**Progress update on Chair's Summary issues (CF20)**
**Fiji ER Program**

| # | ISSUES | STATUS | EVIDENCE (Documents, etc.) |
|---|---|---|---|
| **1** | Demonstration of Fiji's ability to transfer title to ERs to the Carbon Fund is a critical requirement that the Carbon Fund expects to be clarified prior to ERPA signature. | The Ministry of Economy (MoE) is currently working on the Legal Opinion (LO) to demonstrate Fiji's ability to transfer title to ERs to the Carbon Fund. A draft LO has been prepared by a third Party law firm. It refers to the specific provisions of the Climate Change Act regarding the Fiji Emission Reduction Program, including its ability to transfer tittles. A meeting has been convened with the Pollination Team (who is providing this Legal Opinion for Fiji), the REDD+ Unit, TLTB and MoE to finalize the letter. The LO is expected to be shared with the World Bank for review the week of May 18th. . The Climate Change Act has been tabled at the Parliament and is in the process of extensive consultations. It is expected to be passed by the Parliament before end of 2020. In case it will not be passed by ERPA signing it will be come an effectiveness condition for the ERP. In addition, a government letter is expected to be provided by May 25, confirming Fiji Government's strong commitment and intention for the Fiji Climate Change Bill to become law, by being passed as an Act of Parliament. | - Draft legal documents (awaiting for this document from the Ministry of Economy) |
| **2** | Clarify how the emerging Benefit-Sharing Plan will align with applicable | The Advanced Benefit Sharing Plan (BSP) has been accepted by Carbon Fund Partipants as an advanced BSP. The BSP aligns with international and domestic laws; and adoption of the Warsaw | - Draft benefit sharing plan (http://fijireddplus.org/resources/studies/)<br>- REDD+ Benefit Sharing Mechanism (http://fijireddplus.org/resources/studies/) |

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| | international law and domestic laws and regulations. | Framework and Cancun Safeguard. The BSP under the REDD+ ER-P builds on existing laws, regulations, and standard operating procedures. It is informed by a number of existing models including i) the iTaukei Lands Trust Board (TLTB) Lease; (ii) Ministry of Lands – Land Bank; (iii) Ministry of Lands Distribution of Mineral Royalties under the Fair Share Mineral Act 2018 and the Forest Decree 1992 (as well as provisions in the Forest Bill). Building on these models the BSM for the FCPF ER-P in Fiji will use REDD+ license as the vehicle to deliver benefits to REDD+ License holders. In alignment with existing legal instruments, REDD+ Lease issued under (i) and (ii) above is a prerequisite to the issue of a REDD+ License issued by the Ministry of Forestry (MoF) to register REDD+ ER-P beneficiaries.<br>Local laws such as iTaukei Lands Trust Act, Land Use Decree, Forest Decree as well as Forest Bill and proposed Climate Change Act are used to inform and guide the development of the BSP. | |
| **3** | Given the importance of mangroves for local livelihoods and adaptation, Fiji should include activity data monitoring and reporting in their Forest Monitoring System and is encouraged to work on the emission factor to integrate | Fiji considers Mangrove as the major source of carbon sequestration and local livelihood. Fiji has been working on designing National Forest Reference Level, integrating Mangrove forest, as a major carbon source and sink. To this end, the country is prioritizing the management of Mangrove areas with the help of donor partners. To improve the monitoring and reporting on mangrove areas, Ministry of Forestry has completed estimating forest activity data of the nine small islands which were not included in the Carbon Fund's Emission Reduction Program. Also, | - Two Master Level thesis which were witten based on the Mangrove inventory in Fiji (attached).<br>- Delineated area of Mangrove forest in Fiji (Raster Data) |

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| | mangroves into the National Forest Reference Level. | the University of Hamburg , Germany, has carried out two studies that have estimated allometric equations of species Mangrove (*Rhizophora stylosa and R. samoensis; Bruguiera gymnorrhiza*). The Fiji National Forest Inventory to be initiated in the second half of 2020 also covers mangrove areas. These data will be used to design monitoring and reporting on mangroves in the National Forest Monitoring System and the National Forest Reference Level proposed for submission to the UNFCCC at the end of 2021 for technical assessment. | |
| **4** | Continue to improve the methodology for estimating emissions from forest degradation, including self-reported logging and other data, as well as the uncertainty analysis. | Two initiatives have been implemented in Fiji to improve the methodology for estimating emissions from forest degradation.<br><br>First, the country is improving existing logging data collection. To this end, the ministry has conducted several capacity-building activities to the people who are directly and indirectly involved in logging data collection. Approximately 60 government and non-governmental staff were trained. The capacity building activities will bring consistency in data its collection method. People were trained to make them able to use Remote Sensing and Geographical Information System for data collection and reporting.  Also, a Standard Operating Procedure has been developed to maintain consistency in data collection.<br><br>Second, a pilot study has been initiated to estimate forest degradation using remote sensing | - Training Reports http://fijireddplus.org/resources/publications/<br>- Standard Operating Procedure to be prepared during second half of 2020 after the methods are tested.<br>- Draft report on Comparison of Forest Disturbance Datasets in Fiji (attached) |

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| | | methods. A draft report on the preliminary findings has been produced. The pilot study proposes to assess the robustness of remote sensing methods to estimate forest degradation by comparing with ground-truthed data to assess the feasibility of estimating forest degradation and associated uncertainty that meet accounting and reporting requirements. | |
| **5** | Inform the FMT if GCF funding is likely to become available to fund REDD+ activities in the ER Program accounting area and alert the GCF of the existence of the FCPF ER Program. | The Fiji Ministry of Economy has given its confirmation of support to FAO to coordinate the proposed GCF project titled "Climate Resilient Forests, Communities and Value Chain in Fiji" (Letter attached). FAO is currently engaging a consultant to develop the concept paper and the project document for submission to GCF funding in September 2020. Availability of funds is scheduled for September 2021. This GCF funded project will focus on afforestation and reforestation programs around Fiji supporting the Government of Fiji tree planting initiative and ERP activities. | - A letter from the Ministry of Economy supporting the concept paper (attached) |
| **6** | Further clarify the various financing sources to support ER Program implementation, including external funding sources such as GEF, GCF, and the private sector. | The funding streams for the ER-Program Implementation are: -<br>a) Private Logging Companies – self financing (549,140 USD) of the adoption of the Diamter Tree Limit harvesting regime towards the sustainable management of native forests;<br>b) Fiji Pine Limited (6,704,500 USD) and Fiji Hardwood Corporation Limited (1,140,978 USD) – reforestation program towards Carbon Stock Enhancement; | - Evidence for sources a) and b) will be refelceted in the respective companies adoption of the ER-Activities assigned. The implementation of the planting program & achievements will be verified in due course. The funds will be "in-kind" through their respective financial reports.<br>- Fiji Pine Limited & Fiji Harwood Corporation Limited have pledged their support of the ER-Program<br>- For DTL regime in SFM, the concept has been discussed with the Fiji Sawmill Association & Industry in 2019. Although there |

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| | | c) Fiji Government (13,327,244 USD) for the management & monitoring purposes and also support the community tree planting towards Carbon Stock Enhancement;<br>d) External Funding of USD 6.7 m GCF as explained above. In addition, A GEF 5 Ridge to Reef project is ongoing, of which the Ministry of Forest will receive $2.1m to undertake REDD+ work activities, including awareness building and restoration.<br><br>Fiji Government Budget for the next 5-years will reflect the funding of 13,327,244 USD and this wll be allotted according to the ER-Activities assigned to each ministry, which include:<br><br>i) Ministry of Forestry – tree planting & livelihood programs related to tree planting, Forest Protection and ecotourism;<br>ii) Ministry of Agriculture – Climate Smart Agriculture & livelihood programs;<br><br>This is based on the annual budget from 2020 - 2025 | has been some degree of resistance, the regime will be adopted through Regulations under the Forest Act. |
| **7** | Clarify to the public the FGRM arrangement and ensure that it reflects a common understanding of how and to whom feedback can be provided and grievances raised, and | Fiji's FGRM design is robust and contextual to service its unique but complex underlying tenure systems. To this end, it considers current operationalized institutional GRMs and practical linkages to existing resource stakeholders. These have been assessed to render a comprehensive package relating to issues of land ownership membership, boundary disputes, fair and equitable compensation, benefit sharing and general | Fiji's FGRM report can be downloaded from the following weblink:<br><br>file:///C:/Users/WB188675/Downloads/FGRM_D3_final%20(1).pdf |

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| | on how and by whom these will be responded to or resolved. | conditions of contractual agreements. This is in particular to leases and licenses and their impact on ownership rights and interests and the duties and restrictions it attracts. Through wider public consultation amongst landowning units, resource developers, plantation owners, saw millers, Ministry of Land, TLTB and related Ministries such as Mines, Rural Developments and ITaukei Affairs, a common understanding was reached on how best to create the FGRM, consequently by collating the positives of the existing institutional GRMs and incorporating them to the specific demands of REDD+ project. To this end, there is a clear understanding delivered through training and public communication strategies that FGRM renders which is limited to issues pertaining to REDD+ projects.<br><br>FGRM study was carried out under the FCPF REDD+ readiness project and changes in the current FGRM system being done based on the study. The study incorporated feedbacks from extensive consultations and was endorded by the Fiji government. By design, the FGRM clearly identify REDD+ project issues that can be dealt within its process. Through the first contact point of a local forest officer, related issues complained of are registered and assigned tracking reference before it is assessed for progression and ultimate finalization through FGRM process. Where a matter complained is beyond the operational ambit of the FGRM and is for example, suitable for customary land issue determination of the TLTB or | |

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| | | NLFC, procedural steps for its proper direction is provided to ensure such determination is made independent of the FGRM. In the event, remaining issues after such determination is required relating to REDD+ project then the FGRM process is activated accordingly.<br><br>As alluded in the earlier sections of the report, procedural steps of the FGRM has time allocations for feedback for the aggrieved party, to assist in the progress feedback. Progress of a matter therefore can be traced as how and to whom feedback can be provided and grievances raised, and on how and by whom these will be responded to, or resolved within clear guidelines provided within the allotted guideline of agreed days. Further, the FGRM also clearly maps the way forward with second follow up for training for FGRM representatives (currently targeting local Forest Officers) and an action plan for operationalization of the mechanism ( the FGRM structure and the Redd+ Unit), which people to hire, a system of collecting and reporting of grievances and other required logistical process to allow for the smooth operation of the FGRM. | |
| **8** | CFPs welcomed Fiji's commitment to make a Data Management System available to the public, finalize its national nesting guidelines to ensure robust accounting of | The Nakauvadra Community Based Reforestation Project will not generate emission reduction as it is considered by the donor as a Cooprate Social Responsibility of the company to local communities aiming at improved ecosystem services. | - Development of Data Management System and Data Integration is in progress and will be operational by the time of first Monitoring report.<br>- The analytical work to support the development of national nesting guidelines will be initiated soon.<br>- Nakauvadra Community Based Reforestation Project has been supported with Corporate Social Responsibility funding to meet Climate Community Biodiversity Alliance (CCBA) |

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| | ERs, build national coherence of REDD+ programs and projects, prevent double counting of ERs at the national level, as well as Fiji's confirmation that the Nakauvadra Community Based Reforestation project will not generate emission reductions. | | requirements and will NOT generate emission reductions. A government letter is attached to show that Nakauvadra Project will not generate ERs (attached) |

# *METHODOLOGY DEVELOPMENT OF BIOMASS ASSESSMENTS APPLICABLE TO RHIZOPHORA SPP. LOCATED IN THE MANGROVE FOREST OF FIJI.*

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A Thesis Submitted in Partial Fulfilment of the Requirements of the Degree of

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**UNIVERSITY OF HAMBURG**

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FACULTY OF MATHEMATICS, INFORMATICS AND NATURAL SCIENCES

Sarah Simone Reimer

May 2018
HAMBURG, GERMANY

**1st Examiner:** **Prof. Dr. Michael Köhl**

Head of Research Unit
Department World Forestry
University of Hamburg
Institute for Wood Science
Leuschnerstraße 91e
D - 21031 Hamburg

**2nd Examiner:** **Dr. Daniel Plugge**

Technical Advisor REDD+ & Sustainable Forest Management
SPC/GIZ Regional Program
REDD+ - Forest Conservation in Pacific Island Countries II
Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
FNPF Downtown Blvd., Plaza 1, Level 3, 33 Ellery Street,
P.O. Box 14041, Suva, Fiji

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# Contents

## List of Figures

# List of Tables

# List of Equations

# List of Acronyms and Abbreviations

| | |
|---|---|
| AGB | Aboveground wooden biomass including deadwood |
| AGL | Aboveground living wooden biomass without deadwood |
| ANOVA | Analysis of variance |
| B. | *Bruguiera* |
| Ba | In context of this work, always the deltaic area of the Ba River is described. |
| C | Carbon |
| Ci | Confidence interval |
| DBH | diameter at breast height (130cm) |
| EF | Extrapolation factor |
| e.g | exempli gratia; for example |
| FAO | Food and Agriculture Organization of the United Nations |
| GIZ | "Deutsche Gesellschaft für internationale Zusammenarbeit"; German cooperation |
| i.e. | Id est |
| IWP | Indo-West Pacific |
| m | Mass |
| Mg | Megagram |
| MUF | Multiple Use Forests |
| MSD | Management Service Division |
| NGO | Non-government organisation |
| P | Probability value of ANOVA |
| PNG | Papua New Guinea |
| PTF | Protection Forest |
| r | Radius |
| R. | *Rhizophora* |
| $R^2$ | Coefficient of determination |
| REDD+ | Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries |
| RESCCUE | Restoration of ecosystem services and adaptation to climate change |
| Rewa | In context of this work, always the deltaic area of the Rewa River is described. |
| spp. | Species (*Rhizophora stylosa*, *Rhizophora selala*, *Rhizophora samoensis*) |
| sp. | One species |
| SD | Standard deviation |
| SE | Standard error |
| SPC | South Pacific Community |
| u | Water content |
| V | Volume |

## Abstract

In Fiji, there are not jet expressive data about the carbon content of the above ground wooden biomass in mangrove forests. As within the framework of the REDD+ programs (Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries), information of the carbon content in mangroves is required.

In this context, this master thesis focus on determination of the above ground biomass and their carbon stock using inventory procedure and statistical selection in the mangrove forest for two selected deltaic areas Rewa- and Ba of Viti Levu, Fiji Island. This inventory was conducted on 40 mangrove plots and analysed the mangrove species *Rhizophora samoensis*, *Rhizophora stylosa* and the hybrid *Rhizophora x selala*. The destructively sampled plots attend as well as basis for a development of a non-destructive method for biomass determination in mangrove forests in Fiji. On the basis of the collected data, an extrapolation was determined for the two deltas investigated.

The results include recommendations for future mangrove inventories and the optimizing of the developed method.

## Zusammenfassung

Die Auswirkungen des Klimawandels ertönen immer lauter. So werden im Rahmen des regionalen REDD+ Programms (Walderhalt in pazifischen Inselstaaten) Maßnahmen ergriffen, um diesen zu verhindern. Dafür sind Informationen über den Kohlenstoffgehalt, welcher in den fidschianischen Mangroven gespeichert ist, notwendig.

In diesem Zusammenhang konzentriert sich diese Masterarbeit auf die Bestimmung von hölzerner Biomasse und dessen Kohlenstoffvorrat mittels Inventarisierung und statistischer Selektion der Probeflächen in den zwei ausgewählten Flussdeltas (Rewa- und Ba) auf der Hauptinsel Fidschis, Viti Levu. Die Biomasseinventur wurde auf 40 Plots durchgeführt und beschäftigte sich vorwiegend mit den Mangrovenarten *Rhizophora samoensis*, *Rhizophora stylosa* und dem hybrid *Rhizophora x selala*. Diese destruktive Methode, welche auf den Plots durchgeführt wurde, dient zudem als Grundlage für die Entwicklung einer Biomassefunktion für die beschriebenen *Rhizophora* Arten in den Mangrovenwäldern auf Fidschi.

Die Ergebnisse dieser Studie resultieren in einer Hochrechnung der Kohlenstoffwerte für die beiden Deltas und soll zudem Empfehlungen für zukünftige Mangroveninventuren geben.

# 1 Present Situation

The high island Fiji includes over 300 different islands and comprises a total area of 18.000km$^2$. Due to volcanic mountains, high amounts of rainfall occurs, which in turn generates an ideal habitat for coastal mangroves (Spalding, et al., 2010). After Papua New Guinea (PNG) and the Solomon Islands, Fiji has the third largest mangrove area in the Pacific island region (Ellison, 2010). In 1999 a total mangrove area of 42.000ha was recorded and in 2008 48.317ha (Watling, 2013). Over 90% of the mangrove areas are located on the two biggest Islands Viti Levu (28.243ha) and Vanua Levu (18,444ha) (Hughes, et al., 2002)(Figure 1). Viti Levu covers nearly 60% of the total mangrove stands (FAO, 2007). The largest stands of the main island are detected in the deltaic areas of the Rewa, Ba, and Nadi Rivers and the Labasa River on Fiji´s second biggest island Vanua Levu. The Ba, Labasa, and Rewa deltas combined support around 28% of the national resource (Hughes, et al., 2002).

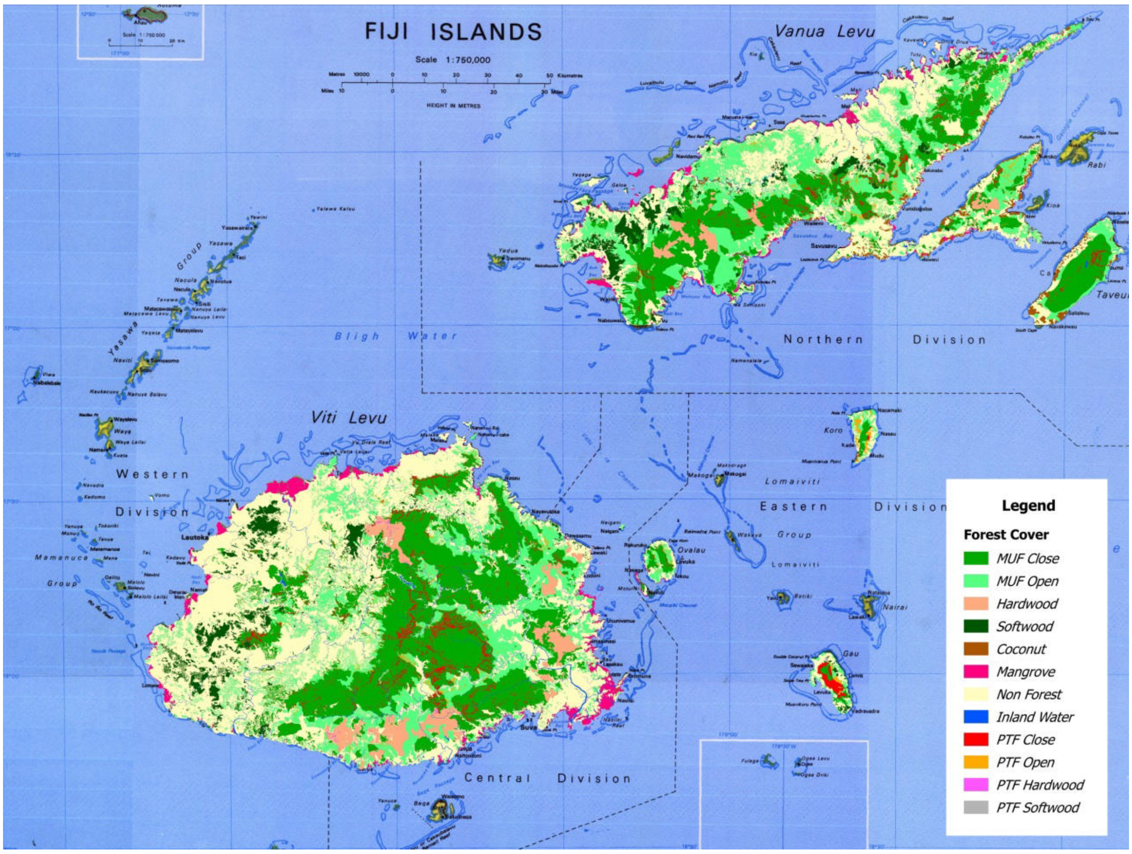


*Figure 1: Forest Cover Map[1], Fiji Islands (MSD, 2008).*

Figure 1 shows the Fiji cover map for the different types of forest with the pink layer marking the mangrove areas of the diverse Fiji Islands. The Forest cover map does not include all islands of the Fiji group, so mangrove determination is only possible for the bigger islands. For example, Taveuni is calculated with a total mangrove area of 152ha, Kadavu shows 1,184 ha, Ovalau 139ha, Gau 154ha and Koro are noted with no mangrove forest (Watling, 2013).

[1] For more information to the forest types, see appendix “Fiji Forest Cover map” and “Forest Classes”.

Until 1975 mangrove forests were considered as part of the national forest reserve and managed by the Forest Department. Nowadays intertidal zones and foreshores (including the mangrove forests) are under jurisdiction of the Department of Lands and Mineral Resources (FAO, 2007).

## 1.1 Costal management

On the 20th of February 2016 the most intense tropical cyclone "Winston" hit the northern coast of the Fiji Islands. It caused huge damage in the mangroves forest in the deltaic area in Ba. Mangroves provide protection against storm surges and cyclones by their ability to slow down water activities and waves.
Worldwide most of the mangrove forests are found in deltaic and estuarine areas but also along open coastlines when wave activity is low or when they are protected by reefs (Spalding, et al., 2010, p. 5) A laboratory test from 2013 showed that an 80m wide *Rhizophora* spp. forest with a density of 0,11 trees/$m^2$ is able to reduce wave height by 80% (Hashim & Sim Mong Pheng, 2013). A field test in Australia showed, that depending on the water depth, a mangrove area is able to reduce wave energy by 63,7 to 94,7% (Brinkman , 2006). Studies also recommend a mangrove belt with a width of 500 to 1500m as optimal coastal protection.
Mangroves also generate new expanses of land through the active deposition of sediments (Spalding, et al., 2010). This land reclamation by the mangroves preserves the landscape from soil erosion at the shorelines and river bone siltation. Above all, mangroves shelter coastal villages from sea level rise. (Duke , et al., 2007).
Subsequently, reforestation of mangroves is related with lots of different benefits, which not only includes coastal protection. In Fiji the replanting of mangroves has long been a topic and is mostly donor driven (Watling, 2013). NGOs, regional organisations as well as national government organizations are committed to it.
For example, in 1993 a reforestation project started with the OISCA organisation. Within the project 143ha mangroves were replanted mainly on the main island, Viti Levu and still nowadays are several projects involved in this topic. The SPC RESCCUE project plant 3.000 mangroves and coastal trees seedlings until beginning of 2018 and the "mangroves for Fiji" project is also still actively involved in a reforestation in mangroves mostly located on the riversides (personal communication, employees of Bequa Adventures, 2017 September 23, & SPC, 2017 November 10).
For a successful reforestation of mangrove forests, some factors must be considered. Mangroves are deeply interrelated with other coastal habitats as coral reefs, seagrasses and other nearshore habitats (Watling, 2013). Quality research and planning of reforestation of mangroves is therefore important so that the right species for the right location and comparative to the tidal frames are planted.

## 1.2 Social benefits of mangroves in Fiji

A complex habitat of flora and fauna is linked to the mangrove forests. The biodiversity of marine life in the mangroves is immense. In coastal mangroves in the Indo-West Pacific, 600 different species of fish are estimated (Spalding, et al., 2010, p. 17). Over seventy species of fish, crabs, and molluscs are caught regularly from the mangrove forests in Fiji (Lai, 1990, p. 33). Most fishing in Fiji for subsistence as well as commercial use is carried out inshore. In addition to that 83% subsistence and 60% commercially caught fish, habits the mangrove forest at some stage of their life cycle (Spalding, et al., 2010, p. 163).

The stilt roots of the *Rhizophora* species are also used by Fijian fishers to enable transport of fishes by stringing them together. In the old days *Rhizophora* and *Bruguiera* species were used for tannin production, suitable for leatherwork, or to recondition fishing lines or nets. The bark of *Rhizophora samoensis* trees can be used to obtain an extract, which helps against stomach ulcers (Lai, 1990, p. 26 and 86).

Mangroves also provide a roosting and nesting habitat for several bird species and domain numerous species of insects.

# 2 Project Overview

The project for this master thesis operated under the regional REDD+ mechanism. It was financed by the GIZ, and technically supported by the world forestry department of the University of Hamburg. Our survey team comprised of employees from the Fiji Forestry Department (MSD), a Fijian student from the University South Pacific (USP) and a forestry apprentice. In the framework of this master thesis, an expatriate stay on Viti Levu, Fiji Islands enabled field work in the deltaic areas, laboratory work, and desk research.

## 2.1 Geographic and Climate Data

The project was conducted in the Rewa River Delta in the southeastern part of the Central Division (18° 5' 41.01" S, 178° 36' 39.298" E) and in the Ba River Delta, located in the Western Division (17° 27' 42.876" S, 177° 41' 25.685" E) of Viti Levu Fiji Island (MSD, 2008).

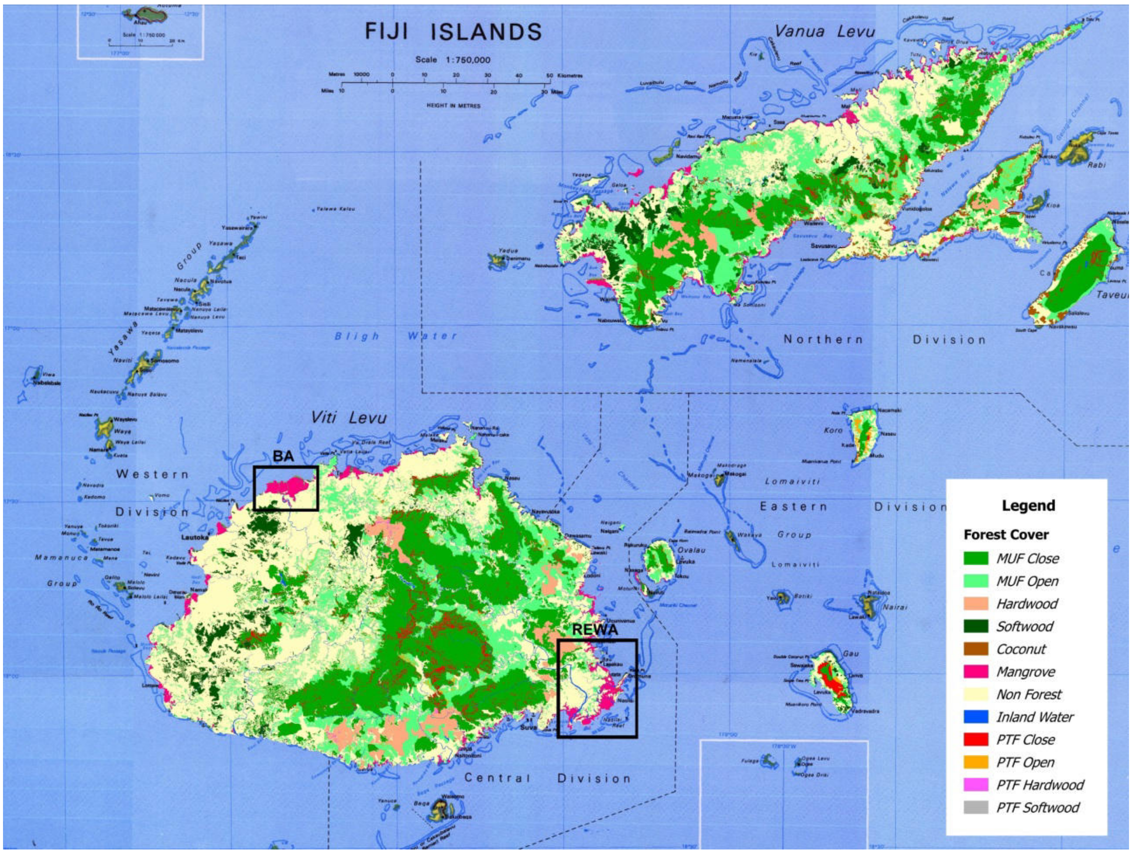

*Figure 2: Forest cover map of Viti Levu with the two deltaic study sites Rewa and Ba (MSD, 2008).*

The study area in the Rewa River delta comprises an area of 8.800ha (QGis, 2017) and shows a highest average annual temperature of 26.5°C in February and the lowest with 22,8°C in July. This area has a significant amount of rainfall (appx. 3.040mm) throughout the year, even during dry months (June to September).

The Ba delta has a mangrove area of approximately 5.700ha with a climate that differs mostly by the average rainfall (2.024mm) to the Rewa River delta. It has an average annual temperature of 25,2°C. Heaviest rain occurs between January and March while the months of July and August are drier.

The Project started during dry season in September 2017 in the Rewa delta and continued through during dry season into October in the Ba delta.

## 2.2 Objectives
The specific objectives for this master thesis are as follows:

- Determination of biomass and carbon stock in the mangrove forest for the selected areas Rewa- and Ba delta using inventory procedures.

- Determination of the biomass and the carbon stock by using statistical selection of the tracts and sampling.

- Designing a suitable tract and plot layout, which is appropriate to *Rhizophora* species, as well as all different locations, included in this project.

- To determine differences of the biomass, plot height, water content and density in relation to the two study areas Rewa- and Ba delta, within the tracts and in relation to the water distance.

- Development of a reprehensive and repeatable, non-destructive methodology, based on measurable attributes.

## 2.3 Limitations
This study is neither able to develop a general overview for all Fiji Islands nor show an accurate distribution of the different species in the mangrove forests. With 40 plots in total for the two study areas (Ba- and Rewa delta) of Viti Levu, this work is only able to show a direction.
This work does not quantify information for other ecosystem services associated with the mangrove forest including biodiversity, fisheries, water quality, coastal protection, sediment capture or other services.
The forest area of the black- and white mangrove species are shortly described to complete this thesis, but are not explained in the further analysis. It also only focused on the species *Rhizophora samoensis*, *Rhizophora stylosa* and the hybrid *Rhizophora x selala*.
Biomass determination in the plots took place for only above ground living wooden biomass and deadwood. Soil sampling or recording biomass from litter is not included in the fieldwork and thus in the mangrove carbon pool estimation.
Fieldwork was limited to a period of 4 months. As working was depending on tidal calendar, time management for fieldwork was very important. To enter the mangroves and accessing the plots the team depended on high- and low tide. The areas within the mangrove forest was often only accessible at high tide and the red mangrove area in particular was difficult to access due to their grown habit. However, working was mostly only possible at low tide. The team had a period of only four hours every day to work efficiently; the data recording was therefore under heavy time pressure. In addition, project financing has not allowed further analysis in the field or in the laboratory.

# 3 *Rhizophoracea* genera in Fiji

Mangrove forest is defined as a littoral plant formation of halophytic (i.e. salt tolerant) trees, shrubs[2] and other mangrove associated plants (e.g. ferns and palms) occurring in brackish to saline tidal waters (Kaufmann & Donato, 2012). The true mangrove vegetation involves 19 representative plant families with 73 species and hybrids around the world. In the Indo-West Pacific (IWP) 62 of the 73 species are located (Spalding, et al., 2010, p. 2). In studies conducted between 1980 and 2005 the FAO noted the following mangroves species for the Fiji Islands (FAO, 2007).

- *Rhizophora samoensis*
- *Rhizophora stylosa*
- *Rhizophora x selala*

- *Bruguiera gymnorrhiza*

- *Xylocarpus granatum* (Fijian name: Dabi)
- Xylocarpus mekongensis (Fijian name: Dabi)
- *Excoecaria agallocha* (Fijian name: sinu gaga)
- *Heritiera littoralis* (Fijian name: ivi)
- *Lumnitzera littorea* (Fijian name: segale or segali)

} Species not part of the *Rhizophoracea* family.

## 3.1 Definition of Mangrove habitat

The total mangrove area is bordered by dry land with open forests or open areas and by a waterfront or reefs. With a zonation the mangrove forest reflects the specific ranges of conditions under which the species subsist (e.g. frequency of tidal inundation, physical and chemical state of the soils, degree of faunal predation) (Ellison, 2010).

[2] Scrub/ scrubby tree or scrubby forest = “Wooden perennial plants, generally more than 0.5 meters and less than 5 meters in height at maturity and without definite crown. Height limits for trees and shrubs should be interpreted with flexibility, particularly the minimum tree and maximum shrub height, which may vary between 5 and 7 meters.” (IPCC, 2007, p. 4.77)

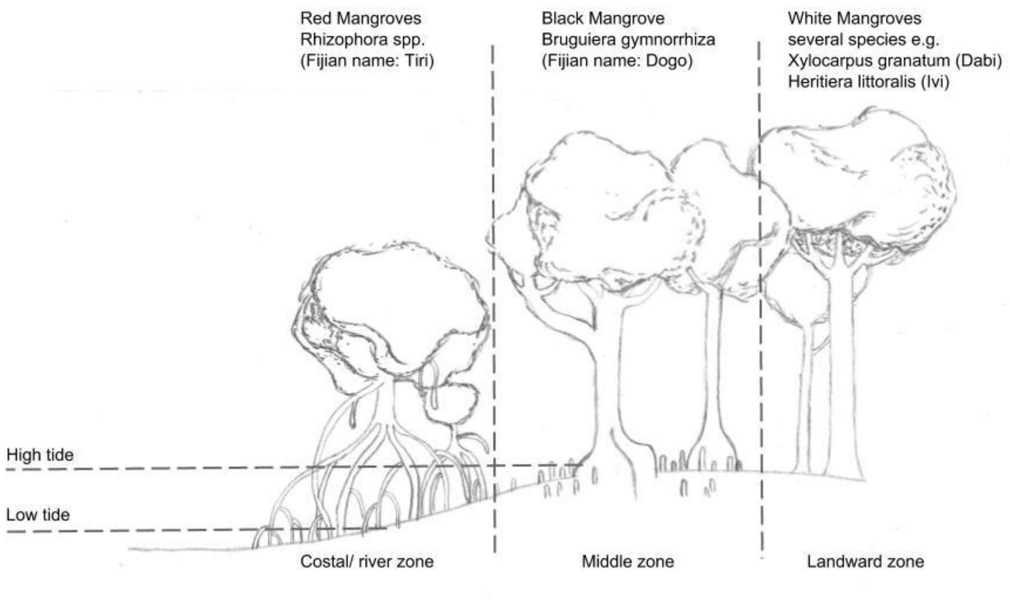


*Figure 3: Forest structure and zonation of species in the mangrove forest of Viti Levu, Fiji (Reimer, 2018).*

The term red mangroves, in Fijian called "*Tiri",* consist of the species *Rhizophora samoensis, Rhizophora stylosa* and one sterile hybrid *Rhizophora x selala* produced naturally in case the two others are present (Tomlinson, 2016, p. 342). Red Mangroves grow primarily at the waterfront facing rivers or sea. They have a slightly higher salt tolerance than black or white mangroves.

In Fiji, black mangroves contains primary the species *Bruguiera gymnorrhiza*, growing in the middle zone after red mangroves and before white mangroves.

White mangroves are mangrove-associated trees, occurring immediately behind the wet mangrove area in slightly higher land. This species is intermixed mangroves, strand or coastal forests. This species is salt-tolerant and survives in saline soil and occasional salt-water inundation. Species of white mangroves in Fiji are in particular the indigenous species *Heritiera littoralis* \`Looking-glass Mangrove\` of the family *Malvaceae* and *Lumnitzera littorea* \`Teruntum Merah Mangrove\` a species of Combretaceae family, found on most islands in Fiji. It is a shrub-growing tree with a height between 3-12m (Keppel & Ghazanfar, 2011).

The species *Xylocarpus granatum* \`Cannonball Mangrove\` as part of the Meliacea family are found often intermixed with *Bruguieria gymnorrihza*. *Xylocarpus mekongensis* (*Meliaceae* family) occur slightly more inland than *X. granatum* trees. The described red- and black mangroves are evergreen species. On the other hand, *Excoecaria agallocha* \`Blind your Eye Mangrove\` (family of *Euphorbiaceae*), *X. granatum* and *X. mekongensis* are deciduous species. The salt absorbed by these species is sent out through their leaves (Sykes, 2007). Salt crystals discarded by the glands of the leaves are sometimes visible and give the leaves a whitish colour (Spalding, et al., 2010, p. 3). This is where the term white mangrove comes from.

## 3.2 Dendrology of *Rhizophora* spp.

*Rhizophora* spp. is the most common mangrove genus worldwide (Duke, et al., 2001). The evergreen *Rhizophora* species are easy to distinguish from other species by their rampant occurrence of stilt roots. Stilt roots outgrow the aerial part of trunk, branches or already existing lignified stilt root, and grow towards the ground. The *Rhizophora* trees stabilized through its stilt roots in soft muddy ground and wavy zones. As the stilt roots are forming the stabilisation for the trees, a steam is mostly not clearly detectable. The stilt roots have innumerable lenticels to function the gaseous exchange in the oxygen poor soil. These lenticels get blocked when the stilt root system is submerged by soil (Spalding, et al., 2010, p. 4).
The distinguishing feature, knee roots, seen by *Bruguiera gymnorrhiza* trees (black mangroves) are absent in the *Rhizophora* species.

### *3.2.1 Rhizophora samoensis*

The Fijian names for the 2-7m height *Rhizophora samoensis* is “Tiriwai” or in the area of the Rewa Delta “Io” or “Ioa” (Keppel & Ghazanfar, 2011). This species is strictly limited to the southwestern Pacific islands. In Australia and New Guinea, this species does not occur anymore (Duke, et al., 2001). The species *Rhizophora mangle* (located in the Atlantic East Pacific) and *R. samoensis* are morphologically almost indistinguishable and so may represent a single species (Spalding, et al., 2010, p. 273f).

*Figure 4: Rhizophora stylosa on the right side, Rhizophora samoensis on the left side, grown together (Reimer, 2018).*

*Rhizophora samoensis* can be classified by its spreading crown, grey and thick outer bark, with a pink outer layer of the slash. The wood shows a creamy colour. As all *Rhizophora* species, *R. samoensis* also shows stilt roots growing down from trunk and branches to anchor in the soft muddy soil. The tree usually grows closer to rivers and not facing direct seaside. It forms seaward and particularly landward the boundaries of mangrove swamps where it stands most of the time half submerged in water. (Keppel & Ghazanfar, 2011)

*Figure 5: Leaves of a Rhizophora samoensis (Forstreuter, 2017).*

A special distinctive feature between *Rhizophora samoensis* and *Rhizophora stylosa* are the leaves. Leaves of both *Rhizophora* species and the hybrid are generally simple, opposite and have a broadly elliptic shape. The upper side of the leathery leave is dark green and the lower surface in a lighter green too yellowish with dark to blackish dots.
The difference of *R. samoensis* to *R. stylosa* and *R. selala* are the top of the leave. *Rhizophora samoensis* has a slightly notched tip and the apical mucro, seen by the other taxon is missing (see Figure 5 and 6).

### *3.2.2 Rhizophora stylosa*

*Rhizophora stylosa* typically forms the seaward zone and directly fronting the waterfront, while *R. samoensis* forms the adjacent zone further inland or the edges of rivers. *R. stylosa* differs from *R. samoensis* in having a pointed tip (see Figure 6) (Keppel & Ghazanfar, 2011).

*Figure 6: Apical mucro on the top of the leaf (Forstreuter, 2017).*

The elliptic shaped leaf has an average size of 10 by 7cm. Compared to *R. samoensis* the leaves of R. stylosa are a little shorter and wider.

Flowers of *Rhizophora stylosa* are small creamy-white too yellowish and arise from the axil or grow amongst the leaves (Keppel & Ghazanfar, 2011).

*Figure 7: Bud of a Rhizophora stylosa shortly before flowering (Forstreuter, 2017).*

The taxon develops little brown ovoid fruits and long seeds. The seeds can reach a length up to 40cm and separate from the fruit to fall to the ground. Within the contact to the soil the seed develop roots.

*Figure 8: Fruits and seeds of Rhizophora stylosa (Forstreuter, 2017).*

### *3.2.3 Rhizophora x selala*

In Fiji *Rhizophora* x selala was firstly recognizes as a hybrid by Henry B. Guppy in 1906 (Tomlinson, 2016, p. 340). It can be easily characterised by its higher stature. *Rhizophora x selala* trees can reach a height up to 30m. A steam is mostly detectable with numerous stilt roots attached to it.

*Figure 9: A 12m height Rhizophora x selala tree (Reimer, 2018).*

The leaves of the hybrid are similar to the leaves of *Rhizophora stylosa*. They show an apical mucro.

*Figure 10: White flowers of the hybrid Rhizophora x selala (Forstreuter, 2017).*

The white small blossoms from a compound inflorescence. They are sterile and so not producing fruits. The vernacular name of the hybrid, selala, means empty flower (Keppel & Ghazanfar, 2011).

## 3.3 Distinguishing characteristics of *Rhizophora* spp. on a microscopic level

Samples of *Rhizophora stylosa*, *R. selala* and *R. samoensis* were analysed for their distinguishing characteristics under the microscope. The samples were finely sanded to make the structure of the cross section visible. In addition, one sample was taken from a stilt root of a *Rhizophora stylosa*[3] to represent the structure of the already lignified root. As the samples were sanded the vessels are clogged with wood flour and emerge white in the cross-sectional images.

The xylem is formed by tracheids, vessels, fibres and paremchyma. Depending on their frequency, arrangement or size, these cells are important distinguishing factors for certain types of wood.

Figure 13 shows the cross section of a *Rhizophora samoensis* sample. A clear distinguishing characteristic is the diffuse porosity of the sample. The vessels are approximately equal in size and evenly distributed over the entire cross-section.

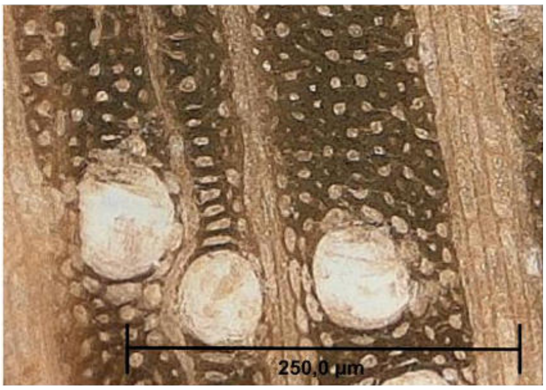


*Figure 11: Section 2 of the cross-sectional image of Rhizophora samoensis (Kushuro, 2018).*

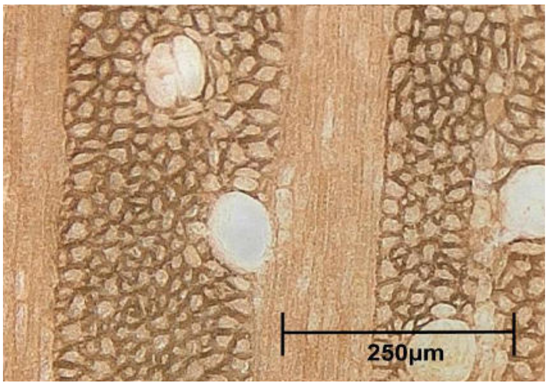


*Figure 13: Section 1 of the cross-sectional image of Rhizophora samoensis (Kushuro, 2018).*

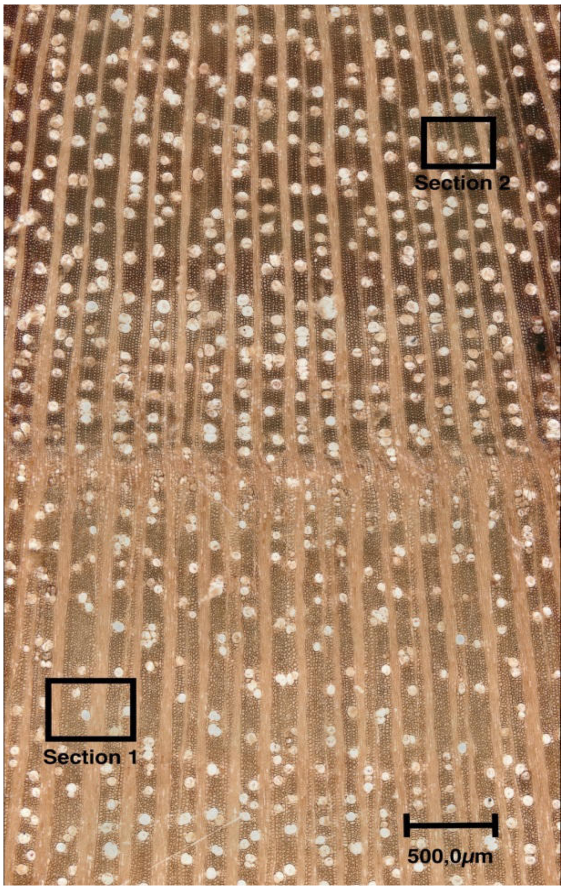


*Figure 12: Microscopic image of the cross section of a Rhizophora samoensis sample (Kushuro, 2018).*

[3] The cross sectional image of the lignified stilt root of *R. stylosa* is not further analysed in this context. The cross sectional image is given appendix “Cross sectional image”.

A growth zone between sections 1 and 2 is easily recognizable. *Rhizophora samoensis* sample, wood rays (ray parenchyma) have 4 to 10 rows and thus, are wide and clearly visible. For wood rays, a distinction is made between a homogeneous and a heterogeneous structure. The homogeneous wood rays consisting of one type of cells. Either of procumbent cells or upright cells. The heterogeneous wood rays are composed both types of cells. For all *Rhizophora* spp. sample only homogeneous wood rays were identified. Section 2 in Figure 11 shows the significant thickening of cell walls in difference to section 1 (Figure 12).

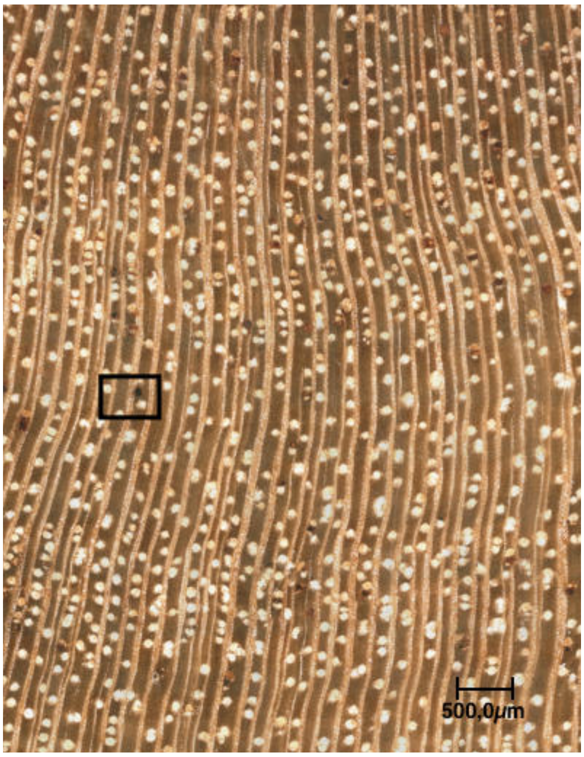


*Figure 15: Microscopic cross section of Rhizophora stylosa (Kushuro, 2018).*

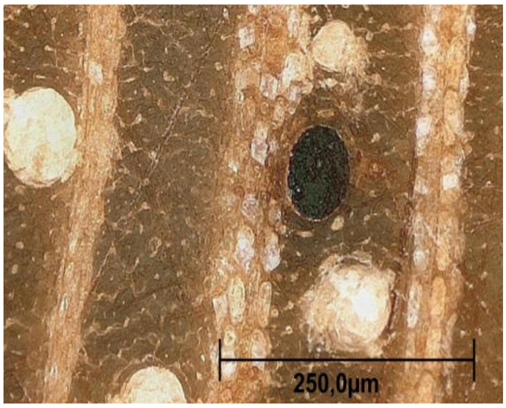


*Figure 14: Detail of a filled vessel from the cross sectional image of Rhizophora stylosa (Kushuro, 2018).*

Compared to the other cross sections of *Rhizophora* spp. samples, in this *Rhizophora stylosa* cross sectional image (Figure 15) an increased appearance of dark coloured vessels is visible. The dark discoloration in the vessels (Figure 14) indicates that phenolic compounds are stored in the xylem. Deposition of phenolic compounds does not function as distinguishing characteristic for *Rhizophora stylosa especially,* as it has been noted in all *Rhizophora* samples studied.

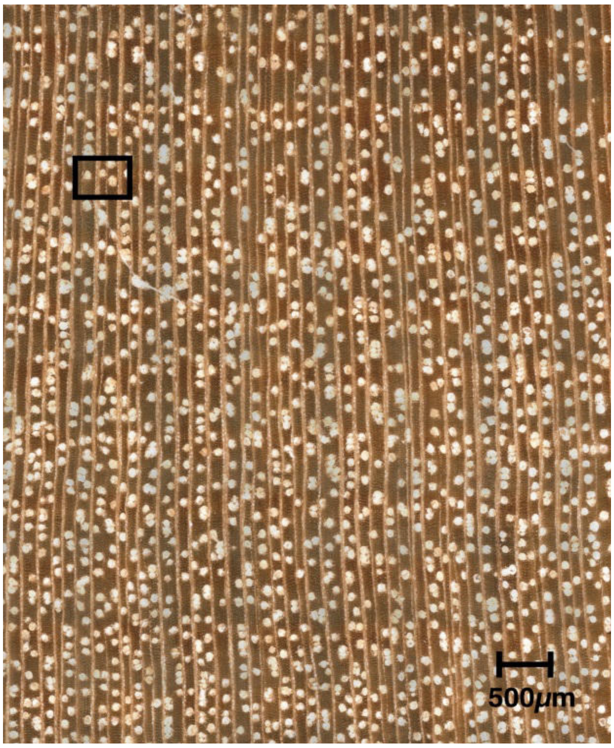


*Figure 17: microscopic cross section of the hybrid Rhizophora x selala (Kushuro, 2018).*

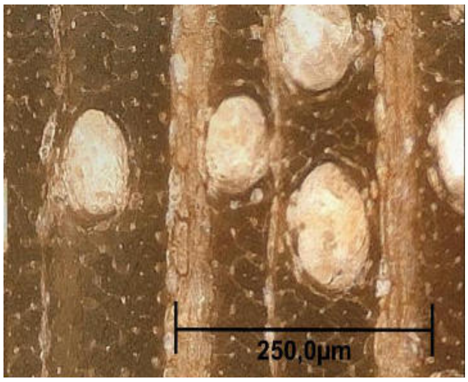


*Figure 16: Detailed section of Rhizophora x selala (Kushuro, 2018).*

In summary, all *Rhizophora* species as well as the stilt root sample tested have a diffuse porosity. The vessels have a size of 80-200 µm and are therefore clearly visible without microscope. The cell walls are immensely thick in some areas of the samples so that almost no lumen is visible (Figure 11, 14 and 16). Growth zones are recognizable in all samples. The colour of the individual wood samples varies but this does not function as a distinguishing characteristic.

Summarized, it can be said that the distinction on a microscopic level of the *Rhizophora* spp. species is not possible. Especially, hybrids are very difficult to distinguish from the other *Rhizophora* taxon, as it is a mixture of the other two. As well a distinction between *Rhizophora* spp. and *Bruguiera gymnorrhiza* was not possible on basis of the cross-sectional images.

# 4 Methodology

For the project, a destructive sampling using tracts was chosen. Tracts are particularly suitable for the mangrove area, as the accessibility of the plots is facilitated. A tract includes four plots and always starts from the edge of the forest. Tracts were also chosen to see the different zoning of the mangroves and cover most of the species in the mangrove belt at the shoreline or river front. This selection was used to ensure the range of biodiversity including all species require for sampling to get representable biomass values.

For *Rhizophora* spp. a destructive method was chosen to generate the aboveground wooden biomass. A recording of the DBH for this species is mostly not possible, and the scrubby trees make a separation of single trees unmanageable. The project was accompanied simultaneously with a tree inventory of *Bruguiera gymnorrhiza* trees using the same tracts (Brielmaier, 2018). The aim of choosing these methods was, that it is also applicable to various other mangrove areas.

To start the actual fieldwork, Department of Lands need to give approval for destructively sampling mangroves. After getting approval, it is very important to inform the villages nearby about the project and enquire approval from their chief.

The evaluation of the data was carried out using R studio version 3.4.3 (2017-11-30) and Excel version 15.27 (161010) 2016.

## 4.1 Selection of tracts

Tracts were selected using a random sampling method. For that, forest cover and forest function maps with a scale of 1:50 000 were covered with a raster with a size of 1x1km.

All maps used were prepared by the cartography section of Department of Lands under the authority of the director of Lands and provided by mapping section, management division, Forestry Department. Mapping of national forest cover with all forest class details is based on digital image processing of LANDST-TM Satellite images recorded between 2000-2003 and GIS applications with Google earth images. The maps used for the Rewa delta mangrove area are out of edition 1 from 2014. Field checks for the two maps (sheet 029 Suva and sheet 028 Nausori area) were conducted in 1987/1989 and 1990.

Intersections with the raster and the forest edges were marked as a possible starting point for tracts. The edges are either from the waterfront, including open ocean, and rivers or from landside with open areas, grassland and other types of forest.

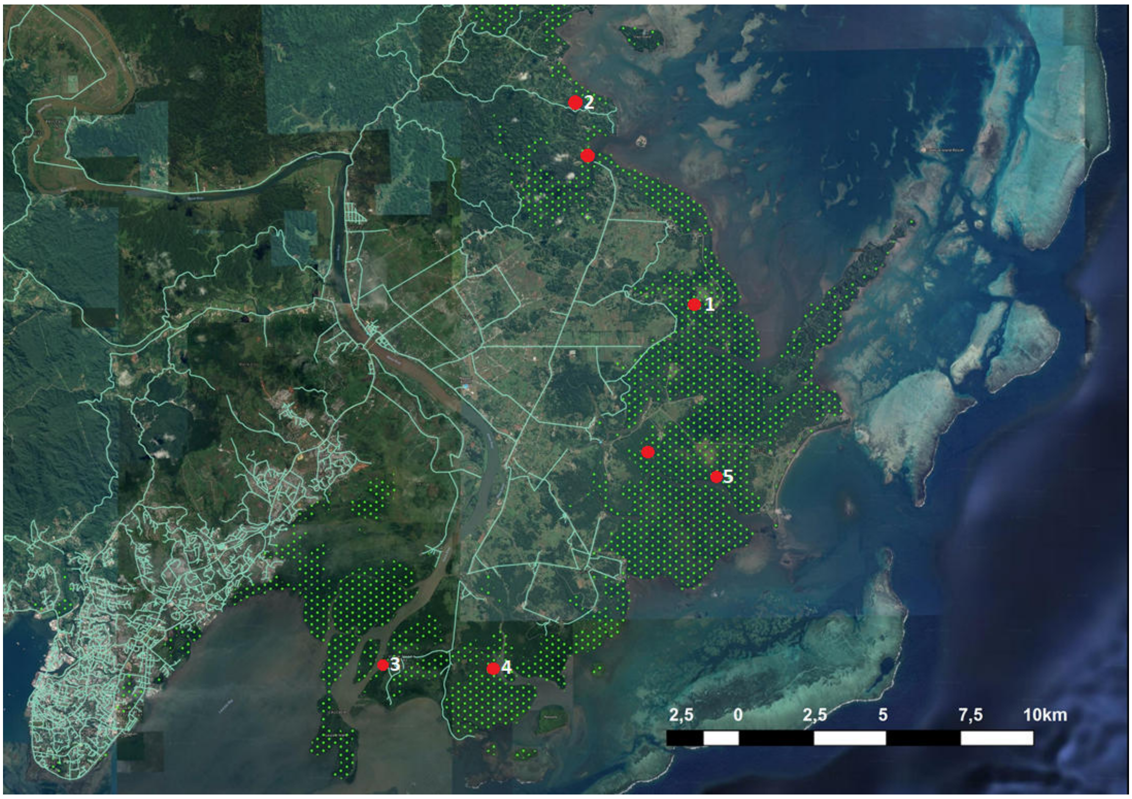


*Figure 18: Map of Rewa River delta with seven randomly chosen starting points for the tracts. Five tracts were realised. Numbering was done according to the order of implementation of the tracts. No.1=190, No.2=240, No.3=30, No.4=57, No.5=141 (Brielmaier, 2018).*

240 Intersections with the raster and the forest were marked. The points were numbered with the x- and y-coordinates from the raster and listed in an excel sheet. Then seven numbers as starting points were randomly selected for each delta. The red points marked in Figure 18 are showing the seven starting points for each tract for the Rewa delta.

