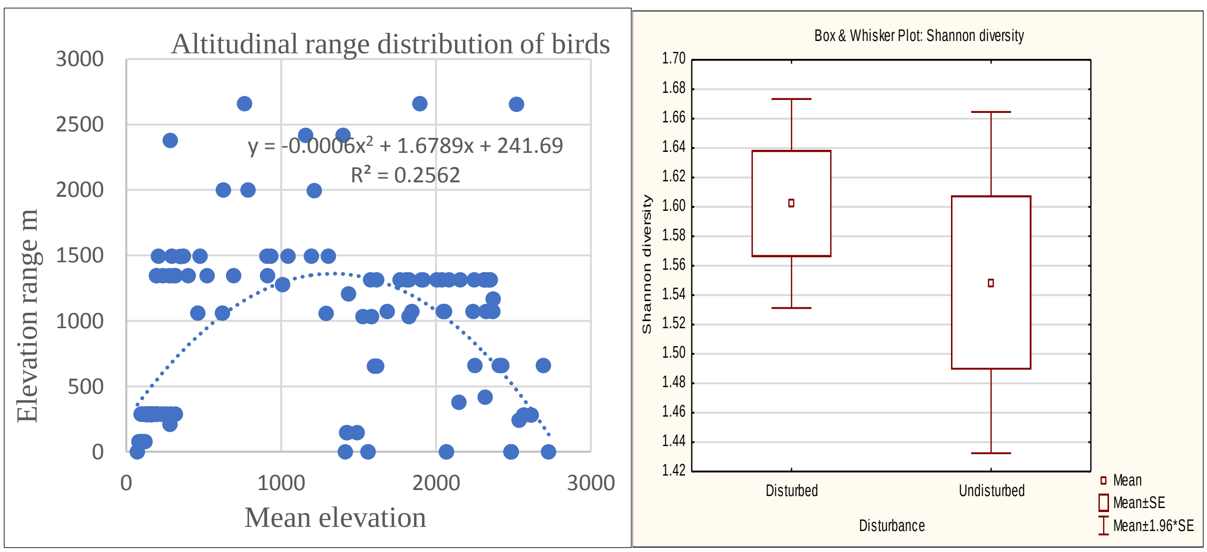


Figure 13 & 14. The distribution between mean elevation and altitudinal range for bird species. The species with mid elevation distribution had wider altitudinal ranges than lowland or high montane species. **Figure 14:** Shannon diversity index for disturbed and undisturbed forests showed no difference in species diversity between the two habitats. (P=0.4401, t- test= 0.80, df= 11).

Discussion

Our study showed for the entire survey that as we increased in elevation, the number of bird species decreased steadily. In our data, low elevations had consistently more species than the higher elevations. This pattern is the most commonly found in bird communities, including at Mt Wilhelm (Sam *et al.*, 2018) and New Guinea in general (Pratt & Beehler, 2015), but it is not the only pattern possible. Numerous bird communities also showed low elevation plateau in species richness, followed by decline toward high elevations, or a mid-elevation diversity maximum (McCain *et al.*, 2009). However, monotonous decline is species diversity is particularly common in wet tropical forests, such as the ones studied here. According to the study at Mt. Wilhelm, the decline in species diversity is best explained by decreasing vegetation complexity, land area, and temperature with increasing elevation

(Sam *et al*., 2018). Insectivorous birds have been shown to be highly sensitive to habitat structure (Sekercioglu, 2002) and to changes in availability of micro habitats (Stratford and Stouffer, 2013). Insectivores were dominant at low elevations, while frugivores at higher elevations in bird communities (Sam, *et al.,* 2017). On the other hand, insectivores remained the dominant guild along entire elevational gradients (Sam, *et al*., 2017, 2018). The relative species richness of feeding guilds corresponded to overall trends in the importance of food types (Sam *et al.,* 2017). The elevational Rapoport's rule predicts an increase of elevational range size with higher mean elevations for bird species (Beck & Liedtke, 2016). This is an extension of the original rule noted for latitudinal range that increases with mean latitude for many animal and plant species. This means tropical species remain distributed within a narrow latitudinal belt, while temperate zone species range across many latitudes. The reason for this pattern is that temperate zone species encounter large variability in temperature in the course of every year due to seasonality so it makes easier for them to move also across latitudes. The altitudinal modification of the Rapoport's rule also suggests that at high altitude it is increasingly difficult to stay within a narrow altitudinal range because of diminishing land area available at high altitudes. Species of birds must move across a range of altitudes, while in large tropical lowlands they have vast areas available within narrow elevation range. For instance, in PNG there is more land within 0-100masl than within 101-4507m elevation range. However, the validity of altitudinal Rapoport's rule in the tropics has been controversial. In our study the rule does not apply as both lowland and high montane species have smaller altitudinal ranges than mid-elevation birds. Bird species did not turn to favour either disturbed or undisturbed forests. This result may be due to the availability of food source in both habitats. Whether the birds are more species rich because ecological conditions allow for more species to be there or whether higher food supply allows for more individuals and therefore also species is not clear. In secondary and disturbed forests, there are higher densities of herbivorous insects than in primary forests (Whitfeld *et al*., 2012) and also pioneer trees are more frequently fruiting than primary forest trees (Turner 2001), providing thus higher quantity of food for both insectivores and frugivorous. In contrast, primary forest is an ecologically more diverse environment than secondary forest, with larger trees, more structured canopy and higher diversity of plant life forms (Turner *et al.,* 2001).

Conclusions and Recommendations

Overall, montane bird species may respond to global warming by shifting their distributions upslope in response to warming temperatures. Warming temperatures are having some direct effect on bird communities moving upslope to colder/cooler climates according to a study conducted in PNG (Freeman & Class., 2014). Species richness of insectivorous birds' decreases faster than species richness of other feeding guilds with increasing elevation. The insectivorous birds along Mt. Wilhelm represented a higher proportion of the avian community at higher elevations (52% at 3700masl) than in lowlands (45% at 200masl). The relative species richness of feeding guilds corresponded to overall trends in the importance of food types in food samples according to study by (Sam, et al 2017). Sound recordings perform at least as well as, if not better than, point counts for assessing bird species richness. However, recordings cannot be as effective as point count Songbirds (oscine passerines) are the most species-rich and cosmopolitan bird group, comprising almost half of global avian diversity (Moyle *et al.,* 2016). Songbirds originated in Australia, but the evolutionary trajectory from a single species in an isolated continent to worldwide proliferation is poorly understood. A recent hypothesis for songbird diversification identified New Guinea as an ancestral range for many nodes deep in the songbird tree, especially within the Corvids. Without visual detection, recordings will not detect silent species, and a thorough avifaunal inventory of a given area is impossible with- out skilled observers in the field. Also, rarely calling species may sometimes be overlooked when using a directional microphone capsule. Sound recording is particularly well-suited to studies focusing on forest passerines in which data are to be collected from many different sites. With some refinement and of the methodology, sound recording has the potential to provide an effective, time efficient tool for avifaunal surveys. Based on the experience from the present study, we suggest continuing with similar studies using the present sampling protocol in the future to document the bird communities and fauna of Papua New Guinea. Sample all elevations across the country so that there are no major gaps, and also the differences among individual montane ranges, main islands, and other geographic regions are captured. The National forest Inventory (NFI) is likely to continue surveys at least until March 2019 but it is desirable to continue beyond this time frame. The field surveys, done almost always in forests owned by indigenous landowners, need to be combined with awareness in local communities about the importance of such research and the need for conservation of their forests (flora and fauna) for the next generations to come. This should be done in person by the researchers as well as by sharing the research results in accessible form with the village landowners, such as to produce brochures and posters about the importance of plants and animals and educate our young children at an early age in schools so that they grow up to take care of the biodiversity in their local communities. I think this is the way forward for Papua New Guinea if we are serious about protecting our wildlife for our future generations.