Random selection was done using the Excel function “randbetween (lower number; higher number)”. To generate 7 random numbers with this function, firstly a field with seven cells must be marked in the excel sheet. The function “=randbetween (1;240)” can be entered in the edit bar and confirmed with control enter. Then a random number will be inserted in each cell of this field. These numbers change when new calculations are made in the worksheet. To generate unchanging random numbers, the seven numbers can be copied and insert again with "just insert values". The tracts are named after the enumerated number (Table1).

*Table 1: Random coordinates for tracts starting points in Rewa River Delta (Reimer, 2018).*

| **Random numbers** (Rewa Delta) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Tract no.** | **141** | **131** | **213** | **240** | **57** | **30** | **190** |
| x/y coordinate | 81,2/88 | 82,2/86 | 92/84 | 94/83,5 | 80,8/75 | 77/75 | 87,5/87 |

For the starting points in Ba, sheet M26 of BA area and sheet L26 of Vomo area of the forest cover and forest function map edition 1 from 2016 were used. The photography for preparing the map took place in the years 1972/1986 and 1982. Field checks were conducted in 1990 and 1991. The map was drawn on Transverse Mercator projection, the origin of which is at 17°00'south Latitude and 178° 45' East Longitude and has false coordinate values of 2000000mE and 4000000mN. Geodetic coordinates are in metres and are in the terms of the WGS72 Spheroid.

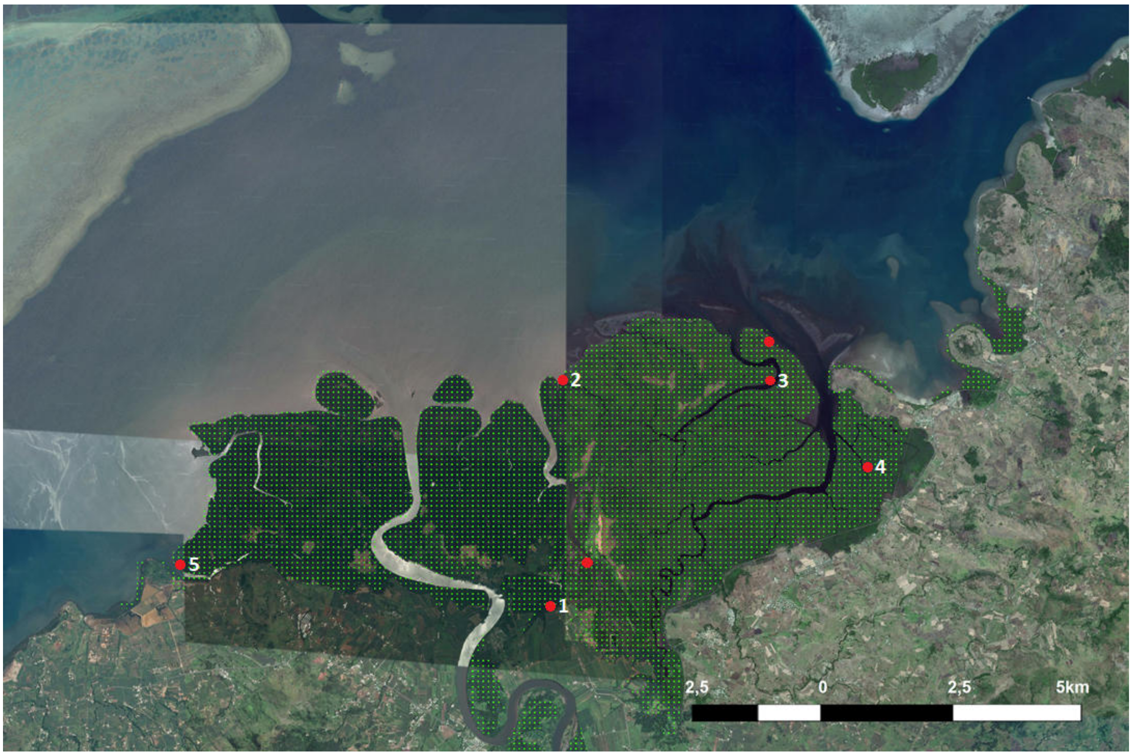


*Figure 19: Map of Ba River delta with seven randomly chosen starting points for the tracts. Five tracts were realised. Numbering was done according to the order of implementation of the tracts. No.1='165, No.2='80, No.3='17, No.4='09, No.5='135 (Brielmaier, 2018).*

For the Ba area, 174 intersections with the raster and the forest were marked in the two map sheets. The seven random numbers shown in Table 2 and mapped in Figure 19 were chosen by the excel function "randbetween (1;174)".

*Table 2: Random coordinates for tracts starting points in BA Delta (Reimer, 2018).*

| **Random number** (BA Delta) | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Tract no.** | **80** | **135** | **13** | **165** | **09** | **17** | **87** |
| x/y coordinates | 86,8/50 | 78,6/47 | 90/51,2 | 85,7/46 | 92/48,8 | 90/50,4 | 86,5/47 |

For both areas seven tracts were chosen to have alternative possibilities. Thus, alternative tracts can be accessed in case, the mapping is faulty and no mangrove forest can be found, already a forest conversion happened or the village in the surrounding area not allow entering or working in the mangrove forest.

### 4.1.1 Tract layout

Tracts always start from the edge of the forest and then go in right angle into the forest. The starting point of each tract has already been determined with the random selection of tracts (4.1). These points could be found using the 'Garmin GPSmaps 62s' with an accuracy of +/- 10m. Starting from this point, a random number between 1 and 10 was chosen. For that, the phone application "Zufallszahl" by UX Apps was used. This number determined the distance between the outer plot edge and forest edge. If the random number is zero, the plot starts directly at the edge of the forest (i.e. the edge of the forest is the edge of the plot to the same time).

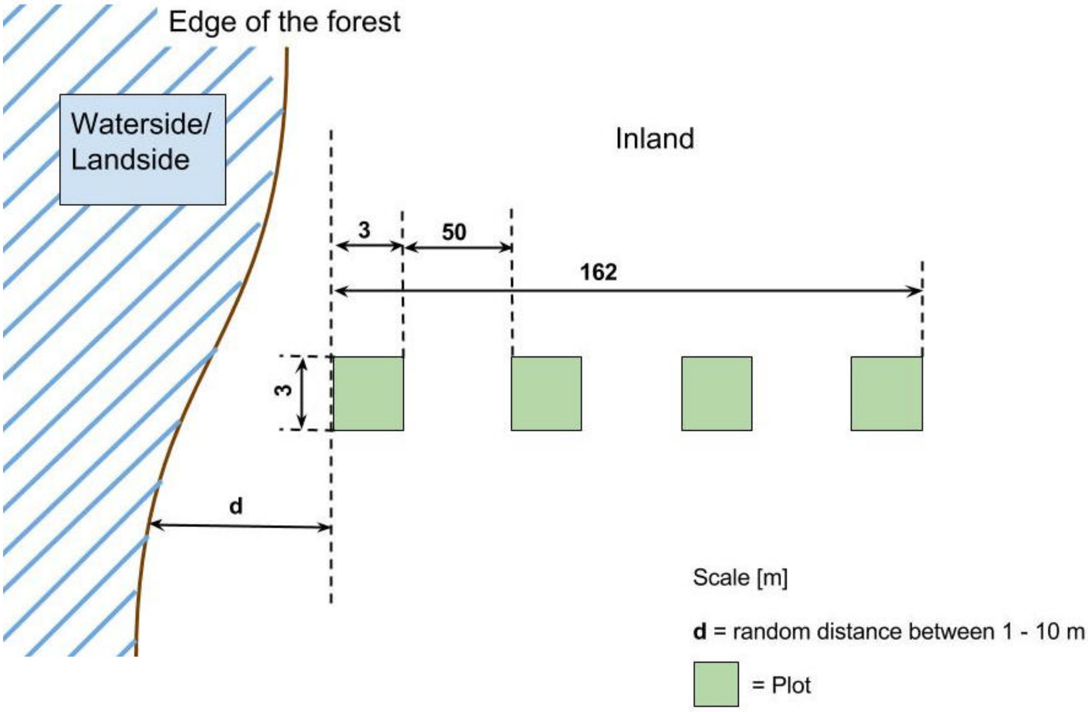


*Figure 20: Tract layout used for the mangrove inventory (Brielmaier, 2018).*

The tract had a total length of 162m (measured from the outermost edge of the first plots to the outer edge of the last plots). There are four plots on every tract with a distance of 50m each. One plot is measured with 3x3m (9m$^2$). To ensure that the plots stay in a straight line, a 162m long path was made. Every 50m a mark was set to mark the plots. Starting from this mark, the pots were always located on the left side. For both deltaic areas the total survey area amounted 0,0306ha. Within accessing the study areas, a total impact to the mangrove forest of around 0,610ha was noted.

## 4.2 Plot

After locating the plot, the two edges of every plot were firstly marked proceeding from the path (4.1.1). Starting from these edges, 3m were measured in a right angle from the path inside the forest. All edges were marked with a red tape. Then the distance between all edges was measured to control the length. As a final check the diagonals between the edges were measured as well. As a next step, the edges of the quadrat were marked vertically by using spray paint. Wooden biomass, which was not part of the plot, can be removed to improve a working area. In further process tree data inside the plot were recorded. This included the dendrology of tree species, an estimation or (if possible) a measurement of the height, damages or peculiarities (e.g. indicator plant or anthropogenesis influence) and recording and collection of deadwood.

### 4.2.1 Segmentation

The biomass of a plot was destructively sampled by making the edges of the plot vertically (4.2). The complete biomass inside this "cube" was weight recorded. Segmentation describes the variation in the biomass distribution of three parts of the *Rhizophora* scrub within a plot. Three segments "stilt roots", "trunk", and "crown" were classified and separately recorded. The biomass determination of the three segments was used to obtain a weight distribution within the plot.

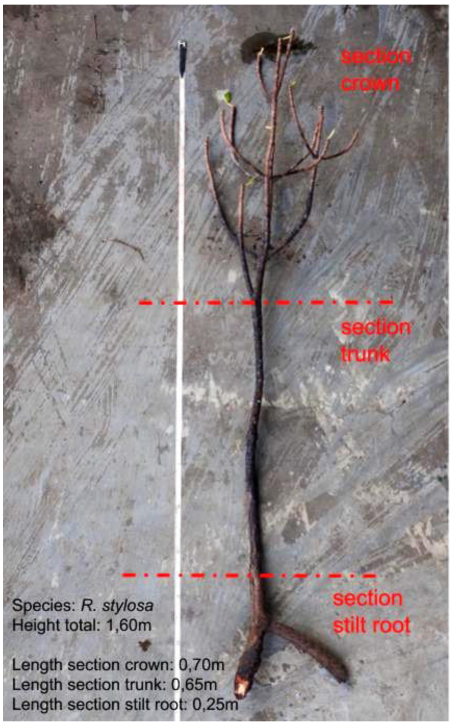


*Figure 21: Segmentation of the three segments (stilt root, trunk and crown) on one example (Reimer, 2018).*

Figure 21 shows the three different segments on an example of a *Rhizophora stylosa*. In this example, the tree has a total height of 1,60m. The stilt root segment shows a height of 0,25m, the segment trunk shows a height of 0,65m and the segment crown a height of 0,7m.

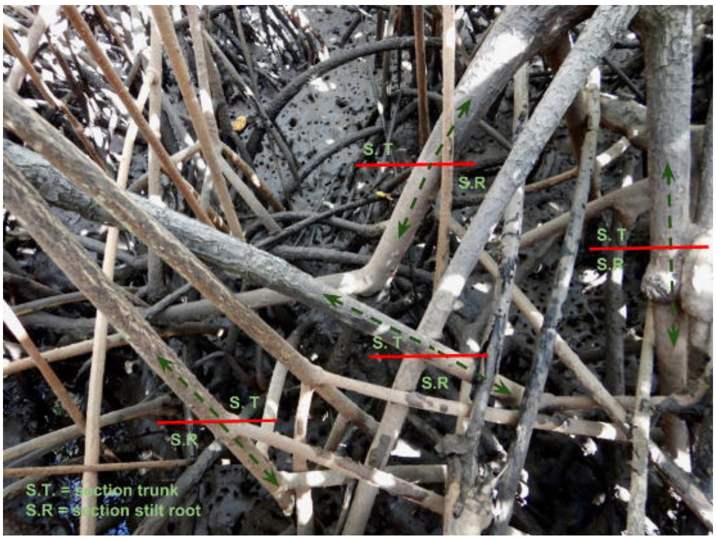


*Figure 22: Segmentation based on bark differences in the root system (Reimer, 2018).*

To differentiate the segments inside the plot, the following distinguishing features have been defined. In the stilt root system of the *Rhizophora* species, the bark conduced as a distinguishing feature for differencing this segment from the rest of the plot. The bark has a clear transition from a smooth, brownish bark in the lower part and a rough, greyish bark in the upper part of the root system. The two segments trunk and stilt root were defined as, the trunk segment begins with the change to the rough bark and the section inside the plot with smooth bark is the stilt root segment (Figure 22). The crown segment is defined as the area that has the last forked foliage.

*Figure 23: Application of segmentation in the field (plot 17'I) (Reimer, 2018).*

To divide the plot into different segments in the field, blue aerosol paint was used (Figure 23). A clear differentiation was not always possible, especially because the trees were often overgrown. If this was the case, a mean height was used for a certain segment.

### 4.2.2 Sampling

Sampling was implemented randomly by taking one sample from every third measurement. The removal of the samples took place from the buckets after weight recording for the biomass collection. Samples were taken for all different segments (i.e. stilt roots, crown and trunk segments) and a maximum of ten pieces were taken per segment. The random selection from the buckets ensure as well, that in case a plot had a very low biomass in total, less samples were taken from the buckets.
The samples were collected separately after segment in the field and sawed to a size of 10 to 20cm after completion of the biomass determination in the plot. The individual samples were collected in bags and labelled according to tract, plot and segment.

*Figure 24: Example of labelling samples of the tract No. 09' (Forstreuter, 2017).*

The labelling of the bags is explained by the following example: *09'RMC* (09' = number of the tract in Ba, R = tree species *Rhizophora* spp., M = plot number and C = segment crown). In detail the samples were labelled numeric (i.e. 09RMC1, 09RMC2 … 09RMC9). When labelling the samples, a distinction was made between R=*Rhizophora* spp. and B=*Bruguiera gymnorrhiza* species only. Which *Rhizophora* species were found explicitly inside a plot was recorded in writing.

## 4.3 Laboratory work

After labelling the samples, the green weight[4] was recorded. The recording of the fresh wood samples took place immediately after sampling in the field. This prevents falsification of the results by air-drying of the samples. The green weight was then noted in an excel sheet.

[4] Green weight = Wood freshly collected from the forest. In general, green wood samples have a moisture content of more than 30%.

### 4.3.1 Determination of Density

The IPCC noted in their Guidelines for National Greenhouse Gas Inventories (2007) a basic wood density for *Rhizophora mangle* of 0,89 t/m$^3$ (oven dry tonnes with moist m$^3$). This data is applicable for the American continents.

The volume of green samples was determined using two different methods, volume determination by immersion test (described as method_W1) and by measuring by hand (described as method_S) using a clipper. With Equation 1 the gross density of each sample can be calculated. For that according to IPCC (2007), the weight of a kiln dry sample (see 4.5 kiln dry) is divided by the volume of the green sample (see 4.3.1.1. and 4.3.1.2).

$$\partial_g = \frac{m_{dry}}{V_{wet}}$$

*Equation 1: Calculation for the gross density of samples.*

$Gross\ density\ of\ a\ sample\ \partial_g\ [g/cm^3]$
$Weight\ or\ mass\ of\ a\ kiln\ dry\ sample\ m_{dry}\ [g]$
$Volume\ of\ a\ green\ wood\ samples\ V_{wet}\ [mm^3]$

To calculate the kiln dry density, the volume intake is carried out with a kiln dry sample instead of a fresh wood sample (see Equation 2).

$$\partial_{kd} = \frac{m_{dry}}{V_{dry}}$$

*Equation 2: Density determination for kiln dry samples.*

$Density\ of\ a\ kiln\ dry\ sample\ \partial_{kd}\ [g/cm^3]$
$Weight\ or\ mass\ of\ a\ kiln\ dry\ sample\ m_{dry}\ [g]$
$Volume\ of\ a\ kiln\ dry\ samples\ V_{dry}\ [mm^3]$

#### 4.3.1.1 Volume determination by immersion test

The volume of a sample can be determinate by an immersion test. For that, the sample is immersed in a vessel filled to the brim with soapy water. Soap water is used to break the surface tension of the water. It then can also flow into gaps or uneven surfaces of the sample. The overflowing water was collected in another vessel. The increase of the water level indicates the actual volume of the body to be calculated. During the immersion test, the water containers were weighed. Using the weight of the overflowing water, the volume for the sample can be derived.

4.3.1.2 Volume determination by measuring

Volume determination by measuring was done using callipers. The samples taken were not symmetrical. Nevertheless, to achieve an accurate volume measurement, two times the diameter was taken from the cross section of the cylindrical samples. This was repeated for the other cross section of the sample. In total, for one sample, four diameters were measured and one length (Figure 25). Out of the four diameters one mean diameter was determined. The radius, used in the volume calculation for cylindrical samples (Equation 4) was calculated by the mean diameters (Equation 3).

$$r = \frac{((\mathrm{d1} + \mathrm{d2} + \mathrm{d3} + \mathrm{d4})/4)}{2}$$

*Equation 3: Calculation of the radius for Equation 4.*

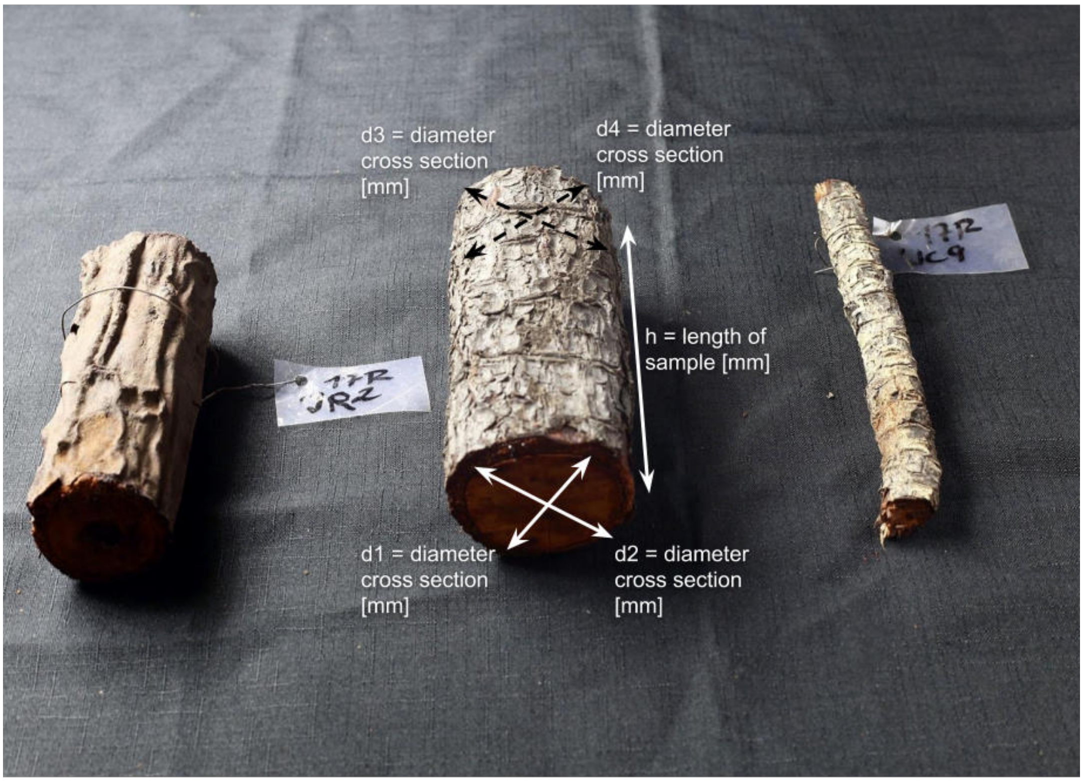


*Figure 25: Samples taken from section: stilt root, trunk and crown of tract no. '17. Measurements for the volume determination explained on the trunk sample (Forstreuter, 2017).*

The volume of a cylindrical body can be then calculated by the following equation (Equation 4).

$$V = \pi \cdot r^2 \cdot h$$

*Equation 4: Volume determination of cylindrical samples.*

$Volume\ V\ [mm^3]$
$Radius\ r\ [mm]$
$Lenght\ or\ height\ of\ the\ sample\ h\ [mm]$

## 4.4 Water Content

To calculate the water content or moisture content of a wooden sample the weight of a green sample and a kiln dry sample is required.

$$u = \frac{m_w}{m_0} \cdot 100 = \frac{m_u - m_0}{m_0} \cdot 100$$

*Equation 5: Calculation for water content determination.*

$water\ content\ u[\%]$
$Green\ weight\ m_w[kg]$
$kiln\ dry\ weight\ m_0[kg]$

Equation 5 shows, that the green weight [$m_w$] divided by the weight of the kiln dry [$m_0$] sample to generate the water content [u].

## 4.5 Kiln dry

After recording the weight of the green samples and measuring the green volume either with immersion test or by measuring. All samples were kiln dried in the “ontherm thermotec 2000” kiln produced in New Zeeland. The procedure was done according to DIN EN 13183-1: 2002:12.
Samples were dried with a temperature of 103 +/- 2°C until moisture equilibrium is reached. This happens when the weight is constant and the weight difference is lower than 1 to 2%.

## 4.6 Estimation of hectare values for the studied locations

For each delta (Rewa and Ba) there are n = 5 tracts (n= number of tracts in one delta) with i = {1,2,…,n}. In the following estimation, each tract represents independent observations (plots). h=4 describes the number of plots per tract with l = {1, 2,…,h}. The area of one plot measures $a_l = 9m^2$. To estimate the mean biomass per hectare for the delta, the following procedure applies.
Firstly, biomass of all `h` plots can be calculated per hectare. For that, the expansion factor (EF) has to be calculated (Equation 6) on basis of the area of the plots ($a_l$).

$$EF_l = \frac{10000}{a_l} = 1111{,}11$$

*Equation 6: Calculation of the expansion factor (EF).*

The expansion factor (EF) for plots is calculated by 1.111,11 (dimension less). As all plots not vary in size ($9m^2$), the EF of 1.111,11 is applicable to all plots.
Using Equation 7 the biomass for a plot located in a tract ($l^{th}$ plot) can be calculated to one hectare, using the expansion factor (EF). $B'_{li}$ describes the mean biomass of the $l^{th}$ plot in the $i^{th}$ tract and $B_{li}$ describes the mean biomass of the $l^{th}$ plot in the $i^{th}$ tract per hectare.

$$B_{li} = B'_{li} \cdot EF_l$$

*Equation 7: Biomass values for one hectare using the expansion factor.*

Equation 8 shows the calculation of the arithmetic mean of the biomass values per hectare per tract.

$$\bar{B}_i = \frac{\sum_{l=1}^{hi} B_{li}}{h}$$

*Equation 8: Arithmetic mean of the biomass values per ha of the $i^{th}$ tract.*

The calculated value $\bar{B}_i$ (in Equation 8) is the mean biomass of the $i^{th}$ tract per hectare. In Equation 9 the estimated mean biomass values per hectare, applicable to one lactation (one delta) can be determined.

$$\bar{B} = \frac{\sum_{i=1}^{n} \bar{B}_i}{n}$$

*Equation 9: Estimation of a mean biomass per ha for one location (delta).*

In order to frame the estimation of Equation 9, an estimation of accuracy (standard error of mean value) can be generated with Equation 10.

$$SE(\bar{B}) = \frac{SD}{\sqrt{n}}$$

*Equation 10: Estimation of accuracy (SE).*

$$SD = \sqrt{SD^2} \qquad \text{and} \qquad SD^2 = \frac{\sum_{i=1}^{n}(B_i - \bar{B})^2}{n-1}$$

*Equation 11: Calculation of the standard derivation (SD) used for Equation 10.*

The calculation of the confidence interval is explained in Equation 12.

$$Ci\ [\bar{B} - SD(\bar{B}) \cdot \phi \ \leq \ \mu \ \leq \bar{B} + SD(\bar{B}) \cdot \phi\ ] = 1 - a$$

*Equation 12: Calculation of the confidence interval (Ci).*

# 5 Results

From the 40 plots in total, 29 contained the biomass of the *Rhizophora* species. On the missing plots no *Rhizophora* species could be sampled. Reasons for that are different tree species such as *Bruguiera gymnorrhiza*, palm trees, other mangrove associated plants, strong deforestations and human influence or complete forest transformation, which is not comparable with the natural mangrove forest.
Out of the 29 plots, six plots started from landside and 23 plots from waterfront. Of the 29 plots, three plots were intermixed with *Bruguiera gymnorrhiza*.
The following analysis of variance was conducted with the R studio version 3.4.3 (2017-11-30). A two factorial analysis of variance (ANOVA)[5] was used. In most analysis factor one describes the locations[6] and factor two describes the different plots. In case other factors as the location were used, it is explicitly noted. If the P-value in the ANOVA result is greater than 0,05, the zero hypothesis is not excluded and following there is no significant variance. This also means that all values smaller than 0,05 show a significant variance for the tested groups. The significant codes are as following: 0 '***'; 0.001 '**'; 0.01 '*'. Unless otherwise noted, all tracts are included in the analysis of variance.

## 5.1 Main attributes

In the following two tables (Table 3 and 4) the main attributes, which were collected for the described *Rhizophora* species, are listed. Table 3 includes all plots located in Rewa while Table 4 includes all plots located in Ba. The boxes (in Table 3 and 4) highlighted in blue, are plots located directly at the edge to the waterfront. The grey boxes are tracts starting from landside. For each delta, there was only one tract, which started from landside.

*Table 3: Main parameter of all plots measured in Rewa.*

| Plot no. | Tree species selected | Distance to water front [m] | Height of plot [m] | AGL green [kg/plot] | Deadwood [kg/plot] |
|---|---|---|---|---|---|
| 190A | *R. selala* | 5,10 | 10,00 | 588,01 | 0 |
| 190B | *R. stylosa* | 58,10 | 5,00 | 380,05 | 0 |
| 190C | *R. stylosa* | 111,10 | 4,00 | 428,89 | 0 |
| 190D | *R. selala* | 164,10 | 7,00 | 494,58 | 0 |
| 240E | *R. stylosa* | 5,00 | 10,00 | 32,62 | 0 |
| 240F | *R. stylosa* | 58,00 | 5,00 | 176,84 | 0 |
| 240G | *R. stylosa* | 111,00 | 8,00 | 205,93 | 0 |
| 240H | *R. stylosa* | 164,00 | 10,00 | 48,11 | 0 |
| 57M | *R. selala* | 9,40 | 14,00 | 745,51 | 0 |
| 141Q | *R. selala* | 8,50 | 7,70 | 50,19 | 0 |
| 141T | *R. selala* | 167,50 | 13,30 | 184,98 | 50,36 |

The highest biomasses as well as the tallest height were collected at a plot located directly at the waterfront. On 57M *Rhizophora selala* was located and measured a total biomass of 745,51kg. On this plot, *Bruguiera gymnorrhiza* trees dominated the

[5] All values of the analyses of variance are listed in detail in appendix "Analysis of variance".
[6] The term location always refers to the two deltaic regions studied Rewa and Ba.

surrounding area. This consequently resulted in a height of 14m for the *R. selala* species. 141T was the only plot on which deadwood was noted for the Rewa delta. It is also explained (4.1.2) that the tract 141 showed the least human impact of all tracts in Rewa.
Comparing the two tables with each other, it is noticeable that in Rewa fewer plots with *Rhizophora* species were noted compared to Ba. In Rewa pure *Bruguiera gymnorrhiza* forests were found. Ba however was dominated only by *Rhizophora* species.

*Table 4: Main parameter of all plots measured in Ba.*

| Plot no. | Tree species selected | Distance to waterfront [m] | Height of plot [m] | AGL green [kg/plot] | Deadwood [kg/plot] |
|---|---|---|---|---|---|
| 165'B | *R. samoensis* | 53 | 4,2 | 35,12 | 116,64 |
| 165'D | *R. selala* | 159 | 4,5 | 283,56 | 0 |
| 80'E | *R. selala* | 4,1 | 5,5 | 465,1 | 149,24 |
| 80'F | *R. stylosa* | 57,1 | 3,8 | 116,75 | 18,56 |
| 80'G | *R. stylosa* | 110,1 | 1,95 | 61,81 | 10,54 |
| 80'H | *R. stylosa* | 163,1 | 1,9 | 53,31 | 20 |
| 17'I | *R. selala* | 4,7 | 4,95 | 822,90 | 0 |
| 17'J | *R. stylosa* | 57,7 | 3,7 | 294,40 | 15,65 |
| 17'K | *R. stylosa* | 110,7 | 3,7 | 193,40 | 8,6 |
| 17'L | *R. selala* | 163,7 | 5,1 | 236,30 | 80,57 |
| 9'M | *R. stylosa* | 9,8 | 4,6 | 66,40 | 41,37 |
| 9'N | *R. stylosa* | 62,8 | 4,4 | 205,30 | 41,77 |
| 9'O | *R. stylosa* | 115,8 | 3,3 | 144,10 | 0 |
| 9'P | *R. stylosa* | 168,8 | 3,65 | 183,10 | 0 |
| 135'Q | *R. selala* | 2,9 | 6,2 | 320,40 | 12,7 |
| 135'R | *R. stylosa* | 55,9 | 1,9 | 79,10 | 50,6 |
| 135'S | *R. stylosa* | 108,9 | 2,95 | 75,30 | 11,54 |
| 135'T | *R. stylosa* | 161,9 | 3,14 | 124,20 | 9,63 |

Table 4 shows significantly more deadwood than Table 3. In Rewa there is only one plot noted with deadwood (141T in Table 3) whereas in Ba only four plots are noted without any deadwood (165'D, 17'I, 09'O and 09'P in Table 4). Reason for this difference can be mostly explained by the cyclone Winston in 2016. Nevertheless, the highest amount of deadwood was collected in plot 165'B. Tract 165 was characterised by a cleared forest as a result of fire.
The mean value of the biomass as well as the height were recorded higher for the Rewa River delta than for Ba. This can be explained by the storm in 2016 and as well as by heavy use of the mangrove forest in Ba. Table 4 shows that the forest in Ba was dominated by *Rhizophora* species with an average small height (e.g. 135'S, 80'G or 80'H) compared to the plots in Rewa (Table 3).
The green biomass was analysed for the three different tree species in relation to the occurrence in the tracts and in relation to the two locations. The analysis of variance shows no significant variation of biomass when set in relation to the two locations as well as the position inside the tract. This result is valid for all *Rhizophora* species analysed together as well each species separately.

For all *Rhizophora* species together the analysis of variance calculated four plots not starting from waterfront in Rewa and 2 in Ba (see Table 3 and 4). For *R. selala* 10 plots were analysed and for *R. stylosa* 18 plots.

### 5.1.1 Plot description

The first tract no. 190 shows a natural, very dense forest with no human impact. This is underpinned by the lack of root dulls or waste as well as and the grown status of e.g. *Bruguiera gymnorrhiza* trees (Brielmaier, 2018).

The tract started with plot 190A, which was 5,1m away from riverside. This plot with the coordinates of the plot centre E 019.86479, N 038.87180 is dominated by the hybrid *Rhizophora selala* (Figure 26).

*Figure 26: Forest workers collecting wooden biomass from plot 190A. Pink tapes marking the edges of the plot. In the top of the image, the river can be seen (Reimer, 2018).*

In plot 190B (E 019.87545, N 038.87009) *Rhizophora stylosa* were found. *Bruguiera gymnorrhiza* trees were found immediately next to the plot. In plot 190C (E 019.87682, N 038.86949) the species *Rhizophora stylosa* were mostly found. *Rhizophora samoensis* were found intermixed with *Rhizophora stylosa* close by.

The forth plot (No. 190D) was located inside a *Bruguiera gymnorrhiza* forest (E 019.87640, N 038.86171). The species *Rhizophora selala* were located inside the plot. The plot was measured with an annual height of 7,0m but in total the plot had a lower density of the scrub so the accessibility was easy.

On tract No 213, the second chosen tract it was not possible to work on. A village started approximately 30m away from the set starting point. The edge of the forest was dominated by *B. gymnorrhiza* and other mangrove associated tree species followed by palm trees and a hog house.

For tract No. 240 the starting point was set landside with a randomly chosen distance of 5m to the first plot. The tract is located in the north- eastern part of the Rewa delta and runs mostly parallel to the edge of the forest.

Plot 240E starts next to a natural open forest (coordinates of the plot centre were noted with E 019.83479, N 038.94018). Close to the plot a mixed mangrove forest of white mangroves and coconut trees with an open mud area were found. Inside the plot *Bruguiera gymnorrhiza* with a DBH under 8cm and *Rhizophora stylosa* with an average height of 10,0m were found[7]. An anthropogenic influence was not directly apart.
Plot 240F (E 019.83511, N 038.94047) is next to dry land, on which no mangroves were found. The plot had a smaller average height. *Rhizophora stylosa*, located at the plot were intermixed and overgrown by climbers which could be seen as an indicator for an anthropogenic influence. *Rhizophora samoensis* were found intermixed with *R. stylosa* in the surrounding area.
Plot 240G (E 019.83551, N 038.94065) was positioned next to a white mangrove area. *Rhizophora stylosa* species and white mangroves were found. Only one *Bruguiera gymnorrhiza* tree was found next to the plot and no obvious indicator of human impact was noticed. Plot 240H was located inside *Bruguiera gymnorrhiza* forest (E 019.83601, N 038.94092). *Bruguiera gymnorrhiza* and *Rhizophora stylosa* occurred inside the plot. No anthropogenic influence was noted in and around the plot.

Tract no. 30 showed immense human impact. The tract is located in the western part of the Rewa delta and started from the riverside, opposite of a village. Freshly cut down *Bruguiera gymnorrhiza* as well as old root dulls were found. *Bruguiera gymnorrhiza* trees are growing right on the waterside with soil erosion at the riverside as a consequence (Brielmaier, 2018, p. 8).
8,5m away from the edge of the forest, the first plot 30I (E 019.770553, N 038.75043) started with *Bruguiera gymnorrhiza*. The juvenile trees had a DBH under 8cm. *Rhizophora* species were not found inside the plot, close to the plot and at the riverside or the edge of the forest. Big anthropogenic influence was seen by root dulls and forest conversion. Plot 30J (E 019.77099 N 038.75032) is dominated by white mangroves and coconut trees. The root dulls of *Bruguiera gymnorrhiza* trees showed the anthropogenic influence of this plot. Inside plot 30K (E 019.77148, N 038.75018) same aged coconut trees were noted (Figure 27).

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[7] See Brielmaier (2018) for more information of the forest inventory for *Bruguiera gymnorrhiza* trees.

*Figure 27: Measuring the distance between plot 30K and 30L. The area around plot 30K is dominated by coconut trees (Reimer, 2018).*

Plot 30L with the coordinates E 019.77194, N 038.74998 is located close to the riverside. The village was visible (Figure 28). Mostly white mangroves and coconut trees, few *Rhizophora selala* were found close to the plot.

*Figure 28: Picture taken from plot 30L. On the other side of the river a house of the village is visible (Reimer, 2018).*

The tract area is mapped as mangrove forest but beside plot J no mangroves were located inside a plot.

The fifth chosen tract (No. 57) runs along a creek. A big amount of garbage and bamboo deadwood were found along the tract, mostly at the edge of the forest.
Plot 57M (E 019.80883, N 038.74922) starts 9,4m inside the forest with *Rhizophora selala*. Anthropogenic influence was seen by a high amount of trash at the edge of the forest.
Plot 57N (E 019.80833, N 038.74906) is located inside a *Bruguiera gymnorrhiza* forest. Inside the plot juvenile regeneration of *Bruguiera gymnorrhiza* trees were found. Most of the juvenile trees were not higher than 0,5m. Inside the plot deadwood and root dulls of *Bruguiera gymnorrhiza* trees, throughout human influence were found.
The third plot (plot 57O with the coordinates of the plot centre E 019.80786, N 038.74901) was located next to a creek inside a *Bruguiera gymnorrhiza* forest. Only *Bruguiera gymnorrhiza* trees were recorded inside the plot and an anthropogenic influence was seen by rood dulls of *B. gymnorrhiza* (Brielmaier, 2018, p. 30).
In plot 57P were neither *Rhizophora* species nor *Bruguiera gymnorrhiza* trees inside the plot. The plot was located inside a mixed mangrove forest (coordinates of the plot centre: E 019.80740, N 038.74839). The white mangroves *Xylocarpus granatum* ‘Dabi’, *Excoecaria agallocha* ‘sinu gaga’, *Heritiera littoralis* ‘Ivi’ were found in a distance of 2 to 7,5m to the plot centre and coconut palms in a distance of 3,9 to 7m. *Bruguiera gymnorrhiza*, few *Rhizophora selala* and *Acrostichum aureum L.* (A fern in Fijian called borete) were also found in the broader surrounding of the plot.

The last tract no. 141 for the Rewa Delta was characterized throughout big diameters of *Bruguiera gymnorrhiza* trees. The *Bruguiera* forest started close to the waterfront and not much *Rhizophora* species were seen. Only *Rhizophora selala* competed with *Bruguiera gymnorrhiza* and occurred cluster wise. This tract was characterised by the least human impact.
Plot 141Q with the GPS coordinates of the plot centre E01988919 N03880359 had *Rhizophora selala* and juvenile *Bruguiera gymnorrhiza* trees inside. The plot is located inside a *Bruguiera gymnorrhiza* forest. Also one *Bruguiera gymnorrhiza* tree was standing inside the plot (Brielmaier, 2018, p. 30). The distance from the waterside to the plot amounted 8,5m. In the surrounding area of the plot, several tall *Rhizophora selala* (Figure 29) were found.

*Figure 29: In the closer area of plot 141Q a Rhizophora x selala tree growing in a Bruguiera forest and competing with B. gymnorrhiza trees in height (Reimer, 2018).*

Plot 141R (plot centre marked with E01980833 N03874906) was located in a *Bruguiera gymnorrhiza* forest right next to a creek. Therefore, no *Rhizophora* species was noted inside the plot. Instead, natural deadwood of *Bruguiera gymnorrhiza* trees were found. The plot had a natural regeneration and lots of juvenile *Bruguiera gymnorrhiza* trees.

Plot 141S (E01989018 N03880383) was located inside a *Bruguiera* forest as well with *Bruguiera gymnorrhiza* trees inside the plot. Mostly juvenile regeneration of the forest and only two trees inside the plot were measured with an DBH above 8cm (Brielmaier, 2018, p. 30). Moreover, natural deadwood of *Bruguiera gymnorrhiza* trees were found. The surrounding of the Plot was mainly dominated by *Bruguiera gymnorrhiza* trees with a vast size[8]. In addition, a small amount of *Rhizophora selala* were found cluster wise close by.

Plot 141T (E01989062 N03880403) was located inside a *Bruguiera* forest and included only *Rhizophora selala*. The *Rhizophora selala* showed the same height as the *Bruguiera gymnorrhiza* trees located in the surrounding area. Natural deadwood was found inside the plot. Other *Rhizophora* species found in the surrounding area were block-like arranged.

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[8] See Brielmaier (2018) for more information of the forest inventory for *Bruguiera gymnorrhiza* trees.

Each tract was named after the random selection of the numbers. The name of the plot starts again with A (first plot in the first tract) but for the Ba delta region an apostrophe was set in front of the letter for each plot and behind the tract numbers (e.g. plot 165‘A).

The first tract, tract No. 165, runs parallel to a gravel road and crosses a small river. On both sides of the river the mangrove area was burned. According to the forestry workers the area was burned down probably for gaining grassland for cattle farming and the fire was set approximately 10 days before. A close by forest showed white mangroves and red mangroves intermixed. On the way from Ba town to the tract lots of sugar cane fields and cattle ranges were seen. Consequently, plot 165‘A marked with the coordinates E01885791 N0 3946016, was a burned mangrove forest or burned grassland. Plot 165‘B (E 018.85079, N 039.49420) was also located in the burned area but the plot was set right next to the small river. The edge of the plot was at the same time the edge of the river at low tide. One *Rhizophora samoensis* with a height of 4,2m was found inside the plot (Figure 30).

*Figure 30: Rhizophora samoensis inside plot 165'B (Reimer, 2018).*

Besides that, lots of deadwood from unknown species was found. The third plot (plot 165‘C with the coordinates E 018.85057, N 039.46468) had no mangroves. the only standing mangroves in the close by area were burned *Rhizophora selala*. Plot 165‘D (E 018.85042, N 039.46506) was located at the beginning of a *Rhizophora* forest with approximately two *Rhizophora selala* trunks inside. One tree was growing horizontally shortly above ground. The second one was also growing horizontally above the first one. Dead stem of another *Rhizophora selala* was standing right next to the plot. Mangrove associated ferns (*Acrostichum aureum L.*) were in and around the plot. The indicator plant climbers were also found in and around the plot which show human impact.

Tract No. 80 started from water side close to the open ocean at the mouth of a river. The first plot (plot 80‘E) was 4,1m away from the waterfront and had direct ocean impact with higher waves and the stilt roots were covered with sea shells. The plot centre was located with the coordinates E 018.86038, N 039.50337. *Rhizophora selala* grew inside the plot, a significant amount of deadwood was found. This was the first plot, where the weight of the leaves was recorded. Two *Bruguiera gymnorrhiza* were found approximately 20m further inside the forest (Brielmaier, 2018).

Inside plot 80‘F (E 018.86080, N 039.50358) *Rhizophora stylosa* were found. The forest had a scrubby structure. Connected to other *R. stylosa* species sampled before, in this case the bark was very grey and rough.
The plot 80‘G with the coordinates E 018.86125, N 039.50377 of the plot centre was located inside a single- species *Rhizophora* forest. No other species were found within a distance of 20m. As the forest structure was quite small, the species were easy to separate. In addition, a trunk was easy to spot and stilt roots were located close to the ground. The plot was thus not as dense grown into each other as other types of *Rhizophora* forests. For this plot leaves were separately calculated as well. On plot 80‘H (E 018.86168, N 039.50398), *Rhizophora stylosa* occurred and showed the same forest structure as plot 80‘G. The plot had a small height and it was easy to separate individual trees.

Tract no. 17 goes 280° from riverside into the forest. The edge of plot 17‘I was 4,7m away from the waterfront. Plot 17‘I is located inside a single- species Rhizophora forest and the coordinates of the plot centre are E 018.90084, N 039.50335. *Rhizophora x selala* species were dominating the plot.
Inside plot 17‘J (S 17.44597, E 177.71440) *Rhizophora stylosa* were found. The structure of the forest resembled the surrounding area of 17’J.
The third plot 17‘K (S 17.4457, E 177.71394) is located inside a mixed mangrove forest. *R. stylosa* occurred inside the plot, *Bruguiera gymnorrhiza* trees were found in a distance of 2 to 20m from the plot centre and within 20m the first *R. selala* tree was spotted.
Between plot 17‘K and plot 17‘L (S 17.44617, E 177.71497) a change in forest structure was seen. Inside plot 17‘L tall *Rhizophora selala* were found. Mostly tall lignified stilt roots of *Rhizophora selala* were located inside the plot. Consequently, the density of the plot was quite low and therefor the accessibility was simplified.

The forth tract (No. 09) is located in the eastern part of the Ba delta and started from riverside right at the mouth to a bigger creek. The GPS coordinates of the starting point were located further inside along the creek. But as the creek was blocked with deadwood, steams and litter, the tract started right in front of the blockade. The shore at the creek abruptly ends and forms a steep border to the water. This can be seen as an indicator for land erosion at the riverside.
The edge of first plot 09‘M (S 17.45952, E 177.73134) was 9,8m away from the edge of the forest. *Rhizophora selala* and *Rhizophora stylosa* were mixed. The plot centre of plot 09‘N (S 17.45963, E 177.73175) was located 64,3m inside the single- species *Rhizophora* forest. A dead, still standing *Rhizophora* sp. was found right next to the plot. Inside the plot *Rhizophora stylosa* species were noted. No other species, besides *Rhizophora* spp. were found in a distance of 20m. Plot 09‘O is located inside a *Rhizophora* forest. The structure of the forest is similar to the area of plot 09’N. Again, no other species were found in a distance of 20m around the plot. The plot centre (S 17.45972, E 177.73218) was 117,3m away from the waterside. Inside this plot no

deadwood of *Rhizophora* species were noted. Plot 09‘P is located inside a *Rhizophora* forest and only the species *Rhizophora stylosa* occurred. The plot centre (S 17.45983, E 177.73256) was 170,3m away from waterside.

The fifth tract (No. 135) is located in the very western part of the Ba delta. It is the only tract starting directly at ocean side. A reef protects the mangrove area in this part of the delta. The tract is located inside a pure *Rhizophora* forest. Outgoing from all plots there were no other species, besides *Rhizophora* spp. found in a distance of 20m around each plot. The distance between the ocean and the edge of plot 135‘Q is 2,9m. Inside the plot a direct influence of the ocean was noted (e.g. wave actions, soft muddy ground, under water stilt roots covered with shells). *Rhizophora selala* were found. Plot 135‘R as well as 135’S was dominated by small *Rhizophora stylosa* trees. Plot 135‘T (S 17.47602, E 177.60934) was dominated by *Rhizophora x selala*.

## 5.2 Segmentation

Segmentation defines the vertical division of the plot into three areas, which are named after the distribution of the *Rhizophora* scrub stilt root (lower area), trunk (middle area) and crown (upper area) (4.2.1). Table 5 describes the percentage distribution of the individual segments for each plot and a weighed mean distribution of the three segments: stilt root, trunk and crown. The proportion for each segment was calculated by setting the weights for the segments in relation to the total weight of each plot.
The segmentation was performed on four plots in Ba (all plots of tract no. 17) and one plot in Rewa (141T).
Plot 1 summarizes all plots, which are located right at the waterfront and on which segmentation was done. That applies to 17'I, 135'Q and 80'E. On plot 135’Q and 80’E only the segment stilt root was separated i.e only segment stilt root comprises three plots. The percentage distribution of trunk and crown segments are generated from plot 17’I. Plot 2 describes plot no 17’J, the second plot inside tract 17, on which segmentation took place. Plot no. 3 reflects plot 17’K. Plot 4 (plots furthest away from the water front) in Table 5 is generated from 17’L (located in Ba) and 141T (located in Rewa)[9].

*Table 5: Segmentation with weighed amount of each segment in per cent.*

| Plots | Leaves [%] | Stilt roots [%] | Trunk [%] | Crown [%] |
|---|---|---|---|---|
| 1 | 3,0 | 29,0 | 59,0 | 13,0 |
| 2 | 5,0 | 58,0 | 36,0 | 6,0 |
| 3 | 10,0 | 57,0 | 33,0 | 10,0 |
| 4 | 4,0 | 41,0 | 49,0 | 11,0 |
| Weighed value: | 5,0 | 40,0 | 50,0 | 10,0 |

Plot 1 had in average, three times as much biomass as the other plots further inside, subsequently the segments collected in the first plot were weighed according to the

[9] All values of the different segments for the examined plots can be found in detail in the appendix “Biomass determination for all plots”.

total amount. Stilt roots, trunk und crown together add up in 100%. Leaves are not part of the segmentation as they are not part of the wooden biomass.
The factor of 5% for leaves can be used, in case complete *Rhizophora* species are weighed, to calculate only the wooden biomass.

### 5.2.1 Shell factor

Wooden biomass is defined as trees, bushes and shrubs without foliage, seeds or other non-wood material (IPCC, 2007). As shells on the stilt root are not part of the biomass and they would falsify the results of the study. A factor for the clams was calculated.

*Figure 31: Stilt root covert with shells (Reimer, 2018).*

For this purpose, nine samples were collected. They were weighed firstly with the shells and after without the shells (see Figure 32). The proportion of shells in the total weight of the stilt roots is 39,4%[10]. The 39,4% were deducted from the total green weight in the stilt roots segment (i.e. only for those sections in the plot which had actually shells on it). The shell factor was thus subtracted from the stilt root segment in plot 135'Q and plot 80'E. No further plots were found with shells at the stilt roots.

*Figure 32: Stilt root sample with shells (left) and without shells (right) (Reimer, 2018).*

[10] A table of all collected samples to calculate the shell factor can be found in appendix "Calculation for a shell factor".

## 5.3 Water content

The water content was determined by 650 samples of *R. stylosa*, *R. samoensis* and *R. selala*. *R. samoensis* was found exclusively on plot 165'B. This tree showed an average water content of 50% (53% in the section stilt root, 43% in section trunk and 56% in section crown). Since there are no comparative values for this tree species (neither in terms of plots nor in terms of location), R. samoensis is not further analysed in this context. This is aggravated by the fact that the environment around this plot was heavily degraded by fire and thus human influence.

*Table 6: Water content determined for the three different segments for the species R. selala and R. stylosa.*

| ***Rhizophora selala*** | | | | ***Rhizophora stylosa*** | | | |
|---|---|---|---|---|---|---|---|
| Water content [%] | | | | Water content [%] | | | |
| Root | Trunk | Crown | Mean | Root | Trunk | Crown | Mean |
| 46,36 | 34,32 | 40,33 | 40,34 | 51,50 | 39,29 | 42,88 | 44,56 |

The analysis of variance was tested for all tracts and all segments together (stilt root, trunk and crown). The comparison of the two locations (Rewa and Ba) shows a significant difference of P=0,0361155*. Furthermore, a significant variance of the section stilt root was evaluated in the comparison (P=0,03269*). The other two segments (trunk and crown) show no significant difference. Looking at the stand inside the tract (analysis of variance in relation to the plot), all segments show a significant variance (explained further in 5.5.3).

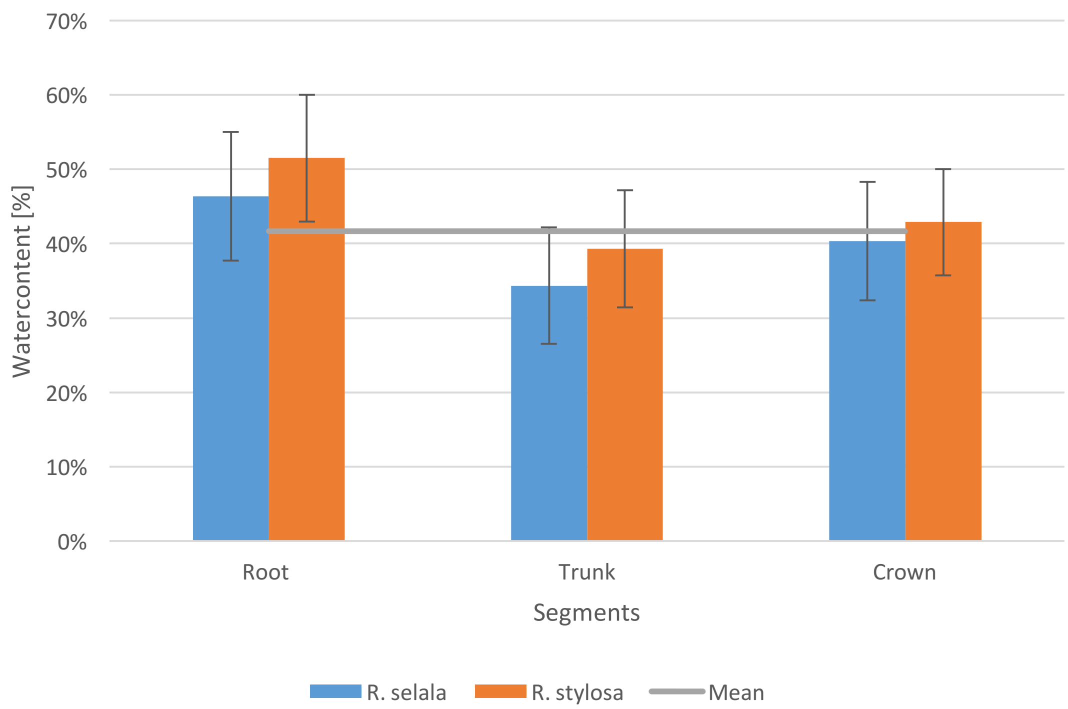


*Figure 33: Distribution of the water content in different segments for R. selala and R. stylosa with the mean value for both study areas Rewa and Ba delta.*

For both species, the water content in section root shows the highest amount, while in section trunk the lowest was measured.
When a weighed[11] water content is formed across the tree species *R. selala* and *R. stylosa*, *R. selala* obtains a higher weighting. *R. selala* shows the largest amount in relation to the total weight. Figure 33 illustrates that the mean water content across all segments is significantly lower for *R. selala* (SD= 0,09) than for *R. stylosa* (SD=0,08). A weighed water content for both species would be proportioned by 48% water content in the stilt root system, 46% water content in the trunk section and 41% for the crown section. This results in a mean water content of 42,45%.

## 5.4 Density

The gross density values were determined exclusively for the deltaic region in Ba. Therefore, an analysis of variance regarding the location as well as an interdependency between location and plots is not possible.
For *Rhizophora samoensis* only 10 samples were collected to analyse the gross density by immersion test and only 4 samples were possible to measure by hand. For the crown section only one sample was immersed and non-measured. As a result, R. samoensis is not fully illustrated in the following figures, but it is included with all segments in table 7 to complete the density values.
The kiln dry density was determined by samples collected in Rewa, mainly from tract number 190, 141 and 240.

### 5.4.1 Calculation of density by volume determination using immersion test

The gross density was ascertained by 225 *Rhizophora selala*, *Rhizophora stylosa* and *Rhizophora samoensis* samples using the immersion test. For *R. stylosa* 113 samples were used (46 from trunk, 44 from section root and 23 from crown). For *R. selala* 102 samples (from section trunk 39 samples, 37 in section root and 26 section crown) were immersed.

[11] Weighting is the evaluation of individual influencing factors with regard to their importance or their frequency. The weighting means that more important or more reliable values have a greater impact on the results.

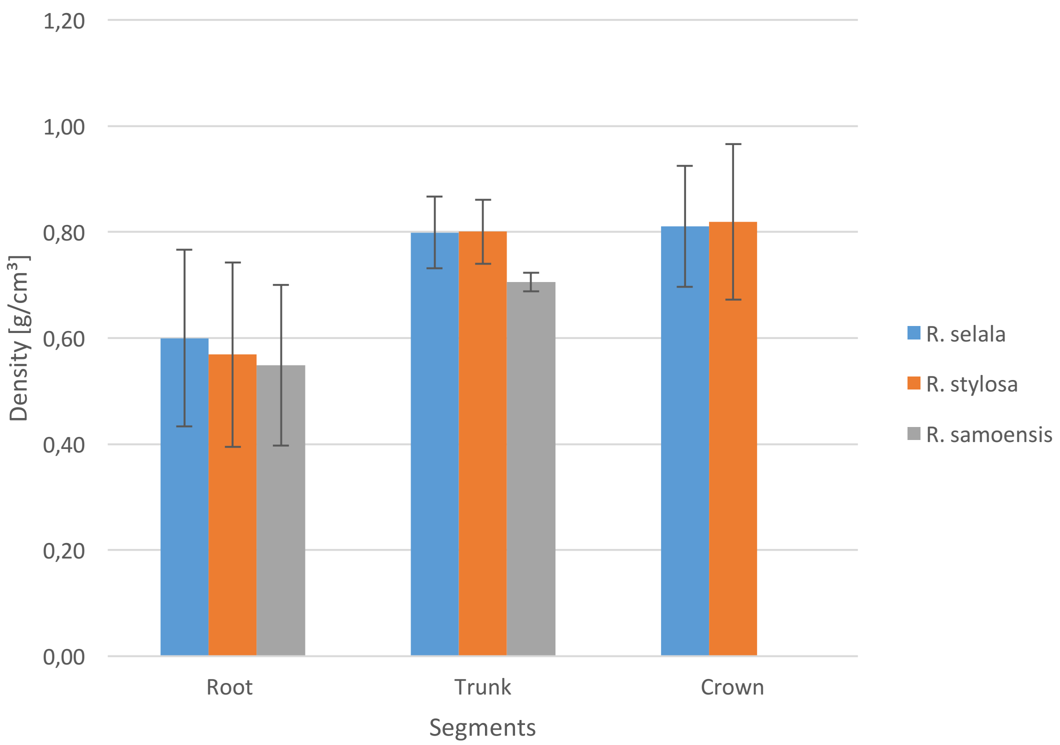


*Figure 34: Density for all samples of Rhizophora species collected in Ba. Green Volume was determined by the immersion test.*

Figure 34 shows, how the density differs in the individual segments. In general the stilt root segment has the lowest density (SD= 0,17) while section crown (SD = 0,15) and trunk (SD = 0,07 ) are higher. The density values of sections crown and trunk for *R. selala* and *R. stylosa* vary around 0,8g/cm$^3$. The density calculated in section stilt roots for *R. stylosa* and *R.selala* range between 0,57g/cm$^3$ and 0,6g/cm$^3$.

On average, samples of the segment crown are significantly smaller than samples from the segments trunk and stilt root. An over- or underestimating of the volume ascertained using the immersion test (method_W1) (4.3.1) has consequently a strong effect on the density. For the segment stilt root, it was not distinguished whether samples taken are young and not yet attached to the ground, and thus have a low density or whether the samples are already lignified (see also segmentation in 4.2.1). If a stilt root is already lignified, the sample can achieve density values that show the same values as determined for the section trunk. The high standard deviation in segment stilt root results out of these variations of values.

The density analysed for all segments in relation to the occurrence inside the tract shows no significant variance. Looking at the segment trunk separately, the analysis results in a difference of P=0,03644* in relation to the different plots.

*Table 7: Density for all Rhizophora species collected.*

| **Method_ W1** | **No. of samples** | $\partial_g$ **stilt root** | | $\partial_g$ **trunk** | | $\partial_g$ **crown** | | **Mean** $\partial_g$ **values**[12] | |
|---|---|---|---|---|---|---|---|---|---|
| [Volume determination by immersion test] | | [g/cm³] | **SD** | [g/cm³] | **SD** | [g/cm³] | **SD** | [g/cm³] | **SD** |
| *R. selala* | 102 | 0,60 | 0,16 | 0,80 | 0,07 | 0,81 | 0,11 | **0,72** | 0,17 |
| *R. stylosa* | 113 | 0,57 | 0,17 | 0,80 | 0,06 | 0,82 | 0,15 | **0,71** | 0,18 |
| *R. samoensis* | 10 | 0,55 | 0,15 | 0,71 | 0,02 | 0,48[13] | - | **0,62** | 0,17 |

An analysis of variance was accomplished using all density values from samples on which the volume was determined using the immersion test (method_W1). The density ascertained with method_W1 in relation to the different species show a difference of P = 0,05382.
This difference results mainly from the below-mean value for *R. samoensis* (see Table 7). The species *Rhizophora stylosa* shows a mean density of 0,71g/cm$^3$ and the hybrid *R. selala* 0,72 g/cm$^3$. The mean density differs only about 0,01g/cm$^3$. The calculated mean values for the densities of the individual species were weighed with regard to the segments.

34 samples were calculated using method_W1 for their kiln dry density. Out of that, 24 samples of *R. selala* were analysed and resulted in a mean kiln dry density of 0,97 g/cm$^3$. 10 samples were calculated from *R. stylosa* and resulted in a weighed mean kiln dry density of 0,59g/cm$^3$.

### 5.4.2 Calculation of density by volume determination by measuring by hand

In total 113 samples were measured by hand (method_S). From that 56 *R. selala* (24 trunk, 15 stilt root and 17 crown), 53 *R. stylosa* (21 trunk, 20 stilt root, 12 crown) and 4 *R. samoensis* (2 trunk and 2 stilt root) samples were measured.
Figure 35 illustrates that density values in the segment stilt root show the lowest values (SD= 0,14), while the sections trunk (SD= 0,07) and crown (SD= 0,09) show higher values.

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[12] Mean density value for each Rhizophora species including all segments.
[13] This value is represented by one sample analysed.

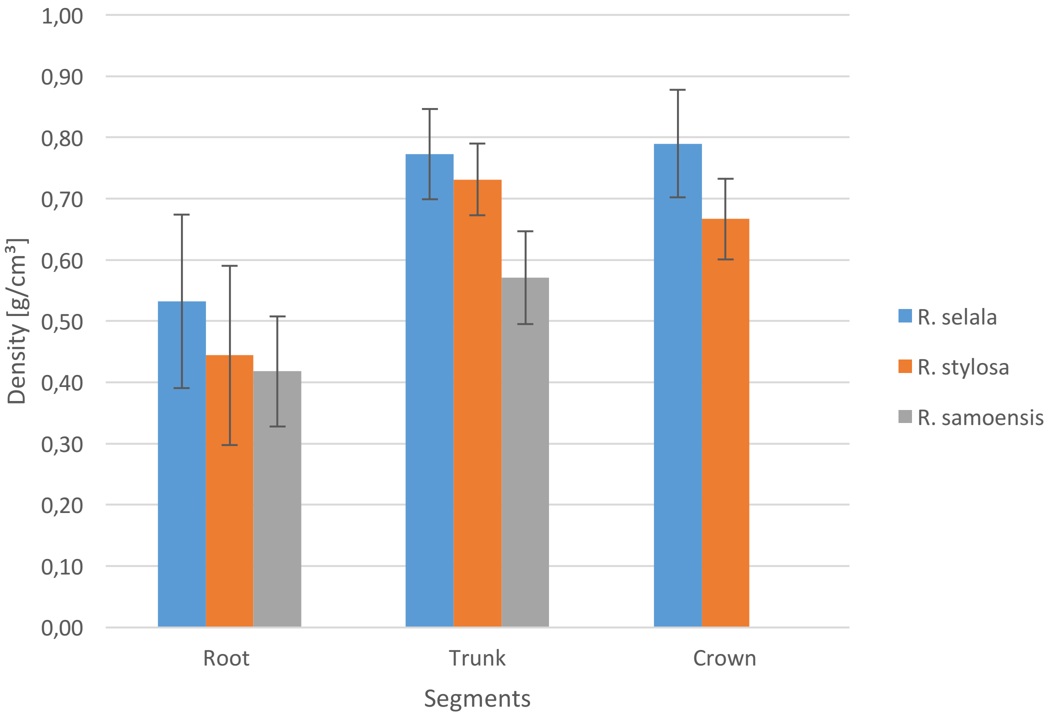


*Figure 35: Density for all samples of Rhizophora species on which volume was determined using method_S (measured by hand).*

The analysis of variance was implemented using all density values from samples, on which the volume was determined by measuring by hand using a clipper (method_S). The density determined with method_S in relation to the different segments shows no significant difference. However, considering the segments separately, a variance in segment trunk (P=0,0135*) and crown (P=0,000151***) can be seen. There was no significant variance between the different tree species analysed (P=0,513). This is also clarified in Table 8. The density values vary around 0,18 $g/cm^3$ between the different species (from 0,5 $g/cm^3$ for *R. samoensis* to 0,68 $g/cm^3$ for *R. selala*).

*Table 8: Density values for all species ascertained using the volume determination method_S.*

| **method_S** | **No. of samples** | $\partial_g$ **stilt root** | | $\partial_g$ **trunk** | | $\partial_g$ **crown** | | **Mean** $\partial_g$ **values**[14] | |
|---|---|---|---|---|---|---|---|---|---|
| Volume determination by measuring | | [$g/cm^3$] | **SD** | [$g/cm^3$] | **SD** | [$g/cm^3$] | **SD** | [$g/cm^3$] | **SD** |
| *R. selala* | 56 | 0,53 | 0,14 | 0,77 | 0,07 | 0,79 | 0,09 | **0,68** | 0,17 |
| *R. stylosa* | 53 | 0,44 | 0,15 | 0,73 | 0,06 | 0,67 | 0,07 | **0,61** | 0,17 |
| *R. samoensis* | 4 | 0,42 | 0,09 | 0,57 | 0,08 | - | - | **0,50** | 0,09 |

Compared to values generated using method_W1, these weighed mean density values are significantly lower in all segments. This result is mainly due to the fact that measuring by hand often leads to an over-determination of the volume which in turn leads to an underestimation of the density values.

[14] Mean density value for the species, including all segments.

The mean kiln dry density was calculated only for *R. selala* with 0,89 g/cm³. For that 5 kiln dry samples were collected and analysed from tract 190.

## 5.5 Trend inside the tract

All plots were sorted according to the distance to the waterfront. Consequently, tract no. 240 and 165' are not included in the following figures and analysis of variance, as both tracts started from landside. This exclusion of the tracts is based on the different forest structure of tracts starting from inland (5.1.1). The following chapter is therefore limited to tracts, that have the same structure and so they are comparable to each other. The following figures include 23 plots from both deltas. For the deltaic region in Rewa only seven plots were destructively sampled in Ba though, 16 plots. In figures of this chapter, plot 1 reflects all plots (blue dots) located directly (depending on the random distance) at the waterfront, while number four shows all plots located furthest away from the waterfront. All following calculations include only living wood of *Rhizophora* spp. without any deadwood.

### 5.5.1 Biomass in relation to the water distance

In Figure 36, both areas are listed together as the analysis of variance could not detect a significant difference for biomass across all tree species in terms of location (P=0,1910).

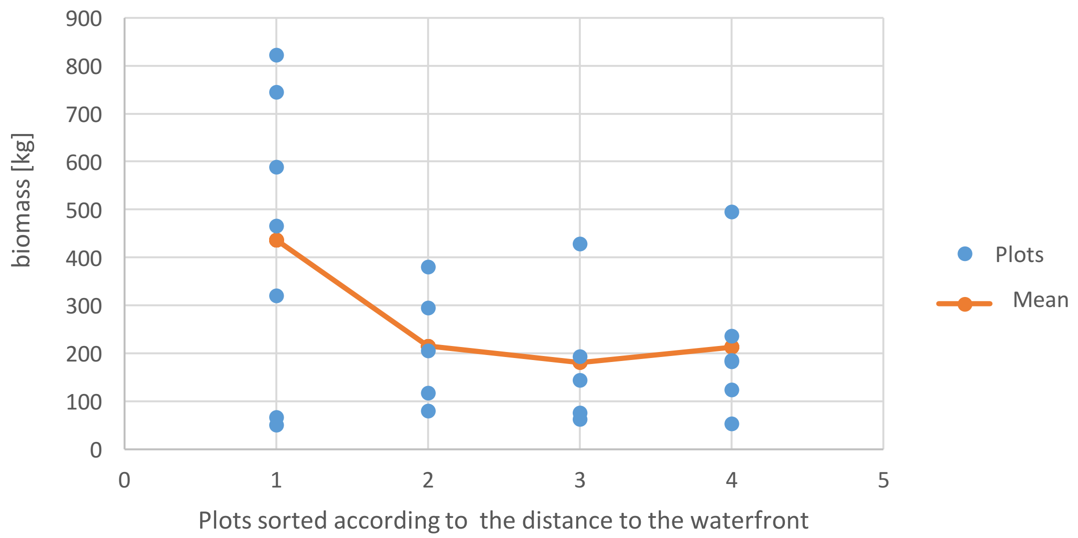


*Figure 36: Green AGL of all plots starting from water and sorted according to distance to the waterfront (including both locations Rewa and Ba).*

A noticeable impact can be seen, when it comes to the development of biomass and to the distance to the waterfront. Plots located directly at the waterfront were recorded with the mean highest biomass. However, in the analyses of variance the biomass in relation to the plots shows no significant difference with respect to the different tree species.

The two below average values for biomass in plots located right at the waterfront are founded in plot 141Q and 09'M. The biomass in 141Q was mainly lignified stilt roots of a tall *R. selala* tree while 09`M was characterized by a high severe storm damage and land erosion. The amount of deadwood is approximately 40% in this plot.

The outlier located in a plot 4 is the biomass of plot 190D. This can be explained by the fact that tract 190 ran over a headland. Due to this, plot 190D was closer to the water and not located further inland. Generally, across all plots, tract 190 had a comparatively high biomass (the outliners on plot 2 and 3 are plot no. 190B and 190C).
In Rewa *R. stylosa* was recorded with a green biomass of 428.89kg/plot (190C) and 380.05kg/plot (190B). In Ba, however, the highest value for *R. stylosa* is 294.4kg/plot (17'J). Therefore, the variance analysis also comes to the result that there are significant differences for *R. stylosa* with respect to the two deltaic locations studied (P=0,003448**). *R. selala* shows no significant variance regarding to the two locations as the green biomass values are high in both deltaic regions.

### 5.5.2 Height in relation to the water distance

The analysis of variance results in a difference of P=0,003378** for the two locations Rewa and Ba, as Ba shows significant low mean heights on several plots (shown in 5.1). However, since the ratio of the height between the plots in relation to the waterfront is similar in both deltas, both areas are shown in the following figure.

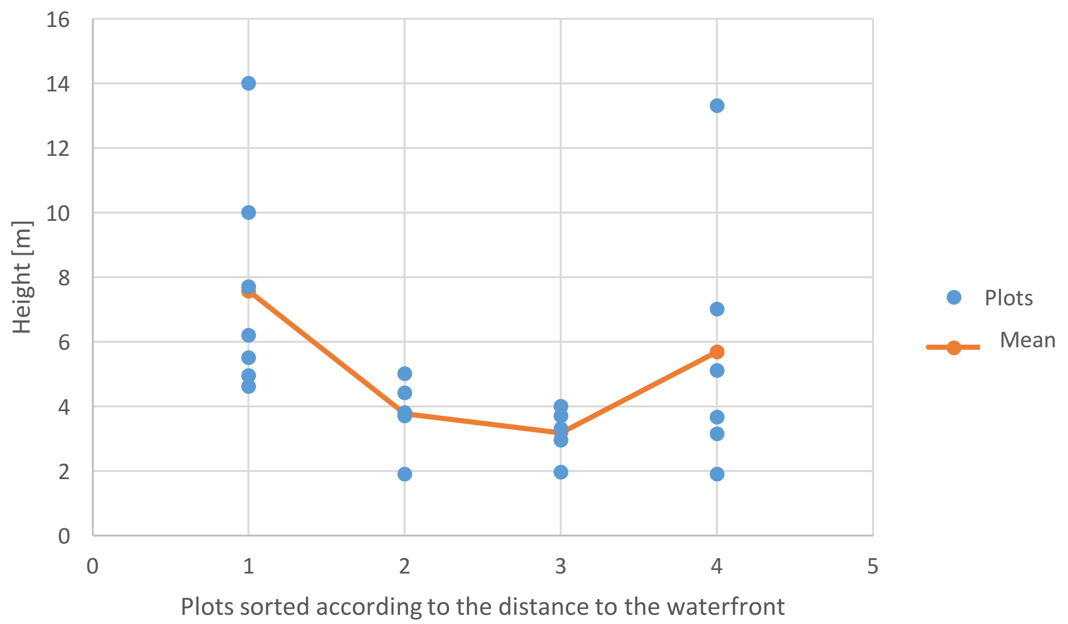


*Figure 37: Height of all plots starting from water and sorted according to distance to the waterfront (including both locations Rewa and Ba).*

Figure 37 shows that the height varies strongly between the individual plots in relation to the distance to the waterfront. It can be clearly seen that the heights of all plots located on plot 1 are with 7,6m highest on average. The average height of the plot decreases inside the tract (3,8m in plot 2 and 3,2m in plot 3) to increase again to an average height of 5,7m in plot 4 (all plots furthest away from waterfront).
Within each tract there is no significant difference (P=0,283507) in relation to the plot height. This is mainly due to the fact that plots on position 2 and 3 inside the tract fluctuate by similar values and there is a renewed increase in height on plot 4.

### 5.5.3 Water content in relation to water distance

The values for the water content were twice weighed. Firstly, in respect to the different segments (see 5.2), secondly according to the tree species (*R. selala* and *R. stylosa*). Figure 38 describes the water content in relation to the water distance. The weighed water content values vary between the two locations (Rewa and Ba) by only 0.7% (Rewa = 42,0% und BA = 41,32%) According to the analysis of variance, the water contents in the different deltaic locations show no statistically relevant significant (P=0,5660513). Consequently, the water contents for both areas can be generated in one figure.

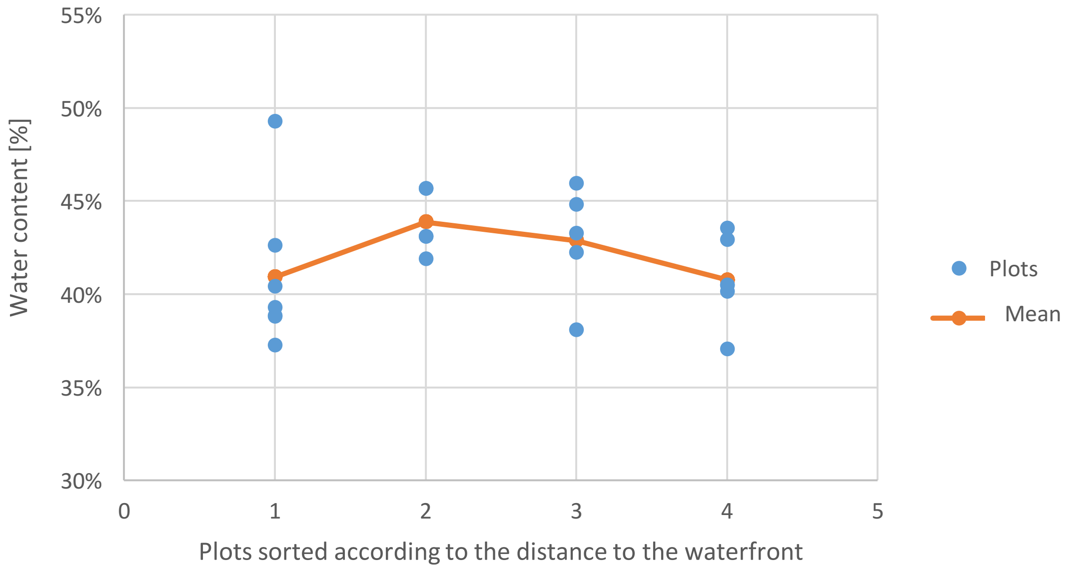


*Figure 38: Water content determined for all plots starting from water and sorted according to the distance to the waterfront (including both locations Rewa and Ba).*

There is a noticeable development of the water content within the distance to the waterfront recognisable. The graph of the water content shows that the first and the last plots have a mean low water content (41%). Plots in-between show higher water content (44% in plot 2 and 43% in plot 3). This trend is also reflected by the analysis of variance. Including all segments and tree species, the analysis of variance demonstrates a higher significance of the individual plots (P=0,0003475***) in relation to the water content. The interdependency between plot and location was tested and showed no significant variance. In total, the water content of all plots ranges between 37% (plot no. 141T furthest away from waterfront) and 49% (plot no. 09'M directly facing the waterfront). The outliner for the first plot (09`M) results from the above-average values in the segment stilt root (61%). The high value can be explained by the fact that *R. stylosa* was collected on this plot. On the other six plots facing the waterfront *R. selala* was found. Analysis (explained in detail in 5.3) demonstrate that *R. stylosa* shows a higher mean water content compared to *R. selala*. This is also confirmed by the variance analysis. The variance between the different tree species is P=3,996e-05***.

Dividing the water content in the individual segments, it can be made out a variance between the locations (Ba and Rewa) for the segment trunk (P=0,001163**). Segments stilt root and crown show no significant variance in relation to the locations.

While trunk and roots (together also the largest amount of the total weight) show a significant difference between the different plots.
The location, whether Rewa or Ba, plays a subordinate part concerning the water content of the collected samples. The variability of the water content is high in relation to the analysed species as well as the position of the plot inside a tract.
In addition, it is noticeable that the water content within the plant system varies greatly. In all samples, the water content in the stilt root system was significantly higher than in the trunk (see again 5.3).

### 5.5.4 Density in relation to water distance

The analysis of density differences in relation to the occurrence inside the tract shows that there are no significant varices. Neither for all segments nor for segments analysed separately. This applies to both methods of volume determination. Whereas the density of the segment crown (calculated by method_S) shows a significant variance in relation to the plots of P=0.02939*. The density (calculated with method_ W) in relation to the different tree species for the tracts starting from waterfront shows a significant variance of P=0,01981*. Density calculated with method_S shows no relevant difference for the tree species.

## 5.6 Biomass function

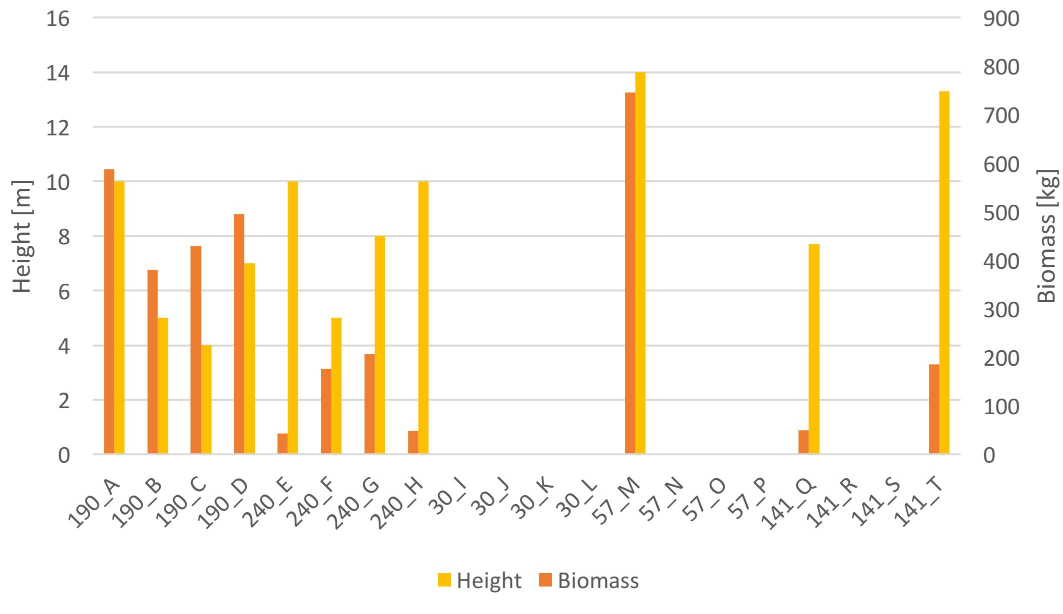


*Figure 39: Height and biomass for all plots located in the Rewa delta.*

Figure 39 clearly shows that many values are missing for the Rewa delta, as *Bruguiera gymnorrhiza* and other tree species were found on many plots instead of *Rhizophora* spp. In addition, it can be seen that on some plots the height and the biomass deviate greatly from one another. I.e. *Rhizophora* species were recorded with great heights, but a very low green biomass. This can be explained by the structure of the forest in Rewa. When plots were found in a mixed forest, *R. selala* especially competes with *B. gymnorrhiza* in height. That for example is the case in plot 141Q and 141T. These *R. selala* were recorded with great height, but low green biomass (see Figure 8 and

Figure 29). If, for example, stilt root of *R. selala* are inside the plot, but the top of the tree already protrudes from the plot, these stilt roots were cut vertically. This, in turn, means that the biomass on the plot is low, but the height was recorded of the entire *R. selala.*

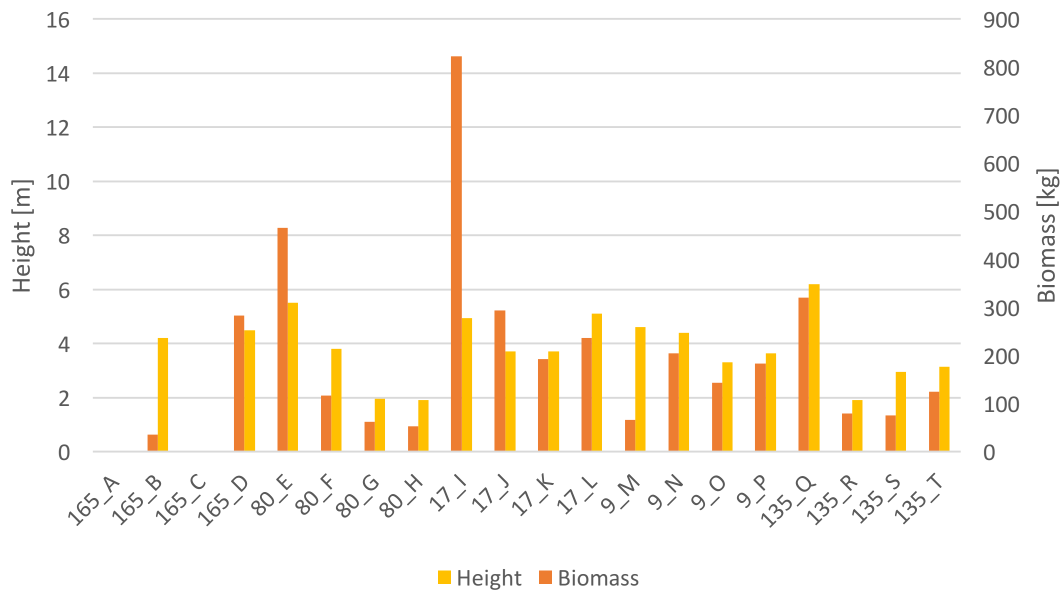


*Figure 40: Height and biomass for all plots located in the Ba delta.*

Figure 36 shows two plots with a below average value of biomass, this two plots (141Q and 09'M) occur again in this Figure 40. But in average the heights and biomass are evenly distributed.

To develop a non-destructive method, an attribute is required which can be measured well and consistently in the field. A possible dependence between height and biomass in mangrove forests can be clarified by a regression analysis. The regression analysis was performed in excel 2016 and the logarithmical function approximation is based on least-squares distances.

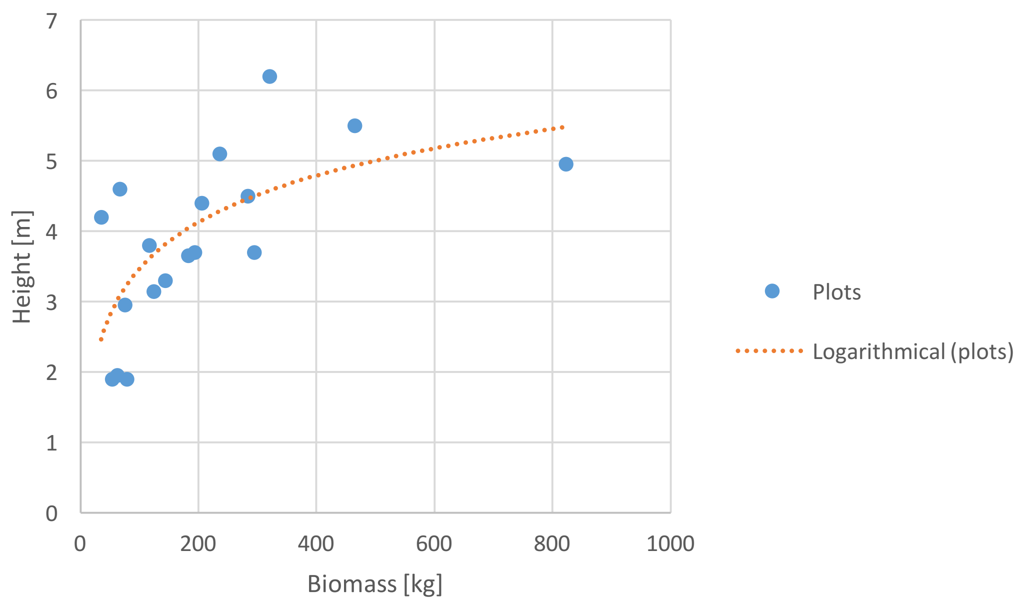


*Figure 41: Regression analysis of biomass in relation to the height of all plots located in Ba.*

The regression analysis for *Rhizophora* species (*R. selala*, *R. stylosa* and *R. samoensis*) measured in the mangroves of the deltaic region in Ba, results in Equation 13.

$$y = 0{,}9554\ln(x) - 0{,}93$$

*Equation 13: Biomass in relation to height for the mangrove forest in Ba.*

$AGL\ biomass\ x\ [kg]$
$height\ y\ [kg]$

The y-value describes the height of a 3x3m plot located in a tract and the x-value describes the AGL green biomass of the comcomplete plot. An estimation of the biomass in relation to the measurable height can be calculated using Equation 13/14.

$$height = 0{,}9554\ln(biomass) - 0{,}93$$

*Equation 14: Equation 13 by using the x-and y-values explained.*

If the coefficient of determination $R^2$ is close to zero, the value height to biomass is not related and thus independent of each other. As the value of $R^2$ approaches one, the examined values depend on each other. For the relation in a pure *Rhizophora* forest in Ba the coefficient of determination was calculate with $R^2 = 0{,}419$. This is how 41,9% of the variance is explained, thus Equation 13 can be used.
For Rewa a regression analysis using linear function approximation is based on least-squares distances.

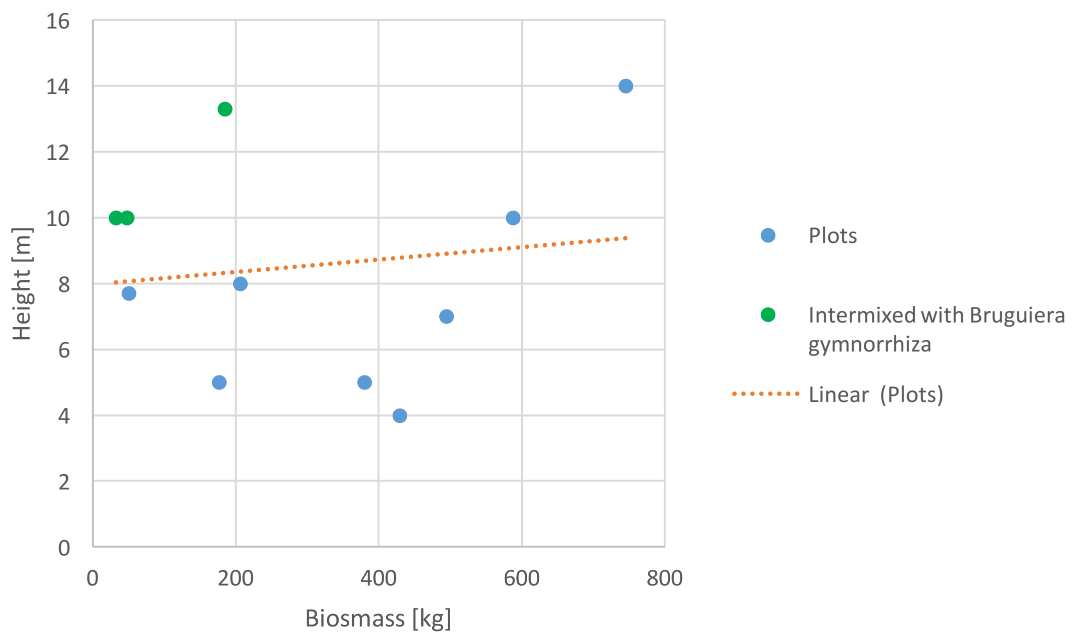


*Figure 42: Regression analysis of biomass in relation to the height of all plots located in Rewa.*

The green dots mark all plots on which *Rhizophora* species were found intermixed with *Bruguiera gymnorrhiza*. These plots have a very low biomass in relation to their height.

$$Y = 0{,}0019x + 7{,}98$$

*Equation 15: Biomass in relation to height for the mangrove forest including mixed mangroves in Rewa.*

The coefficient of determination $R^2 = 0{,}01859$ shows that no dependence of the two components can be derived. Thus 1,86% of the variance is thus explained and a dependency cannot be proven. A derivation of the biomass from the height using Equation 15 is not possible. As the green dots illustrate that, the height deviates strongly as soon as *Rhizophora* spp. is influenced by *Bruguiera gymnorrhiza.* Another dependency can be formed excluding mixed forests.

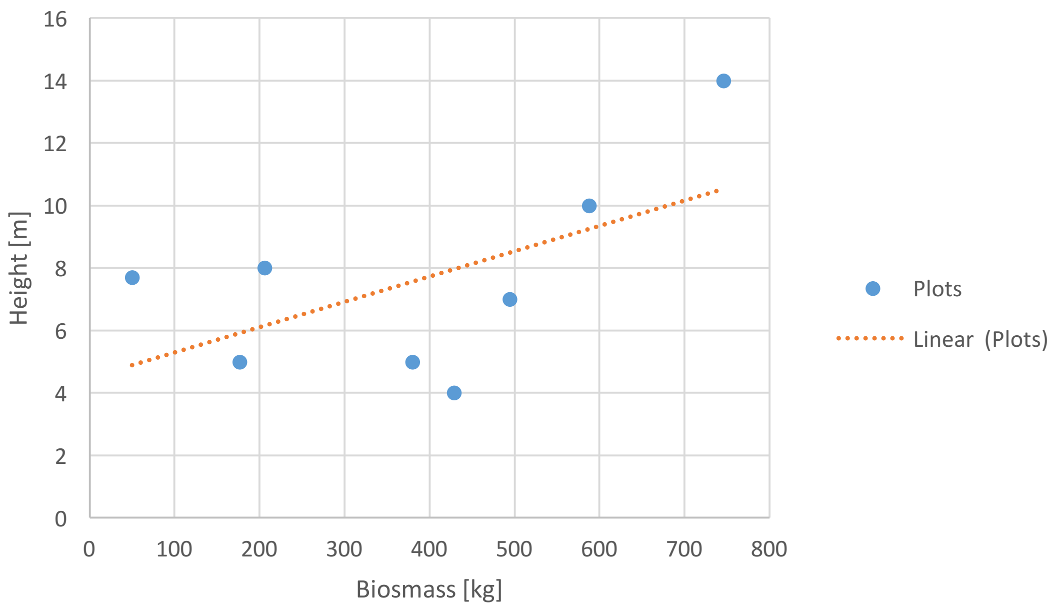


*Figure 43: Linear regression analysis of biomass in relation to the height of plots with only Rhizophora species on it located in Rewa.*

$$y = 0{,}0081x + 4{,}4777$$

*Equation 16: Biomass in correlation to height for pure Rhizophora spp. Forests in Rewa.*

$biomass\ x\ [kg]$
$height\ y\ [kg]$

But even here a relation of $R^2 = 0.33189$ is very low as only 33,19% of the variance is explained by the regression which leads to the conclusion that biomass dependency is difficult to deduce from the height of plots in Rewa. Moreover, the small sample size might be partially responsible for the low $R^2$ values.

## 5.7 Determination of carbon content

To analyse the carbon content of the collected samples, specimens from trunk and stilt roots of the three *Rhizophora* species (*R. stylosa, R. selala, R. samoensis*) were examined. 10g of wood flour was analysed in the elemental analysis vario EL cube with the standard "Alfalfa – 9,4mg".

*Table 9: Carbon analysis of collected wood samples (Kruse, 2018).*

| Samples | Carbon % | |
|---|---|---|
| | measured value | mean |
| Sample 1: *Rhizophora stylosa* [trunk] | 47,29 | |
| Sample 1: *Rhizophora stylosa* [trunk] | 47,28 | 47,28 |
| Sample 2: *Rhizophora* [stilt root] | 46,00 | |
| Sample 2: *Rhizophora* [stilt root] | 46,01 | 46,00 |
| Sample 3: *Rhizophora selala* [trunk] | 47,23 | |
| Sample 3: *Rhizophora selala* [trunk] | 47,24 | 47,23 |
| Sample 5: *Rhizophora samoensis* [trunk] | 47,64 | |
| Sample 5: *Rhizophora samoensis* [trunk] | 47,55 | 47,59 |

The values from the elemental analysis were calculated in the following tables of the dry biomass, taken from the respective plots. The tables are separated according to the two locations Rewa and Ba. The wooden biomass listed in Table 10 and 11, includes only the living wooden biomass (AGL) without deadwood. One plot is measured by 9m$^2$ (4.1.1) If the biomass values or carbon content values are given in the following tables per plot, this always refers to the 9m$^2$ of the plot.

*Table 10: Kiln dry wooden biomass, excluding deadwood and the thereof calculated carbon content of Rhizophora spp. for each plot located in Rewa.*

| Plot no. | Tree species selected | AGL green [kg/plot] | AGL kiln dry [kg/plot] | Carbon content [kg/plot] |
|---|---|---|---|---|
| 190A | *R. selala* | 588,01 | 350,81 | 185,12 |
| 190B | *R. stylosa* | 380,05 | 210,70 | 111,08 |
| 190C | *R. stylosa* | 428,89 | 237,78 | 125,36 |
| 190D | *R. selala* | 494,58 | 295,07 | 155,71 |
| 240E | *R. stylosa* | 32,62 | 18,08 | 9,53 |
| 240F | *R. stylosa* | 176,84 | 98,04 | 51,69 |
| 240G | *R. stylosa* | 205,93 | 114,17 | 60,19 |
| 240H | *R. stylosa* | 48,11 | 26,67 | 14,06 |
| 57M | *R. selala* | 745,51 | 444,77 | 234,71 |
| 141Q | *R. selala* | 50,19 | 29,94 | 15,80 |
| 141T | *R. selala* | 184,98 | 110,36 | 58,24 |

Plots on which no biomass was recorded are not included in Table 10 and 11. Boxes highlighted in blue, are plots located right at the waterfront and boxes highlighted in grey are all plots of a tract starting from landside (5.1).

All values of the kiln dry AGL were determined by subtracting the water content calculated for each of tree species selected (5.3) from the green wooden biomass

(AGL green). The carbon content of the individual tree species calculated in Table 9 were subtracted from the kiln dry AGL of each plot.

*Table 11: Kiln dry wooden biomass, excluding deadwood and the thereof calculated carbon content of Rhizophora spp. for each plot located in Ba.*

| Plot no. | Tree species selected | AGL green [kg/plot] | AGL kiln dry [kg/plot] | Carbon content [kg/plot] |
|---|---|---|---|---|
| 165’B | *R. samoensis* | 35,12 | 17,56 | 9,20 |
| 165’D | *R. selala* | 283,56 | 169,17 | 89,27 |
| 80’E | *R. selala* | 465,1 | 277,48 | 146,43 |
| 80’F | *R. stylosa* | 116,75 | 64,73 | 34,12 |
| 80’G | *R. stylosa* | 61,81 | 34,27 | 18,07 |
| 80’H | *R. stylosa* | 53,31 | 29,56 | 15,58 |
| 17’I | *R. selala* | 822,90 | 490,93 | 259,06 |
| 17’J | *R. stylosa* | 294,40 | 163,22 | 86,05 |
| 17’K | *R. stylosa* | 193,40 | 107,20 | 56,52 |
| 17’L | *R. selala* | 236,30 | 140,99 | 74,40 |
| 9’M | *R. stylosa* | 66,40 | 36,80 | 19,40 |
| 9’N | *R. stylosa* | 205,30 | 113,79 | 59,99 |
| 9’O | *R. stylosa* | 144,10 | 79,87 | 42,11 |
| 9’P | *R. stylosa* | 183,10 | 101,51 | 53,51 |
| 135’Q | *R. selala* | 320,40 | 191,12 | 100,85 |
| 135’R | *R. stylosa* | 79,10 | 43,83 | 23,11 |
| 135’S | *R. stylosa* | 75,30 | 41,75 | 22,01 |
| 135’T | *R. stylosa* | 124,20 | 68,87 | 36,31 |

The AG biomass values listed in table 12 and 13, include living wooden biomass and the collected deadwood (AGB), since no water content values were generated for deadwood in the study areas. In the following, the same water content, which was generated for the different tree species also applies to deadwood.

*Table 12: Kiln dry wooden biomass, including deadwood and the thereof calculated carbon content of Rhizophora spp. for each plot located in Rewa.*

| Plot no. | Tree species selected | AGB green [kg/plot] | AGB kiln dry [kg/plot] | Carbon content [kg/plot] |
|---|---|---|---|---|
| 190A | *R. selala* | 588,01 | 350,81 | 185,12 |
| 190B | *R. stylosa* | 380,05 | 210,70 | 111,08 |
| 190C | *R. stylosa* | 428,89 | 237,78 | 125,36 |
| 190D | *R. selala* | 494,58 | 295,07 | 155,71 |
| 240E | *R. stylosa* | 32,62 | 18,08 | 9,53 |
| 240F | *R. stylosa* | 176,84 | 98,04 | 51,69 |
| 240G | *R. stylosa* | 205,93 | 114,17 | 60,19 |
| 240H | *R. stylosa* | 48,11 | 26,67 | 14,06 |
| 57M | *R. selala* | 745,51 | 444,77 | 234,71 |
| 141Q | *R. selala* | 50,19 | 29,94 | 15,80 |
| 141T | *R. selala* | 235,34 | 140,40 | 74,09 |

Table 12 shows that the biomass value of plot 141T located in Rewa increased by 50.36kg/plot compared to Table 10. This increase of 50.36 kg/plot 141T is due to the fact that for plots in Table 12 and 13 the deadwood values are included and plot 141T is noted as the only plot recorded with deadwood in Rewa River delta. The inclusion of the deadwood therefore also affects the values of AGB kiln dry and the carbon content.

*Table 13: Kiln dry wooden biomass, including deadwood and the thereof calculated carbon content of Rhizophora spp. for each plot located in Ba.*

| **Plot no.** | **Tree species selected** | **AGB green [kg/plot]** | **AGB kiln dry [kg/plot]** | **Carbon content [kg/plot]** |
|---|---|---|---|---|
| 165’B | *R. samoensis* | 151,76 | 75,88 | 39,77 |
| 165’D | *R. selala* | 283,56 | 169,17 | 89,27 |
| 80’E | *R. selala* | 614,34 | 366,52 | 193,41 |
| 80’F | *R. stylosa* | 135,31 | 75,02 | 39,55 |
| 80’G | *R. stylosa* | 72,35 | 40,11 | 21,15 |
| 80’H | *R. stylosa* | 73,31 | 40,64 | 21,43 |
| 17’I | *R. selala* | 822,88 | 490,93 | 259,06 |
| 17’J | *R. stylosa* | 310,05 | 171,89 | 90,62 |
| 17’K | *R. stylosa* | 201,96 | 111,97 | 59,03 |
| 17’L | *R. selala* | 316,89 | 189,06 | 99,77 |
| 9’M | *R. stylosa* | 107,74 | 59,73 | 31,49 |
| 9’N | *R. stylosa* | 247,02 | 136,95 | 72,20 |
| 9’O | *R. stylosa* | 144,06 | 79,87 | 42,11 |
| 9’P | *R. stylosa* | 183,09 | 101,51 | 53,51 |
| 135’Q | *R. selala* | 333,05 | 198,70 | 104,85 |
| 135’R | *R. stylosa* | 129,66 | 71,88 | 37,90 |
| 135’S | *R. stylosa* | 86,84 | 48,14 | 25,38 |
| 135’T | *R. stylosa* | 133,86 | 74,21 | 39,12 |

Table 13 shows the kiln dry AGB and the thereof calculated carbon content. The plots 165’A and 165’C are not shown in this Table, as no wooden biomass including deadwood was recorded for that plots. All plots summarized of tract no. 17 show the highest green biomass measured and thus the highest carbon content.

## 5.8 Extrapolation

The extrapolation is carried out using the values generated in Table 10 to 13. Plots, which are omitted in these tables (Table 10 to 13), must be taken into account in the extrapolation. These plots are calculated with a biomass value of zero.
An extrapolation was made for the respective areas Rewa and Ba using Equation 6 to 12. Equation 12 was calculated with $\phi = 2$. Alternatively, this value can be increased to $\phi = 2{,}78$, as there are less than n=30 tracts per delta to calculate. The extrapolated biomass values were separated between AGL of only living wood and AGB of all wooden biomass including deadwood. Table 14 and 15 show the carbon content of *Rhizophora* spp. per hectare for the two deltaic regions analysed.

*Table 14: Mean values of AG biomass including deadwood.*

| | Rewa delta | | | Ba delta | | |
|---|---|---|---|---|---|---|
| | Mean [Mg/ha] | SE | Ci | Mean [Mg/ha] | SE | Ci |
| AGB green | 188,11 | 81,21 | {25,69; 350,54} | 241,54 | 51,85 | {137,85; 345,23} |
| AGB dry | 109,25 | 47,05 | {15,16; 203,34} | 139,01 | 30,78 | {77,45; 200,57} |
| C-content | 57,63 | 24,82 | {8,00; 107,26} | 73,31 | 16,25 | {40,82; 105,81} |

Table 14 shows that the estimated carbon content per hectare for Ba is 15,68Mg/ha higher than for the Rewa delta. As this extrapolation only includes the species *Rhizophora* spp. the mean carbon content values for Rewa are significantly lower.

*Table 15: Mean values of AG living biomass excluding deadwood.*

| | Rewa delta | | | Ba delta | | |
|---|---|---|---|---|---|---|
| | Mean [Mg/ha] | SE | Ci | Mean [Mg/ha] | SE | Ci |
| AGL green | 185,32 | 82,00 | {21,32; 349,31} | 208,91 | 51,81 | {105,29; 312,52} |
| AGL dry | 107,58 | 47,51 | {12,56; 202,59} | 120,70 | 30,40 | {59,89; 181,51} |
| C-content | 56,75 | 25,06 | {6,63; 106,87} | 63,67 | 16,04 | {31,58; 95,75} |

Table 15 shows that the estimated values of the carbon content for the two locations (Rewa and Ba) are approximated and only differ by 6,92Mg/ha carbon.

Table 14 include the above ground wooden biomass as well as deadwood and Table 15 include only above ground living biomass. Both tables (Table 14 and 15) comprise only the species *Rhizophora* spp. As the values for *Bruguiera gymnorrhiza*, found inside plots are not included in this two tables this therefore not allowed a general estimate is insufficient.

Table 16 shows the estimated values per hectare for an intermixed forest (the tree species *Rhizophora* spp. and *Bruguiera gymnorrhiz*) in the Rewa delta. No trees of the species *Bruguiera gymnorrhiza* have been found on plots in the deltaic region in Ba, the values for an extrapolation in Ba are listed in Table 15. More information about the species *B. gymnorrhiza* and their occurrence can be found in Brielmaier (2018).

*Table 16: Mean values of the AGB including deadwood for Rhizophora spp. and Bruguiera gymnorrhiza.*

| | Rewa delta | | |
|---|---|---|---|
| | Mean [Mg/ha] | SE | Ci |
| AGB green | 296,17 | 85,80 | {124,58; 467,77} |
| AGB dry | 173,52 | 50,70 | {72,12; 274,91} |
| C-content | 90,69 | 26,38 | {37,92; 143,45} |

The estimated carbon content value of Ba (73,31Mg/ha) in Table 14 compared to the estimation including the species *Bruguiera gymnorrhiza* (Table 16) shows that the Rewa River delta has with 90,69Mg/ha a higher carbon content value.

# 6 Discussion

This master thesis addresses the determination of biomass and carbon pool by developing and testing a series of objectives indicating how the different locations and tracts affect the inventory procedure.
The goal of this thesis is the determination of the biomass and the carbon stock by using statistical selection of tracts and the samples. Both, the tracts and the samples were randomly selected to fulfil the statistical selection. Repeatability and reproducibility regarding the selection of the tracts and the samples is therefore given for further studies.

Results of the extrapolation show that the biomass values (AGB) as well the carbon pool of the two analysed deltas vary greatly but as soon as the deadwood is excluded the values determined approach for both locations (Rewa and Ba). The main gaps though, regarding biomass and carbon stock values are located at the data recording, as small size sampling results in a high variability. For expressive data and to minimize variability, in further deltas more plots should be examined in order to determine their variance between each other better and to limit the variations between the tracts.
A calculation of the kiln dry AG biomass value can only be obtained from living wood. For deadwood, the water content was not investigated. Deadwood probably has a lower water content, but since mangrove forests are tidal and submerged by water, the deadwood could also have a higher water content than living wood. In addition, it could be possible that the carbon content in deadwood is significantly higher than in living wood. Moreover, Table 15 shows that carbon values of AGL biomass in Ba is approximated to the value of the carbon in Rewa (compared to values generated in Table 14). As the high proportion of deadwood in Ba is attributable to the storm in 2016, these values can also vary strongly if estimations in other deltas will be conducted.

An additional goal of this thesis is to design a suitable tract and plot layout, which is appropriate to *Rhizophora* species, as well as all different locations (deltaic regions), included in this project.
The choice of 3x3 meter plots is sufficient, as the impact on the forest remains minimal. However, the case described in 5.6 must be considered. For R. selala, which reaches heights of the surrounding *B. gymnorrhiza* forest, 3x3 seems too small or another method must be applied.
The segmentation inside the plots was performed only in BA. The segments were separated on five complete plots as well as for two other plots the segment stilt roots. The percentage distribution of the weights within the plot should therefore be seen critically. For further research in segments, more tests are required.
On five plots, the leaves of *Rhizophora* species were removed and weighed separately. Out of these samples the factor for the leaf proportion (5%) was calculated. Booklet 4 of the Pacific Islands National Forest Inventory (2006) defaults a values of leaf biomass of 3% of above ground biomass for hardwood/broadleaf species. Compared to the results of this thesis, the proportion of 5% for leaf biomass in a *Rhizophora* forest is significantly higher than the defaulted values of the NFI. As the leaves were removed in all plots, the leaf proportion does not play a decisive role for this work. However, if this factor is used for further calculations in other examinations, this must be done considering the error rate. The leaf factor is not representative due to too few samples. The same applies to the calculated factor for the shells on the stilt roots. Only 9 samples were taken. In order to generate a convincing value, more samples have to be analyzed.

Against the background of a statistical inventory, another question that motivates this thesis is, to determine differences of biomass, plot height, water content and density in relation to the two study areas Rewa- and Ba delta, within the tracts and in relation to the distance to the waterfront. Analysis of variance was performed for all described groups. While the research locations (Rewa and Ba) show no significant differences in many areas (such as water content and biomass), the variability of the results depends mainly on the distance of the plots according to the waterfront. As further tracts run into the mangroves and as further away plots are located according to the distance to the waterfront, the forest structure of the mangroves changes. Within the change of the forest structure and without the influence of the waterfront to the mangroves, the collected biomass data change. In this work, a trend was evident for all tracts starting from waterfront. Further investigations could confirm a general validity. In addition, an interesting aspect is to look at the forest structure of the mangroves starting from Inland. In this thesis, sufficient samples are missing to make concrete statements.

A determination of the gross density for the species analysed is necessary to determine carbon pool estimations. Wood density of different studies compared to density values determined in this study show that all values of this determination are mostly underestimated.

This thesis results in a mean gross density of *R. stylosa* ranging from 0,61 g/cm$^3$ to 0,71 g/cm$^3$ while literature wood density values of other analysis range from 0,84 g/cm$^3$ to 1,04 g/cm$^3$ (Oey Djoeng Seng, 1990). Same applies to the mean gross density of *Rhizophora x selala*. In this analysis density values results, ranging from 0,68 g/cm$^3$ to 0,72 g/cm$^3$, while in studies conducted in Australia and PNG show values for *R. selala* ranging from 0.74 g/cm$^3$ to 1.02 g/cm$^3$ (Oey Djoeng Seng, 1990) (Bolza, 1975). The gross density of R. samoensis range from 0,50 g/cm$^3$ to 0,62 g/cm$^3$ whereas the mean density values described in the IPCC for *Rhizophora mangle* show 0,89 g/cm$^3$ (IPCC, 2007). For all analysed samples this results in an underestimation of approximately 0,28g/cm$^3$ for *R. stylosa*, 0,18g/cm$^3$ for *R. selala*, and 0,33g/cm$^3$ for R. samoensis. The underestimation of the density values for the tree species *R. selala* and *R. stylosa* could be partly explained by the fact that all literature values found calculated the density with a mean water content of 15%. As the green samples analysed in this study, the water content ranges between 40% and 44%. A calculation with drier samples would result in higher density values.

It is important to mention that, as already described; the species *Rhizophora samoensis* was hardly to be found. All values resulting from the samples (water content as well as density values) of this species taken have to be seen critically. The study area (tract) was heavily degraded by fire and will therefore falsify the collected samples.

It also has to be considered whether the density of all *Rhizophora* species has been reliably determined. With the immersion test, the volume of the samples was determined in the best possible way, as also unevenness in the wood could be calculated. However, the test has to be carried out according to the German standard (DIN 52182:1976-09) with hot oil and not, as in this experiment, the alternative with soapy water. Although the water surface tension is also broken by soap water, warm oil adapts to the body much better.

For both methods (immersion test and measuring), the bark needs to be removed. Otherwise, the volume of the bark is included in the density calculation. As the density of the bark in all tree species is much lower than the density of wood, the average value for density is falsified.

An optimal density determination can be achieved by cutting cubes out of the wood. Cubes also can be measured by hand much easier. Likewise, a determination of the contraction rule is then possible. The available equipment did not allow this method and thus could not apply for our samples. In addition, the samples for the density determination must be temperate kiln dried to avoid thermal cracks in the wood. Temperate kiln drying of our samples was not possible because of the time pressure for the project. Consequently, the values of the density of the tested *Rhizophora* spp. samples have been underestimated.

Moreover, an objective of this work is to develop a reprehensive and repeatable, non-destructive methodology, based on measurable attributes. The results so far would allow a correlation of the biomass from the plot height in Ba, but not in Rewa. The plot height as a recording attribute is suitable, since it can always be included even with repetitions. In order to be able to better determine the dependence between height and biomass, more investigations, especially with regard to the forest structure, are necessary. For future studies, the non-destructive method should be further investigated.

For further studies that rely on density, segmentation, leaf or shell factors, additional research in these areas must first be undertaken to generate meaningful data.

# 7 Conclusion

In summary, the results show the high variability of the collected data values. The variability of the results depends mainly on the distance to the waterfront and the forest structure. Therefore, in future analysis, a higher number of samples is necessary to achieve reliable results.

The estimated carbon content shows high values for the mangrove forest in the two analysed locations (Rewa and Ba). These values can be corroborated by a comparison with the carbon content of a natural, non-mangrove, forest of Fiji.
A study from 2012 estimated the carbon content of the study area in Nakavu. The carbon of above ground living biomass (ABL) for medium sized trees (10-34 cm DBH) was estimated with approx. 25 t/ha carbon. For trees with a DBH >= 35 a carbon content (AGL) of 45.5 t/ha was estimated. Compared to the carbon values of *Rhizophora* spp. generated in this study the carbon content (AGL) was estimated with 56,75 Mg/ha for the deltaic region in Rewa and 63,67 Mg/ha in Ba. This result would describe that the carbon content stored in mangrove forest (only biomass of *Rhizophora* spp.) in the two deltaic regions (Rewa and Ba) on the main island Viti levu, is twice as high as the carbon content of the tropical forest in Fiji.
It is important to compare the estimated carbon pool on the basis of AGB in the mangroves of this thesis, with values of the National forest inventory (2006). The NFI calculated a mean above ground biomass of 157,99 Mg/ha (SE = 2,71) {152,68; 163,30} for tropical Fijian forest. This would result in a mean carbon content of 83,73 Mg/ha. Compared to the values generated in this thesis, including the species *Rhizophora* spp. and *Bruguiera gymnorrhiza*, the carbon stock in Ba is estimated with 63,67Mg/ha {31,58; 95,75} and in Rewa with 90,69 Mg/ha {37,92; 143,45}. This also makes the point quite clear that the carbon stocks stored in the mangroves is important and is at least equal with the Fijian national forests.
The Fiji Islands include approximately 18.000$km^2$ of mangrove forests on the over 300 different Islands. In summary, all results given above prove that, the mangroves area analysed are highly carbon rich. The potential of the Fijian mangrove forests for climate change mitigation should be therefore recognized both nationally as well as internationally.

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# Appendix

Fiji Forest cover map

Appendix

Forest Classes Description


**Closed Forest** describes a crown cover by trees/ or ferns of 40-100% and ground coverage by palm and bamboo over 20%.
**An Open Forest** area clarify a crown cover by trees/ or ferns of 10-40% and ground coverage by palm and bamboo over 50-80%.
Forest Plantations is land under established plantation with forest species or any land Identified for afforestation to provide forest products for sustainable development under a land plan.