Acknowledgments

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Diversity and Community Composition of Ants in the Forests of Papua New Guinea

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Abstract

The island of New Guinea is a highly hotspot of ant diversity in the world. Previous studies in New Guinea and elsewhere have provided important scientific information about effects of elevation, sampling approaches, arboreal ant communities and other community parameters important on ant species richness and diversity. However, our knowledge of ant's ecology must now include also the impact of anthropogenic activities such as climate change, disturbances combining with altitudes and forest types which will enable us to understand some processes involved in maintaining such biological diversity. Here we used tuna baiting supplemented by hand collection to investigate diversity and community composition of ants, spanning over a total length of 9.6 km transect from 28 to 2700 m asl. We have found 176 species of ants from exposing 297 tuna baits and 72 hand searched plots. This represents 20% of the known species from New Guinea. Baiting samples were strongly dominated by few common species whilst hand searched plots captured more-rare species. The Chao 2 estimator for both methods predicted higher species diversity, despite our searched for ants over the total length of 9.6 km of transects. As expected, ant species diversity and richness significantly decreases with increasing elevation.

Our study documented higher diversity of ground-based ant communities at tuna baits in disturbed compared to undisturbed forests. However, the forest disturbance exhibited much smaller effect on the species composition in ant communities than elevation. Thus, availability of selectively logged forests where diversity of ants may be increased by a mosaic of secondary and primary habitats and maybe driven by the differences in ant communities with disturbance are driven by the fact that undisturbed communities were sampled at all elevations, while disturbed communities were not sampled at high elevation.

Keywords*: Ants diversity, elevation, forest disturbance, New Guinea*

1. Introduction

The National Forest Inventory is the biggest project to gather scientific information from plants, focal insect taxa and birds. For the first time, the inventory combines zoology and botany targeting various forest types across Papua New Guinea. This will develop Papua New Guinea's capacity to carry out national forest monitoring in botany, entomology and ornithology in the future and also generate base-line data on the PNG forests to monitor changes in the years to come. PNG is rich in forest types, varying from extreme ecosystems such as mangrove swamps or savannahs to the dense natural tropical forest spanning the entire altitudinal gradient (Paijmans 1970). These varying ecosystems combine with the New Guinea complex geological history, serving as an ideal natural laboratory for biodiversity research. The keystone taxa of the National Forest Inventory (NFI) include woody and herbaceous plants, as well as the zoological component that consists of a diverse vertebrate group – birds, and three insect taxa representing keystone group of predators – ants, and two herbivore groups feeding respectively on fruits and leaves – fruit flies and geometrid moths. The present study will focus on ants.

Ants are eusocial insects, omnipresent and one of the most diverse, abundant and ecologically important insect taxa in terrestrial ecosystems around the world (Klimes *et al*. 2012). According to the Checklist of ants of New Guinea (Janda *et al*. 2017) we are able to say that Papua New Guinea is one of the most important tropical hot spots of ant diversity. The updated version of the website has about a total of over 900 ant species. This study aims to analyse ant communities across a variety of forest ecosystems in PNG surveyed during the National Forest Survey, and identify ecological variables such as vegetation traits, altitude, and climatic factors, which are the main drivers of ant community composition and diversity. In addition, it will build PNG capacity in the analysis and identification of ants, and important component of forest ecosystems as well as unique reference collection of PNG ant species.

2. Methods

We used two sampling methods, tuna bait and hand collection to sample ant communities in various forest types. We established a 600 transect and exposed 20 baits (Fig.1). Tuna bait is made from tinned fish with 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. Ants were collected by 2 persons from 2 x 2 m plots 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 treated individual sampling units (tuna bait traps, hand collection plots) as statistically independent samples for some analyses, while they were combined for other analyses using the entire samples from 20 baits, or 10 plots, as statistically independent samples. Data were converted to presences/-absence dataset and the proportion of traps (or plots) where a given ant species was present within the cluster was used as a measure of abundance. Sample-based species accumulation curves (Colwell 2012b; Longino 2002) were generated to see the change in relationship between sample size and ant species richness and diversity for different forest types, based on elevation and disturbance. Randomized species accumulation curves were produced with ±95 % confidential intervals using the software EstimateS version 9.1.0. (Colwell, 2012). The observed number of ant species occurring per sampling unit (trap/plot) was compared with the Chao 2 estimator of the total number of species in the sampled system (Colwell 2012; Chao 2005; Longino 2002).

Statistica software was used to test the strength of the relationship (Fig. 2). Thus, it shows that it has a significant difference between elevation and ant species composition. Two highlands clusters were excluded from this analysis because we didn’t collect any ants. Canonical correspondence analysis (CCA) was used to test the relationship between the elevation and species composition of ants across the seven clusters in Canaco5.

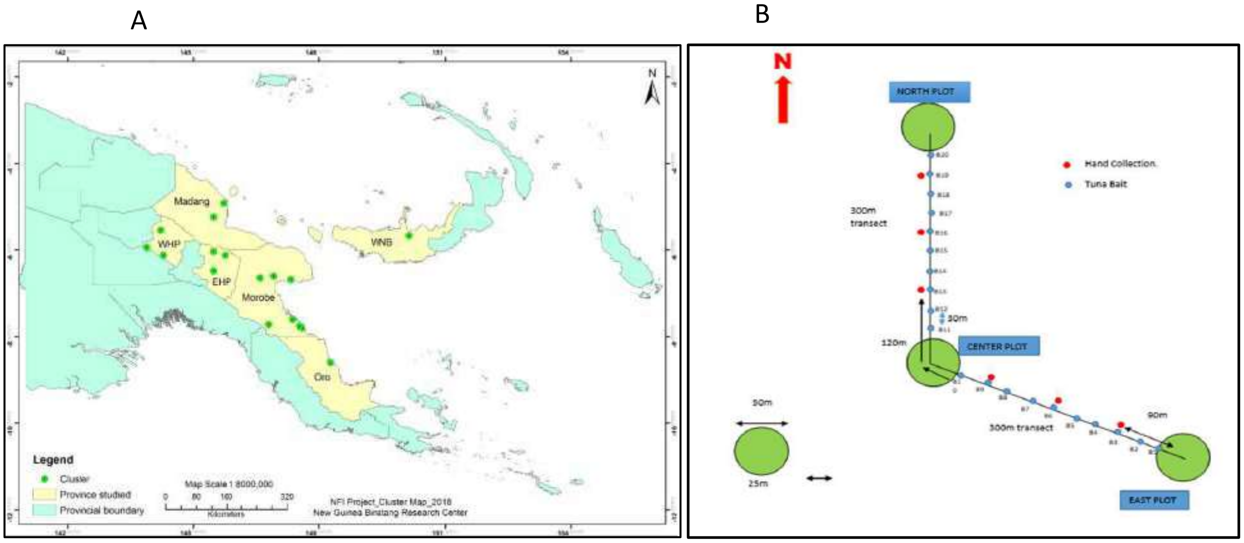

Figure 1. Study sites of ant collection (A) and sampling design of bait and hand collection (B).

Results

We recorded a total of 1753 individuals' representing176 morph species from 42 genera and six subfamilies. This data set resulted from exposing total of 320 tuna baits (including 279 baits occupied by ants) and hand searching 72 plots (24 missing as the landowners did not allow access to them). We captured a total of 61 species present only in tuna bait samples and 51 species exclusive to hand search while both sampling methods shared 64 species. Regarding forest disturbance, 47% species were found only in disturbed forest, 27% only in undisturbed forest and 26% were shared between the two habitats. In terms of taxonomic composition, Myrmicinae constitutes 56% of species diversity (97 species), followed by Formicinae with 19% (34 species) and Dolichoderinae with 13 % (22 species). These proportions reflect their general diversity share in New Guinea ants (P. Klimes pers. communication). Further, listed are the five species rich genera, (with >5 species), Pheidole with 56 species (32% of species total), Camponotus with 12 species, Tetramorium with 11 species, Anonychomyrma with 8 species and Polyrhachis with 7 species. These are known species rich genera also reported as such by other studies from PNG (Moses 2015; Klimes 2012; Janda 2007). The CCA analysis using both elevation and disturbance as environmental factors explained 13.64% of the variability in sample composition by CCA1 and 20.47% when CCA2 was also included. The impact of the explanatory variables were significant (Monte Carlo test on all axes: pseudo-F=1.3, P=0.008). The single factor CCA analysis explained 13.6% of the total variability as associated with elevation (i.e. CCA1). The effect of elevation was significant (Monte Carlo test on CCA1: Pseudo-F=1.3, P=0.004). However, there was also a significant variability not associated with elevation as CCA2 axis contributed additional 13.1% of explained variance. The analysis also showed distributional optimum of species from low elevation (low CCA1 scores) to high elevation. A separate analysis of disturbance explained only 7.0% of variability (CCA1) and disturbance was not significant factor determining species composition of ant communities (Monte Carlo test on CCA1: pseudo-F=0.8, P=0.954).

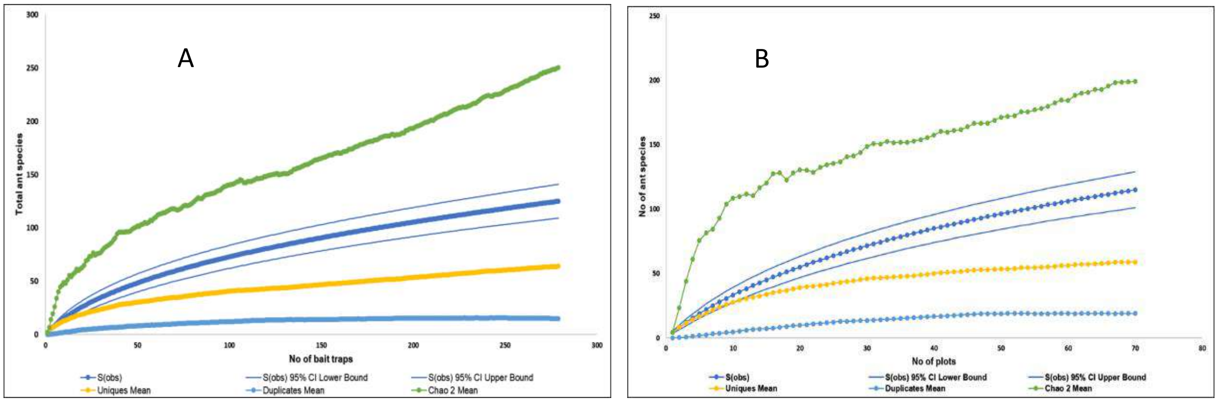

Figure 2. Species accumulation curve for observed S (obs) species recorded from baiting traps (A) and hand searched plots (B) with ±95% CI, with Chao 2 estimator of the total species richness. Unique (present in one sample) and duplicates (in two samples) were used to calculate Chao 2.

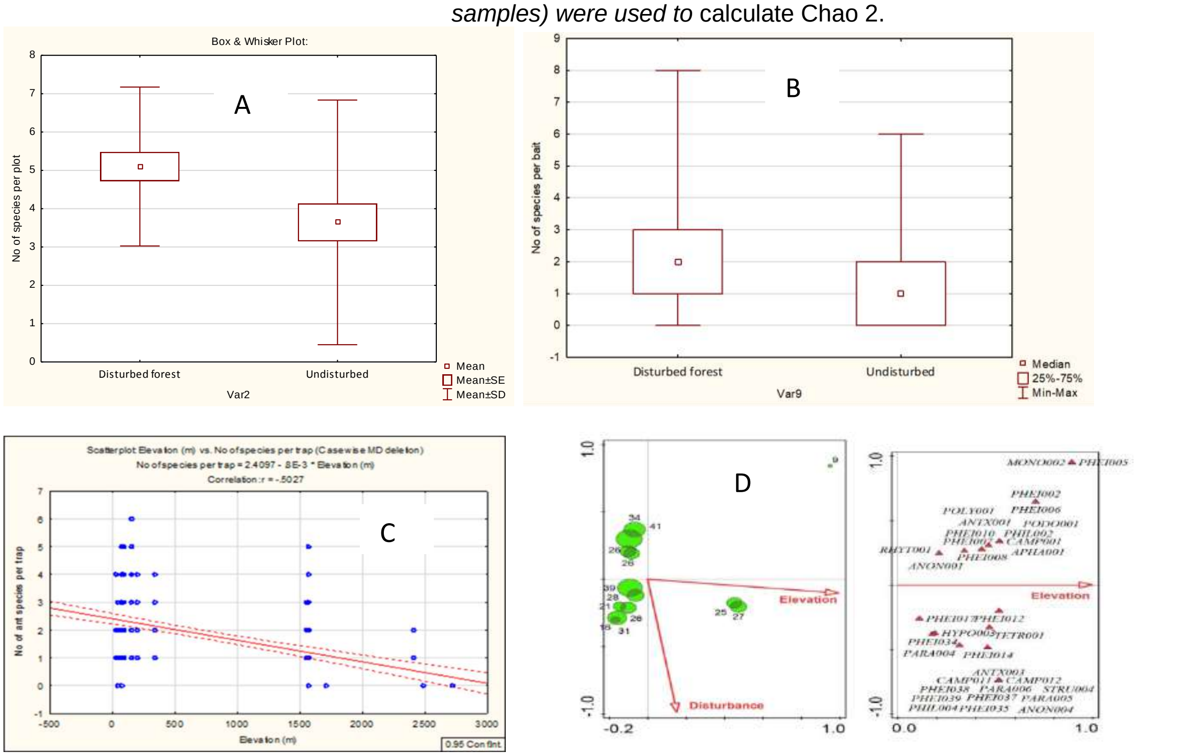

Figure 3. Ant species richness for bait(A) and hand collection (B) in undisturbed and disturbed forests.There is a significant difference between the two major habitats (t-test=2.1899, df=70, p= 0.0318). There is significant difference between forest types (Mann-Whitney test Z=6.8534, p≤= 0.001) (B). There is a significant negative correlation between ant species richness and elevation (C) and Canonical Correspondence analysis (CCA) results shown for the study sites with elevation and disturbance as explanatory variables (the size of each circle corresponds to its species diversity) and separate CCA analyses for elevation and disturbance showing the distributional optimum of the 34 most common ant species (sampled by ≥5 times) (D).

Discussion and Conclusion

Altogether, 176 species from this study represents 21% of the known regional species richness. This is a lower proportion than previous studies along Mt Wilhelm altitudinal gradient with 26% (232 species) (Moses 2015). However, Moses used four different sampling methods (tuna baits, pitfall traps, hand collection, and sugar/lipid/protein baits to study feeding preferences). The Chao 2 estimator for both methods predicted even higher species diversity, despite our search for ants over the total length of 9.6 km of transects. This conforms to the notion by E. O. Wilson that every time we move to a new site, new species are discovered in the New Guinean rainforest (Wilson 1958).

The taxonomic composition comprising of six subfamilies and 42 genera from our records corresponds to other studies in New Guinea (Moses 2015; Klimes 2012; Janda 2007) and other tropical countries (Yusah 2011; Tanaka *et al*. 2010; Schulz & Wagner 2002; Wilkie *et al*. 2010). The 56% of the genera in our collection belongs to the world wide super diverse subfamily Myrmicinae, followed by Formicinae with 19% of genera. The most species rich genus was Pheidole with 32% (56 species), one of the super diverse genera of ground dwelling ants worldwide (Bolton 2013). Pheidole was reported to be mostly found in leaf-litter or moist conditions (Wilson 1958) even some species can be found foraging at the tree trunks and canopy (Klimes 2011). Interestingly, the hyper diverse genus for canopy ants, Camponotus, ranks second in our samples as it represents 7% of species in our assemblage. The significant and rapid decline in species richness of ants with elevation as found by both methods (Fig.3c) used here is a general pattern observed elsewhere in the tropics. There are numerous other insect taxa showing steady decrease in diversity with elevation in the tropics, including butterflies (Sam 2011; Despland *et al*. 2012), fruit flies (Sivinski 2000), or leafhoppers (Dem 2011). However, the decline in species diversity in ants is particularly steep as they entirely disappear in higher montane forest above 2500 m asl. (Orivel *et al*. 2018; Mittelbach 2007; Moses 2015). This is in contrast with for instance butterflies or leafhoppers that persist to the timberline (e.g. Mt. Wilhelm at 3700 m asl.; Novotny & Toko 2015). This rapid decline, recoded in PNG also by Moses (2015), is similar to the decrease in another social insect taxon, termites (Palin *et al*. 2011). Species at lower elevations in temperate regions tend to recruit from various phylogenetic lineages so their community is structured by interspecific competition, while species at high elevation are closely related, structured by environmental filtering caused by low temperature (Machac 2010). The niche constrains, temperature and competition shaped composition in ant communities (Wilson 1955). The decrease in ants with elevation has important ecological consequences, particularly decrease in predation pressure on herbivore insects with elevation (Roslin *et al*. 2017). Species turnover along elevation gradients is an important generator of species diversity, as elevation gradients combine species with different ecological and climatic requirements, segregated by elevation, over small geographical areas. That is why high tropical mountains belong to among the most diverse regions in the world (Barthlott *et al*. 2007). This principle is illustrated by the declining similarity among ant communities with increasing difference in altitude between the communities. At Mt Wilhelm, the PNG's highest peak, the total diversity along elevational gradient was 1.4 – 3.3x higher than maximum local diversity, illustrating thus the impact of montane ranges on biodiversity (Barthlott *et al*. 2007). That impact is important also evolutionary as tropical mountains, including those in PNG, appear to be associated with higher speciation rate of insects (Toussaint *et al*. 2014).