I. Hardwood (Mostly Swietenia Macrophylla) Timber production forest of existing or intended plantation established mainly for timber production

II. Softwood (Mostly Pinus Caribaea) Timber production forest of existing or intended plantation established mainly for timber production

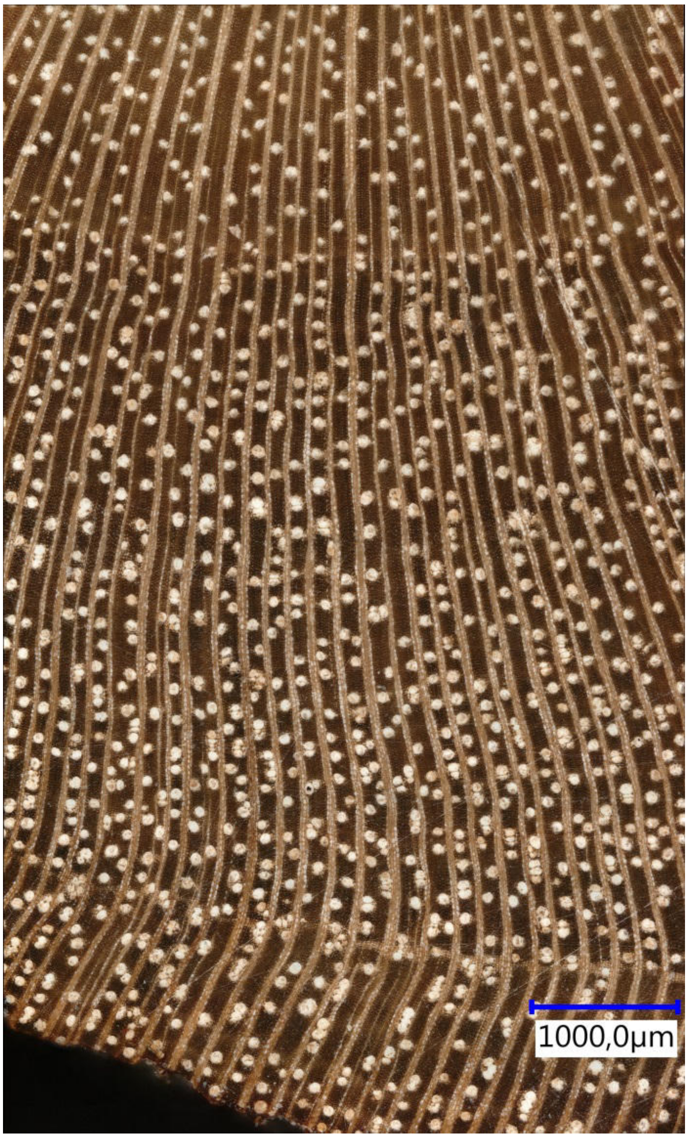
**Muiltiple use forests (MUF)** are indigenous forest to be maintained under forest cover for the production of timber and no timber forest products, catchments protection, wildlife habitat, recreation values and amenity uses
This category includes:

- Natural forest area
- Declared forest reserves
- Forest areas suitable for regeneration enrichment planting or reforestation.

**Mangroves** are labelled when the crown cover by trees/ or ferns of 40-100% and ground coverage by palm and bamboo over 20%.
**Coconuts** are defined areas of mainly `cocos (I) mucifera`
**Non Forest** describes a crown cover by trees and/or ferns of 10% and ground coverage by grass, palm and bamboo with 50-85%. Farmland, grazing and cultivation are included in this category.
The **Protection Forests (PTF)** category applies where the forests biological diversity and ecological integraty with the values such as water supply, soil conservation, cultural or historical significance, or scenic appeal will be protected. Forest will be restricted to harvesting of non-timber forest products, ecotourism and research.
These categories include: Soil and water protection forest with a slope >30 degrees above 650 meters' elevation.

The Forest Cover Map was prepared by Management Service Division in 2016 and applies only for the seven main islands: Vitilevu, Vanua Levu, Taveuni, Kadavu, Ovalau, Koro, Gau.

Cross sectional image of a lignified stilt root from *Rhizophora stylosa*



Calculation for a shell- factor

| | Stilt roots with shells [kg] | Stilt roots without shells [kg] | Difference [kg] |
|---|---|---|---|
| 1 | 1,066 | 0,781 | 0,285 |
| 2 | 1,493 | 0,912 | 0,581 |
| 3 | 1,849 | 0,857 | 0,992 |
| 4 | 0,388 | 0,253 | 0,135 |
| 5 | 0,311 | 0,200 | 0,111 |
| 6 | 0,594 | 0,433 | 0,161 |
| 7 | 0,443 | 0,269 | 0,174 |
| 8 | 0,396 | 0,187 | 0,209 |
| 9 | 0,202 | 0,110 | 0,092 |

Appendix

Field form used for data collection in the field

| Date | Tract no. | Plot no. | Forest type | Species selected | plot height | GPS coordinates (plot center) |
|---|---|---|---|---|---|---|
| | | | | | | |

| Weight stilt root (kg) | Weight trunk (kg) | Weight crown (kg) | Weight deadwood (kg) | Notes: |
|---|---|---|---|---|
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Biomass determination for all plots

Water content determination for all samples

| key_plot | Location | Tree_species | Sample | Weight_green [g] | Weight_kiln dry [g] | Watercontent [%] |
|---|---|---|---|---|---|---|
| 190_A | Rewa | R.selala | 190RAR4 | 42 | 13 | 69,0% |
| 190_A | Rewa | R.selala | 190RAR8 | 16 | 5 | 68,8% |
| 190_A | Rewa | R.selala | 190RAR9 | 16 | 6 | 62,5% |
| 190_A | Rewa | R.selala | 190RAR12 | 56 | 22 | 60,7% |
| 190_A | Rewa | R.selala | 190RAR6 | 21 | 9 | 57,1% |
| 190_A | Rewa | R.selala | 190RAR5 | 51 | 22 | 56,9% |
| 190_A | Rewa | R.selala | 190RAR2 | 23 | 10 | 56,5% |
| 190_A | Rewa | R.selala | 190RAR7 | 39 | 17 | 56,4% |
| 190_A | Rewa | R.selala | 190RAR14 | 83 | 40 | 51,8% |
| 190_A | Rewa | R.selala | 190RAR1 | 29 | 14 | 51,7% |
| 190_A | Rewa | R.selala | 190RAR11 | 82 | 44 | 46,3% |
| 190_A | Rewa | R.selala | 190RAR13 | 113 | 62 | 45,1% |
| 190_A | Rewa | R.selala | 190RAR10 | 51 | 28 | 45,1% |
| 190_A | Rewa | R.selala | 190RAR3 | 38 | 23 | 39,5% |
| 190_A | Rewa | R.selala | 190RAR19 | 302 | 186 | 38,4% |
| 190_A | Rewa | R.selala | 190RAR15 | 182 | 114 | 37,4% |
| 190_A | Rewa | R.selala | 190RAR18 | 242 | 158 | 34,7% |
| 190_A | Rewa | R.selala | 190RAR16 | 195 | 135 | 30,8% |
| 190_A | Rewa | R.selala | 190RAR17 | 98 | 68 | 30,6% |
| 190_B | Rewa | R. stylosa | 190RBR4 | 168 | 65 | 61,3% |
| 190_B | Rewa | R. stylosa | 190RBR13 | 49 | 20 | 59,2% |
| 190_B | Rewa | R. stylosa | 190RBR1 | 44 | 18 | 59,1% |
| 190_B | Rewa | R. stylosa | 190RBR8 | 34 | 14 | 58,8% |
| 190_B | Rewa | R. stylosa | 190RBR2 | 74 | 32 | 56,8% |
| 190_B | Rewa | R. stylosa | 190RBR 3 | 47 | 21 | 55,3% |
| 190_B | Rewa | R. stylosa | 190RBR7 | 540 | 244 | 54,8% |
| 190_B | Rewa | R. stylosa | 190RBR10 | 50 | 23 | 54,0% |
| 190_B | Rewa | R. stylosa | 190RBR12 | 52 | 24 | 53,8% |
| 190_B | Rewa | R. stylosa | 190RBR6 | 47 | 22 | 53,2% |
| 190_B | Rewa | R. stylosa | 190RBR9 | 66 | 33 | 50,0% |
| 190_B | Rewa | R. stylosa | 190RBR5 | 68 | 36 | 47,1% |
| 190_B | Rewa | R. stylosa | 190RBR14 | 134 | 74 | 44,8% |
| 190_B | Rewa | R. stylosa | 190RBR11 | 151 | 89 | 41,1% |
| 190_R | Rewa | R. stylosa | 190RCR7 | 56 | 16 | 71,4% |
| 190_R | Rewa | R. stylosa | 190RCR2 | 47 | 18 | 61,7% |
| 190_R | Rewa | R. stylosa | 190RCR3 | 54 | 21 | 61,1% |
| 190_R | Rewa | R. stylosa | 190RCR4 | 48 | 20 | 58,3% |
| 190_R | Rewa | R. stylosa | 190RCR11 | 89 | 38 | 57,3% |
| 190_R | Rewa | R. stylosa | 190RCR5 | 67 | 29 | 56,7% |
| 190_R | Rewa | R. stylosa | 190RCR1 | 11 | 5 | 54,5% |
| 190_R | Rewa | R. stylosa | 190RCR6 | 96 | 48 | 50,0% |
| 190_R | Rewa | R. stylosa | 190RCR8 | 93 | 51 | 45,2% |
| 190_R | Rewa | R. stylosa | 190RCR10 | 210 | 116 | 44,8% |
| 190_R | Rewa | R. stylosa | 190RCR9 | 161 | 93 | 42,2% |
| 190_R | Rewa | R.selala | 190RDR1+2+3+4+5+6 | 360 | 181 | 49,7% |
| 190_R | Rewa | R.selala | 190RDR7+8+9 | 339 | 193 | 43,1% |
| 190_R | Rewa | R.selala | 190RDR10+11 | 538 | 316 | 41,3% |
| 240_R | Rewa | R. stylosa | 240RER3 | 59 | 23 | 61,0% |
| 240_R | Rewa | R. stylosa | 240RER1 | 61 | 27 | 55,7% |
| 240_R | Rewa | R. stylosa | 240RER5 | 51 | 24 | 52,9% |
| 240_R | Rewa | R. stylosa | 240RER2 | 117 | 58 | 50,4% |
| 240_R | Rewa | R. stylosa | 240RER4 | 56 | 29 | 48,2% |
| 240_R | Rewa | R. stylosa | 240RER6 | 246 | 140 | 43,1% |
| 240_F | Rewa | R. stylosa | 240RFR4 | 37 | 15 | 59,5% |
| 240_F | Rewa | R. stylosa | 240RFR1 | 95 | 41 | 56,8% |
| 240_F | Rewa | R. stylosa | 240RFR6 | 51 | 23 | 54,9% |
| 240_F | Rewa | R. stylosa | 240RFR3 | 39 | 18 | 53,8% |
| 240_F | Rewa | R. stylosa | 240RFR10 | 60 | 30 | 50,0% |
| 240_F | Rewa | R. stylosa | 240RFR9 | 105 | 53 | 49,5% |
| 240_F | Rewa | R. stylosa | 240RFR8 | 102 | 52 | 49,0% |
| 240_F | Rewa | R. stylosa | 240RFR7 | 122 | 65 | 46,7% |
| 240_F | Rewa | R. stylosa | 240RFR2 | 126 | 68 | 46,0% |
| 240_F | Rewa | R. stylosa | 240RFR5 | 147 | 82 | 44,2% |
| 240_G | Rewa | R. stylosa | 240RGR7 | 25 | 9 | 64,0% |
| 240_G | Rewa | R. stylosa | 240RGR4 | 19 | 7 | 63,2% |
| 240_G | Rewa | R. stylosa | 240RGR5 | 13 | 5 | 61,5% |
| 240_G | Rewa | R. stylosa | 240RGR3 | 38 | 15 | 60,5% |
| 240_G | Rewa | R. stylosa | 240RGR8 | 69 | 28 | 59,4% |
| 240_G | Rewa | R. stylosa | 240RGR6 | 35 | 15 | 57,1% |
| 240_G | Rewa | R. stylosa | 240RGR10 | 94 | 42 | 55,3% |
| 240_G | Rewa | R. stylosa | 240RGR9 | 35 | 16 | 54,3% |
| 190_A | Rewa | R.selala | 190RAC6 | 464 | 295 | 36,4% |
| 190_C | Rewa | R.selala | 190RAC5 | 360 | 229 | 36,4% |
| 190_C | Rewa | R.selala | 190RAC4 | 363 | 233 | 35,8% |
| 190_A | Rewa | R.selala | 190RAC3 | 590 | 395 | 33,1% |
| 240_G | Rewa | R. stylosa | 240RGR2 | 150 | 80 | 46,7% |
| 190_A | Rewa | R.selala | 190RAC1 | 923 | 630 | 31,7% |
| 190_A | Rewa | R.selala | 190RAC2 | 860 | 611 | 29,0% |
| 190_B | Rewa | R. stylosa | 190RBC1 | 124 | 68 | 45,2% |
| 240_G | Rewa | R. stylosa | 240RGR1 | 62 | 37 | 40,3% |
| 240_H | Rewa | R. stylosa | 240RHR1 | 15 | 6 | 60,0% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 190_B | Rewa | R. stylosa | 190RBC3 | 118 | 67 | 43,2% |
| 190_B | Rewa | R. stylosa | 190RBC4 | 65 | 38 | 41,5% |
| 190_B | Rewa | R. stylosa | 190RBC6 | 137 | 81 | 40,9% |
| 190_B | Rewa | R. stylosa | 190RBC2 | 117 | 72 | 38,5% |
| 190_B | Rewa | R. stylosa | 190RBC7 | 113 | 70 | 38,1% |
| 190_B | Rewa | R. stylosa | 190RBC5 | 124 | 79 | 36,3% |
| 240_H | Rewa | R. stylosa | 240RHR5 | 14 | 6 | 57,1% |
| 190_B | Rewa | R. stylosa | 190RBC9 | 206 | 135 | 34,5% |
| 190_B | Rewa | R. stylosa | 190RBC8 | 154 | 101 | 34,4% |
| 190_C | Rewa | R. stylosa | 190RCC5 | 70 | 37 | 47,1% |
| 240_H | Rewa | R. stylosa | 240RHR2 | 13 | 6 | 53,8% |
| 190_C | Rewa | R. stylosa | 190RCC4 | 104 | 64 | 38,5% |
| 190_C | Rewa | R. stylosa | 190RCC7 | 138 | 87 | 37,0% |
| 190_C | Rewa | R. stylosa | 190RCC1 | 75 | 48 | 36,0% |
| 190_C | Rewa | R. stylosa | 190RCC8 | 249 | 161 | 35,3% |
| 190_C | Rewa | R. stylosa | 190RCC2 | 51 | 33 | 35,3% |
| 190_C | Rewa | R. stylosa | 190RCC3 | 80 | 52 | 35,0% |
| 190_C | Rewa | R. stylosa | 190RCC6 | 207 | 135 | 34,8% |
| 240_H | Rewa | R. stylosa | 240RHR3 | 26 | 12 | 53,8% |
| 190_C | Rewa | R. stylosa | 190RCC9 | 308 | 201 | 34,7% |
| 240_H | Rewa | R. stylosa | 240RHR4 | 26 | 14 | 46,2% |
| 190_D | Rewa | R.selala | 190RDC5 | 42 | 22 | 47,6% |
| 190_D | Rewa | R.selala | 190RDC1 | 22 | 12 | 45,5% |
| 190_D | Rewa | R.selala | 190RDC2 | 31 | 18 | 41,9% |
| 240_H | Rewa | R. stylosa | 240RHR7 | 124 | 67 | 46,0% |
| 240_H | Rewa | R. stylosa | 240RHR6 | 73 | 40 | 45,2% |
| 240_H | Rewa | R. stylosa | 240RHR8 | 70 | 39 | 44,3% |
| 190_D | Rewa | R.selala | 190RDC4 | 72 | 42 | 41,7% |
| 190_D | Rewa | R.selala | 190RDC9 | 204 | 124 | 39,2% |
| 57_M | Rewa | R.selala | 57RMR6 | 33 | 10 | 69,7% |
| 190_D | Rewa | R.selala | 190RDC10 | 249 | 152 | 39,0% |
| 190_D | Rewa | R.selala | 190RDC11 | 337 | 206 | 38,9% |
| 190_D | Rewa | R.selala | 190RDC7 | 176 | 108 | 38,6% |
| 190_D | Rewa | R.selala | 190RDC8 | 249 | 158 | 36,5% |
| 190_D | Rewa | R.selala | 190RDC6 | 130 | 84 | 35,4% |
| 57_M | Rewa | R.selala | 57RMR7 | 30 | 10 | 66,7% |
| 190_D | Rewa | R.selala | 190RDC3 | 63 | 41 | 34,9% |
| 57_M | Rewa | R.selala | 57RMR2 | 138 | 66 | 52,2% |
| 57_M | Rewa | R.selala | 57RMR8 | 58 | 28 | 51,7% |
| 57_M | Rewa | R.selala | 57RMR5 | 72 | 37 | 48,6% |
| 240_C | Rewa | R. stylosa | 240REC3+4 | 219 | 120 | 45,2% |
| 240_C | Rewa | R. stylosa | 240REC5 | 191 | 105 | 45,0% |
| 57_M | Rewa | R.selala | 57RMR10 | 36 | 19 | 47,2% |
| 240_C | Rewa | R. stylosa | 240REC1+2 | 129 | 72 | 44,2% |
| 240_C | Rewa | R. stylosa | 240RFC1to11 | 1056 | 569 | 46,1% |
| 240_G | Rewa | R. stylosa | 240RGC2 | 70 | 34 | 51,4% |
| 240_G | Rewa | R. stylosa | 240RGC7 | 70 | 38 | 45,7% |
| 240_G | Rewa | R. stylosa | 240RGC6 | 160 | 90 | 43,8% |
| 240_G | Rewa | R. stylosa | 240RGC1 | 87 | 49 | 43,7% |
| 190_T | Rewa | R.selala | 190RAT6 | 240 | 149 | 37,9% |
| 190_T | Rewa | R.selala | 190RAT7 | 627 | 405 | 35,4% |
| 240_G | Rewa | R. stylosa | 240RGC5 | 115 | 65 | 43,5% |
| 240_G | Rewa | R. stylosa | 240RGC3 | 67 | 38 | 43,3% |
| 240_G | Rewa | R. stylosa | 240RGC4 | 141 | 83 | 41,1% |
| 190_T | Rewa | R.selala | 190RAT4 | 1032 | 673 | 34,8% |
| 240_H | Rewa | R. stylosa | 240RHC5 | 23 | 11 | 52,2% |
| 190_T | Rewa | R.selala | 190RAT1 | 261 | 180 | 31,0% |
| 240_H | Rewa | R. stylosa | 240RHC4 | 62 | 32 | 48,4% |
| 240_H | Rewa | R. stylosa | 240RHC7 | 37 | 21 | 43,2% |
| 190_T | Rewa | R.selala | 190RAT5 | 951 | 660 | 30,6% |
| 190_T | Rewa | R.selala | 190RAT3 | 1060 | 750 | 29,2% |
| 190_T | Rewa | R.selala | 190RAT2 | 1347 | 983 | 27,0% |
| 190_B | Rewa | R. stylosa | 190RBT6 | 64 | 38 | 40,6% |
| 190_B | Rewa | R. stylosa | 190RBT5 | 118 | 74 | 37,3% |
| 57_M | Rewa | R.selala | 57RMR3 | 77 | 41 | 46,8% |
| 190_B | Rewa | R. stylosa | 190RBT2 | 158 | 100 | 36,7% |
| 190_B | Rewa | R. stylosa | 190RBT1 | 199 | 133 | 33,2% |
| 190_B | Rewa | R. stylosa | 190RBT4 | 178 | 119 | 33,1% |
| 190_B | Rewa | R. stylosa | 190RBT3 | 165 | 112 | 32,1% |
| 190_T | Rewa | R. stylosa | 190RCT2 | 392 | 195 | 50,3% |
| 190_T | Rewa | R. stylosa | 190RCT6 | 86 | 50 | 41,9% |
| 240_H | Rewa | R. stylosa | 240RHC8 | 40 | 23 | 42,5% |
| 190_T | Rewa | R. stylosa | 190RCT5 | 140 | 87 | 37,9% |
| 190_T | Rewa | R. stylosa | 190RCT3 | 160 | 100 | 37,5% |
| 240_H | Rewa | R. stylosa | 240RHC6 | 78 | 46 | 41,0% |
| 240_H | Rewa | R. stylosa | 240RHC3 | 81 | 48 | 40,7% |
| 240_H | Rewa | R. stylosa | 240RHC1 | 110 | 66 | 40,0% |
| 190_T | Rewa | R. stylosa | 190RCT7 | 329 | 213 | 35,3% |
| 190_T | Rewa | R. stylosa | 190RCT4 | 91 | 60 | 34,1% |
| 57_M | Rewa | R.selala | 57RMR4 | 120 | 66 | 45,0% |
| 190_T | Rewa | R. stylosa | 190RCT1 | 293 | 198 | 32,4% |
| 190_T | Rewa | R. stylosa | 190RCT9 | 928 | 635 | 31,6% |

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|---|---|---|---|---|---|---|
| 240_H | Rewa | R. stylosa | 240RHC2 | 167 | 101 | 39,5% |
| 190_T | Rewa | R. stylosa | 190RCT8 | 1040 | 715 | 31,3% |
| 57_M | Rewa | R.selala | 57RMC6 | 33 | 17 | 48,5% |
| 190_T | Rewa | R.selala | 190RDT10 | 176 | 105 | 40,3% |
| 190_T | Rewa | R.selala | 190RDT2 | 997 | 616 | 38,2% |
| 190_T | Rewa | R.selala | 190RDT4 | 694 | 433 | 37,6% |
| 190_T | Rewa | R.selala | 190RDT8+9 | 320 | 203 | 36,6% |
| 57_M | Rewa | R.selala | 57RMC8 | 21 | 11 | 47,6% |
| 57_M | Rewa | R.selala | 57RMR9 | 28 | 16 | 42,9% |
| 190_T | Rewa | R.selala | 190RDT6 | 507 | 323 | 36,3% |
| 57_M | Rewa | R.selala | 57RMR1 | 192 | 112 | 41,7% |
| 57_M | Rewa | R.selala | 57RMC10 | 50 | 27 | 46,0% |
| 190_T | Rewa | R.selala | 190RDT1 | 1287 | 823 | 36,1% |
| 57_M | Rewa | R.selala | 57RMC7 | 42 | 23 | 45,2% |
| 190_T | Rewa | R.selala | 190RDT3 | 290 | 187 | 35,5% |
| 190_T | Rewa | R.selala | 190RDT5 | 989 | 644 | 34,9% |
| 190_T | Rewa | R.selala | 190RDT7 | 349 | 232 | 33,5% |
| 240_T | Rewa | R. stylosa | 240RET1+2+3+4+5 | 505 | 264 | 47,7% |
| 57_M | Rewa | R.selala | 57RMC5 | 98 | 58 | 40,8% |
| 57_M | Rewa | R.selala | 57RMC11 | 103 | 61 | 40,8% |
| 240_T | Rewa | R. stylosa | 240RET8 | 320 | 186 | 41,9% |
| 240_T | Rewa | R. stylosa | 240RET6 | 273 | 164 | 39,9% |
| 240_T | Rewa | R. stylosa | 240RET7 | 394 | 241 | 38,8% |
| 240_F | Rewa | R. stylosa | 240RFT6 | 224 | 132 | 41,1% |
| 240_F | Rewa | R. stylosa | 240RFT5 | 106 | 64 | 39,6% |
| 240_F | Rewa | R. stylosa | 240RFT4 | 347 | 211 | 39,2% |
| 240_F | Rewa | R. stylosa | 240RFT2 | 119 | 73 | 38,7% |
| 240_F | Rewa | R. stylosa | 240RFT1 | 207 | 127 | 38,6% |
| 240_F | Rewa | R. stylosa | 240RFT3 | 269 | 167 | 37,9% |
| 240_F | Rewa | R. stylosa | 240RFT7 | 159 | 103 | 35,2% |
| 240_G | Rewa | R. stylosa | 240RGT1 | 49 | 23 | 53,1% |
| 240_G | Rewa | R. stylosa | 240RGT5 | 94 | 51 | 45,7% |
| 240_G | Rewa | R. stylosa | 240RGT6 | 162 | 90 | 44,4% |
| 240_G | Rewa | R. stylosa | 240RGT4 | 185 | 106 | 42,7% |
| 57_M | Rewa | R.selala | 57RMC1 | 274 | 167 | 39,1% |
| 240_G | Rewa | R. stylosa | 240RGT2 | 109 | 65 | 40,4% |
| 240_G | Rewa | R. stylosa | 240RGT3 | 125 | 75 | 40,0% |
| 240_G | Rewa | R. stylosa | 240RGT9 | 145 | 87 | 40,0% |
| 57_M | Rewa | R.selala | 57RMC3 | 528 | 326 | 38,3% |
| 240_G | Rewa | R. stylosa | 240RGT7 | 223 | 134 | 39,9% |
| 240_G | Rewa | R. stylosa | 240RGT8 | 267 | 164 | 38,6% |
| 240_G | Rewa | R.selala | 240RGT10 | 575 | 392 | 31,8% |
| 240_H | Rewa | R. stylosa | 240RHT4 | 42 | 21 | 50,0% |
| 240_H | Rewa | R. stylosa | 240RHT2 | 33 | 17 | 48,5% |
| 240_H | Rewa | R. stylosa | 240RHT1 | 50 | 26 | 48,0% |
| 240_H | Rewa | R. stylosa | 240RHT6 | 87 | 49 | 43,7% |
| 240_H | Rewa | R. stylosa | 240RHT5 | 109 | 64 | 41,3% |
| 240_H | Rewa | R. stylosa | 240RHT7 | 55 | 33 | 40,0% |
| 240_H | Rewa | R. stylosa | 240RHT3 | 46 | 35 | 23,9% |
| 57_M | Rewa | R.selala | 57RMC4 | 136 | 84 | 38,2% |
| 57_M | Rewa | R.selala | 57RMT10 | 362 | 221 | 39,0% |
| 57_M | Rewa | R.selala | 57RMC2 | 336 | 208 | 38,1% |
| 57_M | Rewa | R.selala | 57RMT9 | 285 | 180 | 36,8% |
| 57_M | Rewa | R.selala | 57RMT7 | 474 | 301 | 36,5% |
| 57_M | Rewa | R.selala | 57RMT5 | 769 | 494 | 35,8% |
| 57_M | Rewa | R.selala | 57RMT4 | 791 | 509 | 35,7% |
| 57_M | Rewa | R.selala | 57RMT2 | 1131 | 730 | 35,5% |
| 57_M | Rewa | R.selala | 57RMT6 | 635 | 410 | 35,4% |
| 57_M | Rewa | R.selala | 57RMC9 | 63 | 39 | 38,1% |
| 57_M | Rewa | R.selala | 57RMT3 | 1192 | 774 | 35,1% |
| 57_M | Rewa | R.selala | 57RMT8 | 567 | 370 | 34,7% |
| 57_M | Rewa | R.selala | 57RMT1 | 1648 | 1081 | 34,4% |
| 141_R | Rewa | R.selala | 141RQR1+4+5 | 496 | 264 | 46,8% |
| 141_R | Rewa | R.selala | 141RQR2+3+6 | 466 | 254 | 45,5% |
| 141_R | Rewa | R.selala | 141RQR8 | 299 | 195 | 34,8% |
| 141_R | Rewa | R.selala | 141RTR6+7+8 | 81 | 33 | 59,3% |
| 141_T | Rewa | R.selala | 141RQT1 | 414 | 262 | 36,7% |
| 141_T | Rewa | R.selala | 141RTC1 | 42 | 18 | 57,1% |
| 141_T | Rewa | R.selala | 141RQT2 | 437 | 280 | 35,9% |
| 141_T | Rewa | R.selala | 141RQT3 | 407 | 263 | 35,4% |
| 141_T | Rewa | R.selala | 141RTT1 | 381 | 264 | 30,7% |
| 141_T | Rewa | R.selala | 141RTT2 | 517 | 364 | 29,6% |
| 141_T | Rewa | R.selala | 141RTT4 | 474 | 337 | 28,9% |
| 141_T | Rewa | R.selala | 141RTC3 | 129 | 77 | 40,3% |
| 141_T | Rewa | R.selala | 141RTT5 | 795 | 573 | 27,9% |
| 141_T | Rewa | R.selala | 141RTT7 | 568 | 410 | 27,8% |
| 141_T | Rewa | R.selala | 141RTT8 | 734 | 536 | 27,0% |
| 141_T | Rewa | R.selala | 141RTT6 | 525 | 387 | 26,3% |
| 141_T | Rewa | R.selala | 141RTC2 | 190 | 114 | 40,0% |
| 141_T | Rewa | R.selala | 141RTR2 | 113 | 63 | 44,2% |
| 141_T | Rewa | R.selala | 141RTT3 | 544 | 402 | 26,1% |
| 141_T | Rewa | R.selala | 141RTR5 | 102 | 58 | 43,1% |

Appendix

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|---|---|---|---|---|---|---|
| 141_R | Rewa | R.selala | 141RTR1+3+4 | 298 | 185 | 37,9% |
| 9_M | Ba | R. stylosa | 9R'MC2 | 17 | 8 | 52,9% |
| 9_M | Ba | R. stylosa | 9R'MC1+3+4+5+7+8+9 | 196 | 114 | 41,8% |
| 9_M | Ba | R. stylosa | 9R'MC6 | 69 | 41 | 40,6% |
| 9_N | Ba | R. stylosa | 9R'NC3 | 25 | 14 | 44,0% |
| 9_N | Ba | R. stylosa | 9R'N2+4+5+6+7+8+9 | 200 | 120 | 40,0% |
| 9_N | Ba | R. stylosa | 9R'NC1 | 21 | 13 | 38,1% |
| 9_O | Ba | R. stylosa | 9R'OC5 | 22 | 13 | 40,9% |
| 9_O | Ba | R. stylosa | 9R'OC1+2+3+4+6+8+9 | 280 | 170 | 39,3% |
| 135_Q | Ba | R.selala | 135R`QL1 | 466 | 163 | 65,0% |
| 9_O | Ba | R. stylosa | 9R'OC7 | 58 | 36 | 37,9% |
| 9_P | Ba | R. stylosa | 9R'PC1+3+4+6+7+8+9+ | 240 | 140 | 41,7% |
| 135_T | Ba | R.selala | 135R`TL1 | 565 | 206 | 63,5% |
| 9_P | Ba | R. stylosa | 9R'PC5 | 29 | 17 | 41,4% |
| 9_P | Ba | R. stylosa | 9R'PC2 | 86 | 52 | 39,5% |
| 17_R | Ba | R.selala | 17R'IC8 | 76 | 45 | 40,8% |
| 17_R | Ba | R.selala | 17R'IC7 | 66 | 42 | 36,4% |
| 17_R | Ba | R.selala | 17R'IC2 | 75 | 48 | 36,0% |
| 17_R | Ba | R.selala | 17R'IC1 | 135 | 88 | 34,8% |
| 17_R | Ba | R.selala | 17R'IC3 | 57 | 38 | 33,3% |
| 17_R | Ba | R.selala | 17R'IC4 | 153 | 105 | 31,4% |
| 17_R | Ba | R.selala | 17R'IC6 | 85 | 59 | 30,6% |
| 17_R | Ba | R.selala | 17R'IC5 | 143 | 104 | 27,3% |
| 17_R | Ba | R. stylosa | 17R`JC | 358 | 218 | 39,1% |
| 17_R | Ba | R. stylosa | 17R`KC | 314 | 178 | 43,3% |
| 9_P | Ba | R. stylosa | 9R'PL1 | 530 | 210 | 60,4% |
| 17_R | Ba | R.selala | 17R'LC2 | 40 | 24 | 40,0% |
| 17_R | Ba | R.selala | 17R'LC1 | 43 | 26 | 39,5% |
| 17_R | Ba | R.selala | 17R'LC4+5+6+7+10 | 80 | 49 | 38,8% |
| 17_R | Ba | R.selala | 17R`LC8 | 199 | 127 | 36,2% |
| 17_R | Ba | R.selala | 17R`LC9 | 158 | 101 | 36,1% |
| 17_R | Ba | R.selala | 17R'LC3 | 139 | 89 | 36,0% |
| 80_R | Ba | R. stylosa | 80R'GC_all | 105 | 55 | 47,6% |
| 135_S | Ba | R. stylosa | 135R`SL1 | 209 | 86 | 58,9% |
| 80_R | Ba | R.selala | 80R'EC1+2+3+4+5+7+8 | 424 | 245 | 42,2% |
| 80_R | Ba | R. stylosa | 80R'FC_all | 400 | 232 | 42,0% |
| 80_R | Ba | R. stylosa | 80R'HC_all | 231 | 131 | 43,3% |
| 135_5 | Ba | R.selala | 135R'QC1+3+5+6+9+1( | 256 | 144 | 43,8% |
| 135_5 | Ba | R.selala | 135R'QC8 | 116 | 68 | 41,4% |
| 135_5 | Ba | R.selala | 135R'QC2 | 144 | 85 | 41,0% |
| 135_5 | Ba | R.selala | 135R'QC4 | 185 | 113 | 38,9% |
| 135_5 | Ba | R.selala | 135R'QC7 | 254 | 157 | 38,2% |
| 135_5 | Ba | R. stylosa | 135R'RC3+4+5+6+7+8+ | 290 | 160 | 44,8% |
| 135_5 | Ba | R. stylosa | 135R'RC2 | 30 | 17 | 43,3% |
| 135_5 | Ba | R. stylosa | 135R'RC1 | 79 | 45 | 43,0% |
| 135_5 | Ba | R. stylosa | 135R'SC3 | 55 | 30 | 45,5% |
| 135_5 | Ba | R. stylosa | 135R'SC1+2+4+5 | 125 | 70 | 44,0% |
| 135_5 | Ba | R. stylosa | 135R'SC6 | 50 | 29 | 42,0% |
| 165_5 | Ba | R. samoensis | 165R'BC 1+2+3+4 | 52 | 23 | 55,8% |
| 165_5 | Ba | R.selala | 165R'DC4 | 27 | 14 | 48,1% |
| 165_5 | Ba | R.selala | 165R'DC3 | 15 | 8 | 46,7% |
| 165_5 | Ba | R.selala | 165R'DC2 | 35 | 21 | 40,0% |
| 165_5 | Ba | R.selala | 165R'DC1 | 156 | 100 | 35,9% |
| 165_5 | Ba | R.selala | 165R'DC5 | 246 | 159 | 35,4% |
| 165_5 | Ba | R.selala | 165R'DC6 | 253 | 189 | 25,3% |
| 9_M | Ba | R. stylosa | 9R'MR6 | 33 | 11 | 66,7% |
| 9_M | Ba | R. stylosa | 9R'MR8 | 70 | 27 | 61,4% |
| 17_R | Ba | R. stylosa | 17R'KR1 | 103 | 48 | 53,4% |
| 9_M | Ba | R. stylosa | 9R'MR1+2+3+4+5+7 | 470 | 206 | 56,2% |
| 9_N | Ba | R. stylosa | 9R'NR1 | 67 | 24 | 64,2% |
| 9_N | Ba | R. stylosa | 9R'NR10 | 140 | 58 | 58,6% |
| 9_N | Ba | R. stylosa | 9R'NR4+9+7+2 | 339 | 141 | 58,4% |
| 9_N | Ba | R. stylosa | 9R'NR3 | 138 | 60 | 56,5% |
| 9_N | Ba | R. stylosa | 9R'NR5+6+8 | 326 | 154 | 52,8% |
| 9_O | Ba | R. stylosa | 9R'OR11 | 148 | 67 | 54,7% |
| 9_O | Ba | R. stylosa | 9R'OR5 | 93 | 43 | 53,8% |
| 9_O | Ba | R. stylosa | 9R'OR9+2+3+4 | 251 | 117 | 53,4% |
| 9_O | Ba | R. stylosa | 9R'OR1+6+7+8+10 | 348 | 174 | 50,0% |
| 9_P | Ba | R. stylosa | 9R'PR5 | 88 | 37 | 58,0% |
| 9_P | Ba | R. stylosa | 9R'PR1+2+4+6+7+8+9+ | 571 | 276 | 51,7% |
| 9_P | Ba | R. stylosa | 9R'PR3 | 64 | 51 | 20,3% |
| 17_R | Ba | R.selala | 17R'IR3 | 43 | 16 | 62,8% |
| 17_R | Ba | R.selala | 17R'IR5 | 57 | 24 | 57,9% |
| 17_R | Ba | R.selala | 17R'IR2 | 82 | 38 | 53,7% |
| 17_R | Ba | R.selala | 17R'IR9 | 100 | 47 | 53,0% |
| 17_R | Ba | R.selala | 17R'IR1 | 38 | 19 | 50,0% |
| 17_R | Ba | R.selala | 17R'IR6 | 46 | 24 | 47,8% |
| 17_R | Ba | R.selala | 17R'IR7 | 110 | 65 | 40,9% |
| 17_R | Ba | R.selala | 17R'IR10 | 204 | 133 | 34,8% |
| 17_R | Ba | R.selala | 17R'IR8 | 155 | 116 | 25,2% |
| 17_R | Ba | R.selala | 17R'IR4 | 47 | 38 | 19,1% |
| 17_R | Ba | R. stylosa | 17R`JR9 | 230 | 100 | 56,5% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 17_R | Ba | R. stylosa | 17R`JR3+5+7+8 | 516 | 241 | 53,3% |
| 17_R | Ba | R. stylosa | 17R`JR4 | 158 | 74 | 53,2% |
| 17_R | Ba | R. stylosa | 17R`JR1 | 170 | 85 | 50,0% |
| 17_R | Ba | R. stylosa | 17R`JR10 | 111 | 58 | 47,7% |
| 17_R | Ba | R. stylosa | 17R`JR2 | 363 | 196 | 46,0% |
| 17_R | Ba | R. stylosa | 17R`JR6 | 329 | 180 | 45,3% |
| 17_R | Ba | R. stylosa | 17R`KR2 | 66 | 27 | 59,1% |
| 17_R | Ba | R. stylosa | 17R`KR4 | 124 | 54 | 56,5% |
| 17_R | Ba | R. stylosa | 17R`KR3+5+7+8+9+10 | 630 | 303 | 51,9% |
| 17_R | Ba | R. stylosa | 17R`KR6 | 108 | 65 | 39,8% |
| 17_R | Ba | R.selala | 17R`LR4 | 166 | 54 | 67,5% |
| 17_R | Ba | R.selala | 17R`LR10 | 68 | 36 | 47,1% |
| 17_R | Ba | R.selala | 17R`LR1+2+3+7+9+11 | 652 | 364 | 44,2% |
| 17_R | Ba | R.selala | 17R`LR8 | 282 | 161 | 42,9% |
| 17_R | Ba | R.selala | 17R`LR6 | 198 | 118 | 40,4% |
| 80_R | Ba | R.selala | 80R'ER5+7+10 | 188 | 74 | 60,6% |
| 80_R | Ba | R.selala | 80R'ER9 | 155 | 64 | 58,7% |
| 80_R | Ba | R.selala | 80R'ER1 | 351 | 163 | 53,6% |
| 80_R | Ba | R.selala | 80R'ER4 | 158 | 86 | 45,6% |
| 80_R | Ba | R.selala | 80R'ER13 | 228 | 135 | 40,8% |
| 165_D | Ba | R.selala | 165R'DC7 | 383 | 246 | 35,8% |
| 80_R | Ba | R.selala | 80R'ER2 | 263 | 161 | 38,8% |
| 80_R | Ba | R.selala | 80R'ER3 | 212 | 130 | 38,7% |
| 80_R | Ba | R.selala | 80R'ER11 | 187 | 116 | 38,0% |
| 80_R | Ba | R.selala | 80R'ER12 | 262 | 170 | 35,1% |
| 80_R | Ba | R.selala | 80R'ER6+8 | 212 | 142 | 33,0% |
| 80_R | Ba | R. stylosa | 80R'FR5 | 38 | 12 | 68,4% |
| 80_R | Ba | R. stylosa | 80R'FR7 | 181 | 84 | 53,6% |
| 80_R | Ba | R. stylosa | 80R'FR3 | 217 | 104 | 52,1% |
| 80_R | Ba | R. stylosa | 80R'FR4 | 184 | 89 | 51,6% |
| 80_R | Ba | R. stylosa | 80R'FR9 | 91 | 46 | 49,5% |
| 80_R | Ba | R. stylosa | 80R'FR6 | 167 | 93 | 44,3% |
| 80_R | Ba | R. stylosa | 80R'FR1 | 114 | 67 | 41,2% |
| 80_R | Ba | R. stylosa | 80R'FR8 | 141 | 83 | 41,1% |
| 80_R | Ba | R. stylosa | 80R'FR2 | 154 | 97 | 37,0% |
| 80_R | Ba | R. stylosa | 80R'GR_all | 422 | 272 | 35,5% |
| 80_R | Ba | R. stylosa | 80R'HR_all | 763 | 405 | 46,9% |
| 135_5 | Ba | R.selala | 135R'QR5+6+7+8+9+1( | 701 | 350 | 50,1% |
| 135_5 | Ba | R.selala | 135R'QR4 | 212 | 117 | 44,8% |
| 135_5 | Ba | R.selala | 135R'QR3 | 293 | 169 | 42,3% |
| 135_5 | Ba | R.selala | 135R'QR2 | 344 | 212 | 38,4% |
| 135_5 | Ba | R.selala | 135R'QR1 | 534 | 339 | 36,5% |
| 135_5 | Ba | R. stylosa | 135R'RR4 | 31 | 14 | 54,8% |
| 135_5 | Ba | R. stylosa | 135R'RR3+5+9+10 | 160 | 75 | 53,1% |
| 135_5 | Ba | R. stylosa | 135R'RR2+6+8 | 301 | 145 | 51,8% |
| 165_5 | Ba | R.selala | 165R'DTG2_all | 1056 | 720 | 31,8% |
| 135_5 | Ba | R. stylosa | 135R'RR1 | 113 | 58 | 48,7% |
| 165_5 | Ba | R.selala | 165R'DT_half | 1757 | 1215 | 30,8% |
| 135_5 | Ba | R. stylosa | 135R'SR4 | 41 | 17 | 58,5% |
| 135_5 | Ba | R. stylosa | 135R'SR1+3+2+7+8+6 | 321 | 147 | 54,2% |
| 135_5 | Ba | R. stylosa | 135R'SR5 | 249 | 137 | 45,0% |
| 135_5 | Ba | R.selala | 135R'TR8 | 39 | 19 | 51,3% |
| 135_5 | Ba | R.selala | 135R'TR1+3+4+5+6+7+ | 327 | 160 | 51,1% |
| 135_5 | Ba | R.selala | 135R'TR2 | 121 | 63 | 47,9% |
| 165_5 | Ba | R. samoensis | 165R'BR2 | 40 | 17 | 57,5% |
| 165_5 | Ba | R. samoensis | 165R'BR1-7 | 309 | 138 | 55,3% |
| 165_5 | Ba | R. samoensis | 165R'BR7-11 | 230 | 107 | 53,5% |
| 165_5 | Ba | R. samoensis | 165R'BR8 | 42 | 22 | 47,6% |
| 165_5 | Ba | R.selala | 165R'DR_alle | 420 | 222 | 47,1% |
| 165_5 | Ba | R.selala | 165R'DR3 | 98 | 53 | 45,9% |
| 165_5 | Ba | R.selala | 165R'DR3 | 98 | 53 | 45,9% |
| 165_5 | Ba | R.selala | 165R'DR3 | 96 | 53 | 44,8% |
| 9_M | Ba | R. stylosa | 9R'MT1+2+3+4+6+7+9 | 590 | 330 | 44,1% |
| 9_M | Ba | R. stylosa | 9R'MT5 | 201 | 118 | 41,3% |
| 9_M | Ba | R. stylosa | 9R'MT8 | 210 | 135 | 35,7% |
| 9_N | Ba | R. stylosa | 9R'NT7 | 162 | 94 | 42,0% |
| 9_N | Ba | R. stylosa | 9R'NT2 | 375 | 233 | 37,9% |
| 9_N | Ba | R. stylosa | 9R'NT5 | 337 | 211 | 37,4% |
| 9_N | Ba | R. stylosa | 9R'NT4 | 456 | 286 | 37,3% |
| 9_N | Ba | R. stylosa | 9R'NT3 | 349 | 223 | 36,1% |
| 9_N | Ba | R. stylosa | 9R'NT1 | 461 | 303 | 34,3% |
| 9_N | Ba | R. stylosa | 9R'NT6 | 505 | 342 | 32,3% |
| 9_O | Ba | R. stylosa | 9R'OT4+2+3+1 | 384 | 229 | 40,4% |
| 9_O | Ba | R. stylosa | 9R'OT9 | 136 | 82 | 39,7% |
| 9_O | Ba | R. stylosa | 9R'OT7 | 192 | 117 | 39,1% |
| 9_O | Ba | R. stylosa | 9R'OT5+6+8 | 367 | 226 | 38,4% |
| 9_P | Ba | R. stylosa | 9R'PT2 | 130 | 77 | 40,8% |
| 9_P | Ba | R. stylosa | 9R'PT1+4+7+8 | 680 | 422 | 37,9% |
| 9_P | Ba | R. stylosa | 9R'PT5 | 178 | 112 | 37,1% |
| 9_P | Ba | R. stylosa | 9R'PT3+9+6 | 453 | 287 | 36,6% |
| 17_R | Ba | R.selala | 17R'IT1 | 731 | 476 | 34,9% |
| 17_R | Ba | R.selala | 17R'IT4+5 | 664 | 435 | 34,5% |

| | | | | | | |
|---|---|---|---|---|---|---|
| 17_R | Ba | R.selala | 17R'IT3 | 543 | 378 | 30,4% |
| 17_R | Ba | R.selala | 17R'IT2 | 818 | 584 | 28,6% |
| 17_R | Ba | R. stylosa | 17R'JT7 | 77 | 41 | 46,8% |
| 17_R | Ba | R. stylosa | 17R'JT6 | 126 | 76 | 39,7% |
| 17_R | Ba | R. stylosa | 17R'JT5 | 168 | 102 | 39,3% |
| 17_R | Ba | R. stylosa | 17R'JT2 | 496 | 313 | 36,9% |
| 17_R | Ba | R. stylosa | 17R'JT3 | 217 | 138 | 36,4% |
| 17_R | Ba | R. stylosa | 17R'JT1 | 645 | 411 | 36,3% |
| 135_5 | Ba | R.selala | 135R'TC1+2+3+5+7 | 302 | 153 | 49,3% |
| 17_R | Ba | R. stylosa | 17R'JT8 | 203 | 131 | 35,5% |
| 17_R | Ba | R. stylosa | 17R'JT4 | 184 | 121 | 34,2% |
| 17_R | Ba | R. stylosa | 17R`KT4+9+7+10 | 470 | 299 | 36,4% |
| 17_R | Ba | R. stylosa | 17R`KT2+5+6 | 661 | 429 | 35,1% |
| 17_R | Ba | R. stylosa | 17R`KT8 | 191 | 126 | 34,0% |
| 17_R | Ba | R. stylosa | 17R`KT1 | 410 | 275 | 32,9% |
| 17_R | Ba | R. stylosa | 17R`KT3 | 295 | 200 | 32,2% |
| 17_R | Ba | R.selala | 17R'LT9 | 104 | 63 | 39,4% |
| 17_R | Ba | R.selala | 17R'LT5 | 299 | 193 | 35,5% |
| 17_R | Ba | R.selala | 17R'LT1 | 489 | 318 | 35,0% |
| 17_R | Ba | R.selala | 17R'LT10 | 212 | 138 | 34,9% |
| 17_R | Ba | R.selala | 17R'LT6 | 287 | 187 | 34,8% |
| 17_R | Ba | R.selala | 17R'LT8 | 294 | 193 | 34,4% |
| 17_R | Ba | R.selala | 17R'LT11 | 318 | 210 | 34,0% |
| 17_R | Ba | R.selala | 17R'LT7 | 639 | 422 | 34,0% |
| 17_R | Ba | R.selala | 17R'LT3 | 521 | 345 | 33,8% |
| 17_R | Ba | R.selala | 17R'LT4 | 510 | 339 | 33,5% |
| 17_R | Ba | R.selala | 17R'LT2 | 512 | 345 | 32,6% |
| 80_R | Ba | R. stylosa | 80R'GT_all | 293 | 181 | 38,2% |
| 80_R | Ba | R. stylosa | 80R'HT_all | 839 | 518 | 38,3% |
| 80_R | Ba | R.selala | 80R'ET8 | 226 | 126 | 44,2% |
| 80_R | Ba | R.selala | 80R'ET7 | 135 | 76 | 43,7% |
| 80_R | Ba | R.selala | 80R'ET6 | 95 | 55 | 42,1% |
| 80_R | Ba | R.selala | 80R'ET5 | 455 | 282 | 38,0% |
| 80_R | Ba | R.selala | 80R'ET4 | 636 | 416 | 34,6% |
| 80_R | Ba | R.selala | 80R'ET3 | 588 | 393 | 33,2% |
| 80_R | Ba | R.selala | 80R'ET2 | 769 | 531 | 30,9% |
| 80_R | Ba | R.selala | 80R'ET1 | 826 | 586 | 29,1% |
| 80_R | Ba | R. stylosa | 80R'FT5 | 222 | 137 | 38,3% |
| 80_R | Ba | R. stylosa | 80R'FT2 | 160 | 99 | 38,1% |
| 80_R | Ba | R. stylosa | 80R'FT3 | 181 | 112 | 38,1% |
| 80_R | Ba | R. stylosa | 80R'FT7 | 100 | 62 | 38,0% |
| 80_R | Ba | R. stylosa | 80R'FT4 | 133 | 83 | 37,6% |
| 80_R | Ba | R. stylosa | 80R'FT1 | 198 | 126 | 36,4% |
| 80_R | Ba | R. stylosa | 80R'FT6 | 270 | 194 | 28,1% |
| 135_5 | Ba | R.selala | 135R'QT5 | 416 | 263 | 36,8% |
| 135_5 | Ba | R.selala | 135R'QT4 | 450 | 287 | 36,2% |
| 135_5 | Ba | R.selala | 135R'QT6 | 416 | 266 | 36,1% |
| 135_5 | Ba | R.selala | 135R'QT7 | 583 | 374 | 35,8% |
| 135_5 | Ba | R.selala | 135R'QT8 | 512 | 329 | 35,7% |
| 135_5 | Ba | R.selala | 135R'QT3 | 573 | 375 | 34,6% |
| 135_5 | Ba | R.selala | 135R'QT1 | 536 | 351 | 34,5% |
| 135_5 | Ba | R.selala | 135R'QT2 | 554 | 364 | 34,3% |
| 135_5 | Ba | R. stylosa | 135R'RT5 | 83 | 47 | 43,4% |
| 135_5 | Ba | R. stylosa | 135R'RT1+2+3+6+7 | 520 | 310 | 40,4% |
| 135_5 | Ba | R. stylosa | 135R'RT4 | 144 | 88 | 38,9% |
| 135_5 | Ba | R. stylosa | 135R'ST5 | 219 | 127 | 42,0% |
| 135_5 | Ba | R. stylosa | 135R'ST2+3+4+6 | 523 | 309 | 40,9% |
| 135_5 | Ba | R. stylosa | 135R'ST1 | 221 | 132 | 40,3% |
| 135_5 | Ba | R.selala | 135R'TT1 | 196 | 121 | 38,3% |
| 135_5 | Ba | R.selala | 135R'TT3+4+5+6 | 563 | 352 | 37,5% |
| 135_5 | Ba | R.selala | 135R'TT2 | 146 | 94 | 35,6% |
| 165_5 | Ba | R. samoensis | 165R'BT2 | 221 | 122 | 44,8% |
| 165_5 | Ba | R. samoensis | 165R'BT4 | 152 | 86 | 43,4% |
| 165_5 | Ba | R. samoensis | 165R'BT5 | 185 | 105 | 43,2% |
| 165_5 | Ba | R. samoensis | 165R'BT3 | 132 | 75 | 43,2% |
| 165_5 | Ba | R. samoensis | 165R'BT1 | 286 | 164 | 42,7% |
| 165_5 | Ba | R.selala | 165R`DT7 | 342 | 221 | 35,4% |
| 165_5 | Ba | R.selala | 165R'DT5 | 392 | 258 | 34,2% |
| 165_5 | Ba | R.selala | 165R'DT_half | 1547 | 1027 | 33,6% |
| 165_5 | Ba | R.selala | 165R'DT4 | 518 | 347 | 33,0% |
| 165_5 | Ba | R.selala | 165R'DT6 | 295 | 201 | 31,9% |

## Gross density determination for all samples analysed

| plot | location | Tree_species | Segment | Sample | Density_W1 [g/cm³] | Density_W2 [g/cm³] | Density_S [g/cm³] |
|---|---|---|---|---|---|---|---|
| 9_M | Ba | R. stylosa | C | 9R'MC2 | 0,47 | 0,50 | 0,58 |
| 9_M | Ba | R. stylosa | C | 9R'MC1+3+4+5+7+8+9 | 0,68 | 0,72 | |
| 9_M | Ba | R. stylosa | C | 9R'MC6 | 1,11 | 1,17 | 0,71 |
| 9_N | Ba | R. stylosa | C | 9R'NC3 | 0,67 | 0,67 | 0,67 |
| 9_N | Ba | R. stylosa | C | 9R'N2+4+5+6+7+8+9 | 0,79 | 0,80 | |
| 9_N | Ba | R. stylosa | C | 9R'NC1 | 0,65 | 0,65 | 0,75 |
| 9_O | Ba | R. stylosa | C | 9R'OC5 | 0,62 | 0,62 | 0,58 |
| 9_O | Ba | R. stylosa | C | 9R'OC1+2+3+4+6+8+9 | 0,71 | 0,74 | |
| 9_O | Ba | R. stylosa | C | 9R'OC7 | 1,06 | 1,09 | 0,74 |
| 9_P | Ba | R. stylosa | C | 9R'PC1+3+4+6+7+8+9+10+1 | 0,72 | 0,75 | |
| 9_P | Ba | R. stylosa | C | 9R'PC5 | 1,06 | 1,13 | 0,66 |
| 9_P | Ba | R. stylosa | C | 9R'PC2 | 0,95 | 0,96 | 0,73 |
| 17_J | Ba | R. stylosa | C | 17R`JC | 0,69 | 0,71 | |
| 17_K | Ba | R. stylosa | C | 17R`KC | 0,70 | 0,72 | |
| 80_G | Ba | R. stylosa | C | 80R'GC_all | 0,81 | 0,82 | |
| 80_F | Ba | R. stylosa | C | 80R'FC_all | 0,68 | 0,72 | |
| 80_H | Ba | R. stylosa | C | 80R'HC_all | 0,83 | 0,86 | |
| 135_R | Ba | R. stylosa | C | 135R'RC3+4+5+6+7+8+9+10 | 0,69 | 0,72 | |
| 135_R | Ba | R. stylosa | C | 135R'RC2 | 0,59 | 0,61 | 0,64 |
| 135_R | Ba | R. stylosa | C | 135R'RC1 | 1,00 | 1,02 | 0,69 |
| 135_S | Ba | R. stylosa | C | 135R'SC3 | 0,97 | 1,00 | 0,60 |
| 135_S | Ba | R. stylosa | C | 135R'SC1+2+4+5 | 0,76 | 0,79 | |
| 135_S | Ba | R. stylosa | C | 135R'SC6 | 1,12 | 1,12 | 0,65 |
| 9_M | Ba | R. stylosa | R | 9R'MR6 | 0,46 | 0,48 | 0,24 |
| 9_M | Ba | R. stylosa | R | 9R'MR8 | 0,30 | 0,31 | 0,28 |
| 9_M | Ba | R. stylosa | R | 9R'MR1+2+3+4+5+7 | 0,38 | 0,39 | |
| 9_N | Ba | R. stylosa | R | 9R'NR1 | 0,32 | 0,33 | 0,29 |
| 9_N | Ba | R. stylosa | R | 9R'NR10 | 0,34 | 0,34 | 0,37 |
| 9_N | Ba | R. stylosa | R | 9R'NR4+9+7+2 | 0,32 | 0,33 | |
| 9_N | Ba | R. stylosa | R | 9R'NR3 | 0,38 | 0,39 | 0,39 |
| 9_N | Ba | R. stylosa | R | 9R'NR5+6+8 | 0,42 | 0,43 | |
| 9_O | Ba | R. stylosa | R | 9R'OR11 | 0,39 | 0,40 | 0,41 |
| 9_O | Ba | R. stylosa | R | 9R'OR5 | 0,45 | 0,46 | 0,43 |
| 9_O | Ba | R. stylosa | R | 9R'OR9+2+3+4 | 0,38 | 0,39 | |
| 9_O | Ba | R. stylosa | R | 9R'OR1+6+7+8+10 | 0,50 | 0,51 | |
| 9_P | Ba | R. stylosa | R | 9R'PR5 | 0,61 | 0,62 | 0,48 |
| 9_P | Ba | R. stylosa | R | 9R'PR1+2+4+6+7+8+9+10 | 0,45 | 0,46 | |
| 9_P | Ba | R. stylosa | R | 9R'PR3 | 0,59 | 0,61 | 0,50 |
| 17_J | Ba | R. stylosa | R | 17R`JR9 | 0,37 | 0,38 | 0,37 |
| 17_J | Ba | R. stylosa | R | 17R`JR3+5+7+8 | 0,40 | 0,41 | |
| 17_J | Ba | R. stylosa | R | 17R`JR4 | 0,51 | 0,53 | |
| 17_J | Ba | R. stylosa | R | 17R`JR1 | 0,56 | 0,57 | 0,48 |
| 17_J | Ba | R. stylosa | R | 17R`JR10 | 0,67 | 0,67 | |
| 17_J | Ba | R. stylosa | R | 17R`JR2 | 0,60 | 0,61 | 0,57 |
| 17_J | Ba | R. stylosa | R | 17R`JR6 | 0,66 | 0,66 | 0,62 |
| 17_K | Ba | R. stylosa | R | 17R`KR2 | 0,40 | 0,42 | 0,31 |
| 17_K | Ba | R. stylosa | R | 17R`KR4 | 0,40 | 0,40 | 0,34 |
| 17_K | Ba | R. stylosa | R | 17R`KR3+5+7+8+9+10 | 0,39 | 0,39 | |
| 17_K | Ba | R. stylosa | R | 17R`KR6 | 0,90 | 0,94 | 0,67 |
| 80_F | Ba | R. stylosa | R | 80R'FR5 | 0,38 | 0,38 | 0,32 |
| 80_F | Ba | R. stylosa | R | 80R'FR7 | 0,49 | 0,50 | |
| 80_F | Ba | R. stylosa | R | 80R'FR3 | 0,55 | 0,56 | |
| 80_F | Ba | R. stylosa | R | 80R'FR4 | 0,55 | 0,56 | |
| 80_F | Ba | R. stylosa | R | 80R'FR9 | 0,58 | 0,62 | |
| 80_F | Ba | R. stylosa | R | 80R'FR6 | 0,64 | 0,65 | |
| 80_F | Ba | R. stylosa | R | 80R'FR1 | 0,79 | 0,79 | |
| 80_F | Ba | R. stylosa | R | 80R'FR8 | 0,74 | 0,76 | |
| 80_F | Ba | R. stylosa | R | 80R'FR2 | 0,84 | 0,87 | 0,71 |
| 80_G | Ba | R. stylosa | R | 80R'GR_all | 0,51 | 0,53 | |
| 80_H | Ba | R. stylosa | R | 80R'HR_all | 0,59 | 0,60 | |
| 135_R | Ba | R. stylosa | R | 135R'RR4 | 0,82 | 0,82 | 0,51 |
| 135_R | Ba | R. stylosa | R | 135R'RR3+5+9+10 | 0,49 | 0,50 | |
| 135_R | Ba | R. stylosa | R | 135R'RR2+6+8 | 0,45 | 0,46 | |
| 135_R | Ba | R. stylosa | R | 135R'RR1 | 0,61 | 0,61 | 0,50 |
| 135_S | Ba | R. stylosa | R | 135R'SR4 | 0,57 | 0,59 | 0,38 |
| 135_S | Ba | R. stylosa | R | 135R'SR1+3+2+7+8+6 | 0,46 | 0,46 | |
| 135_S | Ba | R. stylosa | R | 135R'SR5 | 0,67 | 0,68 | 0,61 |
| 9_M | Ba | R. stylosa | T | 9R'MT1+2+3+4+6+7+9 | 0,65 | 0,72 | |
| 9_M | Ba | R. stylosa | T | 9R'MT5 | 0,75 | 0,76 | 0,65 |
| 9_M | Ba | R. stylosa | T | 9R'MT8 | 0,82 | 0,84 | 0,63 |
| 9_N | Ba | R. stylosa | T | 9R'NT7 | 0,73 | 0,73 | |
| 9_N | Ba | R. stylosa | T | 9R'NT2 | 0,75 | 0,74 | |
| 9_N | Ba | R. stylosa | T | 9R'NT5 | 0,78 | 0,79 | |
| 9_N | Ba | R. stylosa | T | 9R'NT4 | 0,77 | 0,78 | 0,70 |
| 9_N | Ba | R. stylosa | T | 9R'NT3 | 0,79 | 0,81 | |
| 9_N | Ba | R. stylosa | T | 9R'NT1 | 0,81 | 0,83 | 0,77 |
| 9_N | Ba | R. stylosa | T | 9R'NT6 | 0,84 | 0,86 | |
| 9_O | Ba | R. stylosa | T | 9R'OT4+2+3+1 | 0,71 | 0,74 | |
| 9_O | Ba | R. stylosa | T | 9R'OT9 | 0,83 | 0,85 | 0,70 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 9_O | Ba | R. stylosa | T | 9R'OT7 | 0,87 | 0,90 | 0,78 |
| 9_O | Ba | R. stylosa | T | 9R'OT5+6+8 | 0,76 | 0,78 | |
| 9_P | Ba | R. stylosa | T | 9R'PT2 | 0,75 | 0,77 | 0,71 |
| 9_P | Ba | R. stylosa | T | 9R'PT1+4+7+8 | 0,78 | 0,79 | |
| 9_P | Ba | R. stylosa | T | 9R'PT5 | 0,89 | 0,90 | 0,70 |
| 9_P | Ba | R. stylosa | T | 9R'PT3+9+6 | 0,80 | 0,82 | |
| 17_J | Ba | R. stylosa | T | 17R'JT7 | 0,77 | 0,79 | |
| 17_J | Ba | R. stylosa | T | 17R'JT6 | 0,82 | 0,84 | 0,69 |
| 17_J | Ba | R. stylosa | T | 17R'JT5 | 0,78 | 0,80 | |
| 17_J | Ba | R. stylosa | T | 17R'JT2 | 0,77 | 0,78 | 0,79 |
| 17_J | Ba | R. stylosa | T | 17R'JT3 | 0,80 | 0,83 | 0,75 |
| 17_J | Ba | R. stylosa | T | 17R'JT1 | 0,76 | 0,77 | 0,75 |
| 17_J | Ba | R. stylosa | T | 17R'JT8 | 0,83 | 0,86 | |
| 17_J | Ba | R. stylosa | T | 17R'JT4 | 0,85 | 0,88 | |
| 17_K | Ba | R. stylosa | T | 17R`KT4+9+7+10 | 0,73 | 0,74 | |
| 17_K | Ba | R. stylosa | T | 17R`KT2+5+6 | 0,77 | 0,79 | |
| 17_K | Ba | R. stylosa | T | 17R`KT8 | 0,93 | 0,95 | 0,80 |
| 17_K | Ba | R. stylosa | T | 17R`KT1 | 0,84 | 0,85 | 0,81 |
| 17_K | Ba | R. stylosa | T | 17R`KT3 | 0,87 | 0,88 | 0,77 |
| 80_G | Ba | R. stylosa | T | 80R'GT_all | 0,86 | 0,87 | |
| 80_H | Ba | R. stylosa | T | 80R'HT_all | 0,77 | 0,79 | |
| 80_F | Ba | R. stylosa | T | 80R'FT5 | 0,78 | 0,79 | |
| 80_F | Ba | R. stylosa | T | 80R'FT2 | 0,73 | 0,75 | |
| 80_F | Ba | R. stylosa | T | 80R'FT3 | 0,76 | 0,79 | |
| 80_F | Ba | R. stylosa | T | 80R'FT7 | 0,78 | 0,83 | |
| 80_F | Ba | R. stylosa | T | 80R'FT4 | 0,75 | 0,76 | 0,80 |
| 80_F | Ba | R. stylosa | T | 80R'FT1 | 0,81 | 0,83 | 0,83 |
| 80_F | Ba | R. stylosa | T | 80R'FT6 | 0,87 | 0,90 | |
| 135_R | Ba | R. stylosa | T | 135R'RT5 | 0,96 | 0,98 | 0,66 |
| 135_R | Ba | R. stylosa | T | 135R'RT1+2+3+6+7 | 0,71 | 0,72 | |
| 135_R | Ba | R. stylosa | T | 135R'RT4 | 0,85 | 0,85 | 0,69 |
| 135_S | Ba | R. stylosa | T | 135R'ST5 | 0,72 | 0,73 | 0,63 |
| 135_S | Ba | R. stylosa | T | 135R'ST2+3+4+6 | 0,69 | 0,71 | |
| 135_S | Ba | R. stylosa | T | 135R'ST1 | 0,77 | 0,78 | 0,75 |

| plot | location | Tree_species | Segment | Sample | Density_W1 [g/cm³] | Density_W2 [g/cm³] | Density_S [g/cm³] |
|---|---|---|---|---|---|---|---|
| 17_I | Ba | R.selala | C | 17R'IC8 | 0,79 | 0,82 | |
| 17_I | Ba | R.selala | C | 17R'IC7 | 0,82 | 0,84 | 0,77 |
| 17_I | Ba | R.selala | C | 17R'IC2 | 1,00 | 1,04 | |
| 17_I | Ba | R.selala | C | 17R'IC1 | 0,87 | 0,92 | |
| 17_I | Ba | R.selala | C | 17R'IC3 | 1,12 | 1,12 | 0,79 |
| 17_I | Ba | R.selala | C | 17R'IC4 | 0,85 | 0,88 | |
| 17_I | Ba | R.selala | C | 17R'IC6 | 0,88 | 0,89 | 0,76 |
| 17_I | Ba | R.selala | C | 17R'IC5 | 0,87 | 0,89 | 0,80 |
| 17_L | Ba | R.selala | C | 17R'LC2 | 0,73 | 0,75 | |
| 17_L | Ba | R.selala | C | 17R'LC1 | 0,74 | 0,76 | 0,65 |
| 17_L | Ba | R.selala | C | 17R'LC4+5+6+7+10 | 0,86 | 0,91 | |
| 17_L | Ba | R.selala | C | 17R`LC8 | 0,82 | 0,84 | 0,72 |
| 17_L | Ba | R.selala | C | 17R`LC9 | 0,86 | 0,87 | |
| 17_L | Ba | R.selala | C | 17R'LC3 | 0,89 | 0,90 | 0,69 |
| 80_E | Ba | R.selala | C | 80R'Ecall | 0,71 | 0,74 | |
| 135_Q | Ba | R.selala | C | 135R'QC1+3+5+6+9+10 | 0,72 | 0,73 | |
| 135_Q | Ba | R.selala | C | 135R'QC8 | 0,88 | 0,91 | |
| 135_Q | Ba | R.selala | C | 135R'QC2 | 0,86 | 0,88 | |
| 135_Q | Ba | R.selala | C | 135R'QC4 | 0,84 | 0,88 | 0,72 |
| 135_Q | Ba | R.selala | C | 135R'QC7 | 0,82 | 0,79 | 0,80 |
| 165_D | Ba | R.selala | C | 165R'DC4 | 0,67 | 0,74 | 0,83 |
| 165_D | Ba | R.selala | C | 165R'DC3 | 0,53 | 0,57 | 0,82 |
| 165_D | Ba | R.selala | C | 165R'DC2 | 1,00 | 1,05 | 0,89 |
| 165_D | Ba | R.selala | C | 165R'DC1 | 0,79 | 0,81 | 0,80 |
| 165_D | Ba | R.selala | C | 165R'DC5 | 0,78 | 0,79 | 0,93 |
| 165_D | Ba | R.selala | C | 165R'DC6 | 0,79 | 0,83 | 0,86 |
| 17_I | Ba | R.selala | R | 17R'IR3 | 0,29 | 0,30 | 0,32 |
| 17_I | Ba | R.selala | R | 17R'IR5 | 0,26 | 0,27 | 0,29 |
| 17_I | Ba | R.selala | R | 17R'IR2 | 0,34 | 0,35 | 0,38 |
| 17_I | Ba | R.selala | R | 17R'IR9 | 0,49 | 0,52 | |
| 17_I | Ba | R.selala | R | 17R'IR1 | 0,70 | 0,76 | 0,56 |
| 17_I | Ba | R.selala | R | 17R'IR6 | 0,73 | 0,75 | 0,56 |
| 17_I | Ba | R.selala | R | 17R'IR7 | 0,72 | 0,75 | |
| 17_I | Ba | R.selala | R | 17R'IR10 | 0,72 | 0,73 | 0,73 |
| 17_I | Ba | R.selala | R | 17R'IR8 | 0,87 | 0,90 | |
| 17_I | Ba | R.selala | R | 17R'IR4 | 0,95 | 0,97 | |
| 17_L | Ba | R.selala | R | 17R`LR4 | 0,47 | 0,49 | 0,41 |
| 17_L | Ba | R.selala | R | 17R`LR10 | 0,71 | 0,73 | 0,44 |
| 17_L | Ba | R.selala | R | 17R`LR1+2+3+7+9+11 | 0,57 | 0,58 | |
| 17_L | Ba | R.selala | R | 17R`LR8 | 0,74 | 0,76 | |
| 17_L | Ba | R.selala | R | 17R`LR6 | 0,79 | 0,80 | 0,65 |
| 80_E | Ba | R.selala | R | 80R'ER5+7+10 | 0,33 | 0,32 | |
| 80_E | Ba | R.selala | R | 80R'ER9 | 0,32 | 0,31 | |
| 80_E | Ba | R.selala | R | 80R'ER1 | 0,46 | 0,46 | |
| 80_E | Ba | R.selala | R | 80R'ER4 | 0,61 | 0,62 | 0,53 |
| 80_E | Ba | R.selala | R | 80R'ER13 | 0,73 | 0,72 | |
| 80_E | Ba | R.selala | R | 80R'ER2 | 0,73 | 0,72 | |
| 80_E | Ba | R.selala | R | 80R'ER3 | 0,79 | 0,82 | 0,73 |
| 80_E | Ba | R.selala | R | 80R'ER11 | 0,73 | 0,70 | |
| 80_E | Ba | R.selala | R | 80R'ER12 | 0,85 | 0,85 | |
| 80_E | Ba | R.selala | R | 80R'ER6+8 | 0,76 | 0,74 | |
| 135_Q | Ba | R.selala | R | 135R'QR5+6+7+8+9+10 | 0,53 | 0,53 | |
| 135_Q | Ba | R.selala | R | 135R'QR4 | 0,70 | 0,70 | |
| 135_Q | Ba | R.selala | R | 135R'QR3 | 0,71 | 0,72 | 0,63 |
| 135_Q | Ba | R.selala | R | 135R'QR2 | 0,79 | 0,80 | |
| 135_Q | Ba | R.selala | R | 135R'QR1 | 0,81 | 0,81 | 0,77 |
| 135_T | Ba | R.selala | R | 135R'TR8 | 0,86 | 0,90 | 0,47 |
| 135_T | Ba | R.selala | R | 135R'TR1+3+4+5+6+7+9+10 | 0,50 | 0,50 | |
| 135_T | Ba | R.selala | R | 135R'TR2 | 0,62 | 0,62 | 0,51 |
| 165_D | Ba | R.selala | R | 165R'DR_all | 0,53 | 0,54 | |
| 165_D | Ba | R.selala | R | 165R'DR3 | 0,46 | 0,47 | |
| 165_D | Ba | R.selala | R | 165R'DR3 | 0,53 | 0,54 | |
| 165_D | Ba | R.selala | R | 165R'DR3 | 0,49 | 0,50 | |
| 17_I | Ba | R.selala | T | 17R'IT1 | 0,77 | 0,77 | |
| 17_I | Ba | R.selala | T | 17R'IT4+5 | 0,81 | 0,81 | |
| 17_I | Ba | R.selala | T | 17R'IT3 | 0,86 | 0,88 | 0,81 |
| 17_I | Ba | R.selala | T | 17R'IT2 | 0,95 | 0,96 | 0,82 |
| 17_L | Ba | R.selala | T | 17R'LT9 | 0,80 | 0,82 | |
| 17_L | Ba | R.selala | T | 17R'LT5 | 0,82 | 0,85 | 0,74 |
| 17_L | Ba | R.selala | T | 17R'LT1 | 0,81 | 0,82 | 0,78 |
| 17_L | Ba | R.selala | T | 17R'LT10 | 0,80 | 0,81 | 0,73 |
| 17_L | Ba | R.selala | T | 17R'LT6 | 0,83 | 0,84 | 0,76 |
| 17_L | Ba | R.selala | T | 17R'LT8 | 0,82 | 0,83 | |
| 17_L | Ba | R.selala | T | 17R'LT11 | 0,83 | 0,84 | 0,77 |
| 17_L | Ba | R.selala | T | 17R'LT7 | 0,80 | 0,81 | 0,77 |
| 17_L | Ba | R.selala | T | 17R'LT3 | 0,83 | 0,84 | 0,77 |
| 17_L | Ba | R.selala | T | 17R'LT4 | 0,81 | 0,82 | 0,80 |
| 17_L | Ba | R.selala | T | 17R'LT2 | 0,80 | 0,80 | 0,77 |
| 80_E | Ba | R.selala | T | 80R'ET8 | 0,63 | 0,64 | 0,61 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 80_E | Ba | R.selala | T | 80R'ET7 | 0,67 | 0,67 | |
| 80_E | Ba | R.selala | T | 80R'ET6 | 0,77 | 0,80 | |
| 80_E | Ba | R.selala | T | 80R'ET5 | 0,77 | 0,78 | |
| 80_E | Ba | R.selala | T | 80R'ET4 | 0,76 | 0,78 | |
| 80_E | Ba | R.selala | T | 80R'ET3 | 0,94 | 0,97 | |
| 80_E | Ba | R.selala | T | 80R'ET2 | 0,94 | 0,96 | 0,84 |
| 80_E | Ba | R.selala | T | 80R'ET1 | 0,81 | 0,82 | |
| 135_Q | Ba | R.selala | T | 135R'QT5 | 0,84 | 0,85 | |
| 135_Q | Ba | R.selala | T | 135R'QT4 | 0,82 | 0,82 | 0,80 |
| 135_Q | Ba | R.selala | T | 135R'QT6 | 0,84 | 0,85 | |
| 135_Q | Ba | R.selala | T | 135R'QT7 | 0,81 | 0,82 | 0,79 |
| 135_Q | Ba | R.selala | T | 135R'QT8 | 0,82 | 0,83 | |
| 135_Q | Ba | R.selala | T | 135R'QT3 | 0,85 | 0,86 | |
| 135_Q | Ba | R.selala | T | 135R'QT1 | 0,84 | 0,85 | |
| 135_Q | Ba | R.selala | T | 135R'QT2 | 0,83 | 0,83 | |
| 135_T | Ba | R.selala | T | 135R'TT1 | 0,80 | 0,81 | 0,71 |
| 135_T | Ba | R.selala | T | 135R'TT3+4+5+6 | 0,73 | 0,75 | |
| 135_T | Ba | R.selala | T | 135R'TT2 | 0,75 | 0,76 | 0,72 |
| 165_D | Ba | R.selala | T | 165R`DT7 | 0,79 | 0,80 | 0,87 |
| 165_D | Ba | R.selala | T | 165R'DT5 | 0,79 | 0,80 | 0,77 |
| 165_D | Ba | R.selala | T | 165R'DT_half | 0,99 | 1,00 | |
| 165_D | Ba | R.selala | T | 165R'DT4 | 0,77 | 0,78 | 0,86 |
| 165_D | Ba | R.selala | T | 165R'DT6 | 0,83 | 0,84 | 0,73 |

| plot | location | Tree_species | Segment | Sample | Density_W1 [g/cm³] | Density_W2 [g/cm³] | Density_S [g/cm³] |
|---|---|---|---|---|---|---|---|
| 165_B | Ba | R. samoensis | C | 165R'BC 1+2+3+4 | 0,48 | 0,50 | |
| 165_B | Ba | R. samoensis | R | 165R'BR2 | 0,46 | 0,47 | 0,33 |
| 165_B | Ba | R. samoensis | R | 165R'BR1-7 | 0,36 | 0,37 | |
| 165_B | Ba | R. samoensis | R | 165R'BR7-11 | 0,61 | 0,60 | |
| 165_B | Ba | R. samoensis | R | 165R'BR8 | 0,76 | 0,79 | 0,51 |
| 165_B | Ba | R. samoensis | T | 165R'BT2 | 0,67 | 0,68 | 0,50 |
| 165_B | Ba | R. samoensis | T | 165R'BT4 | 0,73 | 0,74 | |
| 165_B | Ba | R. samoensis | T | 165R'BT5 | 0,71 | 0,72 | 0,65 |
| 165_B | Ba | R. samoensis | T | 165R'BT3 | 0,71 | 0,74 | |
| 165_B | Ba | R. samoensis | T | 165R'BT1 | 0,71 | 0,72 | |

Kiln dry density determination for all samples analysed

| Plot | Location | Tree_species | Segment | Sample no. | Density_W1 [g/cm³] | Density_W2 [g/cm³] | Density_S [g/cm³] |
|---|---|---|---|---|---|---|---|
| 190_R | REWA | R.selala | R | 190RDR1+2+3+4+5+6 | 0,77 | 0,85 | |
| 190_R | REWA | R.selala | R | 190RDR7+8+9 | 0,86 | 0,92 | |
| 190_R | REWA | R.selala | R | 190RDR10+11 | 0,88 | 0,94 | |
| 190_C | REWA | R.selala | C | 190RAC5 | 1,03 | 1,07 | 0,7 |
| 190_C | REWA | R.selala | C | 190RAC4 | 0,98 | 1,00 | 0,9 |
| 240_C | REWA | R.stylosa | C | 240REC3+4 | 0,94 | 0,99 | |
| 240_C | REWA | R.stylosa | C | 240REC5 | 0,99 | 1,04 | |
| 240_C | REWA | R.stylosa | C | 240REC1+2 | 1,06 | 1,16 | |
| 240_C | REWA | R.stylosa | C | 240RFC1bis11 | 0,83 | 0,90 | |
| 190_T | REWA | R.selala | T | 190RAT1 | 1,02 | 1,06 | 1,0 |
| 190_T | REWA | R.selala | T | 190RAT5 | 0,78 | 0,83 | 0,9 |
| 190_T | REWA | R.selala | T | 190RAT2 | 1,22 | 1,25 | 1,1 |
| 190_T | REWA | R. stylosa | T | 190RCT6 | 0,93 | 0,89 | |
| 190_T | REWA | R. stylosa | T | 190RCT5 | 0,94 | 1,05 | |
| 190_T | REWA | R.selala | T | 190RDT10 | 1,04 | 1,13 | |
| 190_T | REWA | R.selala | T | 190RDT2 | 0,91 | 0,95 | |
| 190_T | REWA | R.selala | T | 190RDT4 | 0,95 | 1,02 | |
| 190_T | REWA | R.selala | T | 190RDT8+9 | 1,00 | 1,05 | |
| 190_T | REWA | R.selala | T | 190RDT6 | 0,97 | 1,02 | |
| 190_T | REWA | R.selala | T | 190RDT1 | 0,97 | 1,02 | |
| 190_T | REWA | R.selala | T | 190RDT3 | 1,03 | 1,09 | |
| 190_T | REWA | R.selala | T | 190RDT5 | 0,93 | 0,96 | |
| 190_T | REWA | R.selala | T | 190RDT7 | 1,10 | 1,15 | |
| 240_T | REWA | R.stylosa | T | 240RET1+2+3+4+5 | 0,81 | 0,88 | |
| 240_T | REWA | R.stylosa | T | 240RET8 | 0,94 | 0,98 | |
| 240_T | REWA | R.stylosa | T | 240RET6 | 1,03 | 1,06 | |
| 240_T | REWA | R.stylosa | T | 240RET7 | 1,00 | 1,05 | |
| 141_R | REWA | R.selala | R | 141RQR1+4+5 | 0,83 | 0,89 | |
| 141_R | REWA | R.selala | R | 141RQR2+3+6 | 0,85 | 0,93 | |
| 141_R | REWA | R.selala | R | 141RQR8 | 1,11 | 1,18 | |
| 141_T | REWA | R.selala | T | 141RQT1 | 1,02 | 1,09 | |
| 141_T | REWA | R.selala | T | 141RQT2 | 1,02 | 1,09 | |
| 141_T | REWA | R.selala | T | 141RQT3 | 1,06 | 1,12 | |
| 141_R | REWA | R.selala | R | 141RTR1+3+4 | 1,06 | 1,13 | |

Analysis of Variance

The analysis of variance was conducted with the R studio version 3.4.3 (2017-11-30). An analysis of variance (ANOVA) is used to test the extent to which there are statistically significant differences between factors in a dependent variable. And its average effect among each other.