At low elevations up to 500 m asl, the species diversity of ants was high but also quite variable among individual sites. Interestingly we have found up to six species of ants at single tuna bait despite usual tendency of aggressive foraging ants to exclude other (Janda *et al*. 2007). This coexistence was allowed by different feeding strategies, with for instance Pheidole species penetrating to the bait through the gauze cover while Rhytidoponera foraging at the top of the gauze. We also recorded early arrivals at the bait excluded in the course of time by bigger or more aggressive species. On the other hand, some of the species from Crematogaster, Leptomyrmex, Tapinoma, Aphaenogaster, Pheidole, Nylanderia and Monomorium were seen foraging together at one bait.

This study documented higher diversity of ground-based ant communities at tuna baits in disturbed compared to undisturbed forests. Further, disturbed forests include selectively logged forests where diversity of ants may be increased by a mosaic of secondary and primary habitats available there. The differences in ant communities with disturbance are driven by the fact that undisturbed communities were sampled at all elevations, while disturbed communities were not sampled at high elevation. We know that there is lower species richness of ants at higher elevations, and hence this pattern of sampling is likely to make it appear that undisturbed habitats have lower species richness in this study.

The forest disturbance exhibited much smaller effect on the species composition in ant communities than elevation, as shown by the CCA analysis (Fig. 3D). The similarity of ant communities also decreased with elevation in the same way for both disturbed and undisturbed forests. These results suggest that while there are ants species limited to certain elevations, ant species do not show such selectivity towards disturbed and undisturbed forests. Klimes *et al*. (2012) showed that ant distribution in tropical forests was not responding directly to species composition of the vegetation. However, alien (invasive) species show clear preference for disturbed forests. We have found five invasive species in our data: *Tapinoma melanocephalum* (Fabricius,1862), *Monomorium floricola* (Jerdon 1851), *Monomorium pharaonis* (Linnaeus 1758), *Odontomachus simillimus* (Smith, F 1858) and *Technomyrmex albipes* (Smith, F 1861). These species are considered as introduced species by Pacific Invasive Ants (http://idtools.org/id/ants/pia/PIAkey_v2.html) although the status of the former two species is uncertain as they have Oriental or Australasian origin (Sarnat 2008; Wetterer 2009).

This study presents a comprehensive documentation on ground dwelling ants for New Guinea forests, surveyed by two methods along 9.6 km of transects at study sites from 28 to 2700 m above sea level. Surprisingly, we have not documented significant impact of forest disturbance on ant communities. This may be due to the rather limited disturbance intensity in PNG forests which tends to be relatively small-scale at our study sites, due to low intensity selective logging or slash and burn agriculture. We have not been able to capture complete local or regional species diversity of ants. However, our methods proved to be effective in documenting community structure by a rapid and efficient sampling protocol that allowed us to survey one site in three days and is therefore, suitable for large-scale monitoring programs.

Acknowledgments

We acknowledge all our collaborators and the National Forest Inventory Binatang Research team. This project was funded by EU through PNG Forest Authority with technical assistance provided by FAO.

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Species Richness and Composition of Moths (Lepidoptera: Geometridae) in Lowland and Montane Forests of Papua New Guinea

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Abstract

This study was conducted in collaboration with Papua New Guinea Multipurpose National Forest Inventory to investigate species richness and composition of Geometrid moths (Lepidoptera) in tropical forests of PNG and analyse environmental drivers of geometrid community structure. It was conducted at 14 clusters through-out four provinces of PNG – Eastern Highlands, Western Highlands, Morobe and Madang Province at a period of 12 months. Moths were collected from dusk to midnight (18:00h to 22:00h) using manual light trapping method for four nights per site. A total of 56 light trap sampling nights were obtained.

Results included a total of 4078 individuals from 883 species from lowland and montane forests. Species richness was lower in lowland forests than in montane forests. Low elevations from 69 m to 357m have low species richness than elevations from 1415 m to 2068 m. However, at higher elevations (2447 m to 2728m) there was no difference and richness was decreasing.

Multivariate analysis with ordination using Canonical Correspondence Analysis (CCA) resulted in Geometrid moth species with a majority showing preferences to lowland undisturbed forest and montane undisturbed forest in response to elevation and disturbance. Geometrid moths have a predominantly montane distribution with exceptionally high species richness at mid elevations up to 2100 m a.s.l while species richness at lowest elevations are markedly lower, and also decreases towards very high elevations. Habitat disturbance may have little or no effect on Geometrid moth species due to less number of primary host plants but its succession could provide a suitable habitat for many insects.

Key words: Geometrid moth, species richness, species composition, elevation, lowland forest, montane forest

Introduction

Papua New Guinea (PNG) contains approximately half of the third largest remaining area of tropical rain forest in the world. It is one of the most biodiverse and ecologically distinct forested regions, highly important for both biodiversity conservation and carbon capture (Brooks et al. 2006). Subsistence agriculture, forestry, fire, plantation development, and mining have all driven deforestation (McAlpine & Freyne 2001, Haberle 2007). These practices pose a major threat to terrestrial biodiversity, especially the insect fauna of the island because little is known about it (Novotný & Weiblen 2005).

Herbivorous insects account for a major fraction of global biodiversity (Novotný et al. 2006). Geometrid moths as herbivorous insects from Lepidopteran family represents a truly hyper-diverse insect taxon with 23,000 described and over 40,000 estimated species (Miller et al. 2016). Geometrids have considerable potential to act as a model system with which to study the effects of environmental gradients in habitat conditions on different forest types (Scobble 1999). This paper aims to investigate the richness and composition of geometrid moths from forest inventory data in fourteen clusters throughout tropical forests in PNG. With this aim we analyse richness and composition of geometrids from different forest types and elevations and consider the implications for biodiversity conservation.

This study is part of the multipurpose National Forest Inventory (NFI) survey in Papua New Guinea. Geometrid moth is used as one of the focal taxa representing herbivorous insects. The aim is to investigate the species richness and composition of the Geometrid moths in different forest types and elevations in tropical forests of PNG.

According to the objective these research questions are raised:

a) What is the richness of geometrid moth species in different forest types and if there are any significant differences?
b) Does elevation affect species richness?
c) Are there any habitat preferences of geometrid moths and would there be difference in species composition?

Methods

Study sites

Data were collected from May 2017 to April 2018 in 14 clusters (4 clusters – Eastern Highlands Province, 2 – Western Highlands Province, 7 – Morobe Province and 1 – Madang Province) from four provinces of PNG (Figure 1). The clusters where randomly selected at different forest types (7 – lowland and 7 – montane forest) and elevations, ranging from 69 m above sea level at lowland forest up to the foot of Mt Giluwe (4,367 m) at 2,728 m. Study forests were classified into lowland and montane forest.

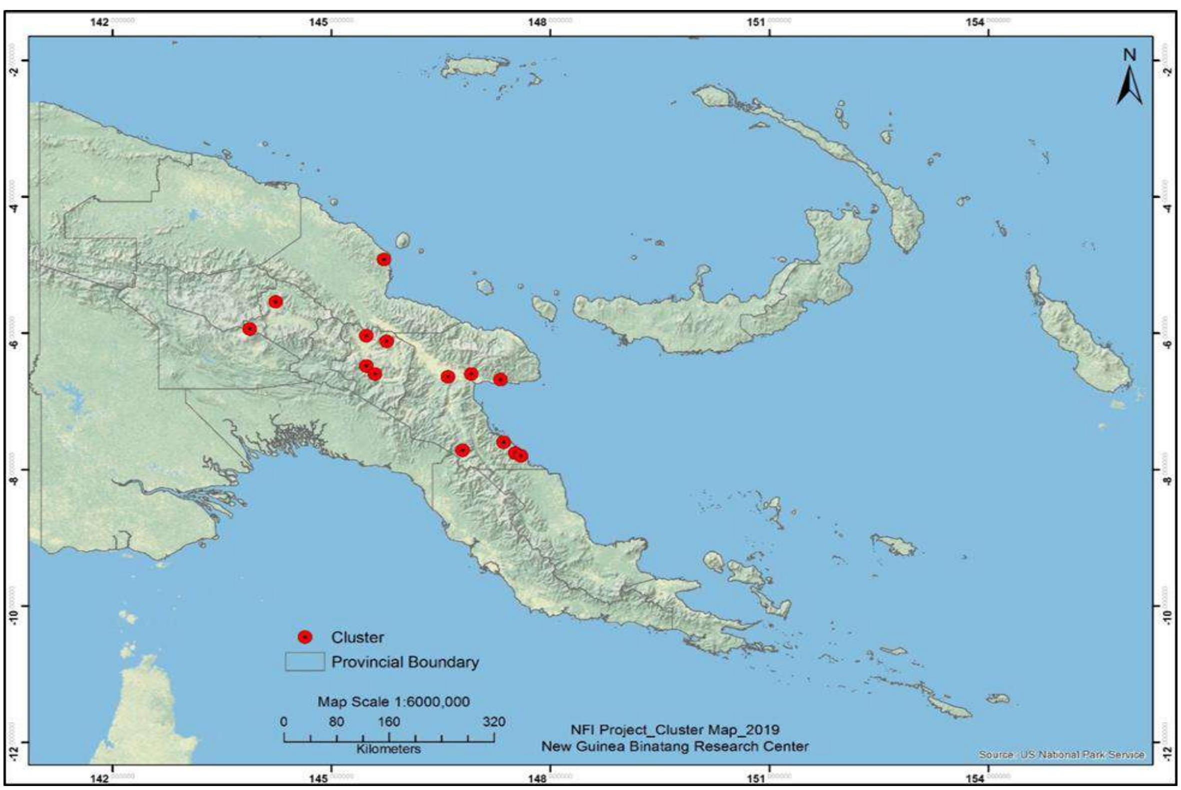

Figure 1 Map of Papua New Guinea showing study locations (clusters) – Western Highlands Province (WHP), Eastern Highlands Province (EHP), Morobe and Madang Province

Study Design

Moth sampling methods

Geometrid moths were sampled manually using quantitative light trapping method from 18:00 to 22:00 hours to coincide with the peak activity of moths. The moths were attracted to a bright light given by mercury vapour (240 W) light bulb powered by Honda generator and reflected by a white sheet 3 m wide and 1.5 m high. Two light traps were running simultaneously at distance 100 m apart for two nights, generating four samples per cluster, each from a different location within the 150 m radius of the NFI cluster design.

Results

We captured a total of 4078 Geometrid individuals from 883 species during 56 sampling nights from 14 clusters. Patterns of species richness varied between different forest types using elevation as continuous variable (Figure 2). Generalized linear model for species richness at lowland forest was significantly different (p = 0.00253) and lower than montane forests. There were significant differences (p = 0.009) also for species richness along elevations (Figure 3). Low elevations from 69 m to 357m were lower in species richness than from mid elevation at 1415 m to 2068 m, however, there was no difference at high elevations (2447 m to 2728 m) and species richness decreases. Thus, we expressed species richness per one light trap sample.

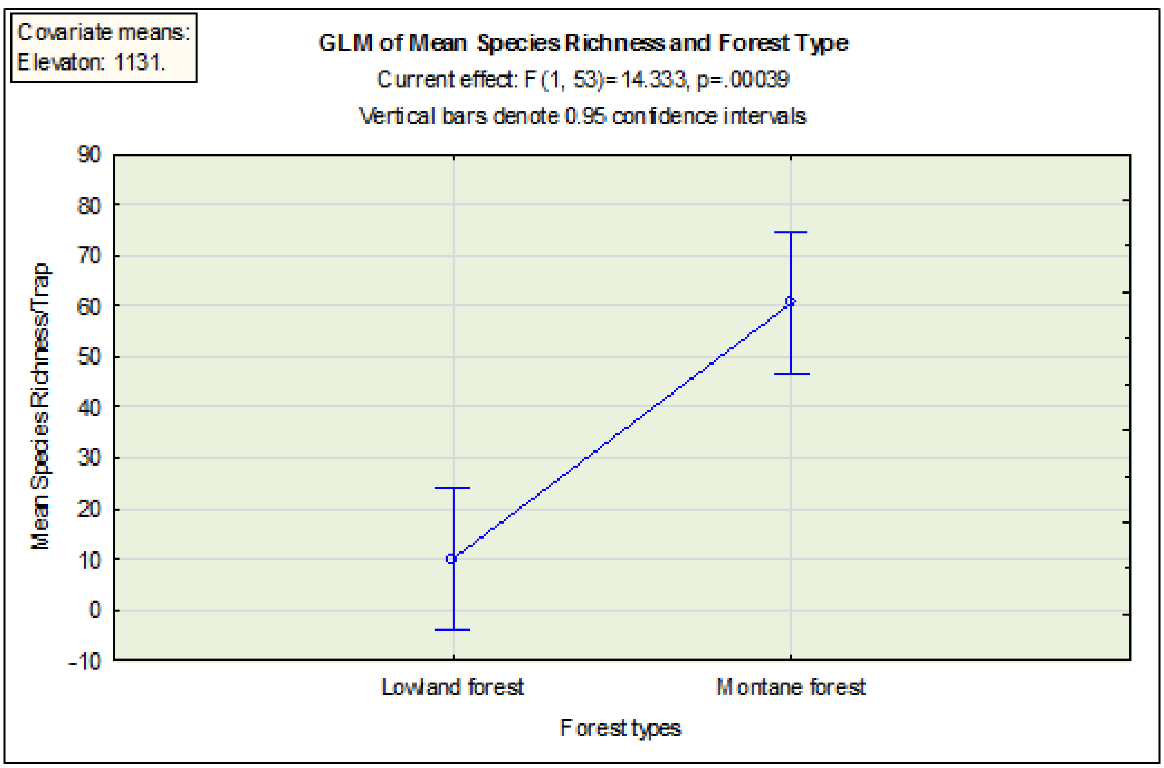

Figure 2 General linear model (GLM) for mean number of species for lowland and montane forest using elevation as the continuous variable