The two-factorial analysis of variance considers two factors to explain the objective variables (Factor A and Factor B). In the analyses carried out, the variables were analysed in relation to Factor A= the locations (Ba and Rewa) and Factor B= plots.

```
Significant codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

**Water content (all *Rhizophora* species) for tracts starting from Waterfront:**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0,5660513 | 0,001163 ** | 0,16109 | 0,4923 |
| Plot | 0,0003475 *** | 0,022775 * | 0,01603 * | 0,3532 |
| Plot/ Location | 0,1712126 | 0,612197 | 0,74848 | 0,1833 |
| Location / Plot | 0,1712126 | 0,612197 | 0,74848 | 0,1833 |

**Water content (all *Rhizophora* species) for all tracts (including tract 240 & 165’):**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0.0361155 * | 0.9466 | 0.03269 * | 0.508729 |
| Plot | 0.0001898 *** | 7.077e-07 *** | 0.02827 * | 0.006773 ** |
| Plot/ Location | 0.06912 . | 0.0001211 *** | 0.77798 | 0.047652 * |
| Location / Plot | 0.0691203 . | 0.0001211 *** | 0.77798 | 0.047652 * |

**Water content (*Rhizophora selala*) for tracts starting from Waterfront:**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0.20122 | 0.09314 . | 0.1348 | 0.05526 . |
| Plot | 0.04783 * | 0.08789 | 0.9215 | 0.24662 |
| Plot/ Location | 0.23244 | 0.46690 | 0.2340 | 0.68070 |
| Location / Plot | 0.2324 | 0.46690 | 0.2340 | 0.68070 |

**Water content (*Rhizophora selala*) for all tracts (including tract 240 & 165'):**

| | All Segments | Trunk | Root | Crown |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0.1180 | 0.1828 | 0.1273 | 0.07565 . |
| Plot | 0.1121 | 0.0682 . | 0.9714 | 0.50367 |
| Plot/ Location | 0.2243 | 0.4514 | 0.015093 * | 0.70025 |
| Location/ Plot | 0.22430 | 0.45139 | 0.015093 * | 0.7003 |

**Water content (*Rhizophora stylosa*) for tracts starting from Waterfront:**

| | All Segments | Trunk | Root | Crown |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0.5535 | 0.08886 . | 0.33095 | 0.02527 * |
| Plot | 0.2959 | 0.55919 | 0.03124 * | 0.53382 |
| Plot/ Location | - | - | – | – |
| Location/ Plot | - | - | – | - |

**Water content (*Rhizophora stylosa*) for all tracts (including tract 240 & 165'):**

| | All Segments | Trunk | Root | Crown |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Location | 0.2119 | 0.002114 ** | 0.25183 | 0.92711 |
| Plot | 0.4041 | 0.009707 ** | 0.05974 . | 0.06179 . |
| Plot/ Location | - | - | - | - |
| Location/ Plot | - | - | - | - |

**Water content (Analyses of variance of *Rhizophora* species in relation to water content) for tracts starting from Waterfront:**

| | All Segments |
|---|---|
| | P-value |
| Location | 0.958 |
| Species | 3.996e-05 *** |
| Species/ Location | 0.7928 |
| Location/ Species | 0.7927575 |

**Water content (Analyses of variance of *Rhizophora* species in relation to water content) for all tracts:**

| | **All Segments** |
|---|---|
| | P-value |
| Location | 0.1471 |
| Species | 6.371e-10 *** |
| Species/ Location | 0.4329 |
| Location/ Species | 0.4329 |

**Density Method W_1[15] (all *Rhizophora* species) for tracts starting from waterfront:**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Plot | 0.3016 | 0.885 | 0.885 | 0.2093 |

**Density Method W_1 (all *Rhizophora* species) for all tracts (including tract 240 & 165'):**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Plot | 0.4772 | 0.03644 * | 0.4482 | 0.08366 . |

**Density Method W_1 (Analyses of variance of *Rhizophora* species in relation to density) for tracts starting from Waterfront:**

| | **All Segments** |
|---|---|
| | P-value |
| Species | 0.01981 * |

**Density Method W_1 (Analyses of variance of *Rhizophora* species in relation to density) for all tracts:**

| | **All Segments** |
|---|---|
| | P-value |
| Species | 0.05382 . |

**Density Method S[16] (all *Rhizophora* species) for tracts starting from Waterfront:**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Plot | 0.513 | 0.5091 | 0.8721 | 0.02939 * |

[15] Method_W1 = Volume determination by the immersion test
[16] Method_S = Volume determination measured by hand with the caliper

**Density Method S (all *Rhizophora* species) for all tracts (including tract 240 & 165'):**

| | **All Segments** | **Trunk** | **Root** | **Crown** |
|---|---|---|---|---|
| | P-value | P-value | P-value | P-value |
| Plot | 0.1238 | 0.0135 * | 0.9023 | 0.000151 *** |

**Density Method S (Analyses of variance of Rhizophora species in relation to density) for tracts starting from Waterfront:**

| | **All Segments** |
|---|---|
| | P-value |
| Species | 0.513 |

**Density Method S (Analyses of variance of *Rhizophora* species in relation to density) for all tracts:**

| | **All Segments** |
|---|---|
| | P-value |
| Species | 0.1238 |

**Biomass for tracts starting from Waterfront:**

| | ***R. selala & R. stylosa & R.samoensis*** | ***R. selala*** | ***R. stylosa*** |
|---|---|---|---|
| | P-value | P-value | P-value |
| Location | 0.1910 | 0.7878 | 0.003448 ** |
| Plot | 0.3995 | 0.4245 | 0.603616 |
| Plot/ Location | 0.5053 | 0.5033 | 0.458321 |
| Location/ Plot | 0.5053 | 0.5033 | 0.45832 |

**Biomass for all tracts:**

| | ***R. selala & R. stylosa & R.samoensis*** | ***R. selala*** | ***R. stylosa*** |
|---|---|---|---|
| | P-value | P-value | P-value |
| Location | 0.5785 | 0.8475 | 0.12622 |
| Plot | 0.4819 | 0.5829 | 0.06394 . |
| Plot/ Location | 0.5875 | 0.5033 | 0.45832 |
| Location/ Plot | 0.5875 | 0.5033 | 0.45832 |

**Height:**

| | **tracts starting from waterfront** | **All tracts** |
|---|---|---|
| | P-value | P-value |
| Location | 0.003378 ** | 0.003378 ** |
| Plot | 0.283507 | 0.283507 |
| Plot / location | 0.100608 | 0.1900589 |
| Location/ plot | 0.100608 | 0.190059 |

## Extrapolation

### Extrapolation of AGB (including deadwood) in Rewa

| Plot | Tree | u | C | AGB green | Mean [kg/plot] | AGB kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGB green | Mean [kg/ha] | AGB kiln dry | Mean [kg/ha] | AGB mean green | SD AGB green | SE AGB green | Ci below value | Ci above value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD | [Mg/ha] | | | | |
| 190_A | R. selala | 0,40 | 0,47 | 588,01 | 472,88 | 350,81 | 273,59 | 185,12 | 144,32 | 205689,49 | 160350,95 | 653343,79 | 525424,47 | 389784,91 | 303985,68 | 188,11 | 181,60 | 81,21 | 25,69 | 350,54 |
| 190_B | R. stylosa | 0,45 | 0,47 | 380,05 | 77,91 | 210,70 | 53,99 | 111,08 | 28,54 | 123423,09 | 31714,51 | 422277,36 | 86563,84 | 234110,57 | 59993,39 | | | | | |
| | | | | | | | | | | | | | | | | AGB mean_dry [Mg/ha] | SD AGB dry | SE AGB dry | | |
| 190_C | R. stylosa | 0,45 | 0,47 | 428,89 | | 237,78 | | 125,36 | | 139284,12 | | 476543,97 | | 264195,98 | | | | | | |
| 190_D | R. selala | 0,40 | 0,47 | 494,58 | | 295,07 | | 155,71 | | 173007,11 | | 549532,78 | | 327851,26 | | | | | | |
| | | | | | | | | | | | | | | | | 109,25 | 105,20 | 47,05 | 15,16 | 203,34 |
| 240_E | R. stylosa | 0,45 | 0,47 | 32,62 | 115,88 | 18,08 | 64,24 | 9,53 | 33,87 | 10593,50 | 37630,97 | 36244,41 | 128749,87 | 20093,90 | 71378,93 | | | | | |
| 240_F | R. stylosa | 0,45 | 0,47 | 176,84 | 76,40 | 98,04 | 42,36 | 51,69 | 22,33 | 57429,65 | 24812,49 | 196488,69 | 84892,96 | 108933,33 | 47064,66 | | | | | |
| 240_G | R. stylosa | 0,45 | 0,47 | 205,93 | | 114,17 | | 60,19 | | 66876,77 | | 228810,88 | | 126852,75 | | Mean_C | | | | |
| 240_H | R. stylosa | 0,45 | 0,47 | 48,11 | | 26,67 | | 14,06 | | 15623,96 | | 53455,50 | | 29635,73 | | [Mg/ha] | SD_C | SE_C | | |
| | | | | | | | | | | | | | | | | 57,63 | 55,49 | 24,82 | 8,00 | 107,26 |
| 30_I | non | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | | | | |
| 30_J | non | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | | | | |
| 30_K | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 30_L | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 57_M | R. selala | 0,40 | 0,47 | 745,51 | 186,38 | 444,77 | 111,19 | 234,71 | 58,68 | 260783,96 | 65195,99 | 828343,62 | 207085,90 | 494189,80 | 123547,45 | | | | | |
| 57_N | non | 0,00 | 0,00 | 0,00 | 322,82 | 0,00 | 192,59 | 0,00 | 101,63 | 0,00 | 112922,77 | 0,00 | 358683,31 | 0,00 | 213990,46 | | | | | |
| 57_O | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 57_P | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 141_Q | R. selala | 0,40 | 0,47 | 50,19 | 71,38 | 29,94 | 42,59 | 15,80 | 22,47 | 17556,77 | 24970,04 | 55766,61 | 79313,81 | 33270,36 | 47318,62 | | | | | |
| 141_R | non | 0,00 | 0,00 | 0,00 | 96,85 | 0,00 | 57,78 | 0,00 | 30,49 | 0,00 | 33879,81 | 0,00 | 107614,47 | 0,00 | 64202,79 | | | | | |
| 141_S | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 141_T | R. selala | 0,40 | 0,47 | 235,34 | | 140,40 | | 74,09 | | 82323,37 | | 261488,63 | | 156004,12 | | | | | | |

Extrapolation of AGB (including deadwood) in Ba

| Plot | Tree | u | C | AGB green | Mean [kg/plot] | AGB kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGB green | Mean [kg/ha] | AGB kiln dry | Mean [kg/ha] | AGB mean green | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD | [Mg/ha] | SD AGB green | SE AGB green | Ci below value | Ci above value |
| 165_A | non | 0,00 | 0,00 | 0,00 | 108,83 | 0,00 | 61,26 | 0,00 | 32,26 | 0,00 | 35844,61 | 0,00 | 120922,10 | 0,00 | 68069,90 | 241,54 | 115,93 | 51,85 | 137,85 | 345,23 |
| 165_B | R. Samoens | 0,50 | 0,48 | 151,76 | 118,39 | 75,88 | 69,58 | 39,77 | 36,70 | 44187,41 | 40780,03 | 168622,05 | 131540,47 | 84311,03 | 77308,62 | | | | | |
| 165_C | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | AGB mean_dry | | | | |
| 165_D | R. selala | 0,40 | 0,47 | 283,56 | | 169,17 | | 89,27 | | 99191,02 | | 315066,35 | | 187968,59 | | [Mg/ha] | SD AGB dry | SE AGB dry | | |
| | | | | | | | | | | | | | | | | 139,01 | 68,83 | 30,78 | 77,45 | 200,57 |
| 80_E | R. Selala | 0,40 | 0,47 | 614,34 | 223,83 | 366,52 | 130,57 | 193,41 | 68,88 | 214899,89 | 76536,57 | 682599,32 | 248696,97 | 407238,75 | 145079,02 | | | | | |
| 80_F | R. stylosa | 0,45 | 0,47 | 135,31 | 226,90 | 75,02 | 136,95 | 39,55 | 72,28 | 43942,58 | 80312,52 | 150344,29 | 252112,00 | 83350,88 | 152171,51 | Mean_C | | | | |
| 80_G | R. stylosa | 0,45 | 0,47 | 72,35 | | 40,11 | | 21,15 | | 23496,02 | | 80388,81 | | 44567,56 | | [Mg/ha] | SD_C | SE_C | | |
| 80_H | R. stylosa | 0,45 | 0,47 | 73,31 | | 40,64 | | 21,43 | | 23807,78 | | 81455,47 | | 45158,91 | | 73,31 | 36,33 | 16,25 | 40,82 | 105,81 |
| 17_I | R. Selala | 0,40 | 0,47 | 822,88 | 412,95 | 490,93 | 240,96 | 259,06 | 127,12 | 287848,46 | 141244,07 | 914310,20 | 458827,32 | 545477,46 | 267734,49 | | | | | |
| 17_J | R. stylosa | 0,45 | 0,47 | 310,05 | 241,03 | 171,89 | 147,13 | 90,62 | 77,66 | 100690,25 | 86291,91 | 344499,66 | 267807,08 | 190990,61 | 163477,46 | | | | | |
| 17_K | R. stylosa | 0,45 | 0,47 | 201,96 | | 111,97 | | 59,03 | | 65587,49 | | 224399,78 | | 124407,24 | | | | | | |
| 17_L | R. selala | 0,40 | 0,47 | 316,89 | | 189,06 | | 99,77 | | 110850,06 | | 352099,65 | | 210062,65 | | | | | | |
| 9_M | R. stylosa | 0,45 | 0,47 | 107,74 | 170,48 | 59,73 | 94,51 | 31,49 | 49,83 | 34989,09 | 55363,40 | 119710,99 | 189419,26 | 66367,77 | 105014,03 | | | | | |
| 9_N | R. stylosa | 0,45 | 0,47 | 247,02 | 51,60 | 136,95 | 28,61 | 72,20 | 15,08 | 80220,95 | 16758,51 | 274466,39 | 57337,23 | 152164,17 | 31787,76 | | | | | |
| 9_O | R. stylosa | 0,45 | 0,47 | 144,06 | | 79,87 | | 42,11 | | 46784,19 | | 160066,51 | | 88740,87 | | | | | | |
| 9_P | R. stylosa | 0,45 | 0,47 | 183,09 | | 101,51 | | 53,51 | | 59459,37 | | 203433,13 | | 112783,33 | | | | | | |
| 135_Q | R. Selala | 0,40 | 0,47 | 333,05 | 170,85 | 198,70 | 98,23 | 104,85 | 51,81 | 116502,93 | 57571,01 | 370055,19 | 189835,92 | 220774,92 | 109149,12 | | | | | |
| 135_R | R. stylosa | 0,45 | 0,47 | 129,66 | 95,44 | 71,88 | 58,89 | 37,90 | 31,09 | 42107,72 | 34545,01 | 144066,52 | 106038,84 | 79870,48 | 65436,14 | | | | | |
| 135_S | R. stylosa | 0,45 | 0,47 | 86,84 | | 48,14 | | 25,38 | | 28201,71 | | 96488,79 | | 53493,39 | | | | | | |
| 135_T | R. stylosa | 0,45 | 0,47 | 133,86 | | 74,21 | | 39,12 | | 43471,69 | | 148733,18 | | 82457,68 | | | | | | |

Extrapolation of AGL (excluding deadwood) in Rewa

| Plot | Tree | u | C | AGL green | Mean [kg/plot] | AGL kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGL green | Mean [kg/ha] | AGL kiln dry | Mean [kg/ha] | AGL mean green | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD | [Mg/ha] | SD AGL green | SE AGL green | Ci below value | Ci above value |
| 190_A | R. selala | 0,40 | 0,47 | 588,01 | 472,88 | 350,81 | 273,59 | 185,12 | 144,32 | 205689,49 | 160350,95 | 653343,79 | 525424,47 | 389784,91 | 303985,68 | 185,32 | 183,35 | 82,00 | 21,32 | 349,31 |
| 190_B | R. stylosa | 0,45 | 0,47 | 380,05 | 77,91 | 210,70 | 53,99 | 111,08 | 28,54 | 123423,09 | 31714,51 | 422277,36 | 86563,84 | 234110,57 | 59993,39 | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 190_C | R. stylosa | 0,45 | 0,47 | 428,89 | | 237,78 | | 125,36 | | 139284,12 | | 476543,97 | | 264195,98 | | Mean_dry | | | | |
| 190_D | R. selala | 0,40 | 0,47 | 494,58 | | 295,07 | | 155,71 | | 173007,11 | | 549532,78 | | 327851,26 | | [Mg/ha] | SD_w_dry | SE_w_dry | | |
| | | | | | | | | | | | | | | | | 107,58 | 106,23 | 47,51 | 12,56 | 202,59 |
| 240_E | R. stylosa | 0,45 | 0,47 | 32,62 | 115,88 | 18,08 | 64,24 | 9,53 | 33,87 | 10593,50 | 37630,97 | 36244,41 | 128749,87 | 20093,90 | 71378,93 | | | | | |
| 240_F | R. stylosa | 0,45 | 0,47 | 176,84 | 76,40 | 98,04 | 42,36 | 51,69 | 22,33 | 57429,65 | 24812,49 | 196488,69 | 84892,96 | 108933,33 | 47064,66 | Mean_C | | | | |
| 240_G | R. stylosa | 0,45 | 0,47 | 205,93 | | 114,17 | | 60,19 | | 66876,77 | | 228810,88 | | 126852,75 | | [Mg/ha] | SD_C | SE_C | | |
| 240_H | R. stylosa | 0,45 | 0,47 | 48,11 | | 26,67 | | 14,06 | | 15623,96 | | 53455,50 | | 29635,73 | | 56,75 | 56,04 | 25,06 | 6,63 | 106,87 |
| | | | | | | | | | | | | | | | | | | | | |
| 30_I | non | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | | | | |
| 30_J | non | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | | | | | |
| 30_K | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 30_L | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 57_M | R. selala | 0,40 | 0,47 | 745,51 | 186,38 | 444,77 | 111,19 | 234,71 | 58,68 | 260783,96 | 65195,99 | 828343,62 | 207085,90 | 494189,80 | 123547,45 | | | | | |
| 57_N | non | 0,00 | 0,00 | 0,00 | 322,82 | 0,00 | 192,59 | 0,00 | 101,63 | 0,00 | 112922,77 | 0,00 | 358683,31 | 0,00 | 213990,46 | | | | | |
| 57_O | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 57_P | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 141_Q | R. selala | 0,40 | 0,47 | 50,19 | 58,79 | 29,94 | 35,08 | 15,80 | 18,51 | 17556,77 | 20565,98 | 55766,61 | 65324,93 | 33270,36 | 38972,86 | | | | | |
| 141_R | non | 0,00 | 0,00 | 0,00 | 75,68 | 0,00 | 45,15 | 0,00 | 23,83 | 0,00 | 26473,65 | 0,00 | 84089,82 | 0,00 | 50167,99 | | | | | |
| 141_S | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 141_T | R. selala | 0,40 | 0,47 | 184,98 | | 110,36 | | 58,24 | | 64707,14 | | 205533,13 | | 122621,06 | | | | | | |

Extrapolation of AGL (excluding deadwood) in Ba

| Plot | Tree | u | C | AGL green | Mean [kg/plot] | AGL kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGL green | Mean [kg/ha] | AGL kiln dry | Mean [kg/ha] | AGL mean green | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD | [Mg/ha] | SD AGL green | SE AGL green | Ci below value | Ci above value |
| 165_A | non | 0,00 | 0,00 | 0,00 | 79,67 | 0,00 | 46,68 | 0,00 | 24,62 | 0,00 | 27354,20 | 0,00 | 88522,13 | 0,00 | 51869,92 | 208,91 | 115,85 | 51,81 | 105,29 | 312,52 |
| 165_B | R. Samoens | 0,50 | 0,48 | 35,12 | 118,59 | 17,56 | 71,08 | 9,20 | 37,52 | 10225,76 | 41684,58 | 39022,18 | 131761,97 | 19511,09 | 78979,30 | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 165_C | non | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | Mean_dry | | | | |
| 165_D | R. selala | 0,40 | 0,47 | 283,56 | | 169,17 | | 89,27 | | 99191,02 | | 315066,35 | | 187968,59 | | [Mg/ha] | SD_w_dry | SE_w_dry | | |
| | | | | | | | | | | | | | | | | 120,70 | 67,98 | 30,40 | 59,89 | 181,51 |
| 80_E | R. Selala | 0,40 | 0,47 | 465,10 | 174,24 | 277,48 | 101,51 | 146,43 | 53,55 | 162694,82 | 59498,93 | 516777,26 | 193602,58 | 308309,31 | 112785,27 | | | | | |
| 80_F | R. stylosa | 0,45 | 0,47 | 116,75 | 169,68 | 64,73 | 102,49 | 34,12 | 54,09 | 37915,13 | 60102,68 | 129722,09 | 188536,42 | 71917,93 | 113878,05 | Mean_C | | | | |
| 80_G | R. stylosa | 0,45 | 0,47 | 61,81 | | 34,27 | | 18,07 | | 20073,10 | | 68677,71 | | 38074,92 | | [Mg/ha] | SD_C | SE_C | | |
| 80_H | R. stylosa | 0,45 | 0,47 | 53,31 | | 29,56 | | 15,58 | | 17312,68 | | 59233,27 | | 32838,93 | | 63,67 | 35,87 | 16,04 | 31,58 | 95,75 |
| | | | | | | | | | | | | | | | | | | | | |
| 17_I | R. Selala | 0,40 | 0,47 | 822,88 | 386,74 | 490,93 | 225,58 | 259,06 | 119,01 | 287848,46 | 132229,27 | 914310,20 | 429710,68 | 545477,46 | 250647,77 | | | | | |
| 17_J | R. stylosa | 0,45 | 0,47 | 294,40 | 254,35 | 163,22 | 154,49 | 86,05 | 81,54 | 95607,84 | 90603,72 | 327110,78 | 282605,96 | 181350,22 | 171656,53 | | | | | |
| 17_K | R. stylosa | 0,45 | 0,47 | 193,36 | | 107,20 | | 56,52 | | 62794,60 | | 214844,23 | | 119109,64 | | | | | | |
| 17_L | R. selala | 0,40 | 0,47 | 236,32 | | 140,99 | | 74,40 | | 82666,18 | | 262577,52 | | 156653,75 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 9_M | R. stylosa | 0,45 | 0,47 | 66,37 | 149,69 | 36,80 | 82,99 | 19,40 | 43,75 | 21553,98 | 48613,37 | 73744,37 | 166324,83 | 40883,88 | 92210,49 | | | | | |
| 9_N | R. stylosa | 0,45 | 0,47 | 205,25 | 52,86 | 113,79 | 29,31 | 59,99 | 15,45 | 66655,94 | 17166,29 | 228055,33 | 58732,42 | 126433,87 | 32561,25 | | | | | |
| 9_O | R. stylosa | 0,45 | 0,47 | 144,06 | | 79,87 | | 42,11 | | 46784,19 | | 160066,51 | | 88740,87 | | | | | | |
| 9_P | R. stylosa | 0,45 | 0,47 | 183,09 | | 101,51 | | 53,51 | | 59459,37 | | 203433,13 | | 112783,33 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 135_Q | R. Selala | 0,40 | 0,47 | 320,35 | 149,74 | 191,12 | 86,39 | 100,85 | 45,57 | 112060,39 | 50633,46 | 355944,09 | 166372,06 | 212356,24 | 95991,88 | | | | | |
| 135_R | R. stylosa | 0,45 | 0,47 | 79,06 | 100,37 | 43,83 | 61,40 | 23,11 | 32,41 | 25675,12 | 36011,86 | 87844,36 | 111520,67 | 48700,91 | 68221,89 | | | | | |
| 135_S | R. stylosa | 0,45 | 0,47 | 75,30 | | 41,75 | | 22,01 | | 24454,04 | | 83666,58 | | 46384,75 | | | | | | |
| 135_T | R. stylosa | 0,45 | 0,47 | 124,23 | | 68,87 | | 36,31 | | 40344,30 | | 138033,20 | | 76525,60 | | | | | | |

Extrapolation of AGB of *Rhizophora* spp. and *Bruguiera gymnorrhiza* in Rewa

| Plot | Tree | u | C | AGB green | Mean [kg/plot] | AGB kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGB green | Mean [kg/ha] | AGB kiln dry | Mean [kg/ha] | AGB mean green | SD AGB green | SE AGB green | Ci below value | Ci above value |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD | [Mg/ha] | | | | |
| 190_A | R. selala | 0,40 | 0,47 | 588,01 | 472,88 | 350,81 | 273,59 | 185,12 | 144,32 | 205689,49 | 160350,95 | 653343,79 | 525424,47 | 389784,91 | 303985,68 | 296,17 | 191,85 | 85,80 | 124,58 | 467,77 |
| 190_B | R. stylosa | 0,45 | 0,47 | 380,05 | 77,91 | 210,70 | 53,99 | 111,08 | 28,54 | 123423,09 | 31714,51 | 422277,36 | 86563,84 | 234110,57 | 59993,39 | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 190_C | R. stylosa; R. samoensis | 0,45 | 0,47 | 428,89 | | 237,78 | | 125,36 | | 139284,12 | | 476543,97 | | 264195,98 | | Mean_dry | | | | |
| 190_D | R. selala | 0,40 | 0,47 | 494,58 | | 295,07 | | 155,71 | | 173007,11 | | 549532,78 | | 327851,26 | | [Mg/ha] | SD_w_dry | SE_w_dry | | |
| | | | | | | | | | | | | | | | | 173,52 | 113,37 | 50,70 | 72,12 | 274,91 |
| 240_E | R. stylosa; B. gymnorrhiza | 0,45 | 0,47 | 79,02 | 190,71 | 43,81 | 105,73 | 23,10 | 55,74 | 25662,13 | 61934,00 | 87799,91 | 211899,79 | 48676,27 | 117477,24 | | | | | |
| 240_F | R. stylosa | 0,45 | 0,47 | 176,84 | 79,17 | 98,04 | 43,89 | 51,69 | 23,14 | 57429,65 | 25711,89 | 196488,69 | 87970,16 | 108933,33 | 48770,66 | Mean_C | | | | |
| 240_G | R. stylosa | 0,45 | 0,47 | 205,93 | | 114,17 | | 60,19 | | 66876,77 | | 228810,88 | | 126852,75 | | [Mg/ha] | SD_C | SE_C | | |
| 240_H | R. stylosa; B. gymnorrhiza | 0,45 | 0,47 | 301,05 | | 166,90 | | 87,99 | | 97767,46 | | 334499,67 | | 185446,61 | | 90,69 | 58,99 | 26,38 | 37,92 | 143,45 |
| | | | | | | | | | | | | | | | | | | | | |
| 30_I | B. gymnorrhiza | 0,40 | 0,49 | 77,16 | 19,29 | 46,30 | 11,57 | 23,73 | 5,93 | 26368,12 | 6592,03 | 85733,25 | 21433,31 | 51439,95 | 12859,99 | | | | | |
| 30_J | 0 | 0,00 | 0,00 | 0,00 | 33,41 | 0,00 | 20,05 | 0,00 | 10,28 | 0,00 | 11417,73 | 0,00 | 37123,59 | 0,00 | 22274,15 | | | | | |
| 30_K | 0 | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 30_L | 0 | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 57_M | R. selala | 0,40 | 0,47 | 745,51 | 196,93 | 447,31 | 118,16 | 236,04 | 62,26 | 262270,16 | 69173,68 | 828343,62 | 218810,89 | 497006,17 | 131286,54 | | | | | |
| 57_N | B. gymnorrhiza | 0,40 | 0,49 | 42,21 | 317,19 | 25,33 | 190,31 | 12,98 | 100,48 | 14424,55 | 111639,72 | 46899,95 | 352434,36 | 28139,97 | 211460,62 | | | | | |
| 57_O | B. gymnorrhiza | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| 57_P | B. gymnorrhiza | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | | | | | |
| | | | | | | | | | | | | | | | | | | | | |
| 141_Q | R. selala; B. gymnorrhiza | 0,40 | 0,49 | 1101,50 | 452,97 | 660,90 | 271,78 | 338,78 | 139,85 | 376417,47 | 155385,86 | 1223883,06 | 503295,57 | 734329,84 | 301977,34 | | | | | |
| 141_R | B. gymnorrhiza | 0,40 | 0,49 | 258,51 | 374,72 | 155,11 | 224,83 | 79,51 | 114,94 | 88341,40 | 127715,19 | 287233,05 | 416359,43 | 172339,83 | 249815,66 | | | | | |
| 141_S | B. gymnorrhiza | 0,40 | 0,49 | 216,52 | | 129,91 | | 66,59 | | 73992,03 | | 240577,54 | | 144346,52 | | | | | | |
| 141_T | R. selala | 0,40 | 0,47 | 235,34 | | 141,20 | | 74,51 | | 82792,53 | | 261488,63 | | 156893,18 | | | | | | |

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## Consent form

Kandidatin: Sarah Simone Reimer
Studienabschluss: M.Sc. Holzwirtschaft
Thema: „Methodology development of a biomass assessment applicable to *Rhizophora* spp. located in the mangrove forest of Fiji"

**Sperrvermerk:** Die Arbeit wird in Bezug auf die Einsichtnahme Dritter bzw. die Ausleihe

☐ gesperrt ☒ nicht gesperrt.

Die Sperre gilt ab dem Datum der Abgabe für die Dauer von ☐ Jahren.

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Hamburg, den ______________________ ______________________

Unterschrift (Kandidat/in)

***Methodology development of a tree volume function applicable to Bruguiera gymnorrhiza located in the mangrove forest of Fiji***

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**A Thesis Submitted in Partial Fulfilment of the Requirements of the Degree of**

MASTER OF SCIENCE (M.Sc.)
WOOD SCIENCE AND TECHNOLOGY

**UNIVERSITY OF HAMBURG**

DEPARTMENT OF BIOLOGY
FACULTY OF MATHEMATICS, INFORMATICS AND NATURAL SCIENCES

Burkhart Ludwig Brielmaier

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HAMBURG, GERMANY

**1st Examiner:** **Prof. Dr. M. Köhl**
University Hamburg
Leuschnerstraße 91
21031 Hamburg, Germany

**2nd Examiner:** **Dr. D. Plugge**
Deutsche Gesellschaft für Internationale Zusammenarbeit
(GIZ), SPC/GIZ Regional Program
REDD+ - Forest Conservation in Pacific Island Countries II
FNPF Downtown Blvd., Plaza 1, Level 3, 33 Ellery Street
PO Box 14041
Suva, Fiji

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# Contents

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# List of Abbreviations

| | |
|---|---|
| AGB | Above ground biomass |
| AGL | Aboveground level |
| ANOVA | Analysis of variance |
| BGB | Below ground biomass |
| BRH | Buttress root height |
| C | Carbon |
| Ci | Confidence interval |
| DBH | Diameter at breast height (130cm) |
| DBRH | Diameter at buttress root height (End of buttress root) |
| DSM | Destructive sampling method |
| F | Form factor |
| FAO | Food and Agriculture Organization of the United Nations |
| FRA | Global Forest Resource Assessment |
| GIZ | Deutsche Gesellschaft für internationale Zusammenarbeit |
| GWP | Global warming potential |
| Ha | Hectare |
| i.e. | Id est |
| kgC | Kilogram of carbon |
| KTDSM | Ktree distance sampling method |
| Mg | Megagram |
| MUF | Multiple use forests |
| MSD | Management Service Division |
| P | Probability value |
| PTF | Protection Forest |

| | |
|---|---|
| REED+ | **R**educing **E**missions from **D**eforestation and Forest **D**egradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries |
| r | Radius |
| $R^2$ | Coefficient of determination |
| $SD^2$ | Variance |
| SD | Standard derivation |
| SE | Standard error |
| spp. | Species |
| sp. | One specie |
| SPC | Pacific Community |
| Tg | Tera-gram |
| u | Water content |
| V | Volume |

# Abstract

This project is intended to support Fiji determining its the national forest carbon stock within the framework of the regional REDD+ project: “REDD+ Forest Conservation in Pacific Island Countries”. The data collection and analysis was conducted in cooperation with Fiji’s Department of Forestry, Pacific Community (SPC), the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and the University of Hamburg.

This study examined two different methods for inventorying *Bruguiera gymnorrhiza* in Fijian mangrove forests.
The study sites were located on the main island Viti Levu in the Rewa and Ba delta respectively.
The main emphasize of the study was a) to derive operational methodologies to estimate the carbon stock of Fijis mangrove forest, b) to test the practicability methodologies and c) to analyze the gathered data. The dense and entwined vegetation of the mangrove forests has a strong effect on the design and the operability of the methods.

The analysis of the recorded data allows determining physical properties like water content or gross density and thereby deriving the carbon content of *Bruguiera gymnorrhiza*.
The main objective of this study was to develop a practicable method for inventorying a *Bruguiera gymnorrhiza* forest. In addition, the data was analyzed towards gaining insides on the forest structure. Adding to this, another objective of this study was to determine a per hectare value of the C-pool for the wooden above ground biomass for each method.
This study should help as foundation for further research in examination of mangrove forests.

# Zusammenfassung

Dieses Projekt lief im Rahmen der Unterstützung Fidschis zur Erfassung des nationalen Waldkohlenstoffvorrats durch das regionale REDD+ Projekt: „Walderhalt in pazifischen Inselstaaten". Die Datenerhebung und Auswertung wurde in Kooperation mit dem nationalen Forstamt, der Pazifischen Gemeinde (SPC) der Deutschen Gesellschaft für internationale Zusammenarbeit (GIZ) und Universität Hamburg durchgeführt.

Diese Studie untersucht zwei unterschiedliche Methoden zur Inventarisierung von *Bruguiera gymnorrhiza* in fidschianischen Mangrovenwäldern.
Die untersuchten Gebiete befanden sich auf der Hauptinsel Viti Levu in Rewa und Ba Delta.
Das Hauptaugenmerk der Studie lag auf a) der Ableitung operativer Methoden zur Schätzung des Kohlenstoffvorrats in Mangrovenwäldern von Fidschi, b) der Prüfung der Praktikabilität der Methoden und c) der Analyse der aufgenommenen Daten. Die dichte Vegetation der Mangrovenwälder wirkt sich maßgeblich auf das Design und der Praktikabilität der Methoden aus.
Die Analyse der Daten ermöglicht eine Ermittlung von physikalische Größen, wie zum Beispiel dem Wassergehalt oder der Rohdichte. Diese Größen sind notwendig um den Kohlenstoffgehalt von *Bruguiera gymnorrhiza* zu ermitteln.

Das Hauptziel dieser Studie war eine praktikable Methode zur Inventarisierung eines *Bruguiera gymnorrhiza* Waldes zu entwickeln. Zusätzlich wurden die Daten analysiert, um Einblicke in die Waldstruktur zu erhalten. Ein weiteres Ziel dieser Studie war einen Hektar-Wert des Kohlenstoffvorrats für die hölzerne oberirdische Biomasse für jede Methode zu bestimmen.

Diese Studie soll als Grundlage für weitere Forschungen zur Untersuchung von Mangrovenwäldern dienen.

# 1 Introduction

The consequences of global climate change are more threating than ever. The United Nations Framework Convention on Climate Change (UNFCCC) developed the REDD+ mechanism (**R**educing **E**missions from **D**eforestation and Forest **D**egradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries) to foster activities in tropical forest countries to reduce greenhouse gas emissions from the forest sector, e.g. by reducing deforestation rates. To enable countries to participate in REDD+ they must have a thorough knowledge about the carbon that is stored in the biomass of their forest ecosystems. In this context, the purpose of this study was to develop a methodology for a biomass survey in the mangrove forests of Fiji to determine their carbon content.

## 1.1 Climate change

The burning of fossil fuels, changing landscapes and emissions from industrial production have caused the release of brown[1] and black carbon[2]. In the meantime, there is a scientific consensus from 130 countries that an increase of a carbon content inside the atmosphere has caused a global temperature increment, and a presumption that human activities effect the climate change as well (IPCC, 2007). The Intergovernmental Panel on Climate Change (IPCC) estimate that the risk of serious consequence will follow, if the temperature rises over the threshold of 2°C. The threshold of 2°C is associated to the temperature before human impact (EPA, 2006). If the anthropogenic influence on greenhouse gases emission doesn't decline, the average global temperature will rise till by 6°C to the end of the current decade. This would be enough to trigger natural catastrophes or rather a more frequent appearance of floods, dry periods or other natural disasters. After 2020 the emissions shouldn't continue to rise and by 2050 the level of emissions should be 50% of the level recorded in 1990 (UK Government, 2009). The inevitable achievement of a "Low Carbon Economy" will be one of the most important developments of the 21th century.

## 1.2 The role of mangroves

Mangroves are a very important ecosystem. They are important against climate change and counteract its impacts e.g. by absorbing and weakening waves, thus tempering the force of a tsunami. Mangroves also play an important role for costal inhabitants, with their deep anchoring into the ground preventing soil erosions and protecting the coastline from erosion. Furthermore, the typical stilt roots prevent the impact of river arise siltation (Duke , et al., 2007). In addition, coral reefs, seagrass and shipping lines

[1] Brown carbon: ''Organic matter in atmospheric aerosols of various origins, e.g., soil humics, humic-like substances, tarry materials from combustion, bioaerosols, etc.'' (Andreae & Gelencser, 2006)
[2] Black carbon: ''Distinct type of carbonaceous material that is formed primarily in flames'' (Bond, et al., 2013)

depend on the protection of mangroves (FAO, 2007). This is not only important for humans. The livelihood of many fish and marine species depend on mangroves. The litter from mangroves is a valuable fertilizer for coral reefs. Mangroves are highly productive. The capacity to sequester CO2 from the atmosphere is a conducive quality of mangroves. Mangroves and the costal vegetation store large amounts of carbon. From all carbon storage captured by photosynthetic activities (green carbon) on earth, more than half (55%) is stored in the costal and marine ecosystem (Nellemann, et al., 2009). This carbon storage has been termed 'blue carbon' and includes mangroves, salt marsh seagrass and another marine organism (Pendleton, et al., 2012). The mangrove forest has been proven to have extraordinary high rates of primary productivity (Alongi, 2002). Even in areas where the above ground biomass (AGB) is low, the below-ground biomass (BGB) can be still extraordinary high. Due to their ability to thrive on shore lines, they have their natural growth habitat on organic rich soils. This is also an outcome of the extensive root system of mangroves. The entangled roots capture organic and non-organic litter and provide a base of sediments. These sediments rest under water and have low oxygen conditions, which slows down the decay process. Therefor the soil accumulates a higher percentage of carbon (Krauss, et al., 2010). Annually the mangrove forest sequesters up to 14 – 17 Tg organic matter into the sediment worldwide (Spalding, et al., 2010). Figure 1 shows, that the soil of a mangrove forest alone stores a much higher amount of carbon, than all others tropical forest types in total. The mean carbon stock value for the whole ecosystem estimated from (Alongi, 2014) is about 956 MgC/ha in the mangrove forest. This value is much higher compare to rain forest (241 MgC/ha), peat swamp (593 MgC/ha) or see grass 142 MgC/ha.

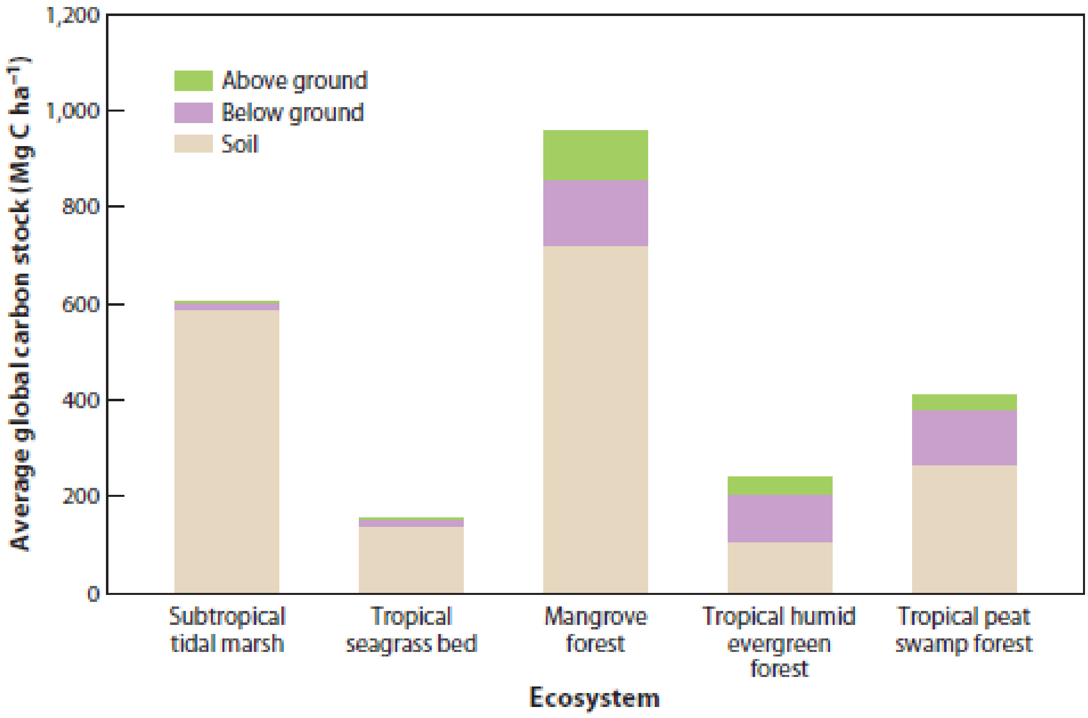



*Figure 1: Average global carbon stocks of subtropical tidal marsh, tropical seagrass bed, tropical humid evergreen forest and tropical peat swap forest compared with those of subtropical and tropical mangrove ecosystems (Alongi, 2014)*

## 1.3 Deforestation and the subsequent impact

Global deforestation accounts for close to 20% of global greenhouse gas emissions (Nellemann, et al., 2009). The Mangrove forest is disappearing largely by 1 to 2% per year due to anthropogenic activities worldwide. This rate is greater or equal to the deforestation of tropical rain forest (Duke , et al., 2007). Mangroves cover approximately 152,000 $km^2$ in 123 different countries. In the last 25 years the mangrove forest declined by around 20%. Costal development is the principal reason for the deforestation of the mangrove forest (Spalding, et al., 2010). Deforestation reduces the two key capacity of providing an atmospheric CO2 sink and an essential source of blue carbon (Duke , et al., 2007). If due to anthropogenic influence blue carbon turns into brown carbon the emission of greenhouse gases would potentially accelerate at an enormous rate (Nellemann, et al., 2009), which would affect the Global Warming Potential (GWP) significantly. In this process the carbon rich soil would transform to dry land and release the sequester carbon into the atmosphere. Mangroves play an important role in the carbon budget.

## 1.4 Project Overview

This master thesis is based on a project which ran under the REED+ mechanism. The project started during dry season in August 2017 in the Rewa Delta and continued also during dry season in October in the BA Delta. For the project a survey team included employees of the Fiji Forestry Department (MSD), a Fijian student from the University of the South Pacific (USP) and a forestry apprentice. The project was supported by the GIZ and well as technical support from Prof. Dr. Michael Köhl from World Forestry Department of the University of Hamburg and Dr. Daniel Plugge (GIZ) on-side. For this project the survey team worked with the Fiji Forestry Department (MSD), the South Pacific Community (SPC) and the University South Pacific (USP). The expatriate stays of four months in the Rewa Delta and BA Delta of Viti Levu, Fiji Islands enabled field work in the mangrove forests of the deltaic areas, desk research and laboratory work.

## 1.5 Objectives

The Objectives for this work are as follows:

- Designing of a practicable plot layout and accordingly tracts
- Destructive sampling method
- K-tree distance sampling method
- Volume, weight and density determination of Bruguiera gymnorrhiza
- Knowledge of the biomass and carbon stock in a *Bruguiera gymnorrhiza* forest
- Survey of the structure of the mangrove forest, especially at the boundary areas
- Development of reprehensive and repeatable yield methodology

The development of a practicable and repeatable methodology for mangrove inventories is needed, to gain more knowledge about mangrove forests. The results of the inventory are intended to facilitate the estimation of the value of mangrove forests.

## 1.6 Limitations

This study focuses on Bruguiera gymnorrhiza. With the recorded data it is not possible to get a general overview of the mangrove forest on Viti Levu, due to significant differences between the study areas. With 40 plots in total the results show mostly the functionality of the developed methodology. To get a better overview of the Fijian mangrove forest further research must be undertaken. The focus of this master thesis is to develop a tree volume function of Bruguiera gymnorrhiza, to ascertain knowledge about biomass and carbon stock. This study only focuses on the wooden AGB and dead wood biomass. BGB is not considered in this study. In addition, the typical knee roots of *Bruguiera gymnorrhiza* were not recorded. Anthropogenic and natural impacts of the mangrove forest must be considered, especially in the Rewa delta where fuelwood of the *Bruguiera gymnorrhiza* plays an important role for the inhabitants. In the Ba delta the former cyclone Winston had a big impact on the mangrove forest. The fieldwork in the mangrove forest is depending on tides and as well as accessibility.

## 2 The Fijian mangrove forest

Mangroves appear around all Fiji's Islands. The biggest occurrence is found in river estuaries or rather in river deltas and in mud-covered stream banks in tidal zones. The main island Viti Levu accounts for 60% of the total mangrove forest of Fiji (FAO, 2005). The Rewa delta is the biggest mangrove habitat on Viti Levu. The second biggest habitat is the Ba delta. Figure 2 shows the forest cover map of the main islands Viti Levu and Vana Levu and the Rewa delta and Ba delta. A more detailed map and further information are given in the appendix.

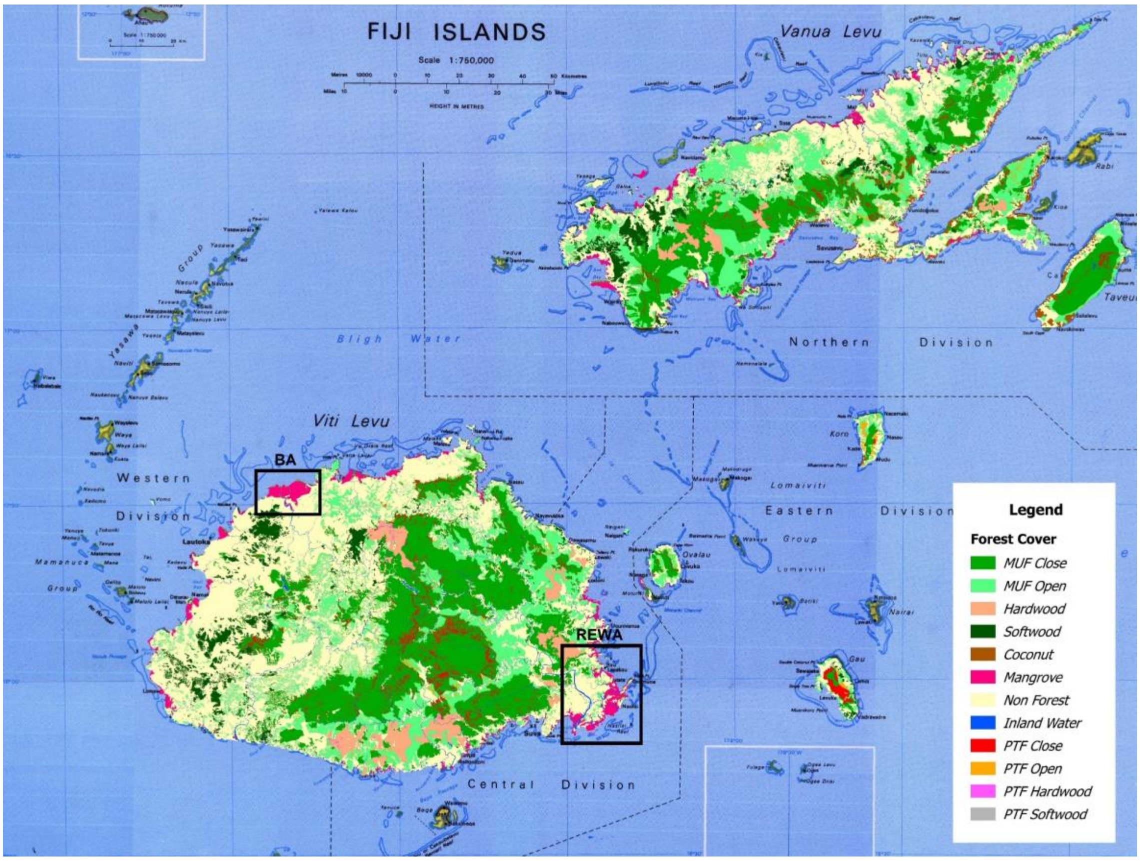


*Figure 2: Forest Cover Map Fiji Islands (MSD, 2017)© MSD*

The change of the Fijian forest is difficult to identify. Firstly, the structure of forest owners isn't easy to determine. In cases of inheritance the property gets divided between all relatives. Secondly, fuelwood is still an important source of energy for inhabitants of the mangroves. Table 1 shows an estimation from the FAO for the forest change between 1980 and 2005.

*Table 1:Summary status of mangrove area extent over time (FAO, 2005)*

| | Most reliable, recent mangrove area estimate | | Mangrove area estimate 1980 | Mangrove area estimate 1990 | Mangrove area estimate 2000 | Mangrove area estimate 2005 |
|---|---|---|---|---|---|---|
| | ha | year | ha | ha | ha | ha |
| **Fiji** | 42 464 | 1989 | 47 000 | 43 000 | 38 700 | 36 600 |

The values of Table 2 show the forest size of Fiji determined after the Global Forest Resource Assessment (FRA).

*Table 2: Mangrove forest development (FAO, 2014)*

| National Class | Area (1000 hectares) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1990 | 1991 | 2000 | 2005 | 2007 | 2010 | 2015 |
| Mangrove forest | 41.808 | 42.000 | 39.892 | 38.934 | 28.742 | 54.185 | 57.390 |

## 2.1 Definition of Mangrove habitat

The Fiji Islands have an occurrence of 9 different mangrove species (FAO, 2007; Spalding, et al., 2010). These species are divided into red mangroves (*Rhizophora* spp.), black mangroves (*Bruguiera gymnorrhiza*) and white mangroves. The natural mangrove habitat is structured as shown in Figure 3. If the forest shows a different structure, it is an indicator that the mangrove forest has undergone a change due to a previous anthropogenic influence or a past natural impact e.g. a cyclone.

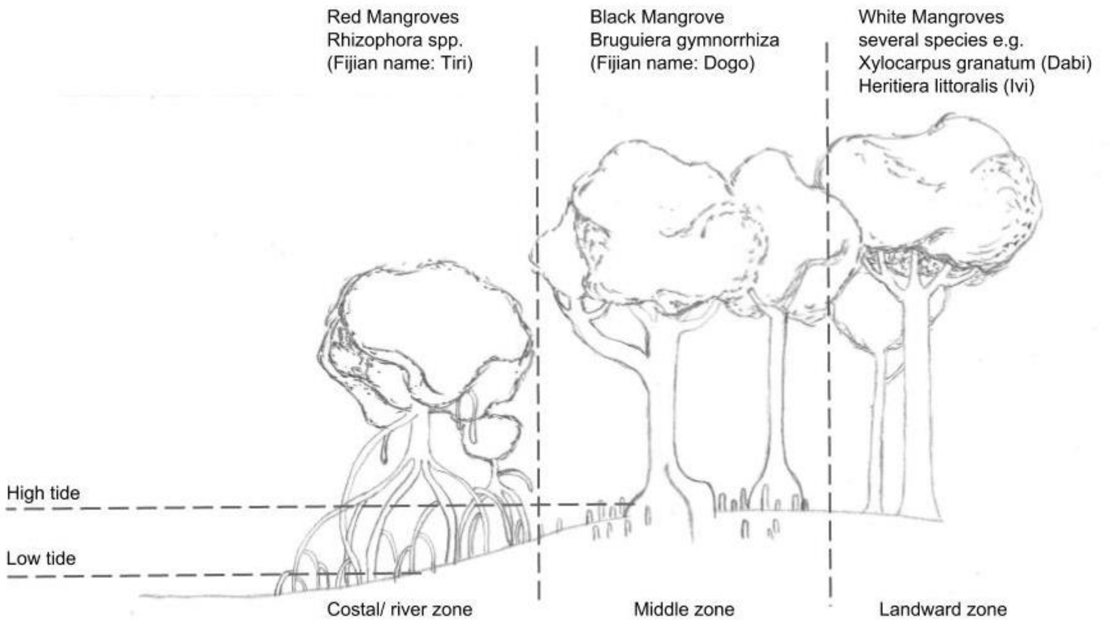



*Figure 3 Mangrove forest structure (Reimer, 2018)*

The term red mangroves (Fijian name “Tiri”) describes the *Rhizophora* spp. and occurs in costal shores and river zones. With their typical stilt and areal roots, they can thrive even in very muddy and soft soil. The term black Mangroves (Fijian name *“Dogo”*) describes *Bruguiera gymnorrhiza* and occurs in the middle zone between the red and white mangroves. The *Bruguiera gymnorrhiza* grows in muddy areas, which are flooded at high tide. But rather than *Rhizophora* spp. the tree develops knee roots, which stick up out of the ground. Often the middle zone is intermixed with *Bruguiera gymnorrhiza* and *Rhizophora* spp. The white mangroves define several other halophytic plants. They grow in the landward zone behind the black mangroves (Keppel & Ghazanfar, 2011).