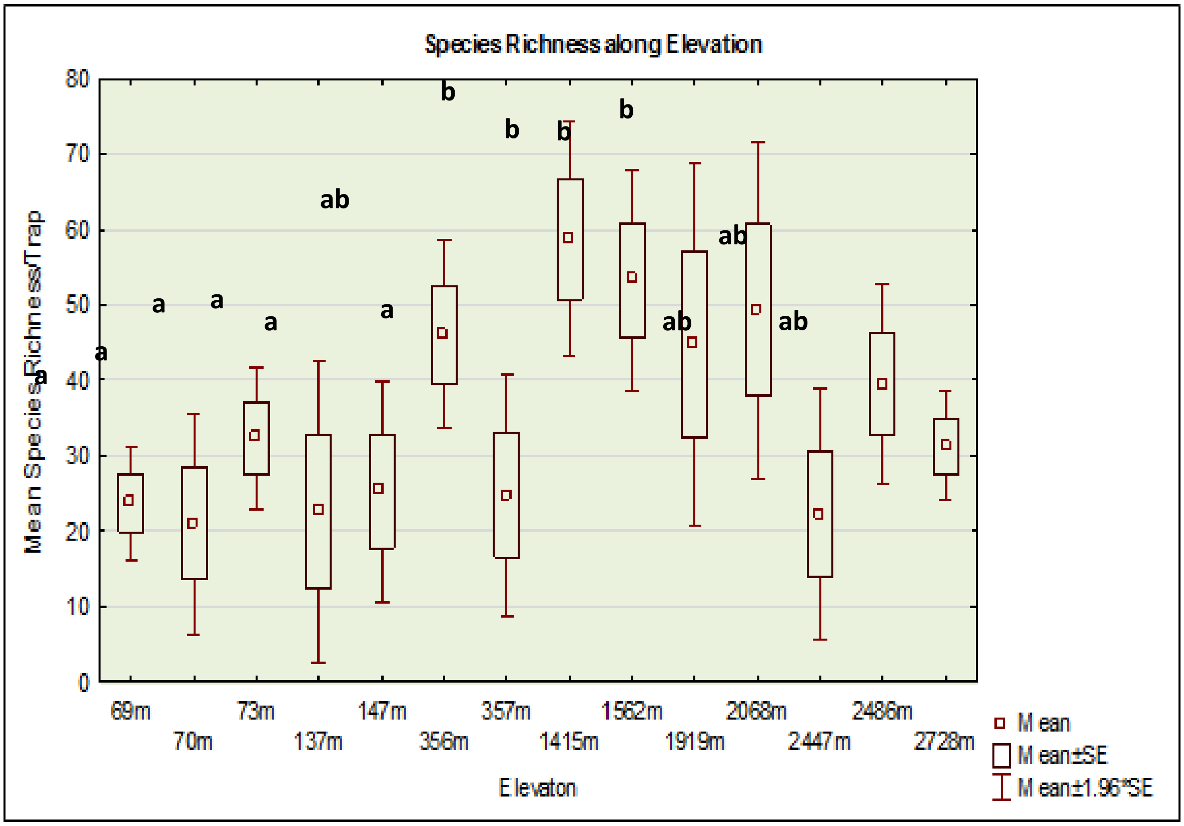

Figure 3 showing species richness along different elevations. Lower case letters designate statistically different means (ANOVA with post-hoc Tukey tests)

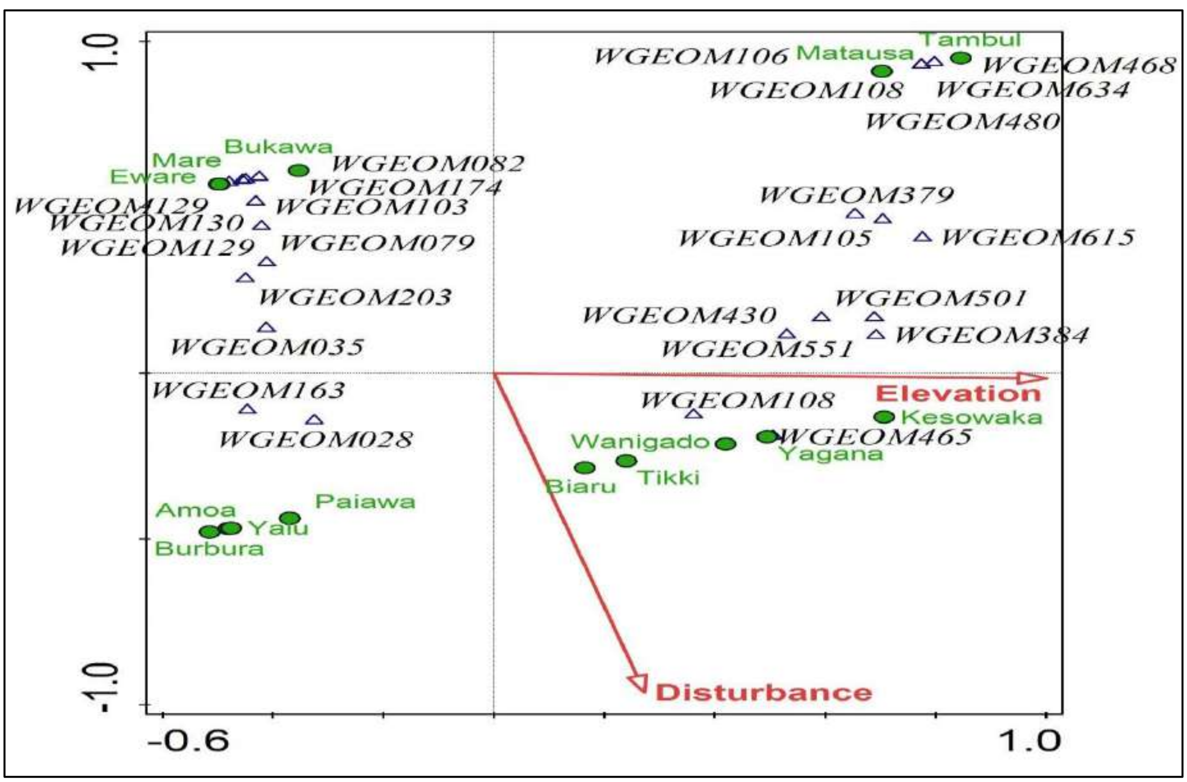

Figure 4 CCA graph showing species composition of 25 most common Geometridae species and clusters (green dots) with response to elevation and disturbance (permutation test: pseudo F=1.4, P=0.002)

For species composition, multivariate analysis with ordination using Canonical Correspondence Analysis (CCA) shows significant difference (P=0.002) with explanatory variables (elevation and disturbance) accounting for 20.6% variation. Geometrid species preferences and composition with response to disturbance and elevation using CCA have organized the species from two extremes of lowland forest and montane forest habitats with a majority showing preferences to lowland undisturbed forest and montane undisturbed forest (Figure 4).

Discussion

Moth assemblages, especially Geometridae moths had been used widely as bio-indicators or for ecological monitoring often involving groups of samples from different forest types and habitats. Brehm *et. al* (2007) confirms that geometrid moths have a predominantly montane distribution with exceptionally high species richness at mid elevations up to 2100 m a.s.l while species richness at lowest elevations are markedly lower, and also decreases towards very high elevations. This patterns are explained by a combination of decreasing temperature that limits the activity of insects with decreasing plant diversity with altitude, important for insect herbivores. It remains unclear why geometrids show a mid-elevation peak, but it appears to be a global pattern (Beck *et al*. 2016).

One possible explanation is that their richness is limited by high predation pressure on caterpillars by birds and ants and on adults by bats, in the lowlands, and by harsh climatic conditions and low vegetation diversity at the high altitudes. Although butterfly communities remain most species rich in the lowlands, despite facing similar predation pressures on their caterpillars, they do not face bats as another group of their predators. This maybe important since bats are particularly abundant and important in the lowlands (Amick unpublished).

Habitat disturbance may not or have little effect on the Geometrids throughout different forest types in Papua New Guinea. Lepš *et al*. (2001) stated that tropical successions in the early stage can be a suitable habitat for many insects. The habitat disturbance may not have many of the primary host plants but its succession could provide a suitable habitat for many insects.

To conclude, this study can be used as a baseline for further sampling of species distribution and diversity of Geometridae moths throughout the rest of the forests in PNG under the Multipurpose National Forest Inventory Survey. As Shearman *et al* (2009) stated that PNG forests is under threat of forest destruction by increased human activities and such study with other related taxa studies is very important for biodiversity conservation and also proper land use planning in protecting PNG's biodiversity and resources.