## 2.2 Deforestation of mangrove forest in Fiji

During the 16 year period 1991 – 2007, a deforestation of 3.464 ha was calculated on basis of the forest cover maps. That equals a median loss of 0,5 % per year and that in turn corresponds to 217 ha deforestation per year. The values were generated by the two largest islands, Viti Levu and Vanua Levu, as well as Taveuni and Kadavu. For the other, smaller islands there were no data recorded. The largest deforestation (40% of the total loss) apparently happened in the Rewa Riva and in the Suva region (Watling, 2013).

The deforestation of mangroves in the deltaic area of the Rewa River and the suburb of Suva can be explained mainly by the spreading city and the associated industry, which accompanies this. Examples of this are, amongst others, the construction of the Rokobili port in the Suva Harbor 2008, seawall construction and the municipal park in Suva, or a conversion of mangroves in Waidamu in the Rewa delta region for agriculture.
Agriculture (primarily sugar cane) is the main reason for mangrove losses in the deltaic region of Ba (examples seen in Nailaga or Natunuku). Another reason for deforestation of mangrove areas in Fiji is tourism. This happened for example in Denarau, Vulani (Sabeto River) and Saweni at the Nadi Bay (Watling, 2013).
Another loss of mangrove areas can be seen near our sample areas in the Rewa River delta. According to (Watling, 2013) is dredging in the Rivers a “substantial but undocumented loss“.

## 2.3 Deforestation of mangrove forest found during the study

*Figure 4: Bruguiera gymnorrhiza on river zone (Brielmaier, 2017)*

Figure 4 shows an unnatural habitat of Bruguiera gymnorrhiza. The trees are located directly on the river zone and not further inside the forest. These occurrence is quite unusual, as described in chapter 2.1.

The typical knee roots are already totally developed. This is an indicator for a medium or a fully-grown tree. There was no such as tree found in a range of 25 m. It can be assumed, that the corresponding tree and the surrounding got already cut down for fuel wood.

*Figure 5: Stump inside river (Brielmaier, 2017)*

Next to the plot a stump of *Bruguiera gymnorrhiza* was found inside the water. Land erosion can be recognized on Figure 5. This is most likely the consequence of a too intense harvesting. It can be assumed, that river zone is already totally eroded.

## 2.4 Bruguiera gymnorrhiza

*Bruguiera gymnorrhiza* belong to the mangrove family of *Rhizophoraceae*. In the Fijian language the tree is called “Dogo” (Keppel & Ghazanfar, 2011) and it is also known as Large-Leaved Mangrove (Allen & Duke, 2006). The tree is indigenous to the Indo-West Pacific and it is found on several Fiji Islands (Viti Levu, Vanua Levu, Taveuni, Koro, Lau etc. (Spalding, et al., 2010)). The natural habitat is further to the landward edges of mangrove swamps and is mostly found in brackish water near the ocean. The low to medium sized tree is around 4 to 15 m tall and shows a typically dense rounded crown.

### 2.4.1 Leaves, Flower and Seed

The long, slim leaves of *Bruguiera gymnorrhiza* are opposite and decussate, leathery and elliptic (Keppel & Ghazanfar, 2011).

*Figure 6: Flowers and leaves of* Bruguiera gymnorrhiza *(Forstreuter, 2017)*

The inflorescence of *Bruguiera gymnorrhiza* is one flowered. Figure 6 shows the calyx formed red-white flower. It is opened and the pistil is ready to pollinate. This image was taken in November 2017.

*Figure 7: The flower of* Bruguiera gymnorrhiza *(Forstreuter, 2017)*

Each flow develops just one seedling. The seedling is around 9 to 14 cm long.

*Figure 8: A seed and leaves of Bruguiera gymnorrhiza (Forstreuter, 2017)*

### 2.4.2 Trunk

*Figure 9 Trunk of a Bruguiera gymnorrhiza in an intermixed mangrove forest with Rhizophora spp. (Brielmaier, 2017)*

The trunk is well shaped. The bark of the tree is rough, thick and dark brown. On the bark the water level of high tide can be recognize. The part inside the water is smoother, compared to the rough bark, which is outside of the water on high tide.

### 2.4.3 Roots

Figure 10 shows a *Bruguiera gymnorrhiza* forest with its wide spreading root system. The image shows the forest at low tide. The moss on the tree marks the water level at height tide. The tree develops buttress roots, which have excellent structural properties on soft subsoil and are adapted to natural forces (Mattheck, 1998). The typical knee roots of a *Bruguiera gymnorrhiza* forests are inverted-u-shaped and characterized by the fact that they first grow like pneumatophores to then forming a curve and anchor again in the soil. They form a “rounded knop-like extrusion” (Spalding, et al., 2010, p. 3). Knee roots growing up to 30cm aboveground level (AGL) around the main trunk. The main task of knee roots, same as other root systems of the mangrove forest, is to facilitate gas exchange in the oxygen poor soil. In general, stilt roots, seen in Rhizophora species, are absent.

*Figure 10 Bruguiera gymnorrhiza forest (Brielmaier, 2017)*

In some cases, the tree develops stilt roots to compensate inner tension. Mostly the tree is already quite old and inclined. Additionally, in most instances the stilt roots dry up, before they can reach the ground. Figure 11 shows a tree with, which is developing stilt roots.

*Figure 11: Stilt roots (Brielmaier, 2017)*

### 2.4.4 Microscopic cross section

Mostly in the cross section distinguishing feature can be found. Those are needed to identify the species. Therefore, the samples were finely sanded to get a smooth surface. In this process step the vessels got filled with wood flour and vessels appear bright. The wood rays are homogeneous constructed. The average size of a wood ray varies between one and four rows. This corresponds to a width between 30 and 100µm.

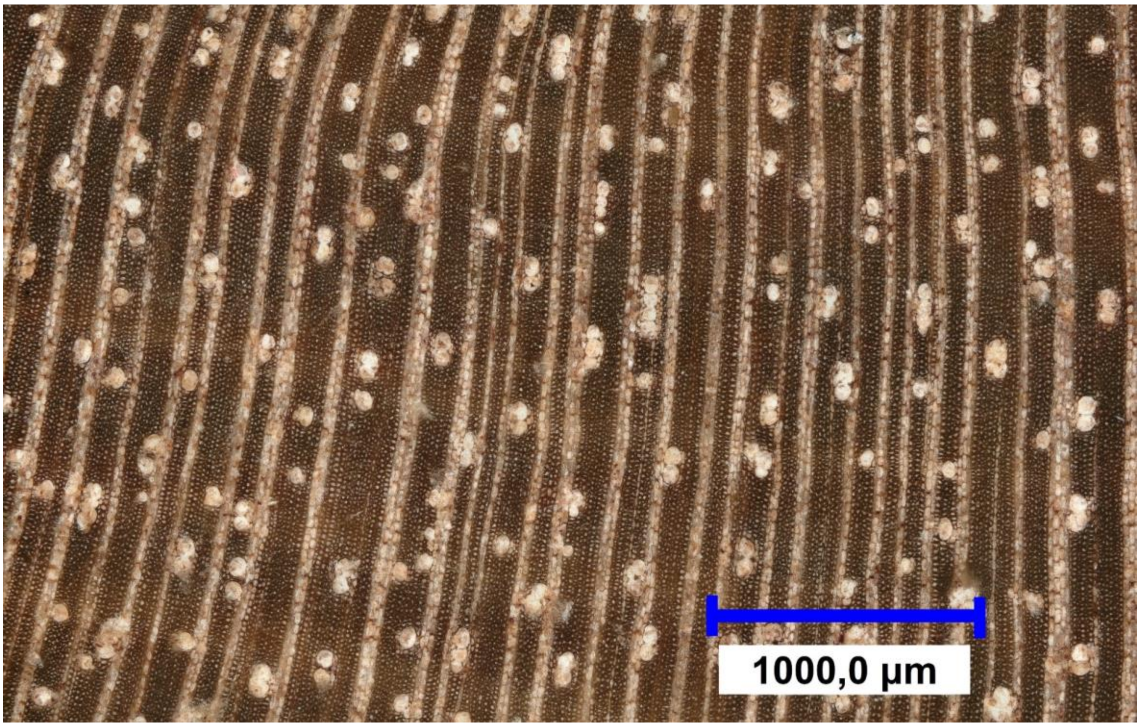



*Figure 12 Microscopic cross section of Bruguiera gymnorrhiza (Ksuhuro , 2018)*

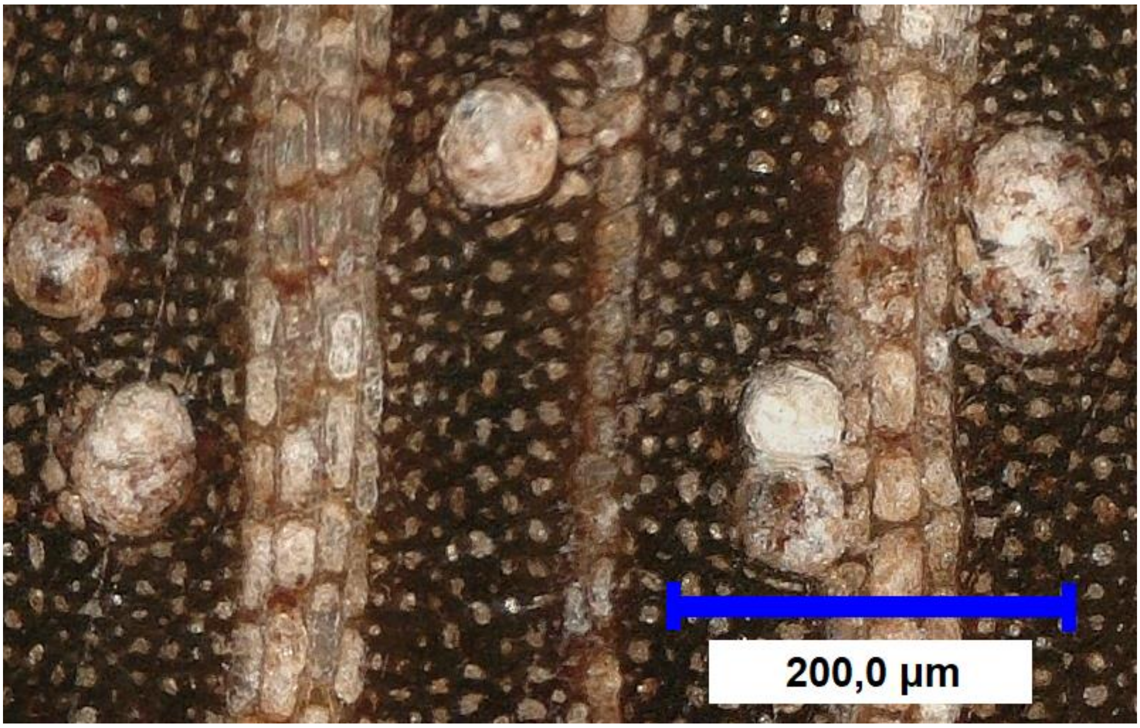



*Figure 13 Microscopic cross section of Bruguiera gymnorrhiza (Ksuhuro , 2018)*

Figure 13 shows the structure in depth. The vessels have a size of 80-100µm. Small components of phenolic components are partially recognizable. For example, the vessel on the left-hand side shows partly darker spots inside, which is most likely phenolic or colored components stored in the vessel. The cell walls are relatively thick, which points to a high density of the wood. The light thin strips are caused by the sanding and are not a distinguishing feature. The analysis under the microscope showed, that there are no significant distinguishing characteristics for Bruguiera gymnorrhiza. In addition, in-between the *Rhizophora* spp. no distinguishing characteristics were found Reimer (2018). Although differences in color were found, this does not serve as a distinguishing feature.

# 3 Material and Methods

## 3.1 Preparation

All types of mangrove forest are strictly protected in Fiji. For a destructive sampling method an approval from the Department of Lands is needed. Even though the mangrove forest belongs to the state, the villages close by must be informed in advance due to cultural and historical reasons. With a traditional “sevu sevu” the chief of the village may accept the proposition.

## 3.2 Selection of the Tracts

In this research the mangrove inventory gets conducted with tracts. In order to get an overview of the forest structure, this procedure has plenty of advantages. A simple repeatability of the method for the plots inside the tracts is given. Working with tracts gives a good coverage of the forest structure as well. The starting points of the tracts were selected by using a random selection method (Reimer, 2018). Therefor edition 1 of the forest function map from 2016 was used. Each tract starts from an edge of the mangrove forest, either from the waterside or from the border between the mangrove forest and non-mangrove. In each delta seven potential starting points were selected. In order to have alternative possibilities only five of the seven starting points were implemented.

## 3.3 Tract layout

The tracts are composed with four plots in a straight line, which run vertical to the edge of the mangrove forest or rater waterside/ landside. Figure 14 shows the tract layout. Each tract is 162 m long and the plots have a size of 3 by 3 m. The distance between the plots is 50 m. In many cases the edge of the forest can't be determined clearly, therefore a random distance (d) between 1 to 10 m was chosen using the phone application (UX Apps) "Zufallszahl".

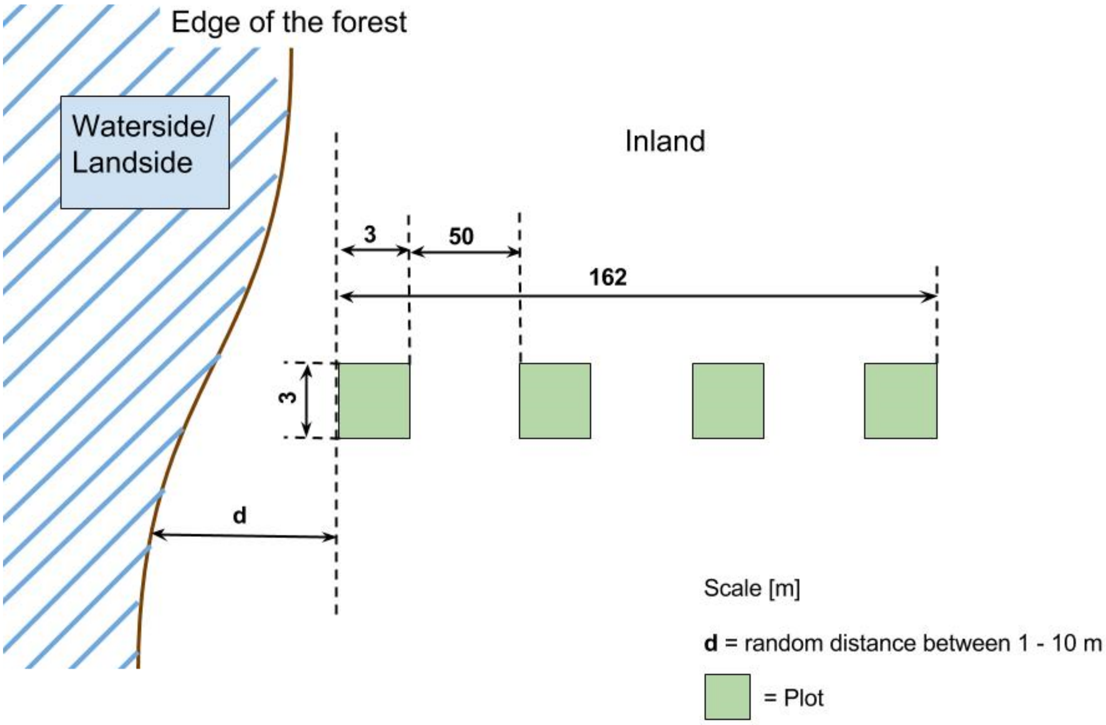



*Figure 14 Tract layout (Brielmaier, 2017)*

In all plots a destructive sampling of was taken. In each delta five tracts were investigated. The total survey area was 0,0306 ha. For getting access to the plots, mostly in the *Rhizophora* spp. forest, a way had to be cut inside the mangroves. In addition, a little area around the plot had to be cut clear for simplified measuring. The total impact to the mangrove forest was around 0,6 ha. The actual value is lower, because in pure *Bruguiera gymnorrhiza* forest the accessibility from plot to plot is given and it was not necessary to cut down a way an area around the plot.

## 3.4 Study areas

The project took place in the deltaic area of the Rewa river. The delta is located in the south- eastern part of the Central Division of the main island Viti Levu.
The Rewa river delta measures a total area of 8.800ha. The delta has an average temperature of 25,5 °C and with 3.040mm per $m^2$ the area has a significant amount of rainfall. Dry months occur between June and September (MSD, 2017).

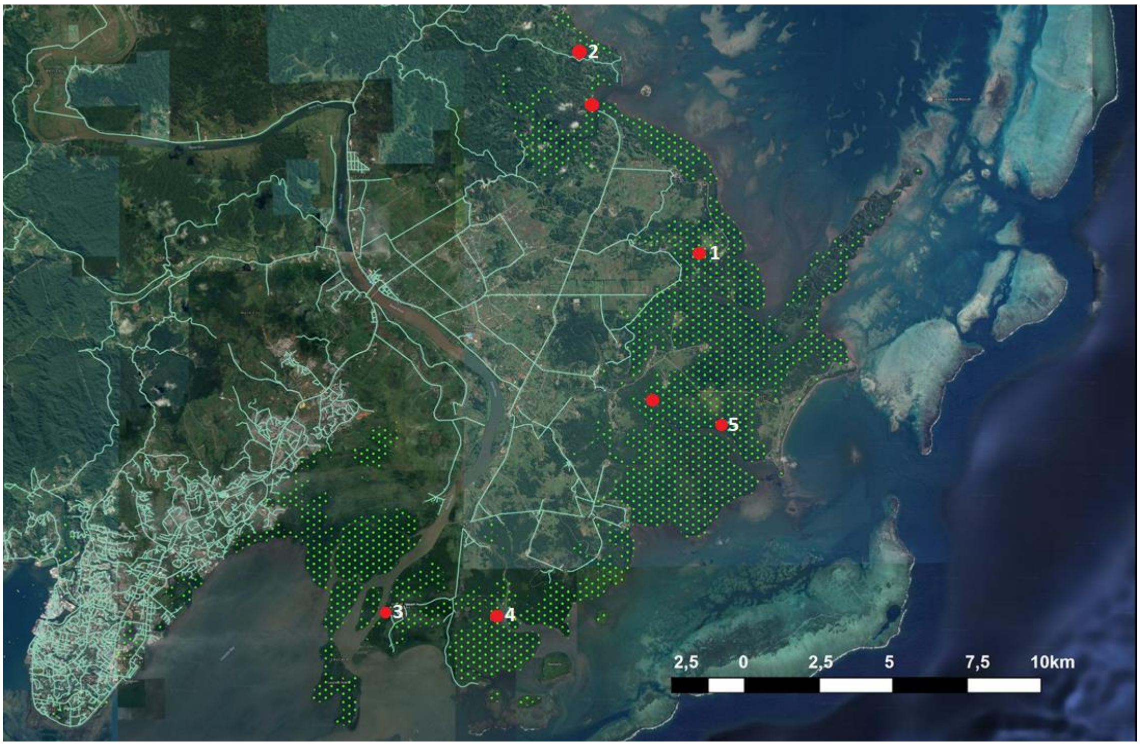



*Figure 15: Mangrove areas in the Rewa Delta; 1 Point = Tract 190, 2 Point = Tract 240, 3 Point = Tract 30, 4 Point = Tract 57, 5 Point = Tract 141 (Brielmaier, 2017)*

The second study area is located in the Ba River Delta, in the Western Division of Viti Levu Fiji Island. This delta has a mangrove area of approximately 5.700 ha (QGIS, 2017) and an average annual temperature of 25.2°C. The deltaic region in Ba differs mostly by the average of rainfall. The average rainfall amounts 2.024mm per $m^2$. Heaviest rain occurs between January and March while the months of July and August are drier.

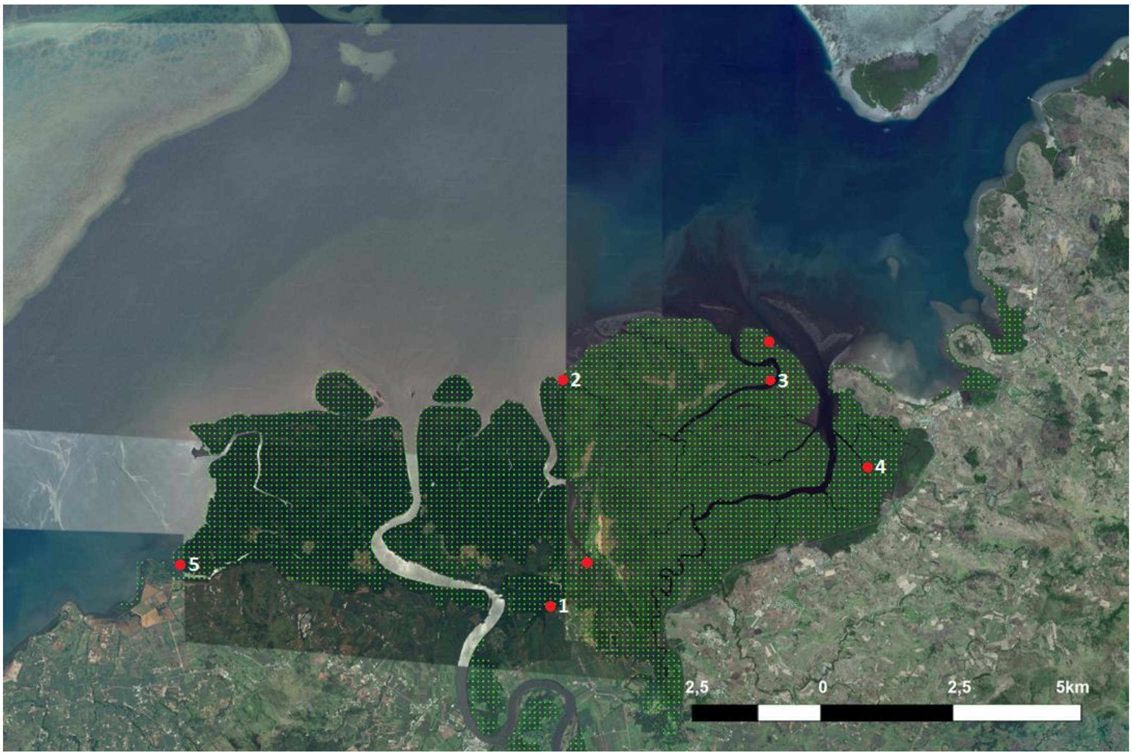



*Figure 16: BA- Delta with statin points; 1 Point = Tract 165, 2 Point = Tract 80, 3 Point = Tract 17, 4 Point = Tract 9, 5 Point = Tract 135 (Brielmaier, 2017)*

## 3.5 Methods for inventory

Several methods can be used for inventorying a *Bruguiera gymnorrhiza* forest. In a dense intermixed forest, it must be considered, that the accessibility and the visibility in is limited. The *Rhizophora* spp. especially hinder accessibility and the visibility.

### 3.5.1 Destructive sampling method

The destructive sampling method (DSM) considers only the trees inside the plot. Trees with a DBH under 8 cm are determined as biomass and not inventoried as tress. All trees with a DBH above 8 cm are measured with the attributes from chapter 3.6. If it is not explicit, whether the tree is inside the plot or outside, a uniform plot boundary demarcation is necessary to avoid errors. As described in Figure 17 the tree is inside the plot, if the butt of the trunk is more the half inside the plot.

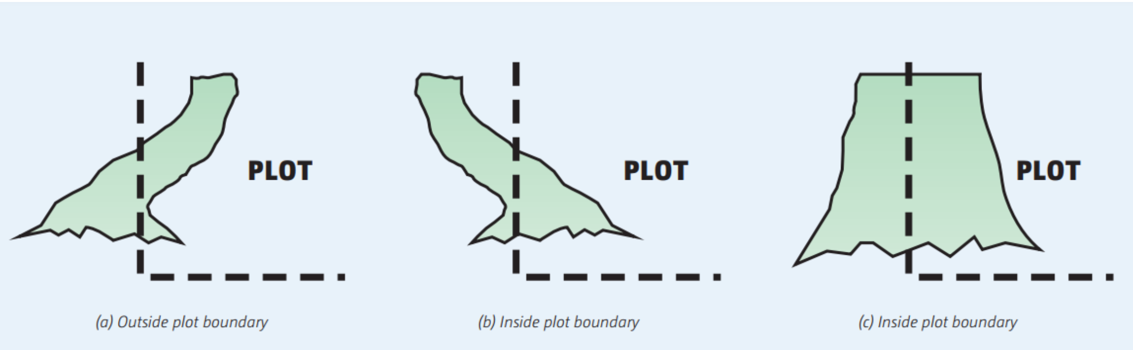



*Figure 17 Plot boundary demarcation (UNFCCC, 2015)*

At least two trees should be subjected to destructive sampling in each tract. Initially, all trees (or rather all AGB inside the tract) underwent destructive sampling. If there were not two trees inside the tract, two plots centers inside the tract were randomly selected and the closest tree to these plot centers underwent destructive sampling. During this study the maximum DBH of a selected the tree was limited to 50 cm for feasible reasons. If the closest tree had a DBH above 50 cm the second closest tree got selected and so on. All attributes from chapter 3.6 got measured, before the destructive sampling took place. After, the trees got destructive sampled and weighed separately in the segments trunk, branches and leaves. In each meter of the trunks or branches one sample was cut out for the laboratory work with a maximum width of 5 cm.

#### 3.5.1.1 Estimation for a hectare value using the destructive sampling method

With the following equations the biomass per hectare can be estimated. ‘n’ describes the number of tracts. In each delta (Rewa and Ba) are n = 5 tracts with i = {1,2,…,n}. Each tract has independent plots. ‘h’ describes the number of plots. In each tract are h = 4 plots with l = {1,2,…,h}. The size of a plot is $a_l$ = 9 m². For estimate a hectare value an expansion factor (EF) gets calculated with Equation 1.

$$EF_l = \frac{10000}{a_l} = 1111,11 \qquad [EF_l \; is \; dimension \; less]$$

*Equation 1: Calculation of the expansion factor for the DSM*

All plots have the same size. Therefore, for all plots the same EF can be used. $B'_{li}$ describes the median biomass of the l$^{th}$ plot of the i$^{th}$ tract. $B_{li}$ describes the mean biomass per hectare of the l$^{th}$ plot of the i$^{th}$ tract and can be calculated by using Equation 2.

$$B_{li} = B'_{li} \cdot EF_l$$

*Equation 2: Biomass values for one hector using the expansion factor*

Using Equation 3 the arithmetic mean of the biomass values per hectare per tract can be calculated. $\bar{B}_i$ is the median biomass per hectare of the i$^{th}$ tract.

$$\bar{B}_i = \frac{\sum_{l=1}^{hi} B_{li}}{h}$$

*Equation 3: Arithmetic mean of the biomass values per ha of the i$^{th}$ plot*

Using Equation 4 the median biomass per hectare per delta can be calculated.

$$\bar{B} = \frac{\sum_{i=1}^{n} \bar{B}_i}{n}$$

*Equation 4: Estimation of a mean biomass per ha for one location (delta)*

With Equation 5 the standard error (SE) can calculated. Therefore, the standard derivation (SD) is needed, which is generated from Equation 6.

$$SE(\bar{B}) = \frac{SD}{\sqrt{n}}$$

*Equation 5: Calculation of the standard error*

$$SD = \sqrt{SD^2} \qquad \text{and} \qquad SD^2 = \frac{\sum_{i=1}^{n}(B_i - \bar{B})^2}{n-1}$$

*Equation 6: Calculation of the standard derivation*

With Equation 7 the confidence interval can be calculated.

$$Ci \; [\bar{B} - SD(\bar{B}) \cdot \phi \; \leq \; \mu \; \leq \bar{B} + SD(\bar{B}) \cdot \phi \;] = 1 - a$$

*Equation 7: Calculation of the confidence interval (Ci)*

### 3.5.2 K-tree distance sampling method

The k-tree distance sampling method (KTDSM) works with distance based plots and can be combined with the tract layout from chapter 3.3. During this study the number of trees was increased from three to six. At each plot the six closest trees to the plot center was measured within a maximum circular range of 25 m. The measurement considers all attributes from chapter 3.6, except the recording of deadwood. The “6-tree technique” is a variation of the k-tree distance sampling and was proposed from (Prodan, 1968). Figure 18 shows a potential plot inside the mangrove forest. The plot center is marked with a cross and the maximal circular distance is 25 m.

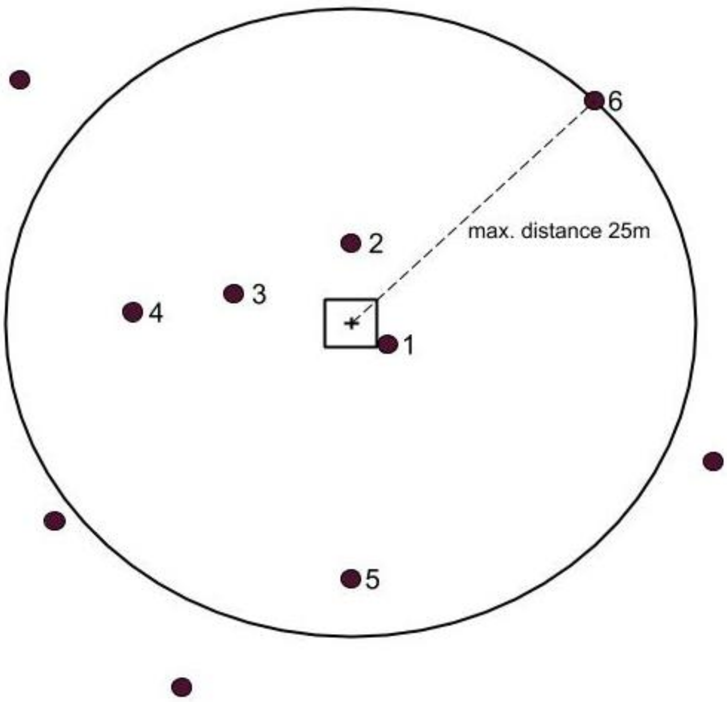



*Figure 18: Plot of the KTDSM*

#### 3.5.2.1 **Estimation for a hector value using the k-tree distance sampling method**

With the following equations the biomass per hectare can be estimated. ‘n’ describes the number of tracts. In each delta (Rewa and Ba) are n = 5 tracts with i = {1,2,…,n}. Each tract has independent plots. ‘h’ describes the number of plots. In each tract are h = 4 plots with I = {1,2,…,h}. The plots are nonuniform and have an individual radius ($r_{md}$), which can be calculated with Equation 8. The distance to the k-tree is declared as $d_k$.

$$r_{md} = \frac{1}{2}\,(d_k + d_{k+1})$$

*Equation 8: Radius of circular plot*

The size of a plot ($a_l$) can be calculated with Equation 9.

$$a_l = \pi r^2{}_{md}$$

*Equation 9: Size of a plot for the KTDSM*

For estimate a hectare value an expansion factor (EF) gets calculated with Equation 10.

$$EF_l = \frac{10000}{a_l}$$

*Equation 10: Calculation of the expansion factor for the KTDSM*

Each plot has a different size. Therefore, for all plots a corresponding EF must be calculated. $B'_{li}$ describes the median biomass of the $l^{th}$ plot of the $i^{th}$ tract. $B_{li}$ describes the mean biomass per hectare of the $l^{th}$ plot of the $i^{th}$ tract and can be calculated by using Equation 11.

$$B_{li} = B'_{li} \cdot EF_l$$

*Equation 11: Biomass values for one hector using the expansion factor*

Using Equation 12 the arithmetic mean of the biomass values per hectare per tract can be calculated. $\overline{B}_i$ is the median biomass per hectare of the $i^{th}$ tract.

$$\overline{B}_\iota = \frac{\sum_{l=1}^{hi} B_{li}}{h}$$

*Equation 12: Arithmetic mean of the biomass values per ha of the $i^{th}$ plot*

Using Equation 13 the median biomass per hectare per location/ delta can be calculated.

$$\bar{B} = \frac{\sum_{i=1}^{n} \overline{B}_\iota}{n}$$

*Equation 13: Estimation of a mean biomass per ha for one location*

With equation 14 the standard error (SE) can calculated. Therefore, the standard derivation (SD) is needed, which is generated from Equation 15.

$$SE(\bar{B}) = \frac{SD}{\sqrt{n}}$$

*Equation 14: Calculation of the standard error*

$$SD = \sqrt{SD^2} \quad \text{and} \quad SD^2 = \frac{\sum_{i=1}^{n}(B_i - \bar{B})^2}{n-1}$$

*Equation 15: Calculation of the standard derivation used for Equation 10*

With Equation 16 the confidence interval can be calculated.

$$Ci\ [\bar{B} - SD(\bar{B}) \cdot \phi \leq \mu \leq \bar{B} + SD(\bar{B}) \cdot \phi\ ] = 1 - a$$

*Equation 16: Calculation of the confidence interval (Ci)*

## 3.6 Attributes for the inventory

Measuring of the parameters:

- Distance to plot center
- DBH (diameter at breast height)
- DBRH (diameter at buttress root height)
- Height of buttress root
- Height: Base, first branch, total
- Crown radius
- Angle of tree to plot center
- Deadwood
- Abnormality

**Distance to plot center**

Of each tree the distance to the plot center is measured.

**DBH**

The DBH must be measured in a uniform way. Inhomogeneity of growths, like tree forks or inclination must be considered. Figure 19 shows the measuring in exceptional cases.

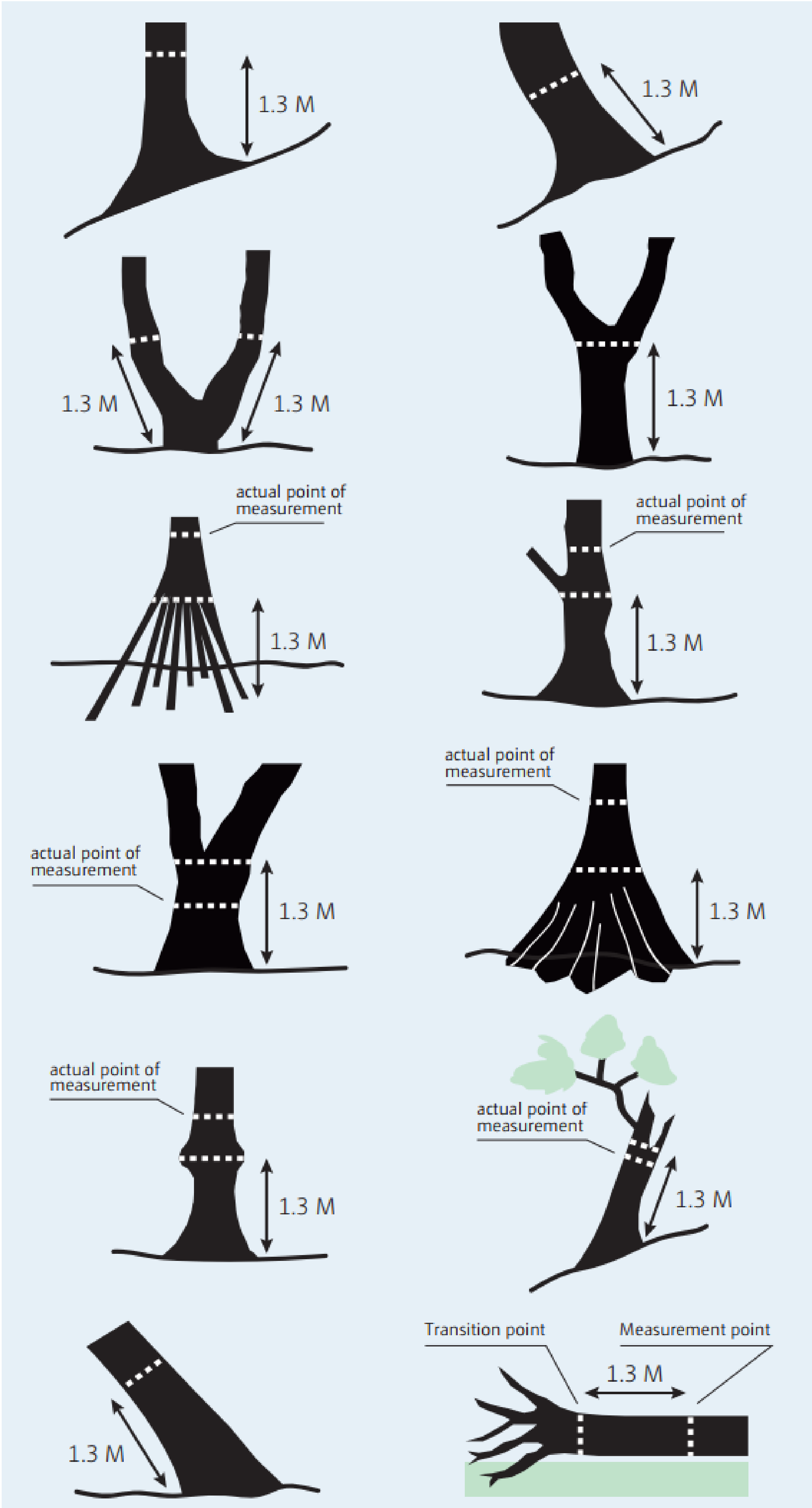



*Figure 19 Measuring of the BHD (UNFCCC, 2015)*

**DBRH**
The diameter at buttress root height is measured at the end of the buttress root. At the spot, where the trunk starts to get homogeneous and well-shaped the buttress root height must measure.

**Height of buttress root**
The measurement is started at ground level and then up to the end of the buttress roots. If the buttress roots vary in height immensely, it is possible to measure more than one height. Afterwards a median value can be calculated for the height.

**Height: Base, first branch, total**
All heights get measured with a "Sunnto PM-5 /360" clinometer. The measured angel should not be above 45°. As taller the angle, as higher the source of errors. For measuring the height with a clinometer it is important to choose a point with a good view of the tree. The distance between this point and the tree must be notated for further calculation. The base is the bottom of the tree. The first branch is normally where the crown starts to appear and the total height is the point of the top. If it isn't possible to get a clear value, it makes sense to look at the tree from different perspectives.

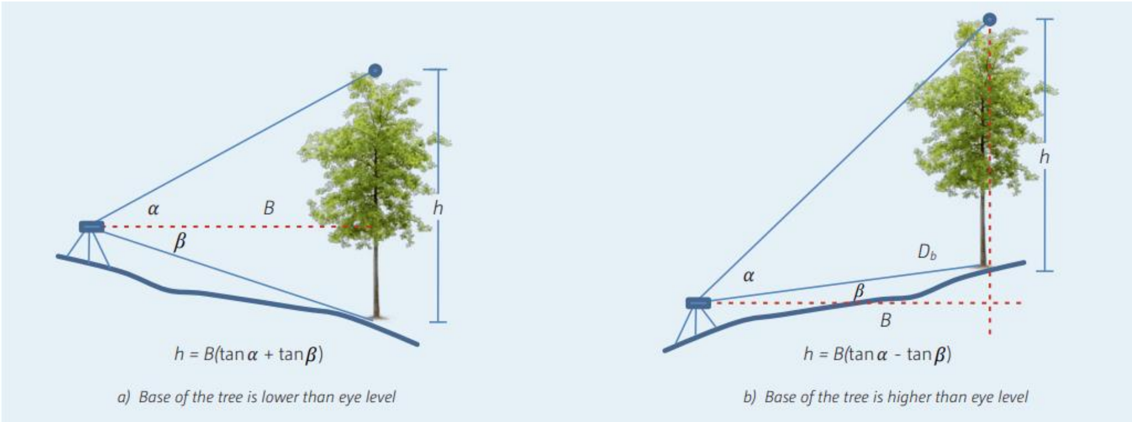



*Figure 20: Determination of the height with the trigonometric principle (UNFCCC, 2015)*

**Crown radius**
The crown radius is important to get better knowledge about the canopy cover. To get the crown radius the distance must be measured in all four cardinal directions. With straight grown trees the starting point is the trunk until to the edge of the branches. If the tree growth is very inclined it is better to put the starting point directly under the crown and note the inclination.

**Angle of tree to plot center**
The angel of each tree is measured outgoing from the center of each plot. The angle has been set with a compass. The northern direction was defined as 0° and south with 180°. After noting the angle of the trees, the distance from tree to plot center was measured. With knowledge of the angles and the distance of the trees a tree distribution can be calculated.

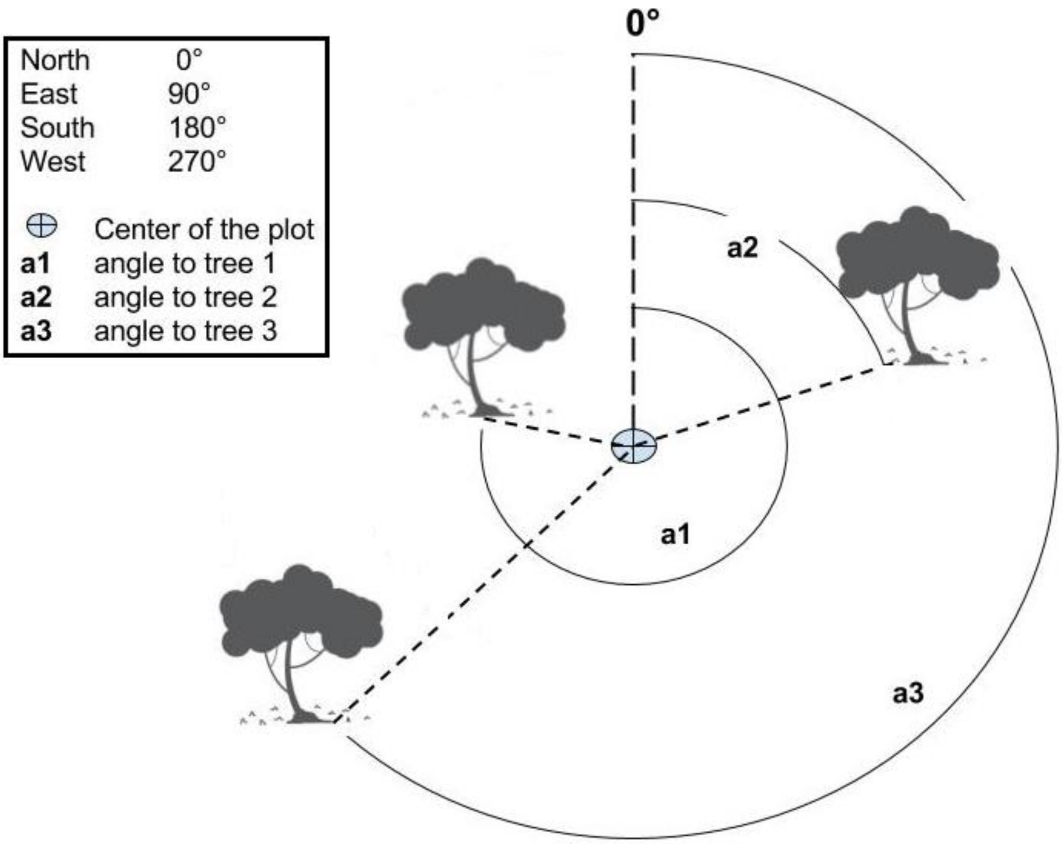



*Figure 21: Procedure to determine the angle of trees to the plot center (Brielmaier, 2017)*

Figure 21 describes the procedure for the tree distribution using the angle. Outgoing from the plot center the six closest trees were measured.

**Deadwood**

For this study deadwood was defined after the good practice guidance of the IPCC. The definition is listed in the appendix. Deadwood inside the plot was weighed and recorded. Deadwood around the plot was recorded as well, to make assumptions of the causes.

**Abnormality**

Abnormality on and around the plot was documented. Factors like anthropogenic influence, incarnation or rater abnormal growths must be considered.

## 3.7 Laboratory work

Each sample was weighed immediately after the fieldwork to get the greenwood weight $[m_w]$. A weight recording immediately after fieldwork prevents a possible pre air-drying and therefore a misrepresentation of the values. Weight recording was done with a scale of the Model SW CAS Cooperation 2011 (serial no: 110441505 and approval no.: 6/4C7 260). After weight recording all values were noted in an excel sheet and labeled.

### 3.7.1 Labeling of the samples

Each sample was labeled with five or six indicators e.g. **17|B|'|K|T|2**. The first Number (**17**) indicates the tract number. The second indicator (**B**) describes the tree species. **B** stands for Bruguiera gymnorrhiza. The third indicator (**'**) stands for the Ba delta. If a label doesn't have this indicator (**'**), means the sample is from the Rewa delta. Although the first indicator shows where the sample was taken from, the third indicator verifies it. The forth indicator (**K**) stands for one specific plot. **K** is the eleventh letter in the alphabet. Therefor it is the eleventh plot, which was measured. The fifth indicator (**T**) describes the section of the tree. T stands for trunk, B stands for branches and L stands for leaves. The last indicator (**2**) describes the sample number.

### 3.7.2 Determination of the Volume with immersion test

Using the immersion test the exact volume of an object can be determined. The selected object gets dipped into a liquid. During the same procedure the suppression of the liquid is measured. The suppression of the liquid has the same volume as the selected object itself. To measure the suppression of the liquid different methods can be used. In our case we measured the loss of the suspension (1. Method) and the suspension itself (2. Method). With an application of two results the outcome is more significant and mistakes can be determinate.
Two vessels and a scale are necessary for the immersion test. The weight of the two vessels must be known before the test can start. Vessel_1, which holds the liquid must be brimful and stands into vessel_2. Vessel_2 will hold the suspension. After the object is dipped into vessel_1, vessel_1 and vessel_2 must be measured separately.
No. 1 result: The difference of vessel_1 before the immersion and after the immersion is the equal volume of the dipped object.
No. 2 result: The difference of vessel_2 before the immersion drains into it and after the procedure is the equal volume of the dipped object.
With knowledge about the density of the liquid, the volume can be calculated. In our case we used water which has the density of 1 g/cm$^3$. Therefore, 1g of suppression is equal to 1cm$^3$ of the selected object. The immersion test has some advantages. The shape of the selected object does not hold any significance. Curviness doesn't influence the result either. Cavities are filled up with liquid and don't have a negative impact on the result. On the other hand, the measuring of very small objects is imprecise. A certain water displacement or rather volume is needed to break the surface tension. As well does the viscosity of the liquid influence the results. Therefore, it is recommended to

measure both vessels to determinate mistakes. With the differences in the results conclusions about the liquid, which sticks to the object, can be reached. The DIN 52182 (Testing of wood; determination of density) describes the procedure in detail.

#### 3.7.2.1 Example immersion test

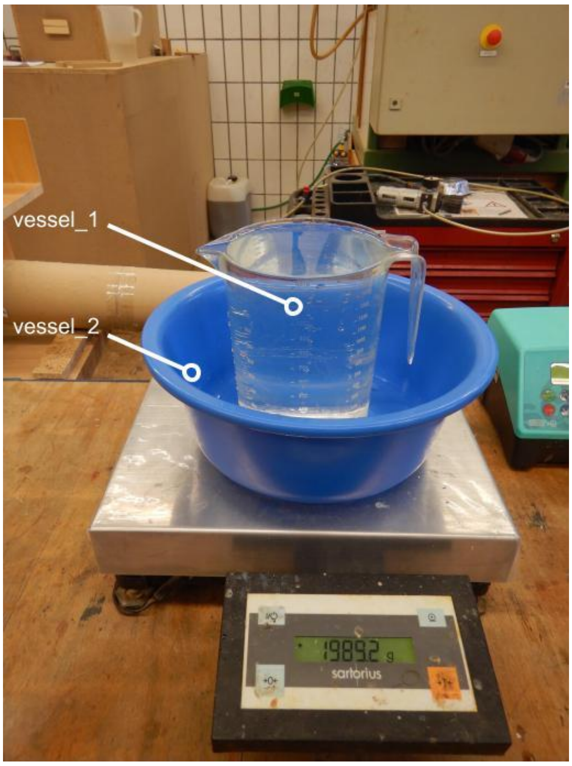



Figure 22 apparat for the immersion test (Brielmaier, 2017)

Vessle_1 brimful and vessel_2 empty

Scale shows weight with one decimal places.
Figure 22: 1989,2 g

Weights:
Vessel_1 empty: 215 g
Vessel_2 brimful: 1774,2 g
Apparat total: 1989,2 g

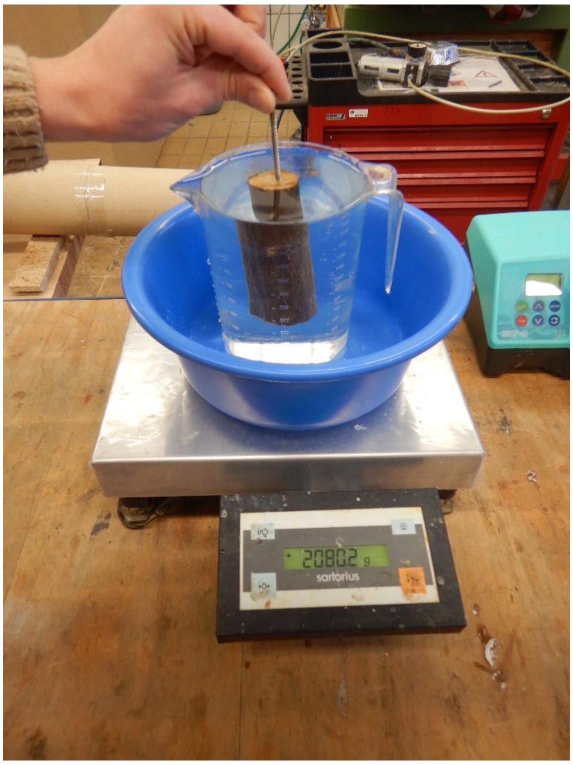



Figure 23 Sample dipped in vesse_1 (Brielmaier, 2017)

Vessle_1 with dipped sample and vessel_2 with drained suspension

Scale shows weight with one decimal places.
Figure 23: 2080,2 g

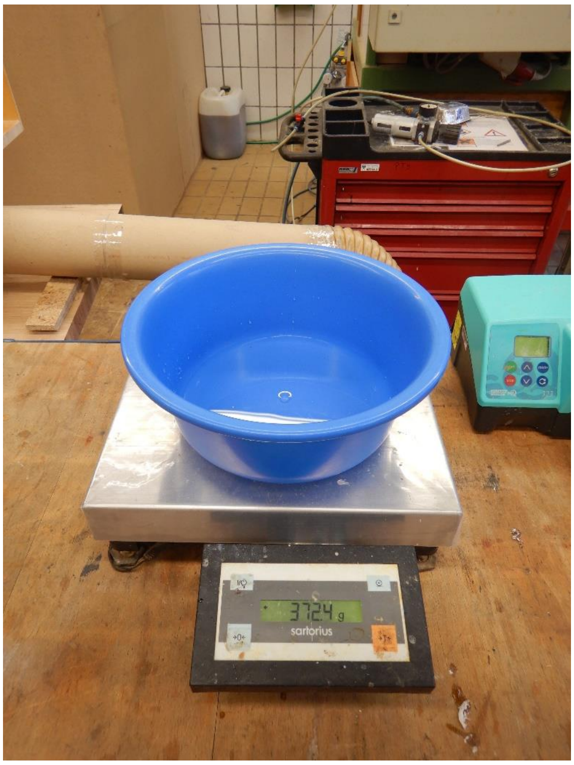
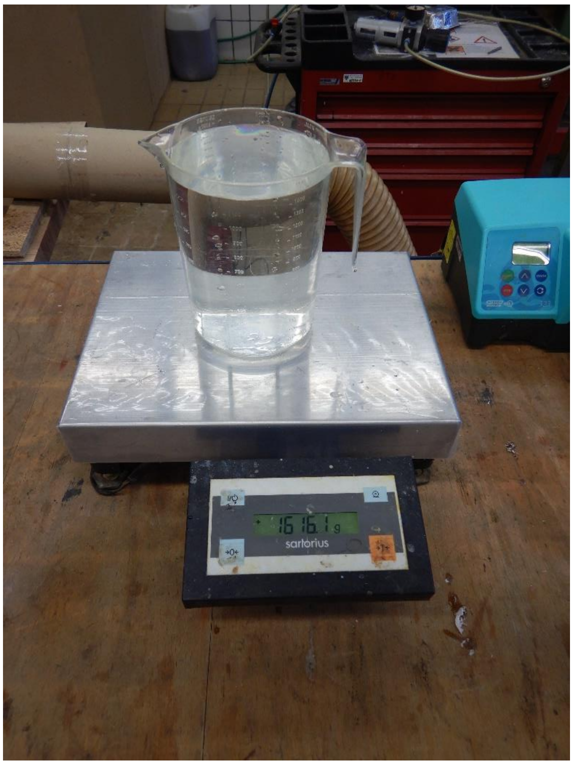



Figure 24 Vessle_2 holds the drainage and respectively the suspension (Brielmaier, 2017)

Vessle_2 with suspension

Scale shows weight with one decimal places.
Figure 24: 372,4 g




Vessel_1 brimful minus suspension

Scale shows weight with one decimal places.
Figure 25: 1616,1 g

*Figure 25 Vessel_1 after immersion (Brielmaier, 2017)*

| | | | | | | |
|---|---|---|---|---|---|---|
| 1. Method | Vessel_1 brimful | – | Vessel_1 after immersion | = | Suspension |
| | 1774,2g | – | 1616,1 g | = | 158,1 g |

| | | | | | |
|---|---|---|---|---|---|
| 2. Method | Vessel_2 with suspension | – | Vessel_2 weight | = | Suspension |
| | 372,4g | – | 215 g | = | 157,4 g |

The 1. Method shows a suspension of 158,1 g, which is equal to 158,1 $cm^3$.
The 2. Method shows a suspension of 157,4 g, which is equal to 158,1 $cm^3$

The difference of 0,6 g respectively 0,6 $cm^3$ is the liquid, which holds to the sample itself.

### 3.7.3 Determination of the volume by manual measuring

Samples with a good shape got manual dimensioned with a caliper. Sample with a cylindrical compound got determined with Equation 17 and samples with a shape of a bar got determined with Equation 18.

$$V = \pi \cdot r^2 \cdot h \qquad [V\ in\ cm^3; r\ and\ h\ in\ cm]$$

*Equation 17 Volume cylindrical compound*

$$V = l \cdot w \cdot h \qquad [V\ in\ cm^3; l, w, h\ in\ cm]$$

*Equation 18 Volume shape of a bar*

### 3.7.4 Kiln dry

After the weight and the volume were measured, the samples were kiln dried with the kiln dry method of DIN EN 13183-1: 2002:12. For that an oven model ‘ontherm thermotec 2000’ was used.
The kiln dry method is a destructive method of testing. Mechanical properties such as tensile strength, compressive strength, transverse tensile strength are lost. The samples were cut out of each section in form of discs or cylinders. The samples were dried in the oven (103 ± 2 °C) untill the moisture equilibrium was reached.

### 3.7.5 Water content

After the wood was kiln dried the weight ($m_0$) had to be taken again. The wood moisture ($u$) content of the samples was calculated with the Equation 19.

$$u = \frac{m_w}{m_0} \cdot 100 = \frac{m_u - m_0}{m_0} \cdot 100 \qquad [u \; in \; \%; \; m_w \; and \; m_0 \; in \; kg]$$

*Equation 19 Moisture content*

The samples for the wood moisture content measuring were taken each meter from the bottom of the trunk to the top of the trunk. Identical procedure was taken with one branch of the tree.

### 3.7.6 Gross density

All samples were weighed before and after kiln drying. In addition, the volume of the samples was measured before and after kiln drying. With Equation 20 the gross density ($\partial_g$) can be determined.

$$\partial_g = \frac{m_{dry}}{V_{wet}} \qquad [\partial_g \; in \; g/\,cm^3; \; m \; in \; g; \; V \; in \; cm^3]$$

*Equation 20 Gross density*

### 3.7.7 Kiln dry density

The kiln dry density ($\partial_{kd}$) describes the density of dried wood with a moisture content of 0%. With the kiln dry density wood can be determined as softwood or hardwood. Wood with a kiln dry density above 0,55 g/cm³ (500 kg/m³) is hardwood and wood below 0,55 g/cm³ softwood. With Equation 21 the kiln dry density can be determined.

$$\partial_{kd} = \frac{m_{dry}}{V_{dry}} \qquad [\partial_{kd} \; in \; g/\,cm^3; \; m \; in \; g; \; V \; in \; cm^3]$$

*Equation 21 Kiln dry density*

# 4 Results

During this study a high occurrence of *Bruguiera gymnorrhiza* was found in the Rewa delta. The tree is clearly dominating the middle zone. Compare to the Ba delta, the occurrence of *Bruguiera gymnorrhiza* is rather marginal.
Concerning the destructive sampling method (DSM) *Bruguiera gymnorrhiza* was found in 7 plots out of 40. All these 7 plots appeared in the Rewa delta. Table 3 shows on which plot *Bruguiera gymnorrhiza* was found and how much biomass was measured.

*Table 3: DSM: Biomass found on plots*

| Tract_Plot | Biomass [kg] |
|---|---|
| 240_E | 46.4 |
| 240_H | 252.94 |
| 30_I | 77.16 |
| 57_N | 42.21 |
| 141_Q | 1051.31 |
| 141_R | 258.51 |
| 141_S | 216.52 |

Concerning the k-tree distance sampling method (KTDSM) *Bruguiera gymnorrhiza* was found in 19 plots out of 40. In this case 17 plots were recorded in the Rewa delta and 2 plots in the Ba delta. Table 4 shows the occurrence of the trees recorded during the KTDSM.

*Table 4: KTDSM: Trees found on plots*

| Tract_Plot | Mesured trees on plot |
|---|---|
| 190_A | 3 |
| 190_B | 3 |
| 190_C | 3 |
| 190_D | 3 |
| 240_E | 3 |
| 240_F | 3 |
| 240_G | 1 |
| 240_H | 5 |
| 30_I | 3 |
| 57_M | 6 |
| 57_N | 6 |
| 57_O | 6 |
| 57_P | 6 |
| 141_Q | 6 |
| 141_R | 6 |
| 141_S | 8 |
| 141_T | 6 |
| 80_E | 2 |
| 17_K | 6 |

In total 85 *Bruguiera gymnorrhiza* trees were measured by the KTDSM and 12 trees measured by the DSM. The tallest tree inventoried was around 21,3 m high and had a DBH of 0,97 m. The biggest DBH inventoried was 1,18 m. Around 250 samples were examined to determine the water content, the gross density and the kiln dry density.
The following figures were generated with Excel 2016. The logarithmic and power functions are calculated with the least-square function approximation. The two- factorial analysis of variance (ANOVA) described in the following analysis were conducted with R studio version 3.4.3 (2017-11-30). If the ANOVA results a P-value greater than 0,05, the zero hypothesis is not excluded. This also means that all values smaller than 0,05 show a significant variance for the tested groups. All analyses of variance are listed in the appendix.

## 4.1 Biomass proportion

From the destructive sampled trees, the segments (trunk, branches, leaves) were weighed separately and were analyzed regarding their proportion. The proportions of the segments are listed in Table 5 and are calculated from the table "Weighed in segments" in appendix. In comparison to the deltas, the segments trunk and branches are like oppositional.

*Table 5: Proportion of above ground biomass per segment*

| | Trunk | Branches | Leaves |
|---|---|---|---|
| Rewa delta | 61% | 24% | 14% |
| Ba delta | 23% | 66% | 11% |

In the analysis of variance, the weight of the destructive sampled trees showed no significant difference between the two locations ($P = 0.5117$) or in relation to the position of a plot inside the tract ($P = 0.2621$). While the interdependency between plot and location show a variance of $P = 2.628e-05$.

## 4.2 Water content

Table 6 shows the water content (u) per segment. The percentage values are averages from all samples divided in segments and study side. The differences between the Rewa and Ba delta is negligibly small. Due to the milder climate in the central division of Fiji all segments do have a higher u in the Rewa delta. As Table 6 shows, the water content is just above the fiber saturation point.

*Table 6: Water content per segment*

| | Trunk | Brenches | Leaves |
|---|---|---|---|
| Rewa delta | 40% | 44% | 68% |
| Ba delta | 39% | 40% | 62% |

Table 7 shows a weighed standard value for the water content. This value is generated from all above ground wooden biomass (segments trunk and branches together) and is generated from table 5 and 6. E. g. a higher precentral proportion of the trunk means, that the u of the trunk counts more into the standard value. Table 7 shows, that the u between the two different locations is marginal and can be averaged to 40.12%.

*Table 7: Standard value of the water content for Rewa - and Ba delta*

| | Rewa | Ba |
|---|---|---|
| Standard value | 40.88% | 39.36% |
| SD | 0.07 | 0.08 |

The analysis of variance of the water content (in the components trunk and branches) for all tracts show a significant difference in relation to the appearance inside the tract (P = 0,01596). A significant difference between the two deltas is not present (P = 0,79528). While the interdependency of plot and location show a variance of P = 0,05799. In analysis, concerning only branches, the result shows a significant variance of P = 0,002226 between the two locations (Rewa and Ba).

## 4.3 Gross density

The gross density was determined as described in chapter 3.7.6 and is generated only from samples from the Ba delta. All samples were measured with bark. Therefore, the actual values is underestimated. Further results are calculated with the density from the immersion test.

*Table 8: Gross density*

| | Immersion test | Caliper |
|---|---|---|
| Gross density | 0,75 g/cm³ | 0,62 g/cm³ |
| SD | 0.16 | 0.15 |

## 4.4 Kiln dry density

The kiln dry density was determined as described in chapter 3.7.7 and is generated only from samples from the Rewa delta. All samples were measured with bark. Therefore, the actual values is underestimate.

*Table 9: Kiln dry density*

| | Immersion test |
|---|---|
| Kiln dry density | 0,99 g/cm³ |
| SD | 0.14 |

## 4.5 DBH in relationship to height

The DBH and the height are two influencing variables for the calculations of the volume function. Figure 26 shows the relationship between DBH and height. The blue and green points representing trees. The variance of the measured trees is quite high. This is due to the qualities of a mature *Bruguiera gymnorrhiza* forest. There are two principal reasons for the high variance. Firstly, some trees are inclined and the inclination is not considered in this study. Secondly, the green point represents the trees from the Ba delta. All those trees have approximately the same dimensions. More precisely, the trees from the Ba delta have a small variance in height ($SD^2 = 0.15$) and small variance in the DBH ($SD^2 = 0.004$). This does affect the function to have a lower inclination, because all trees in the Ba delta are smaller in height, compared to most of the trees in the Rewa delta. The two outstanding points or rather trees with a DBH/ Height of 0,97 m/ 21,33 m and 1,18 m/ 20,26 m are positive giant trees and belonging to the same plot (141S). These two trees have by far the biggest DBH and the highest volume of all inventoried trees.
Figure 26 shows two functions. The linear function and as well the logarithmic function were generated with the least-square function approximation. For the available data, the linear function is decisive. The linear function does represent the values better, compared to the logarithmic function. First, the linear function does have a higher coefficient of determination ($R^2 = 0.3369$). Second, the logarithmic function is influenced of the frequency of small trees and has therefore a smaller inclination.

$$y = 13.128x + 7.2086 \qquad [y\ is\ Height\ in\ m;\ x\ is\ DBH\ in\ m]$$

*Equation 22: DBH in relationship to the Height using the linear function*

The analysis of variance shows a significant relation (P = 5.8035E-09) between DBH and Height (SE = 2.02).

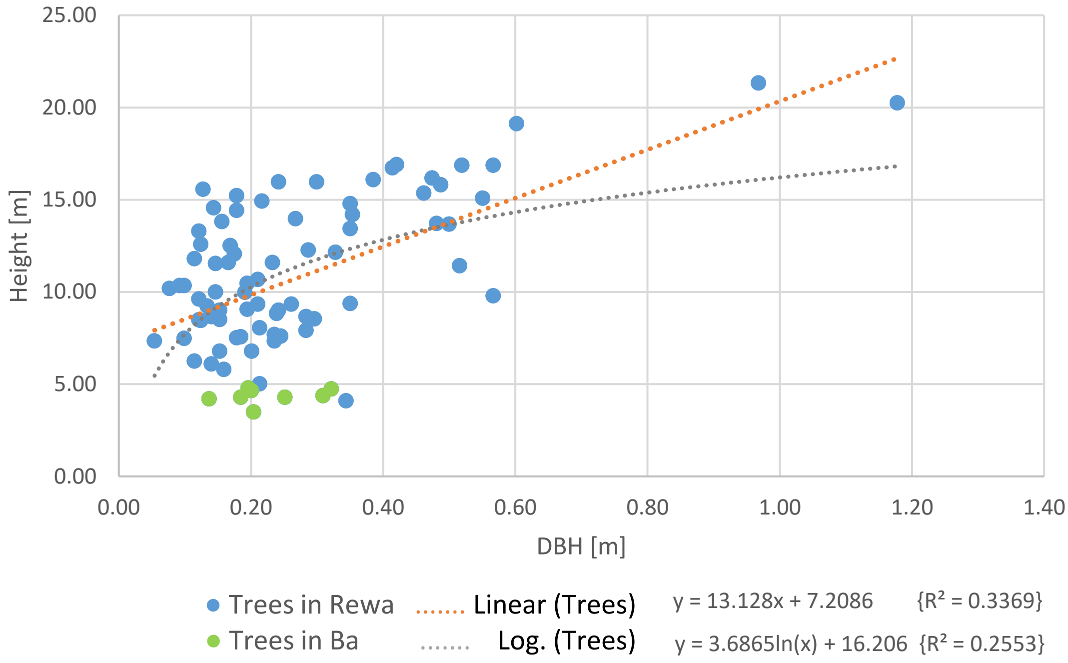



*Figure 26: DBH in relationship with Height*

## 4.6 From factor

The form factor (F) is the ratio of the actual volume of the tree trunk ($V_T$) in relationship with the volume of a cylinder ($V_c$). The $V_T$ gets determinate with Equation 23. Therefore, the weight ($m_t$) of the trunk was measured already in the study area and the density ($\partial$) was determined as described in chapter 3.7.6.

$$V_T = \frac{m_t}{\partial} \qquad [V_T \; in \; m^3; m_t \; in \; g \; and \; \partial \; in \frac{kg}{m^3}]$$

*Equation 23: Volume tree*

The $V_c$ gets determinate with Equation 24. Therefore, the DBH and the height (H) were measured already in the study area as described in chapter 3.6.

$$V_c = \pi \cdot (\frac{DBH}{2})^2 \cdot H \qquad [V_c \; in \; m^3; \pi \; is \; dimensionless; \; DBH \; and \; H \; in \; m; \;]$$

*Equation 24: Volume cylinder*

The form factor ($F_{1,3}$) is generated from all destructive sampled trees and calculated by Equation 25. The F is determinate to be 0,62.

$$F_{1,3} = \frac{V_T}{V_c} \qquad [F_{1,3} \; is \; \text{dimensionless}; \; V_T \; and \; V_c \; in \; m^3]$$

*Equation 25: From factor*

## 4.7 Volume function

With the volume function and the from factor (F) the volume of a trunk can be quickly determined. An easy measurable parameter, like the BHD or the height, is needed to generate the equation. With Equation 26 the volume of the trunk is calculated.

$$V_T = \pi \cdot (\frac{DBH}{2})^2 \cdot H \cdot DQ \qquad [V_T \; in \; m^3; DBH \; and \; H \; in \; m; \; \pi \; and \; DQ \; are \; \text{dimensionless}]$$

*Equation 26: Volume of a tree*

### 4.7.1 Volume function using DBH

Figure 27 shows the relationship between the DBH and the Volume. The volume increases exponentially with a bigger DBH. This relation is used to estimate the volume of the trunk with only knowing DBH. For this purpose, the power function $y = 7.4952x^{2.2975}$ with $R^2 = 0.9189$ *was* generated.

$$y = 7.4952x^{2.2975} \qquad [y \; is \; Volume \; in \; m^3; \; x \; is \; DBH \; in \; m]$$

*Equation 27 Volume function using DBH*

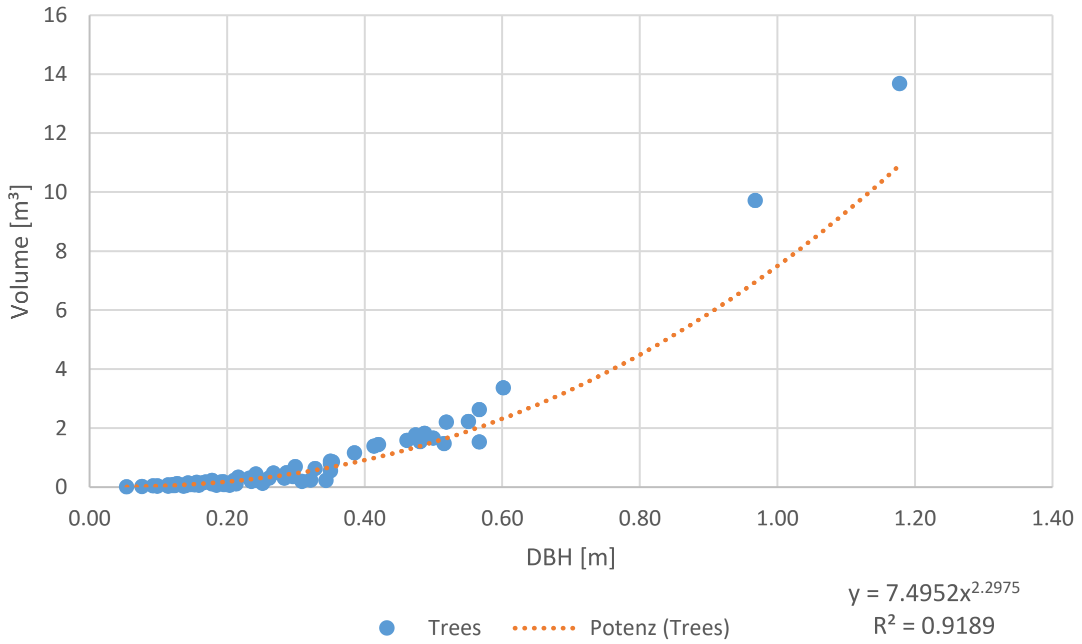



*Figure 27: DBH in relationship to Volume*

### 4.7.2 Volume function using Height

Figure 28 shows the relationship between the volume of the trunk and the height. As bigger the volume as smaller the increase of height. The volume function using the height has a stability factor of *$R^2 = 0.4149$.*

$y = 13.085x^{0.2001}$ $[y\ is\ Height\ in\ m^3;\ x\ is\ Volume\ in\ m]$

*Equation 28: Volume function though Height*

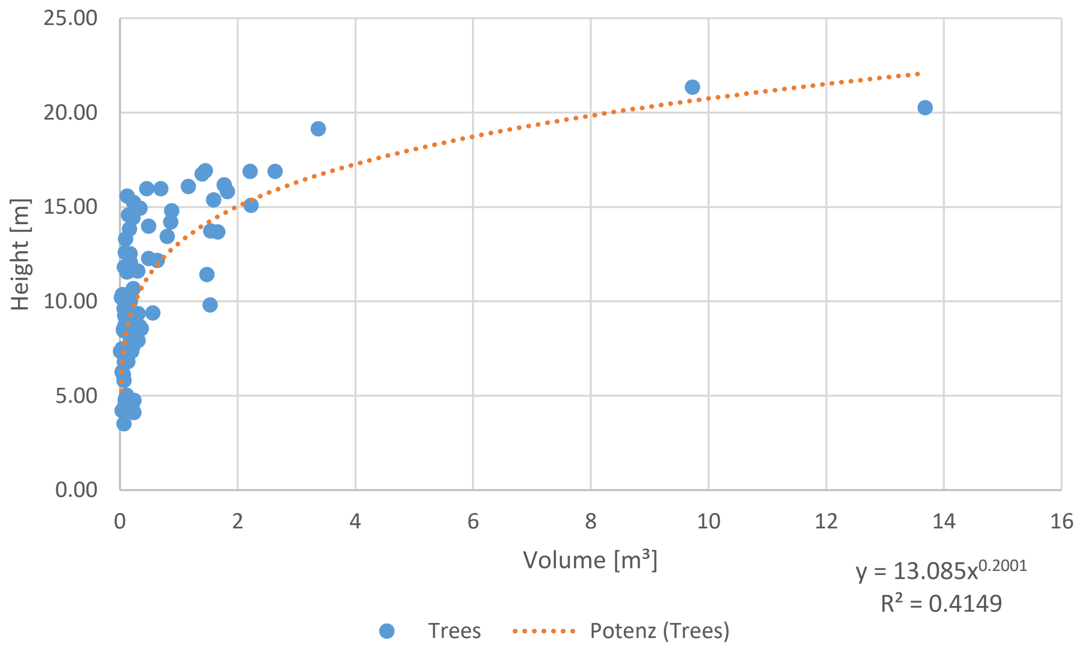



*Figure 28: Volume in relationship to Height*

### 4.7.3 Volume function using DBH 2.0

The volume functions from chapter 4.7.1 don't consider the volume of the branches. With table 5 *(Proportion of above ground biomass per segment)* a more precise volume can be determined. For the following volume function only, the wooden biomass is considered from table 5. Therefor a proportion factor for the branches of 28,26% gets added to the volume. A new volume function can be generated.

Figure 29 shows the relationship between the DBH and the total Volume. The volume increases exponentially with a bigger DBH. This relationship is used to estimate the total volume with only the DBH. For this purpose, the power function $y = 9.6115x^{2.2975}$ with $R^2 = 0.9189$ *gets* generated.

$$y = 9.6115x^{2.2975} \qquad [y \; is \; Volume \; in \; m^3; \; x \; is \; Height \; in \; m]$$

*Equation 29: Total Volume function using BDH*

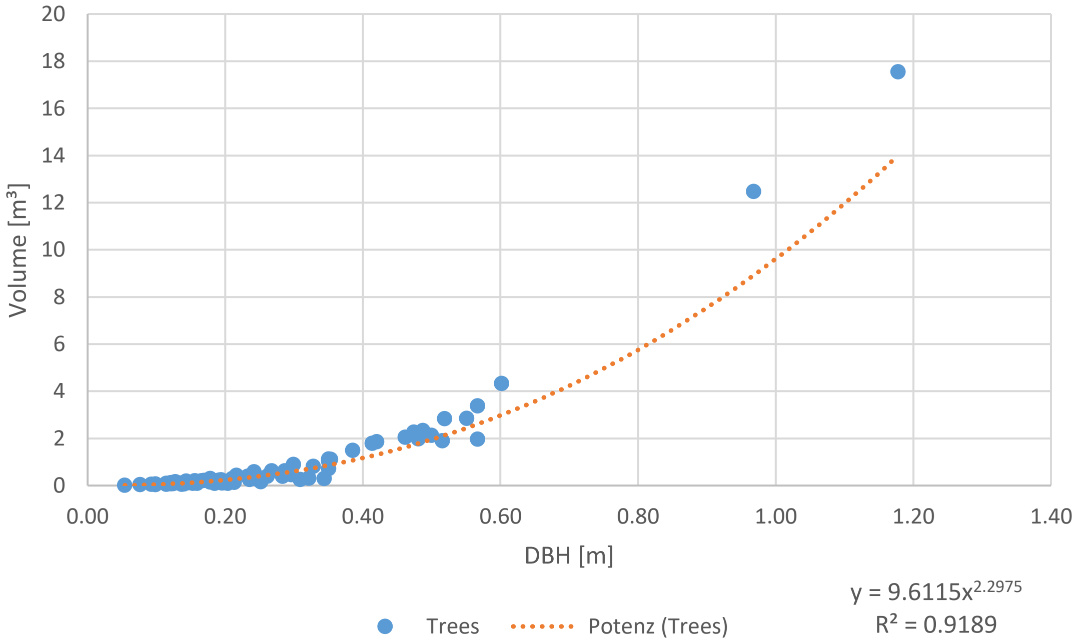



*Figure 29: DBH in relationship to volume with proportion factor branches*

### 4.7.4 Volume function using Height 2.0

Figure 30 shows the relationship between the total volume and the height. As bigger the volume as smaller the inclination of the function. The total volume function using the height has a stability factor of $R^2 = 0.4149$.

$$y = 12.449x^{0.2001} \qquad [y\ is\ Height\ in\ m;\ x\ is\ Volume\ in\ m^3]$$

*Equation 30: Total Volume function using Height*

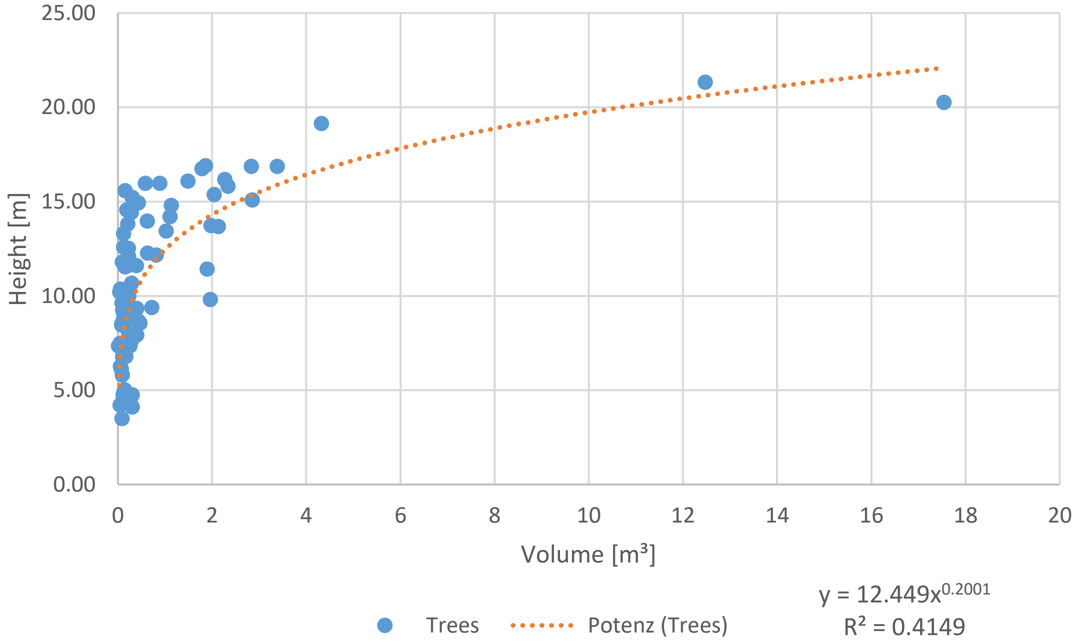



*Figure 30: Volume in relationship to Height with proportion factor branches*