Acknowledgements

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Significance of NFI Zoological Data in Biodiversity Modelling and Environmental Management

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Abstract

Modelling provides an effective means of integrating the complementary strengths of biodiversity data derived from in situ observation. There are number of roles that modelling can play in biodiversity assessment, these roles place different levels of emphasis on explanatory versus predictive modelling. Therefore, it is vital for planning of future biodiversity conservation strategies and for assisting decision makers facing questions that have an impact on ecosystems. It is also an essential part of shaping the agenda for future scientific research. Hence, as vital as other NFI data, zoological data can be used for biodiversity modeling such as Species Distribution Models (SDM) which shows the distribution of species across a geographical area and can also predict the potential areas of occurrence of certain specie(s) both present and future. Therefore, with such model(s) it will help in conservation strategies and sustainable management of the biodiversity.

Thus, based on the NFI zoological data, the species diversity declined with elevation for ants and fruit flies very rapidly, and for birds at a lower rate, while the geometrids showed mid-elevation maximum in species diversity. Forest disturbance caused change in animal species composition, but not necessarily decline in their species numbers. This implies that preserving primary forests along long altitudinal gradients is the key measure in ensuring comprehensive biodiversity preservation. Forest disturbance can have both positive and negative impact on species diversity, depending on the taxon studied. However, there is a marked change in species composition between primary and secondary forests in many taxa. Therefore, with such information, with the appropriate biodiversity models, one can identify potential areas of conservation and even make sound policies and decision making by addressing the biodiversity issues without compromising any economic development.

Introduction

PNG is part of third largest forest in the world with high level of endemism with more than 5% of world's biodiversity. However, with rapid population increase, shifting cultivation been the main drivers of forest lost followed by logging and large scale agricultural practices. Also, with climate change effect, PNG had been experiencing extreme climatic conditions such as drought, flood, sea level rise, etc. Thus, the country's biodiversity is at a very critical risk. Therefore, sound policies and decisions need to be made to address the biodiversity issues without compromising any economic development. In order to come up with that, proper baseline biodiversity information is needed, in which the NFI data can be manipulated to produce very useful information.

One of the best options is the use of modelling, since it provides an effective means of integrating the complementary strengths of biodiversity data derived from in situ observation. There are number of roles that modelling can play in biodiversity assessment and place different levels of emphasis on explanatory versus predictive modelling. And since the NFI survey cover different geographical areas ranging from sea level up to timberline, use of biodiversity modelling can provide useful information when it comes to sustainable biodiversity management.

Hence, as vital as other NFI data, zoological data can be used for biodiversity modeling such as Species Distribution Models (SDM) which shows the distribution of species across a geographical area and can also predict the potential areas of occurrence of certain specie(s) both present and future. Therefore, with such model(s) it will help in conservation strategies and sustainable management of the biodiversity.

Methods

Quantitative community data obtained from replicated samples at a network of study sites covering various forest types and environments include data sets obtained by light trapping data for geometrid moths (Lepidoptera), tuna baits and hand collecting for ants (Hymenoptera), Steiner lure traps for fruit flies (Diptera) and point counts, McKinnon Checklist and song meter for birds. Their composition and diversity were analyzed with respect to elevation and disturbance level, using GML models, ordination and other statistical techniques. The results were then used to generate species distribution models.

Results

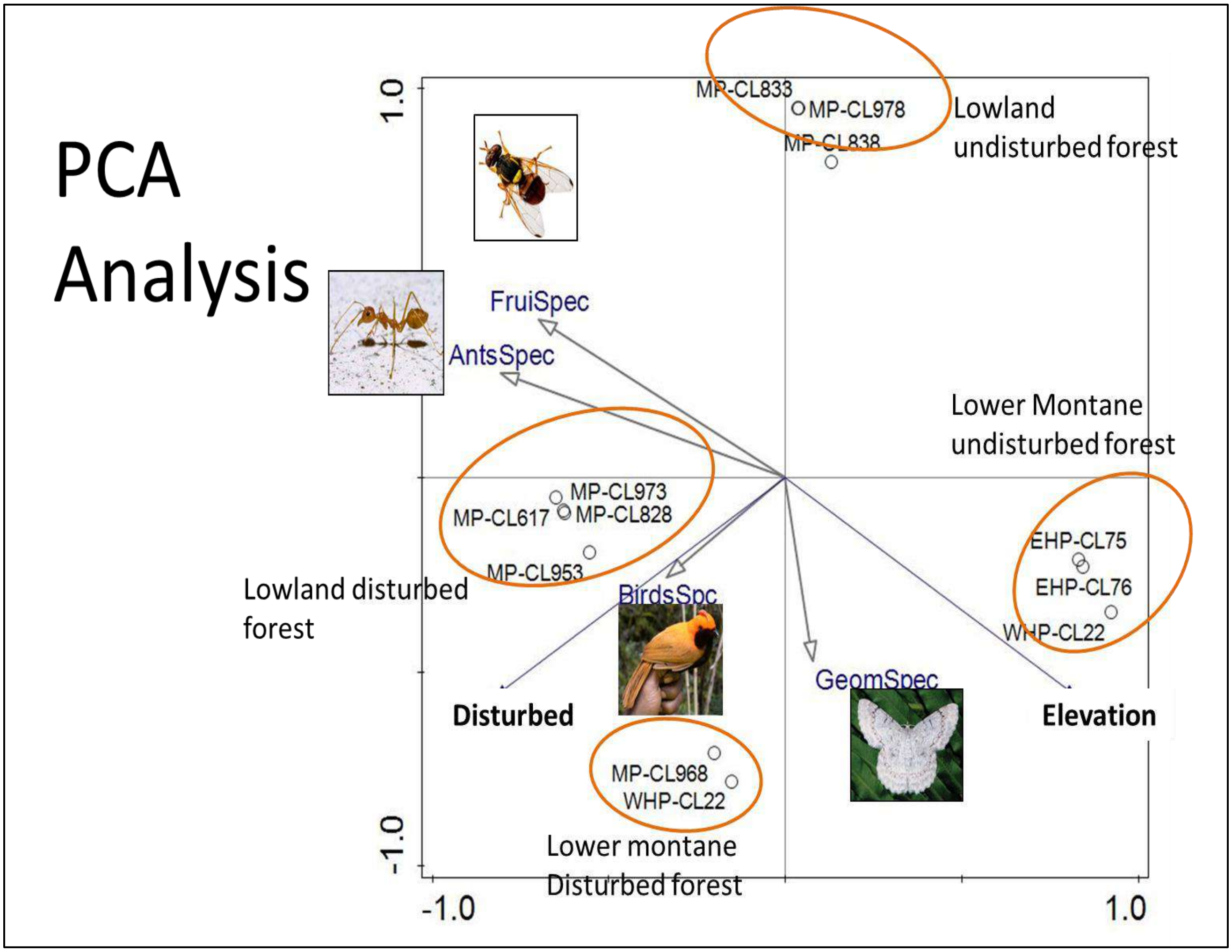

Figure 9: Ordination graph showing general distribution of 4 zoological taxa against elevation and forest types (disturbed & undistur

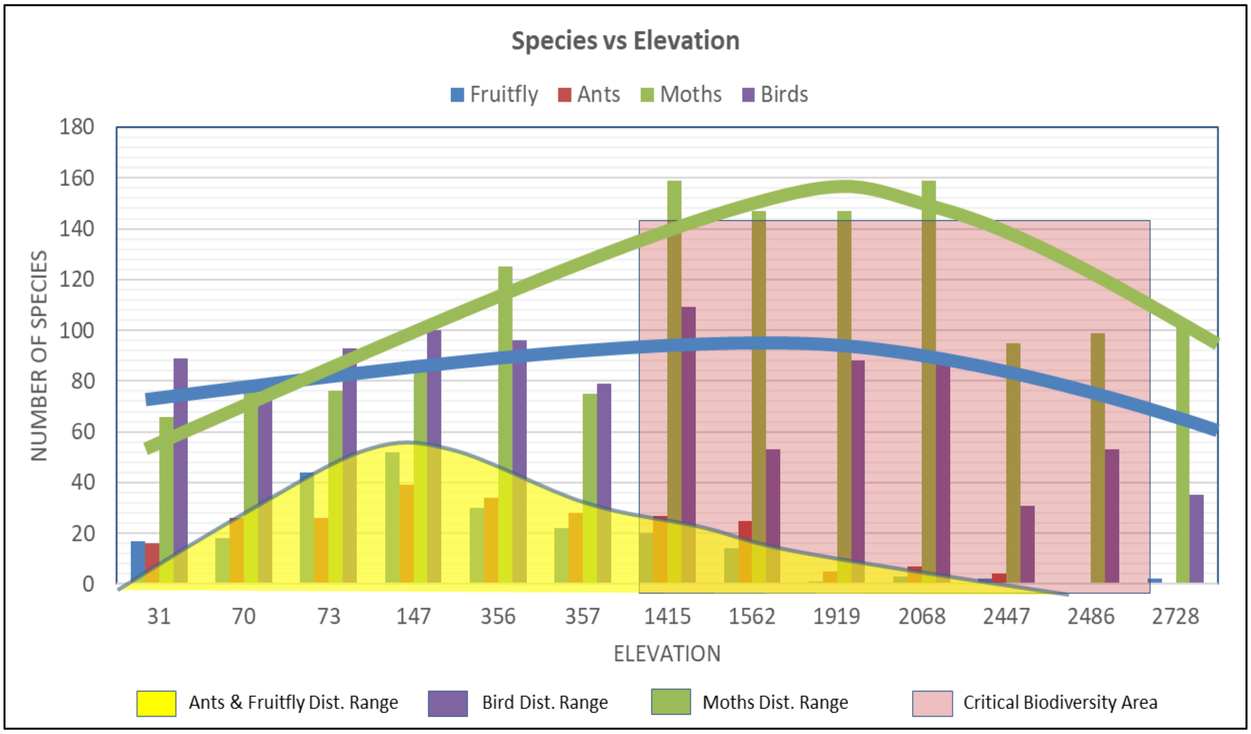

Figure 10: General distribution range of species with proposed critical biodiversity area with reference to elevation

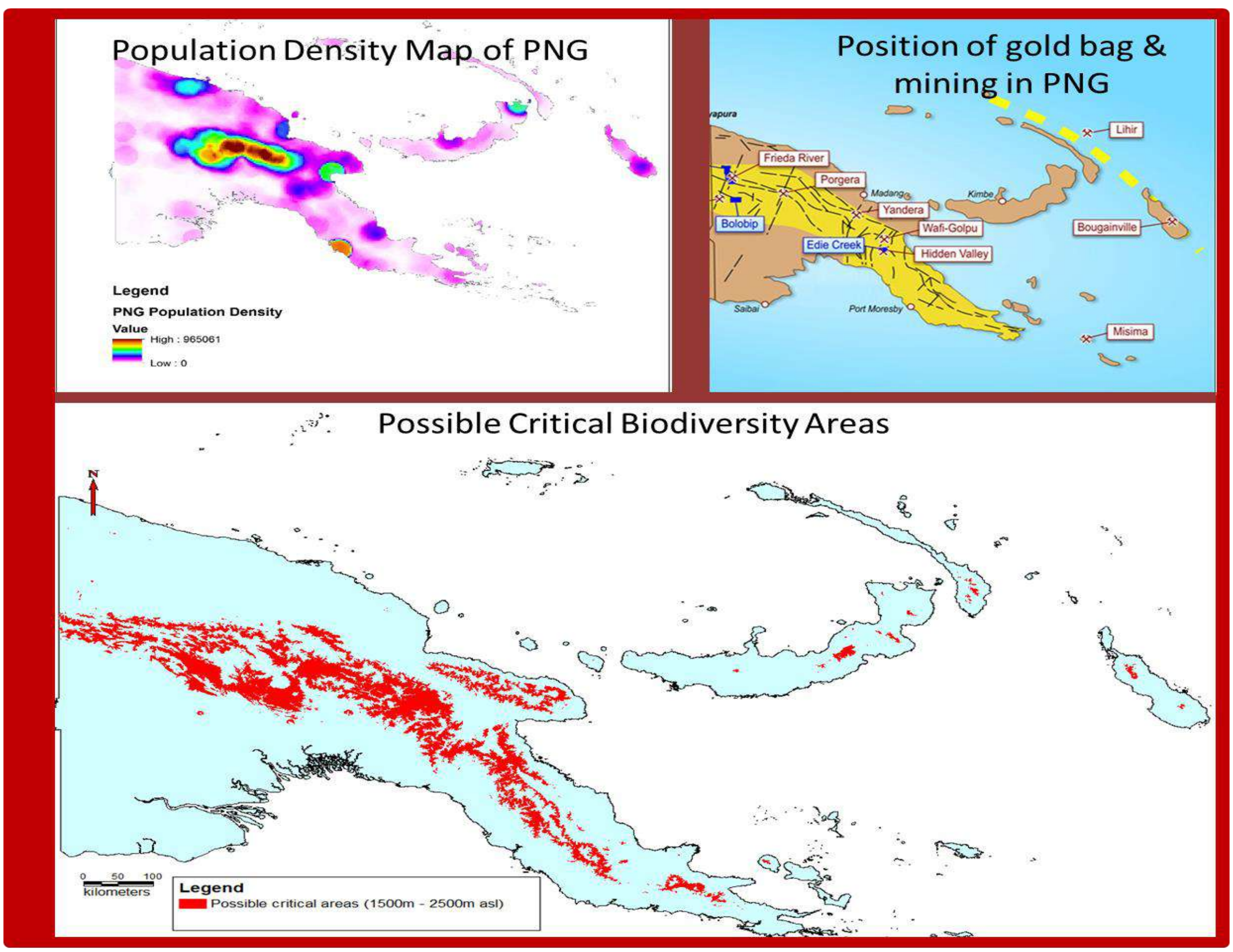

Figure 11: Population density maps & mining locations and possible critical areas in the country

Discussion

As vital as other NFI data, zoological data was used for biodiversity modeling as shown in figures 1 & 2 above, where species diversity declined with increasing elevation for ants and fruit flies very rapidly, and for birds at a lower rate, while the geometrids showed mid-elevation maximum in species diversity. Forest disturbance caused change in animal species composition, but not necessarily decline in their species numbers. Thus, by looking at the species distribution, much information can be derived from the results. However, discussed here were only two of many areas NFI data can be used to address; (1) science expedition and (2) species refuge and conservation.

Science Expedition

With the NFI data, it will help to give a clear picture on how different species were distributed and even helps to predict the potential area of occurrences of certain species of interest. For instance, an ant researcher will focus on elevation up to 2500m and will expected to find more ants at 100m-200m asl. On the other hand, a bird watcher will not waste his/her time looking for targeted bird species if proper species distribution model was made using the NFI data.

Species Refuge and Conservation

PNG forests are coming under increased pressure from shifting cultivation, logging and land conversion to agriculture and together with climate change. These pressures had significant threats on biodiversity, including impacts on species distributions, abundance and ecological interactions as well as biotic responses such as adaptation and migration. Hence, from figure 2 it shows that ants and fruit flies were distributed up to no more than 2500m while moths (geometridae) were more diverse in the elevation range of 1400m to 2500m. This implies that preserving primary forests along long altitudinal gradients is the key measure in ensuring comprehensive biodiversity preservation. Also, preserving forest along altitudinal gradient will acts as a corridor for species to transit/pass through and even for refuge purposes if similar elevation with forest for certain species had been compromised by some economic development such as mining and logging.

Also, with general warming trends, climate envelopes tend to shift towards higher altitudes affecting the dispersal and resource availability, thus, species are expected to track the shifting climate and likewise shift their distributions upward in elevation (Fengyi Guo, et al, 2018). Hence, along an altitudinal gradient, abiotic response (adaptation and migration) of a species will have both direct and indirect effect on the other species. There are four main trends in elevational species richness (McCain & Grytnes, 2010): decreasing richness with increasing elevation; plateaus in richness across low elevations; the decreasing with or without a mid-elevation peak and a unimodal pattern with a mid-elevational peak. Thus, preserving biodiversity along altitudinal gradient is vital for sustainable biodiversity conservation. Hence, with NFI data, such information can be derived from appropriate biodiversity models, which one can identify potential areas of conservation and even make sound policies and decision making by addressing the biodiversity issues without compromising any economic development.

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