## 4.8 Stump inventory

In the case of deforestation for fuel wood the stumps of the trees almost always don't get harvested. The dimension of the buttress root makes a ground cut more difficult. Therefore, only the trunk above the buttress root gets harvested and the buttress roots themselves remain inside the forest. It is a valuable index to make a conclusion about the height and volume of the harvested tree, with only the dimension of the remained buttress root.

### 4.8.1 DBRH in relationship to height

Figure 31 shows the relationship between the DBRH and the Height of the tree. The blue and green points representing trees. The linear function and as well the logarithmic function were generated with the least-square function approximation. The coefficient of determination of the linear function and the logarithmic function are not significantly different. Therefore, logarithmic was chosen to describe the relationship between DBRH and Height. Equation 31 has the coefficient of determination of *$R^2$ = 0.4214.*

$$y = 5.0989 ln(x) + 17.621 \qquad [y\ is\ Height\ in\ m;\ x\ is\ DBRH\ in\ m]$$

*Equation 31: Height function*

The analysis of variance shows a significant relation (P = 2.3559E-12) between DBRH and Height (SE = 1.80).

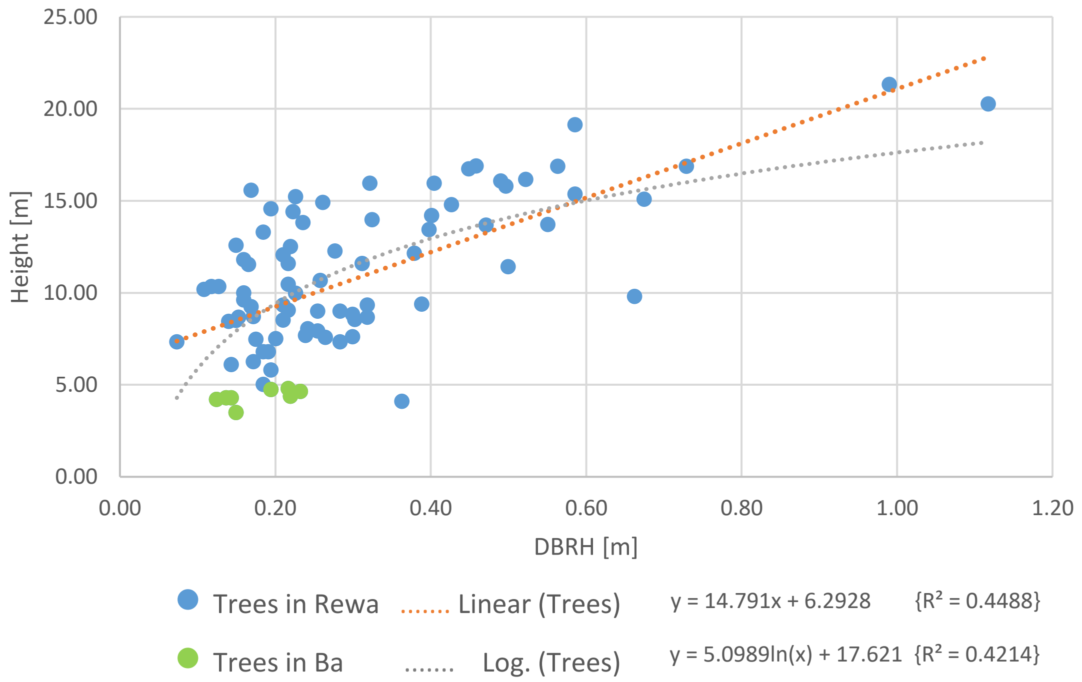



*Figure 31: DBRH in relationship to Height*

### 4.8.2 Volume function using DBRH

Figure 32 shows the relationship between the DBRH and the Volume of the trunk. The volume increases exponentially with a bigger DBRH. This relationship is used to estimate the volume of the trunk with only the DBRH. The same from factor of 0,62 was used to generate the volume function as shown in Equation 32.

$$y = 7.1455x^{2.4892} \qquad [y\ is\ Volume\ in\ m^3;\ x\ is\ DBRH\ in\ m]$$

*Equation 32: Volume function using DBRH*

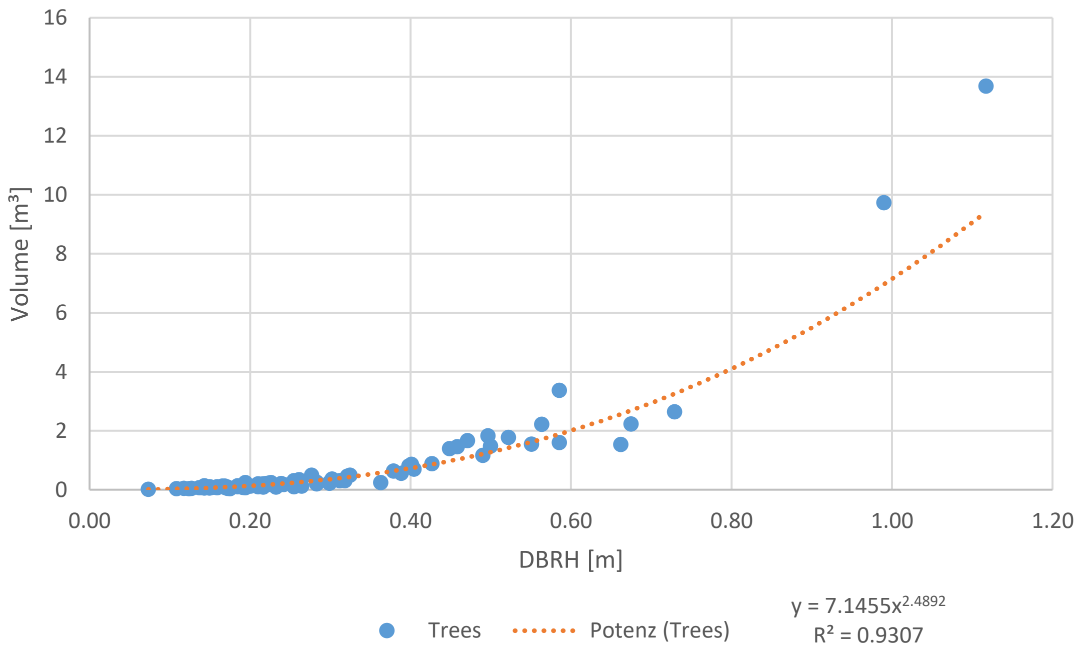



*Figure 32: DBRH in relationship to Volume*

### 4.8.3 Volume function using DBRH 2.0

The volume functions from chapter 4.8.2 don't consider the volume of the branches. With table 5 *(Proportion of above ground biomass per segment)* a more precise volume can be determined. Only the wooden biomass is considered from Table 5. Thereforr the proportion factor of 28,26% from the branches is added to the volume function from chapter 4.8.2 and a new volume function can be generated.

$$y = 9.163x^{2.4892} \qquad [y\ is\ Volume\ in\ m^3;\ x\ is\ DBRH\ in\ m]$$

*Equation 33: Total Volume function using DBRH*

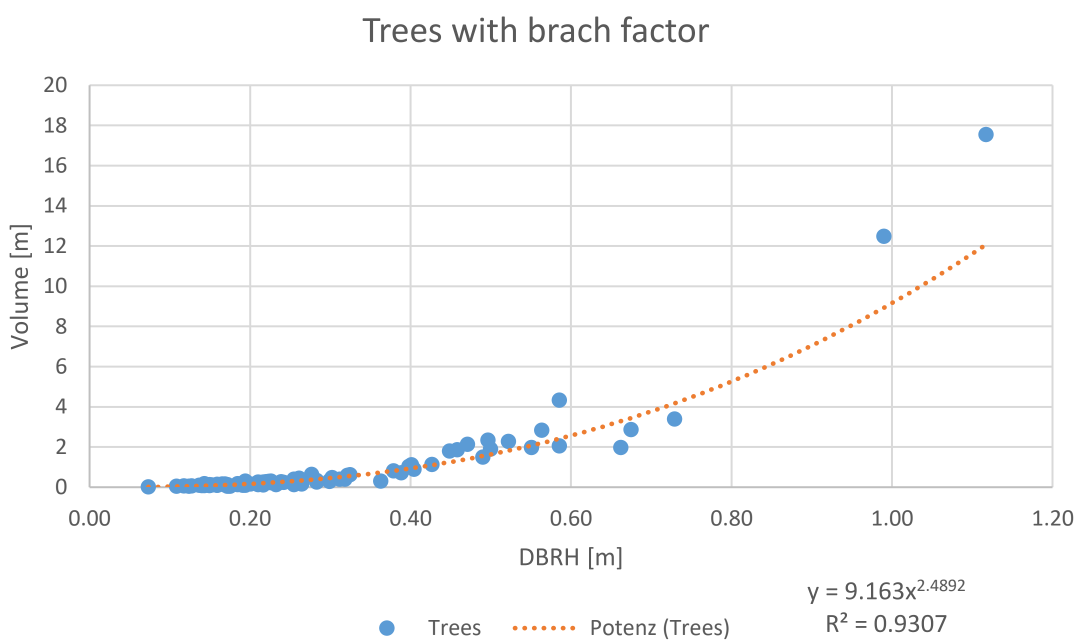



*Figure 33: DBRH in relationship to volume with proportion factor branches*

## 4.9 Crown dimension

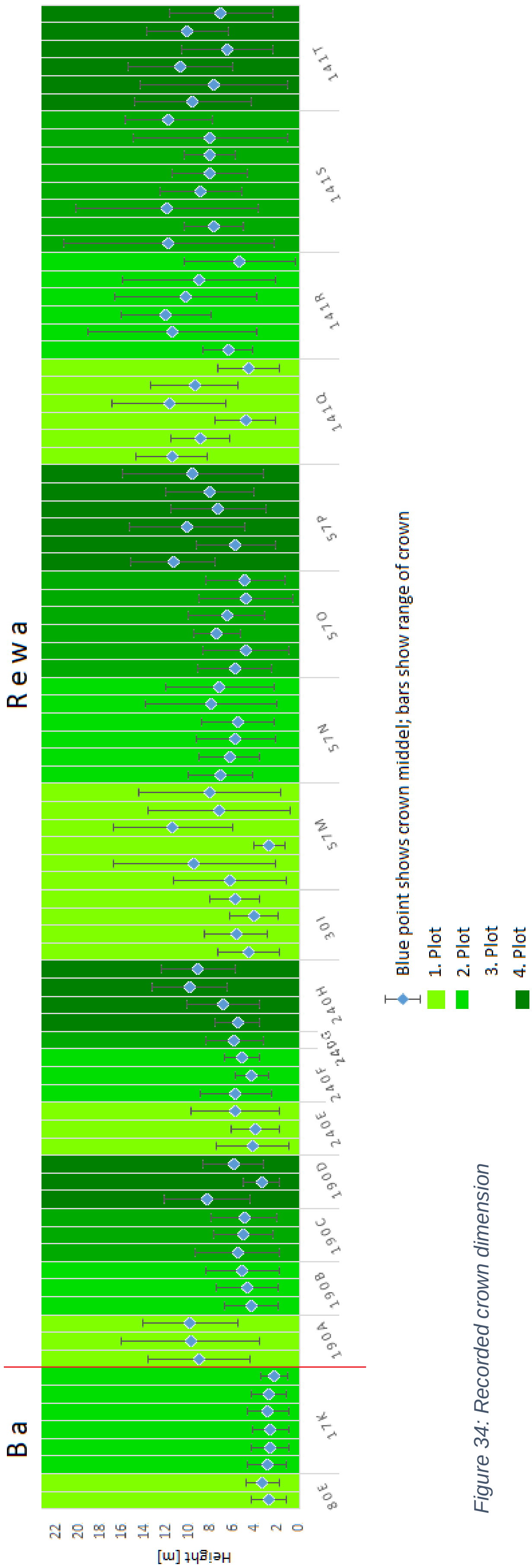



Figure 34: Recorded crown dimension

Figure 34 shows the crown dimension of all recorded trees. Starting from every tract the trees are listed according to occurrence. At a closer look the figure shows the total height of the tree with the top of the bar, the blue point represents the middle of the crown and the bottom of the bar shows the first branch of the crown. The bars show the dimension of the height or rather the crown from of vertical few or rather a front few of the tree. The colors describe the distance to the waterfront. The darker the color, the further away the tree is from the waterfront. Only tract 240 started from the landside. In this case, the darker the color the further the plot is inside the forest. Only eight trees on two tracts (80'E and 17'K) were recorded in the Ba delta. All those trees have around the same crown dimension and the same height. A similar relationship was already found in chapter 4.5 between the DBH and the height. In addition, the distance to the waterfront doesn't influence the crown dimension and the height in the Ba delta.

## 4.10 Geographical arrangement and graphic representation of the crown canopy cover

The following graphics will show the distribution of the trees in relation to the plot center. Out of 40 plots, 4 plots were chosen to describe the forest structure. The chosen plots reflecting to forest structure as described in chapter 2.1 and the crown dimensions as described in chapter 4.9. Figure 35, Figure 36 and Figure 37 are Plot located in the Rewa delta. Figure 38 is a Plot located in the Ba delta. As described in chapter 3.5.2 the numbers of recorded trees were increased from three to six during this study. The positive y-values are equivalent to north. The positive x-values are equivalent to east. The negative y-values are equivalent to south and the negative x-values are equivalent to west. The plot is marked as a red square and the plot center is located, where the grid is intersecting. The crown canopy cover is described as 'tree' and marked as green circles. The position of the trunk is located directly under the canopy cover. The size of the circles is proportional to the crowns, but they are under proportionally represented in relation to the distance of the tree coordinates. The measured crown radii in the direction of north, east, south and west usually showed distinct decentralized crown formation. Thus, the illustrated crowns do not correspond to the scale. As well, on some plots an inclination of the trees was found and only partly respected

.

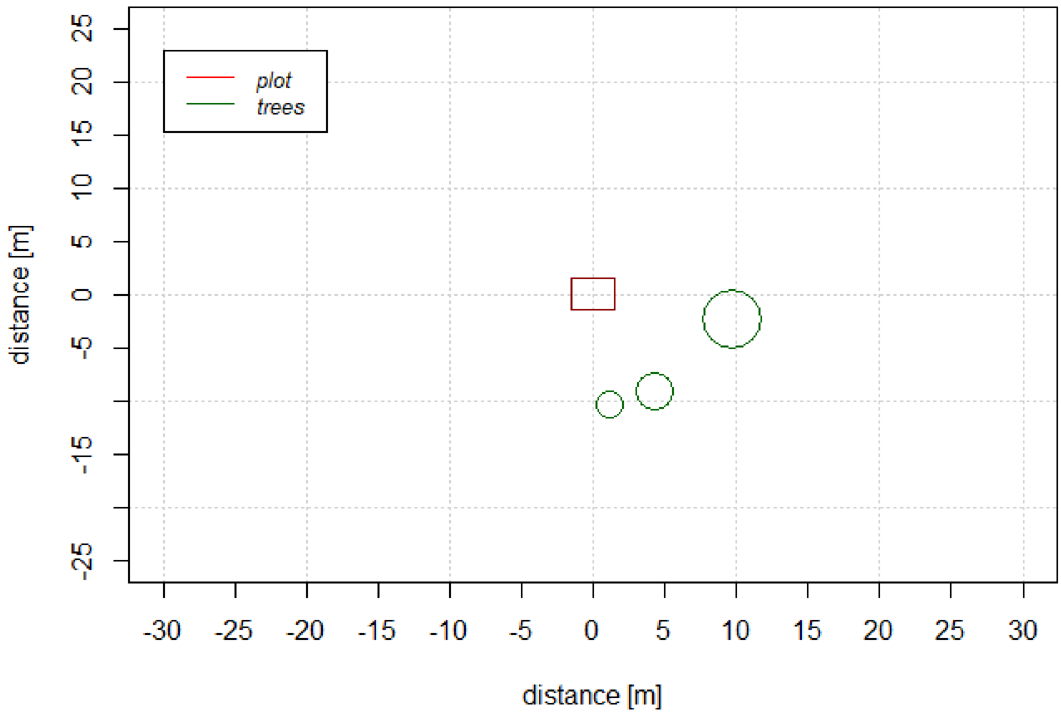



*Figure 35: geographical arrangement and crown canopy cover for plot no. 190A*

Figure 35 shows the geographical arrangement of the recorded trees at plot 190A. In tract 190, only the three closest trees to the plot center were surveyed. As seen in Figure 35 all surveyed trees are evenly distributed to the plot center. The distance to the plot center varies between 10 m to10,40 m. At plot 190A the waterfront is in the cardinal direction North-West and 5,1 m away from the plot border. Tract 190 is in an intermixed mangrove forest as described in chapter 2.1. Therefore, straight on the riverside *Bruguiera gymnorrhiza* does not grow.

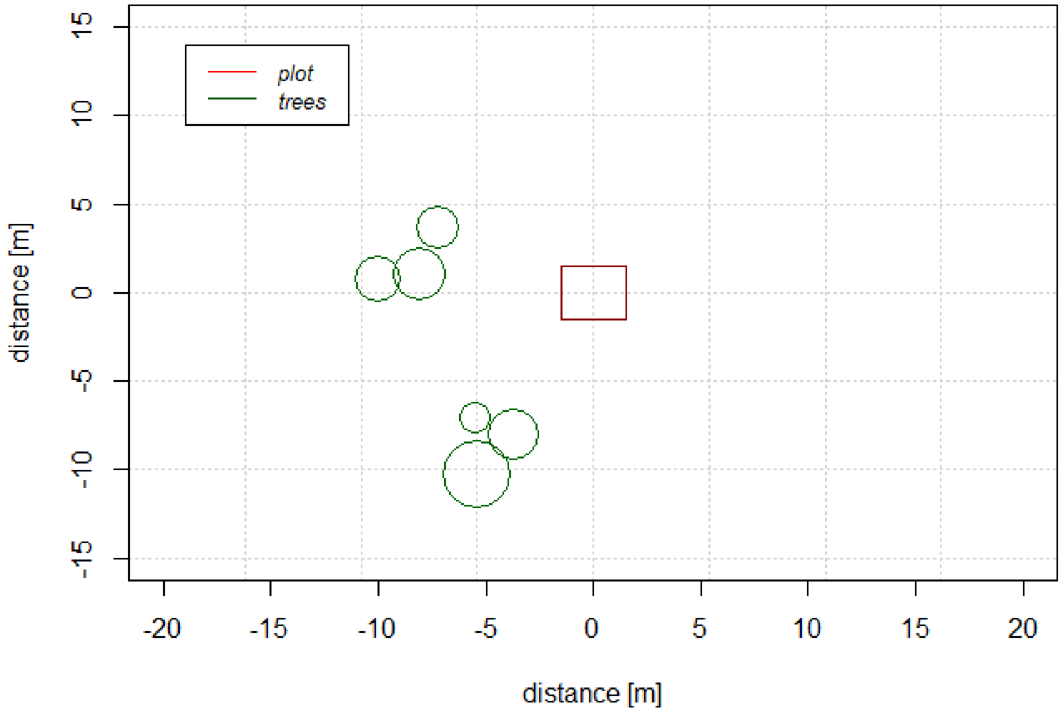



*Figure 36: geographical arrangement and crown canopy cover for plot no. 57M*

Figure 36 shows plot 57M. Plot 57M is the starting plot of the tract and located next to the waterfront. The waterfront is in direction east and 9,4 m from the plot border away. Figure 36 shows, that the distribution of *Bruguiera gymnorrhiza* is cluster wise and on the other side of the plot compare to the waterfront. The closest tree is located 8,1 m away from the plot center. The furthest tree away is located 11,6 m away from the plot center. The three trees from the southern cluster are around 60° inclined in direction north-east. Tract 57 starts in a mixed forest.

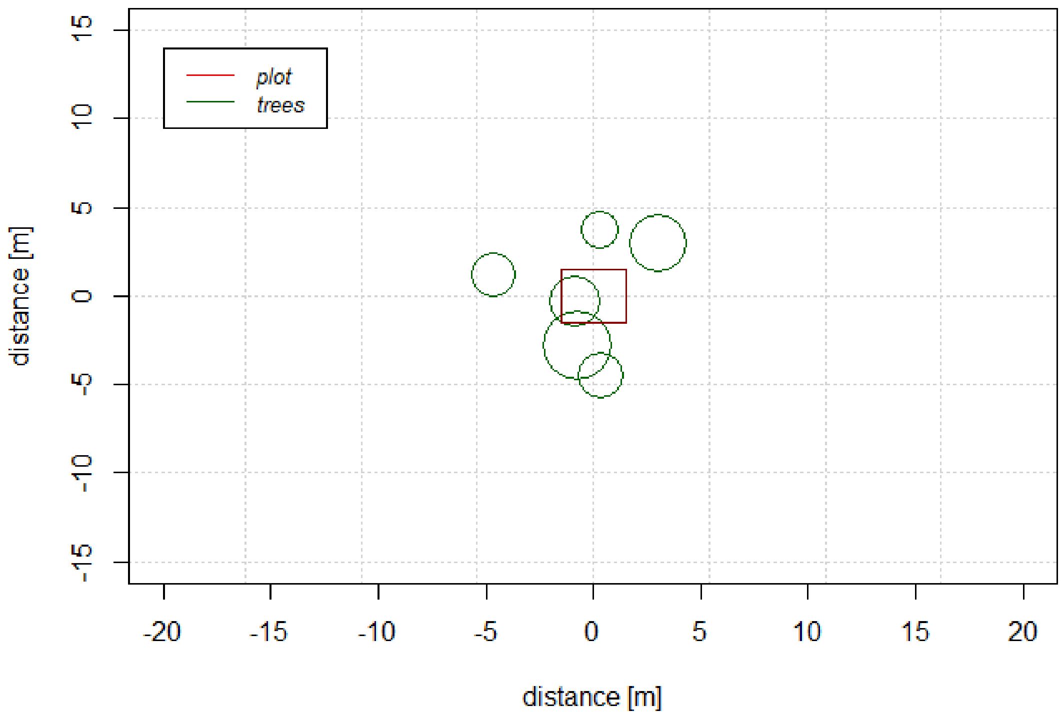



*Figure 37: geographical arrangement and crown canopy cover for plot no. 141Q*

Plot 141Q shows a high density of B. gymnorrhiza trees in a *Bruguiera gymnorrhiza* dominated forest. The waterfront is in direction south-west and 8,5 m away from the plot border. The closest tree was measured 0,95 m away from the plot center and is located inside the plot. All trees are inclined towards the waterfront in direction south-west.

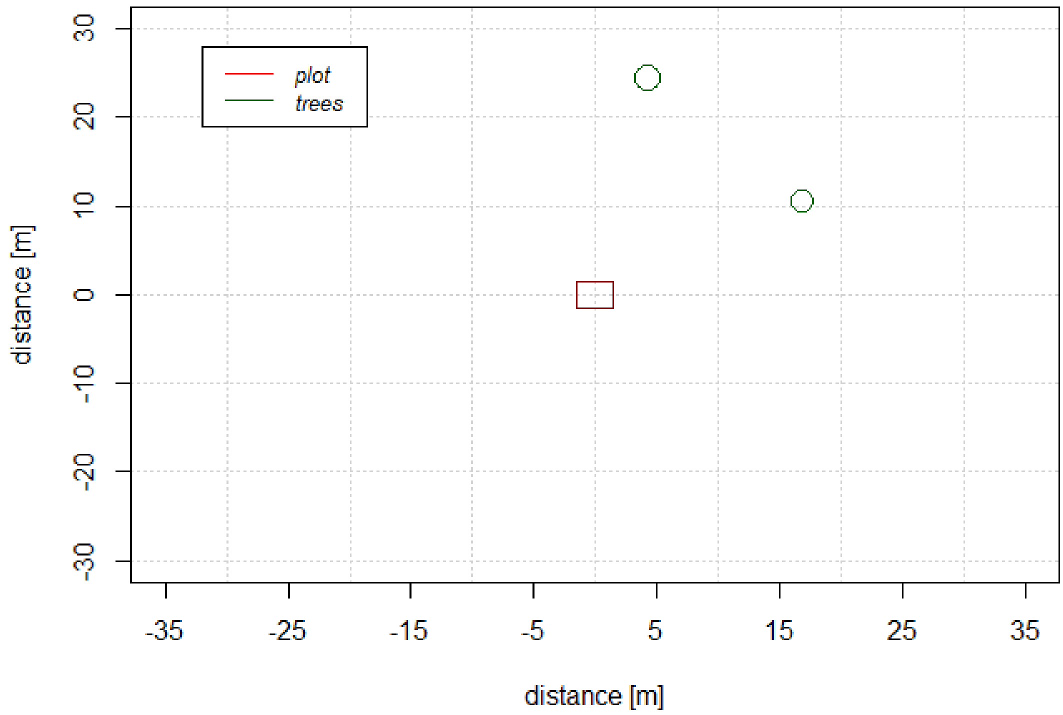



*Figure 38: geographical arrangement and crown canopy cover for plot no. 80'E*

In Ba on plot no. 80'E only two trees were found in the surrounding area. The closer tree was standing 19,9m away from the plot center. The second tree was located 24,9 m away from the plot center inside the forest. The trees were located between the first plot (plot 80'E) and the second plot (80'F). The waterfront is in direction south-east.

The geographical arrangement and crown canopy cover for all separate plots are listed in the appendix.

The analysis of variance for the crown canopy cover shows no significant difference in relation to the different plots (P = 0.47586), but a significant variance for the locations Rewa and Ba (P = 0,03701). Tracts starting from waterfront the analysis of variance showed a significant difference in relation to the two locations (P = 0,02525). The interdependency plot to location and location to plot shows no significant variance.

## 4.11 Dependency from all recorded trees in relationship to the water distance

During this study *Bruguiera gymnorrhiza* was mostly found in the Rewa delta. The typical mangrove forest as described in chapter 2.1 did not appear in the Ba delta. Additionally, a single-species *Bruguiera gymnorrhiza* forest didn't appear in the Ba delta. The tree was only found next to two plots (80'E and 17'K) and grows in clusters. All trees have almost the same dimensions. This is a clear indicator for an unnatural forest structure. It can be assumed, that a deforestation on a big scale took place several decades ago. The following figures are generated from the k-tree distance sampling method (KTDSM) (chapter 3.5.2) and will show, that *Bruguiera gymnorrhiza* is completely different in the locations Ba - and Rewa delta.
For each plot a mean value was generated. In addition, the plots were sorted by the distance to the waterfront. The 1st plot is the closest plot to the waterfront and the 4th is the furthest away from the waterfront. For a general overview the tracts 240 and 165, which didn't start from the waterside, won't show up in the following figures as well as the following analysis of variance.

### 4.11.1 Water content

Table 10 shows the mean value per plot of all recorded samples. The value values for the water content are weighed as described in chapter 4.2. In addition, the plots were sorted by the distance to the waterfront.

*Table 10: Mean water content per plot*

| Plot | Water Content (u) | Plots sorted according to distance to waterfront |
|---|---|---|
| 190A | 36% | 1 |
| 240F | 38% | 2 |
| 240H | 41% | 4 |
| 57N | 43% | 2 |
| 57O | 44% | 3 |
| 57P | 44% | 4 |
| 141R | 37% | 2 |
| 141S1 | 45% | 3 |
| 80'E | 37% | 1 |
| 17'K1 | 41% | 3 |
| 17'K3 | 41% | 3 |

Table 11 shows the mean for the plots sorted to water distance.

*Table 11: Mean water content; Plots sorted to water distance*

| 1. Plot | 2. Plot | 3. Plot | 4. Plot |
|---|---|---|---|
| 36.64% | 39.69% | 42.65% | 42.21% |

Figure 39 shows Table 10 and Table 11 combined. The blue points are the values from Table 10 and the orange line is the values from Table 11. The closer the plot is located to the water front, the lower the water content. The water content (u) also decreases on the way to the 4th plot. The 4th plot was sometime on the edge to the forest and already intermixed with whit mangroves. In those habitats the subsoil is already dryer, which could influence the u of the tree.
The analysis of variance, tested all trees located in tracts starting from waterfront. It shows a significant difference (P = 0,01173) of the water content in relation to the position of the trees inside the tract. Separating the trees in the components 'trunk' and 'branches', there is a significant difference for both components in relation to the plot (trunk: P = 9,935e-07; branches: P = 1,321e-11). The water content determined for branches also shows a significant difference in relation to the two locations (Ba and Rewa) (P = 0.001001). The interdependency was tested for all components as well.

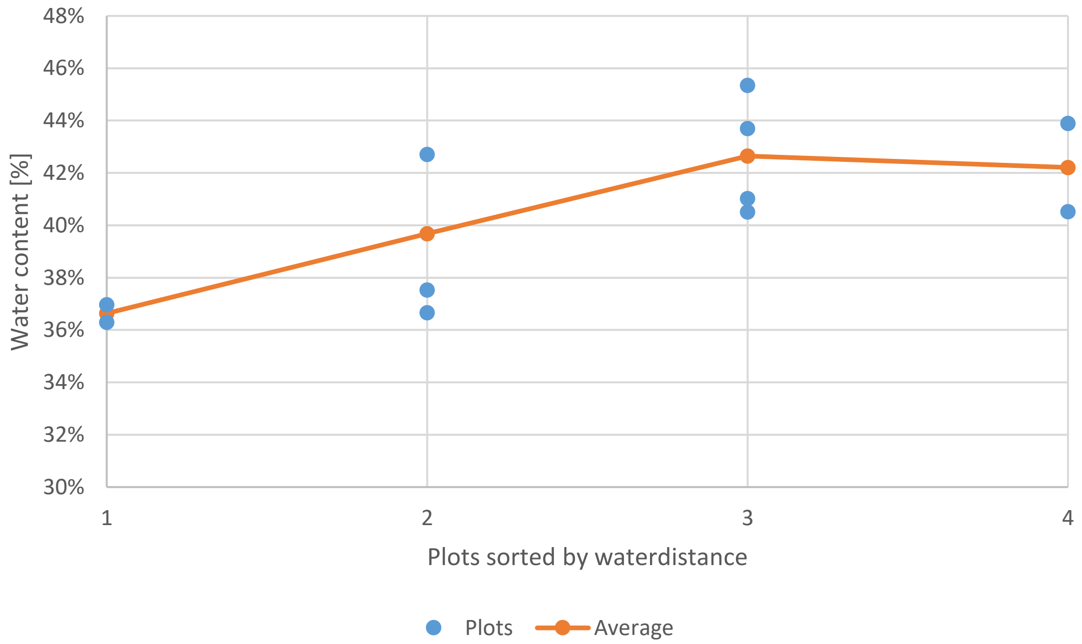



*Figure 39: Water content sorted to water distance*

### 4.11.2 DBH range from 0.08 m to 1.18 m

In the Rewa delta all dimensions of the DBH were found. Analysis of variance for the DBH in relation to the locations (Rewa and Ba) and plots and their interdependency show no significant difference. As shown in Figure 40 the biggest DBH's were found at the 3rd plot and the smallest DBH on the 4th plot. The distribution of the dimensions is quite equal and is not influenced by the distance to the water. Compared with Figure 41 the dimensions of the DBH's are smaller. Only on the 1st and 2nd plot trees were found in Ba. On these two plots, the dimensions are equal and they are not influenced from the distance to the water. On both figures it seems, that the DBH decreases from the 1st plot to the 2nd plot.

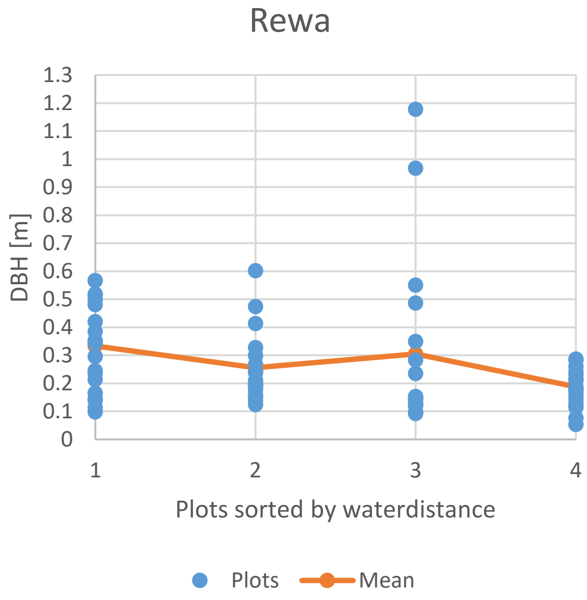



*Figure 40: Rewa - DBH sorted to water distance*

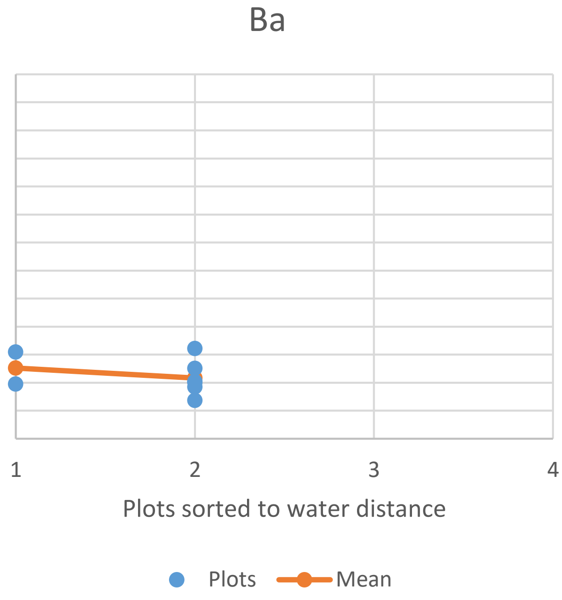



*Figure 41: Ba - DBH sorted to water distance*

The analysis of variance showed, that there is no significant difference of the DBH in relation to the two locations (P = 0.3809) and the position inside a tract (P = 0.1398).

### 4.11.3 Height range from 4 m to 21 m

Figure 42 and Figure 43 reflecting partly the dimensions of the DBH in chapter 4.11.2. It seems, that the mean height from the 1st to 2nd decreases as well. On the other hand, the mean height is increasing on the way to the 4th plot. A reason could be that mostly the first and second plot were intermixed mangrove forest. The *Rhizophora* spp. can't reach the dimensions of a *Bruguiera gymnorrhiza* tree and stays in the scrub. Therefore, the tree doesn't have big competition and can grow in width. However, the 4th plot was mostly a pure *Bruguiera gymnorrhiza* forest. Therefore, the competition is high and the trees must grow fast in height, to reach to the light. In the Ba delta the height does not have a high variance. The significant difference of the height in the two locations is clarified by the analysis of variance. Tract sorted according to water distance show a significate difference (P =5,449e-07) in relation to the location and no significant difference (P = 0,8937) in relation to the position inside a tract.

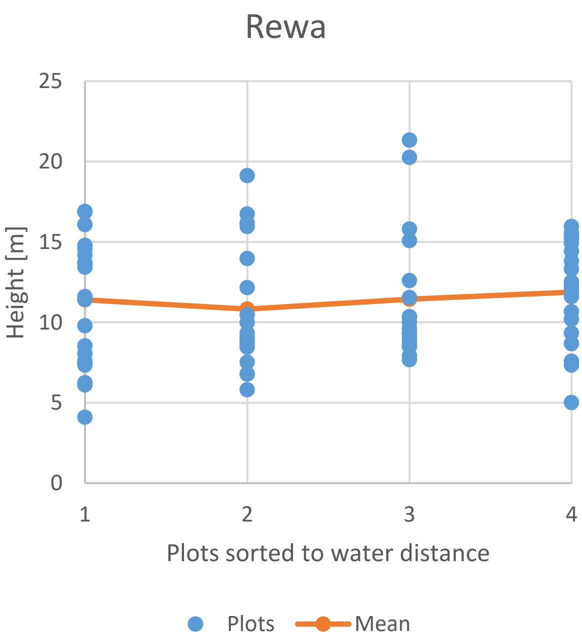



Figure 42: Rewa - Height sorted to water distance

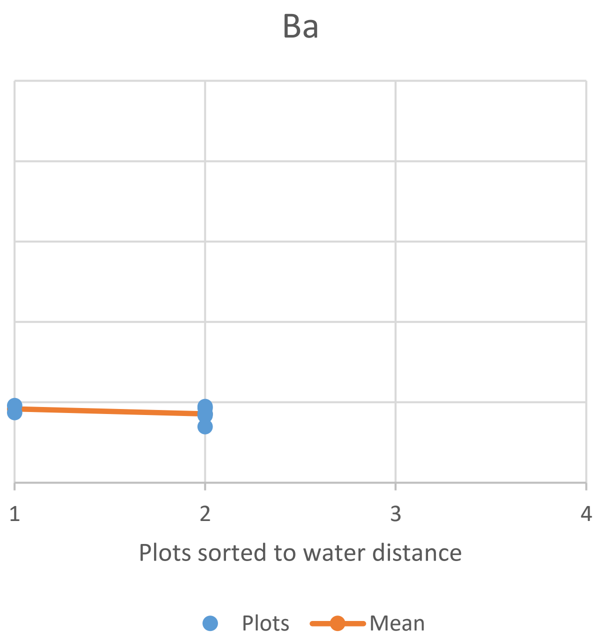



Figure 43: Ba - Height sorted to water distance

### 4.11.4 Crown dimension

Figure 44 describes the vertical dimension of the crown or rather the tree from a front view. The bars show the range of the crown. The top of the bar corresponds to the top of the tree. The bottom of the bar corresponds to the first branch of the tree. The blue point stands for the mean crown center. Figure 44 describes the mean crown dimension for the Rewa – and Ba delta. The tree got sorted to the water distance in order to detect dependencies.

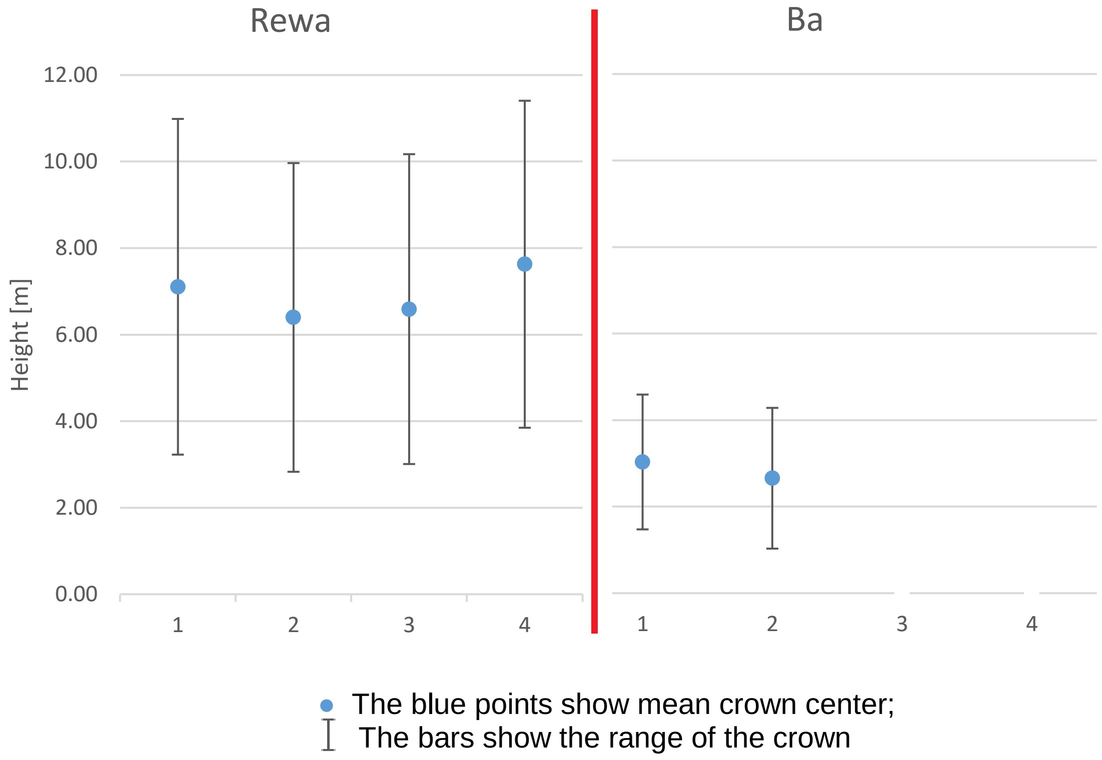



*Figure 44: Crown dimensions sorted to water distance*

The analysis of variance shows no significant difference (P = 0,09309) for all tracts in relation to the locations (Ba and Rewa delta). Selecting only tracts starting from waterfront the analyses of variance shows no significant variance (P = 0,07275) in relation to the locations (Rewa and Ba).

## 4.12 Carbon Content

The elementary analysis determines the carbon content. The analysis was conducted with the Elementar vario EL CUBE Modus CHNS (06/12). The analysis was done by (Kruse, 2018).

Table 12: Carbon content

| Sample | Carbon % | Average |
|---|---|---|
| 1. Brugueria gymnorriza trunk | 48.72 | |
| 2. Brugueria gymnorriza trunk | 48.75 | |
| | | 48.74 |

## 4.13 Extrapolation

As described in chapter 3.5 two different methods were used to inventory the mangrove forest. With an extrapolation, estimations about a hectare value or about the whole location can be done. Statements about the above ground biomass green (AGB green), the above ground biomass dry (AGB dry) and the carbon pool can also be made.

### 4.13.1 Extrapolation using the destructive sampling method

By considering only the occurrence inside the plots, *Bruguiera gymnorrhiza* was only found in the Rewa delta. Table 13 shows the weight of the AGB of *Bruguiera gymnorrhiza* found inside the plots.

Table 13: Bruguiera gymnorrhiza located inside the plots

| Plots | Weight living wood per plot [kg] | Weight deadwood per plot [kg] | Wood total per plot [kg] |
|---|---|---|---|
| 240_E | 46 | 0 | 46 |
| 240_H | 253 | 0 | 253 |
| 30_I | 77 | 0 | 77 |
| 57_N | 42 | 0 | 42 |
| 141_Q | 1051 | 0 | 1051 |
| 141_R | 195 | 63.41 | 259 |
| 141_S | 217 | 0 | 217 |

All 20 plots get considered for the extrapolation, even those without *Bruguiera gymnorrhiza* and which are not listed in Table 13. Table 14 shows an estimated hectare value for the Rewa delta for the AGB green, the AGB dry and the C-pool. The AGB green value was calculated with the procedure from chapter 3.5.1.1. The AGB dry value got calculated using the AGB green less the water content from chapter 4.2. The C-pool got calculated using the AGB dry less the carbon content from chapter 4.12.

*Table 14: Extrapolation with* Bruguiera gymnorrhiza *in the Rewa delta*

| | mean [Mg/ha] | SE | Ci + / - |
|---|---|---|---|
| **AGB green** | 108.06 | 71.80 | {35.55;251.66} |
| **AGB dry** | 64.83 | 43.08 | {21.33;151.00} |
| **C- Pool** | 33.26 | 22.08 | {10.93;77.40} |

In the location Ba delta, no *Bruguiera gymnorrhiza* was found inside a single plot. Therefore, an extrapolation is not possible.

Table 15 shows the actual estimated hectare value for an intermixed mangrove forest for the Rewa delta. Table 15 consider the AGB green, the AGB dry and the C-Pool from *Bruguiera gymnorrhiza* and from *Rhizophora* spp. Further information about the *Rhizophora* spp. are described by Reimer (2018).

*Table 15: Extrapolation with Bruguiera gymnorrhiza and Rhizophora spp. in the Rewa delta*

| | mean [Mg/ha] | SE | Ci + / - |
|---|---|---|---|
| **AGB green** | 296.17 | 85.80 | {124,58; 467,77} |
| **AGB dry** | 173.52 | 50.70 | {72,12; 274,91} |
| **C- Pool** | 90.69 | 26.38 | {37,92; 143,45} |

### 4.13.2 Extrapolation using the k-tree distance sampling method

Table 16 shows an estimated hectare value for the Rewa delta for the AGB green, the AGB dry and the C-Pool. The AGB green value was calculated with the procedure from chapter 3.5.2.1. The AGB dry value was calculated using the AGB green less the water content from chapter 4.2. The C-pool was calculated using the AGB dry less the carbon content from chapter 4.12.

Table 16: Extrapolation with Bruguiera gymnorrhiza in the Rewa delta

| | mean [Mg/ha] | SE | Ci |
|---|---|---|---|
| **AGB green** | 113.86 | 53.41 | {7.04; 220.67} |
| **AGB dry** | 68.18 | 31.98 | {4.22; 132.14} |
| **C- Pool** | 34.95 | 16.39 | {2.16; 67.73} |

Table 17 shows an estimated hectare value for the Ba delta for the AGB green, the AGB dry and the C-Pool. The values are small due to a minimal concurrency of *Bruguiera gymnorrhiza* in the Ba delta. In comparison with the values from the Rewa delta, the values from the Ba delta are negligible.

Table 17: Extrapolation with Bruguiera gymnorrhiza in the Ba delta

| | mean [Mg/ha] | SE | Ci |
|---|---|---|---|
| **AGB green** | 0.45 | 0.34 | {-0.23; 1.13} |
| **AGB dry** | 0.27 | 0.20 | {-0.14; 0.68} |
| **C- Pool** | 0.14 | 0.10 | {-0.07; 0.35} |

# 5 Discussion

This study analyses several objectives for a mangrove forest inventory and in specific a biomass assessment. The two executed methods for this mangrove forest inventory working on a different level and yield similar results. Each method has advantages and disadvantages. The first parameter was to design a practicable plot layout and accordingly tracts. The destructive sampling method (DSM) works with a the plot size of 3 x 3 m. This is not ideal for a *Bruguiera gymnorrhiza* forest, because in a mature *Bruguiera gymnorrhiza* forest the trees are spread out and a plot of 3 x 3 m vanishes inside the forest. A bigger plot would reflect the actuality more precise and decrease human failure. On the other hand, a bigger plot would increase the time frame, the costs and the anthropogenic impact. The destructive sampling method (DSM) is limited to a certain DBH, cause of feasible reasons. Inside the field it is not practicable to destructive sample a giant tree. The DSM has the huge advantage, that other tree species, like the *Rhizophora* spp. can be inventoried at the same time. The *Rhizophora* spp. does grow in scrubs and does not develop a definable trunk. With the DSM a trunk is not needed as measurable parameter and abnormality also does not influence the precision of the method. The DSM does consider the deadwood as well.
The k-tree distance sampling method (KTDSM) works with circular plots and accordingly tracts. The circular plot size is individual for each plot and has a maximum radius of 25 m. Species, like *Rhizophora* spp., which do not form a definable trunk can not be inventoried with the KTDSM. In general, inside an intermixed mangrove forest a *Bruguiera gymnorrhiza* tree is hard to detect. Often the visibility though the dense scrub is only 4 to 6 m. Even, when a *Bruguiera gymnorrhiza* is detected, the bad accessibility through a dense intermixed mangrove forest hindered the inventory, by for example measuring the distance to the plot center. Measuring the attributes for the KTDSM are better and faster to handle, compare to a destructive sampling. Considering only *Bruguiera gymnorrhiza* the KRDSM is more efficient compared to the DSM.
The results from the laboratory work are quite confident. The determined gross density (chapter 4.3) of 0,75 g/cm³ (immersion test) and 0,62 g/cm³ (caliper) is close to the literature value of 0,73 g/cm³ (ITTO, 2013). In this study the samples got measured with the bark. Therefore, the actual density must be higher. The density measured with the immersion test is overestimated, as described in chapter 3.7.2. For the determination of the density of 0,62 g/cm³ the volume got measured with a caliper and with bark. Bark has a lower density compared to wood. Therefore, the density must be higher. In further research a factor for the bark should be determined to have a more actual value.

The variance of the DBH in relationship to the height is quite high (chapter 4.5). A mature forest has most likely a higher variance, compare to managed forests. A high variance is the result of abnormality in growth or competition from regeneration or intermixed species. More samples or rather a bigger inventory would clarify the variance. That applies as well for the form factor from chapter 4.6. The from factor was generated from 12 trees. More samples would generate a more precise form factor.
The volume functions (chapter 4.7) yield profound knowledge about the development status of a tree. Either the DBH or the height can be used to estimate the volume. For generating the function several DBHs and heights got measured in advance. Measuring the height by a clinometer has a high source of errors. Even the smallest deviation influences the actual value enormously. However, the DBH get measured by hand with a measure tape and has therefore a minimal source of errors. Resulting from these two

aspects, the volume function using the DBH is more precise, compare the volume function using the height.
Another objective was to survey the structure of the mangrove forest, especially on the boundary areas. The geographical arrangement and graphic representation of the crown canopy cover (chapter 4.10) reflecting the structure of mangrove forests. Directly on the water font is most likely no occurrence of Bruguiera gymnorrhiza. However, using this statement is disputable for describing a natural forest structure. In some Plots, *Bruguiera gymnorrhiza* occurred directly on the waterfront (Plot 30I and 141Q). Those plots seemed to be unnatural, cause of earth erosion. Also, the trees were inclined towards to the water front. Analyses of satellite images would give further knowledge about the natural habitat of Bruguiera gymnorrhiza. The dimension of a tree is not influenced from the distance to the waterfront, as shown in chapter 4.11. Neither the DBH, the height nor the crown dimension is significant increasing or rather decreasing with further distance to the water front. Due to the tall height, *Bruguiera gymnorrhiza* is the dominating species in the river and middle zone. Therefore, each tree grows under same conditions.
The extrapolations (chapter 4.13) yield confident results. The estimated carbon stock for the Rewa delta of 33.26 MgC/ha using the destructive sampling method (DSM) is close to the estimated carbon stock of 34.95 MgC/ha using the k-tree distance sampling method (KTDSM). The margin of 1.69 MgC/ha corresponds to 5% of the extrapolations. With more plots or rather a more extensive inventory this value would be minimalize. Table 15 shows the estimated carbon stock of 90.69 MgC/ha for an intermixed mangrove forest in the Rewa delta. This value considers all mangrove species occurred inside the plots. The estimated value for the wooden above ground biomass (AGB) of 90.69 MgC/ha is similar to the carbon stock estimated from Alongi (2014) (Figure 1).

# 6 Conclusions

From the results of this study several conclusions can be drawn, which are helping to achieve a better overview of the Fijian mangrove forest.
Firstly, the biomass proportions (chapter 4.1) provide valuable knowledge regarding the composition of the Bruguiera gymnorrhiza. In further research, a plot can be analyzed by destructive sampling in one go and afterwards the biomass can be divided in proportion. This will save time and resources.
As addition, the volume functions (chapter 4.7) bring consolidated knowledge, about the DBH and Height in relationship to the Volume. These functions will help to estimate the volume of other *Bruguiera gymnorrhiza* forests, without the DSM or KTDSM.
Another important finding is the deduced knowledge about anthropogenic influence. Thanks to the stump inventory (chapter 4.8) anthropogenic influence of *Bruguiera gymnorrhiza* is measurable. In further mangrove inventories a current value and an anticipated value, which relate to the forest before anthropogenic influence, can be generated.
This study demonstrated high carbon stock values for the examined mangrove forests. The results confirmed the importance of mangrove forest and the importance to maintain and protect the mangroves.

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# Appendix

## Terms and Definitions

**Biomass**

Organic material both above-ground and below-ground, and both living and dead, e.g., trees, crops, grasses, tree litter, roots etc. Biomass includes the pool definition for above - and below - ground biomass.

(IPCC. 2003. Good Practice Guidance for LULUCF - Glossary)

The term is mainly related to FRA 2005 National Reporting Table T6.

(Note however that countries are not requested to provide information on the biomass of Litter for FRA 2005)

**Above-ground biomass**

All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage.

(IPCC. 2003. Good Practice Guidance for LULUCF - Glossary)

<u>Explanatory note:</u>

1. Where the forest understorey is a relatively small component of the above-ground biomass, it is acceptable to exclude it, provided this is done in a consistent manner throughout the inventory time series.

The term is mainly related to FRA 2005 National Reporting Table T6.

**Below-ground biomass**

All living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter.

(IPCC. 2003. Good Practice Guidance for LULUCF - Glossary)

<u>Explanatory notes:</u>

1. May include the below-ground part of the stump.

2. The country may use another threshold value than 2 mm for fine roots, but in such a case the threshold value used must be documented.

The term is mainly related to FRA 2005 National Reporting Table T6.

**Dead wood biomass**

All non-living wooden biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

Explanatory note:

1. The country may use another threshold value than 10 cm, but in such a case the threshold value used must be documented.

The term is mainly related to FRA 2005 National Reporting Table T6.

**Carbon Stock**

The quantity of carbon in a "pool", meaning a reservoir or system which has the capacity to accumulate or release carbon.

Explanatory note:

1. For FRA 2005 purposes, examples of carbon pools are Living biomass (including Above and below-ground biomass); Dead organic matter (including dead wood and litter); Soils (soils organic matter). The units are mass.

(IPCC. 2003. Good Practice Guidance for LULUCF - Glossary)

**Carbon in above-ground biomass**

Carbon in all living biomass above the soil, including stem, stump, branches, bark, seeds, and foliage.

Explanatory note:

1. Where the forest under-storey is a relatively small component of the above ground biomass carbon pool, it is acceptable to exclude it, provided this is done in a consistent manner throughout the inventory time series.

The term is mainly related to FRA 2005 National Reporting Table T7.

**Carbon in below-ground biomass**

Carbon in all living biomass of live roots.

Explanatory notes:

1. Includes the below-ground part of the stump.

2. The country may use another threshold value than 2 mm for fine roots, but in such a case the threshold value used must be documented.

3. Fine roots of less than 2 mm diameter are excluded, because these often cannot be distinguished empirically from soil organic matter or litter.

The term is mainly related to FRA 2005 National Reporting Table T7.

**Carbon in dead wood biomass**

Carbon in all non-living wooden biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.

Explanatory note:

1. The country may use another threshold value than 10 cm, but in such a case the threshold value used must be documented.

The term is mainly related to FRA 2005 National Reporting Table T7.

## Forest Classes Description


**Closed Forest** describes a crown cover by trees/ or ferns of 40-100% and ground coverage by palm and bamboo over 20%.

**An Open Forest** area clarify a crown cover by trees/ or ferns of 10-40% and ground coverage by palm and bamboo over 50-80%.

Forest Plantations is land under established plantation with forest species or any land Identified for afforestation to provide forest products for sustainable development under a land plan.

I. Hardwood (Mostly Swietenia Macrophylla) Timber production forest of existing or intended plantation established mainly for timber production

II. Softwood (Mostly Pinus Caribaea) Timber production forest of existing or intended plantation established mainly for timber production

**Muiltiple use forests (MUF)** are indigenous forest to be maintained under forest cover for the production of timber and no timber forest products, catchments protection, wildlife habitat, recreation values and amenity uses

This category includes:

- Natural forest area
- Declared forest reserves
- Forest areas suitable for regeneration enrichment planting or reforestation.

**Mangroves** are labelled when the crown cover by trees/ or ferns of 40-100% and ground coverage by palm and bamboo over 20%.

**Coconuts** are defined areas of mainly `cocos (l) mucifera`

**Non Forest** describes a crown cover by trees and/or ferns of 10% and ground coverage by grass, palm and bamboo with 50-85%. Farmland, grazing and cultivation are included in this category.

The **Protection Forests (PTF)** category applies where the forests biological diversity and ecological integraty with the values such as water supply, soil conservation, cultural or historical significance, or scenic appeal will be protected. Forest will be restricted to harvesting of non-timber forest products, ecotourism and research.

These categories include: Soil and water protection forest with a slope >30 degrees above 650 meters' elevation.

The Forest Cover Map was prepared by Management Service Division in 2016 and applies only for the seven main islands: Vitilevu, Vanua Levu, Taveuni, Kadavu, Ovalau, Koro, Gau.

Appendix

A3 Format….

# Water content

| Plot | Location | Sample no. | Weight_green [g] | Weight kiln dry [g] | Water content u [%] |
|---|---|---|---|---|---|
| 141_S | REWA | 141BS1 | 303,00 | 160 | 0,472 |
| 141_S | REWA | 141BS2 | 206,00 | 130 | 0,369 |
| 141_S | REWA | 141BS3 | 190,00 | 120 | 0,368 |
| 141_S | REWA | 141BS4 | 212,00 | 133 | 0,373 |
| 141_S | REWA | 141BS5 | 162,00 | 101 | 0,377 |
| 141_S | REWA | 141BS6 | 198,00 | 118 | 0,404 |
| 141_R | REWA | 141BRL1 | 288,00 | 98 | 0,660 |
| 141_S | REWA | 141BSB4 | 23,00 | 10 | 0,565 |
| 141_S | REWA | 141BSB5 | 24,00 | 11 | 0,542 |
| 141_S | REWA | 141BSB2 | 15,00 | 7 | 0,533 |
| 141_S | REWA | 141BSB7 | 30,00 | 15 | 0,500 |
| 141_S | REWA | 141BSB6 | 33,00 | 18 | 0,455 |
| 141_S | REWA | 141BSB3 | 95,00 | 52 | 0,453 |
| 141_S | REWA | 141BSB1 | 160,00 | 94 | 0,413 |
| 190_B | REWA | 190BAB16 | 115,00 | 61 | 0,470 |
| 190_B | REWA | 190BAB15 | 121,00 | 69 | 0,430 |
| 190_B | REWA | 190BAB14 | 201,00 | 119 | 0,408 |
| 190_B | REWA | 190BAB12 | 322,00 | 194 | 0,398 |
| 190_B | REWA | 190BAB4 | 386,00 | 235 | 0,391 |
| 190_B | REWA | 190BAB17 | 108,00 | 66 | 0,389 |
| 190_B | REWA | 190BAB1 | 250,00 | 153 | 0,388 |
| 190_A | REWA | 190BAL1 | 1003,00 | 262 | 0,739 |
| 57_O | REWA | 57BOL1 | 591,00 | 181 | 0,694 |
| 57_P | REWA | 57BPL1 | 371,00 | 116 | 0,687 |
| 57_N | REWA | 57BNL1 | 482,00 | 162 | 0,664 |
| 190_B | REWA | 190BAB13 | 271,00 | 166 | 0,387 |
| 240_H | REWA | 240BHL1 | 523,00 | 179 | 0,658 |
| 190_B | REWA | 190BAB7 | 346,00 | 212 | 0,387 |
| 190_B | REWA | 190BAB8 | 487,00 | 301 | 0,382 |
| 190_B | REWA | 190BAB5 | 280,00 | 174 | 0,379 |
| 190_B | REWA | 190BAB9 | 602,00 | 376 | 0,375 |
| 190_B | REWA | 190BAB11 | 182,00 | 114 | 0,374 |
| 190_B | REWA | 190BAB10 | 234,00 | 149 | 0,363 |
| 190_B | REWA | 190BAB3 | 679,00 | 433 | 0,362 |
| 190_B | REWA | 190BAB2 | 277,00 | 177 | 0,361 |
| 190_B | REWA | 190BAB6 | 175,00 | 115 | 0,343 |
| 141_B | REWA | 141BRB5 | 305,00 | 144 | 0,528 |
| 141_B | REWA | 141BRB6 | 141,00 | 83 | 0,411 |
| 141_B | REWA | 141BRB3x | 249,00 | 155 | 0,378 |
| 141_B | REWA | 141BRB4 | 299,00 | 188 | 0,371 |
| 141_B | REWA | 141BRB1x | 387,00 | 244 | 0,370 |
| 141_B | REWA | 141BRB2x | 264,00 | 167 | 0,367 |
| 141_B | REWA | 141BRB4x | 213,00 | 135 | 0,366 |
| 141_B | REWA | 141BRB3 | 350,00 | 222 | 0,366 |
| 141_B | REWA | 141BRB2 | 270,00 | 173 | 0,359 |
| 30_I | REWA | 30BIT1 | 499,00 | 260 | 0,479 |
| 141_B | REWA | 141BRB1 | 424,00 | 281 | 0,337 |
| 240_F | REWA | 240BFB6 | 91,00 | 51 | 0,440 |
| 240_F | REWA | 240BFB4 | 235,00 | 134 | 0,430 |
| 240_F | REWA | 240BFB8 | 43,00 | 25 | 0,419 |
| 240_F | REWA | 240BFB3 | 199,00 | 116 | 0,417 |
| 240_B | REWA | 240BEB1+2+: | 274,00 | 157 | 0,427 |
| 240_T | REWA | 240BET3 | 180,00 | 104 | 0,422 |
| 240_F | REWA | 240BFB2 | 320,00 | 187 | 0,416 |
| 240_F | REWA | 240BFB1 | 457,00 | 269 | 0,411 |
| 30_I | REWA | 30BIT2 | 297,00 | 154 | 0,481 |
| 30_I | REWA | 30BIT3 | 153,00 | 83 | 0,458 |
| 240_F | REWA | 240BFB7 | 57,00 | 34 | 0,404 |
| 240_F | REWA | 240BFB5 | 149,00 | 89 | 0,403 |
| 30_I | REWA | 30IB1 | 105,00 | 56 | 0,467 |
| 240_H | REWA | 240BHB10 | 35,00 | 20 | 0,429 |
| 30_I | REWA | 30IB10 | 21,00 | 10 | 0,524 |
| 30_I | REWA | 30IB11 | 51,00 | 26 | 0,490 |
| 240_H | REWA | 240BHB9 | 38,00 | 22 | 0,421 |
| 240_H | REWA | 240BHB11 | 74,00 | 43 | 0,419 |
| 30_I | REWA | 30IB2 | 87,00 | 47 | 0,460 |

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|---|---|---|---|---|---|
| 30_I | REWA | 30IB3 | 45,00 | 21 | 0,533 |
| 240_H | REWA | 240BHB3 | 246,00 | 145 | 0,411 |
| 240_H | REWA | 240BHB2 | 359,00 | 214 | 0,404 |
| 240_H | REWA | 240BHB12 | 104,00 | 62 | 0,404 |
| 240_H | REWA | 240BHB1 | 403,00 | 241 | 0,402 |
| 240_H | REWA | 240BHB4 | 169,00 | 102 | 0,396 |
| 30_I | REWA | 30IB4 | 106,00 | 56 | 0,472 |
| 30_I | REWA | 30IB5 | 42,00 | 20 | 0,524 |
| 240_H | REWA | 240BHB7 | 77,00 | 47 | 0,390 |
| 240_H | REWA | 240BHB8 | 114,00 | 70 | 0,386 |
| 30_I | REWA | 30IB6 | 27,00 | 12 | 0,556 |
| 240_H | REWA | 240BHB5 | 134,00 | 84 | 0,373 |
| 240_H | REWA | 240BHB6 | 78,00 | 49 | 0,372 |
| 30_I | REWA | 30IB7 | 26,00 | 12 | 0,538 |
| 57_N | REWA | 57BNB2 | 35,00 | 17 | 0,514 |
| 30_I | REWA | 30IB8 | 29,00 | 14 | 0,517 |
| 57_N | REWA | 57BNB9 | 72,00 | 36 | 0,500 |
| 57_N | REWA | 57BNB8 | 29,00 | 15 | 0,483 |
| 57_N | REWA | 57BNB1 | 84,00 | 44 | 0,476 |
| 57_N | REWA | 57BNB4 | 70,00 | 37 | 0,471 |
| 57_N | REWA | 57BNB3 | 80,00 | 43 | 0,463 |
| 57_N | REWA | 57BNB5 | 231,00 | 129 | 0,442 |
| 141_R | REWA | 141BRB5 | 305,00 | 144 | 0,528 |
| 141_R | REWA | 141BRB6 | 141,00 | 83 | 0,411 |
| 57_N | REWA | 57BNB6 | 132,00 | 74 | 0,439 |
| 141_R | REWA | 141BRB3x | 249,00 | 155 | 0,378 |
| 57_N | REWA | 57BNB7 | 112,00 | 63 | 0,438 |
| 57_O | REWA | 57BOB1 | 23,00 | 10 | 0,565 |
| 57_O | REWA | 57BOB2 | 27,00 | 13 | 0,519 |
| 141_R | REWA | 141BRB4 | 299,00 | 188 | 0,371 |
| 57_O | REWA | 57BOB3 | 54,00 | 26 | 0,519 |
| 141_R | REWA | 141BRB1x | 387,00 | 244 | 0,370 |
| 141_R | REWA | 141BRB2x | 264,00 | 167 | 0,367 |
| 57_O | REWA | 57BOB5 | 57,00 | 28 | 0,509 |
| 141_R | REWA | 141BRB4x | 213,00 | 135 | 0,366 |
| 141_R | REWA | 141BRB3 | 350,00 | 222 | 0,366 |
| 57_O | REWA | 57BOB6 | 42,00 | 21 | 0,500 |
| 141_R | REWA | 141BRB2 | 270,00 | 173 | 0,359 |
| 57_O | REWA | 57BOB9 | 63,00 | 32 | 0,492 |
| 141_R | REWA | 141BRB1 | 424,00 | 281 | 0,337 |
| 57_O | REWA | 57BOB7 | 49,00 | 25 | 0,490 |
| 57_O | REWA | 57BOB4 | 68,00 | 35 | 0,485 |
| 57_O | REWA | 57BOB8 | 106,00 | 56 | 0,472 |
| 57_O | REWA | 57BOB10 | 138,00 | 73 | 0,471 |
| 57_O | REWA | 57BOB12 | 96,00 | 53 | 0,448 |
| 57_O | REWA | 57BOB11 | 132,00 | 73 | 0,447 |
| 57_P | REWA | 57BPB1 | 36,00 | 17 | 0,528 |
| 57_P | REWA | 57BPB5 | 57,00 | 28 | 0,509 |
| 57_P | REWA | 57BPB3 | 34,00 | 17 | 0,500 |
| 57_P | REWA | 57BPB2 | 28,00 | 15 | 0,464 |
| 57_P | REWA | 57BPB6 | 98,00 | 53 | 0,459 |
| 57_P | REWA | 57BPB4 | 20,00 | 11 | 0,450 |
| 57_P | REWA | 57BPB9 | 178,00 | 98 | 0,449 |
| 57_P | REWA | 57BPB7 | 87,00 | 48 | 0,448 |
| 57_P | REWA | 57BPB8 | 199,00 | 113 | 0,432 |
| 141_S | REWA | 141BSB4 | 23,00 | 10 | 0,565 |
| 141_S | REWA | 141BSB5 | 24,00 | 11 | 0,542 |
| 141_S | REWA | 141BSB2 | 15,00 | 7 | 0,533 |
| 141_S | REWA | 141BSB7 | 30,00 | 15 | 0,500 |
| 141_S | REWA | 141BSB6 | 33,00 | 18 | 0,455 |
| 141_S | REWA | 141BSB3 | 95,00 | 52 | 0,453 |
| 141_S | REWA | 141BSB1 | 160,00 | 94 | 0,413 |
| 190_R | REWA | 190BAR1 | 406,00 | 216 | 0,468 |
| 141_S | REWA | 141BST1 | 692,00 | 390 | 0,436 |
| 141_S | REWA | 141BST7 | 117,00 | 69 | 0,410 |
| 141_S | REWA | 141BST6 | 181,00 | 109 | 0,398 |
| 240_T | REWA | 240BET2 | 225,00 | 133 | 0,409 |

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|---|---|---|---|---|---|
| 240_T | REWA | 240BET1 | 340,00 | 201 | 0,409 |
| 240_B | REWA | 240BEB5+6+ | 307,00 | 165 | 0,463 |
| 141_S | REWA | 141BST5 | 236,00 | 149 | 0,369 |
| 141_S | REWA | 141BST3 | 380,00 | 240 | 0,368 |
| 240_T | REWA | 240BET6 | 186,00 | 101 | 0,457 |
| 240_T | REWA | 240BET4 | 79,00 | 43 | 0,456 |
| 240_T | REWA | 240BET7 | 206,00 | 120 | 0,417 |
| 240_T | REWA | 240BET5 | 345,00 | 201 | 0,417 |
| 141_S | REWA | 141BST4 | 246,00 | 156 | 0,366 |
| 141_S | REWA | 141BST2 | 268,00 | 174 | 0,351 |
| 141_R | REWA | 141BRT4 | 835,00 | 514 | 0,384 |
| 141_R | REWA | 141BRT1 | 1704,00 | 1064 | 0,376 |
| 141_R | REWA | 141BRT6 | 493,00 | 313 | 0,365 |
| 141_R | REWA | 141BRT2 | 1217,00 | 774 | 0,364 |
| 141_R | REWA | 141BRT7 | 540,00 | 344 | 0,363 |
| 141_R | REWA | 141BRT5 | 773,00 | 495 | 0,360 |
| 141_R | REWA | 141BRT3 | 736,00 | 488 | 0,337 |
| 141_T | REWA | 141BRT4 | 835,00 | 514 | 0,384 |
| 141_T | REWA | 141BRT1 | 1704,00 | 1064 | 0,376 |
| 141_T | REWA | 141BRT6 | 493,00 | 313 | 0,365 |
| 141_T | REWA | 141BRT2 | 1217,00 | 774 | 0,364 |
| 141_T | REWA | 141BRT7 | 540,00 | 344 | 0,363 |
| 141_T | REWA | 141BRT5 | 773,00 | 495 | 0,360 |
| 30_I | REWA | 30IB9 | 250,00 | 120 | 0,520 |
| 141_T | REWA | 141BRT3 | 736,00 | 488 | 0,337 |
| 141_S | REWA | 141BST1 | 692,00 | 390 | 0,436 |
| 190_T | REWA | 190BAT3 | 406,00 | 256 | 0,369 |
| 190_T | REWA | 190BAT2 | 445,00 | 294 | 0,339 |
| 190_T | REWA | 190BAT1 | 411,00 | 276 | 0,328 |
| 240_T | REWA | 240BFT3 | 547,00 | 332 | 0,393 |
| 240_T | REWA | 240BFT1 | 523,00 | 323 | 0,382 |
| 240_T | REWA | 240BFT4 | 612,00 | 381 | 0,377 |
| 240_T | REWA | 240BFT5 | 498,00 | 312 | 0,373 |
| 240_T | REWA | 240BFT2 | 417,00 | 262 | 0,372 |
| 240_H | REWA | 240BHT6 | 1175,00 | 667 | 0,432 |
| 240_H | REWA | 240BHT5 | 977,00 | 573 | 0,414 |
| 240_H | REWA | 240BHT3 | 763,00 | 448 | 0,413 |
| 240_H | REWA | 240BHT1 | 370,00 | 220 | 0,405 |
| 240_H | REWA | 240BHT2 | 668,00 | 400 | 0,401 |
| 240_H | REWA | 240BHT4 | 471,00 | 286 | 0,393 |
| 57_N | REWA | 57BNT11 | 118,00 | 65 | 0,449 |
| 57_N | REWA | 57BNT10 | 276,00 | 158 | 0,428 |
| 57_N | REWA | 57BNT1 | 523,00 | 303 | 0,421 |
| 57_N | REWA | 57BNT3 | 965,00 | 561 | 0,419 |
| 57_N | REWA | 57BNT2 | 939,00 | 546 | 0,419 |
| 57_N | REWA | 57BNT9 | 275,00 | 160 | 0,418 |
| 141_S | REWA | 141BST7 | 117,00 | 69 | 0,410 |
| 57_N | REWA | 57BNT4 | 376,00 | 221 | 0,412 |
| 57_N | REWA | 57BNT8 | 206,00 | 123 | 0,403 |
| 57_N | REWA | 57BNT6 | 201,00 | 121 | 0,398 |
| 57_N | REWA | 57BNT7 | 244,00 | 148 | 0,393 |
| 57_N | REWA | 57BNT5 | 316,00 | 193 | 0,389 |
| 141_S | REWA | 141BST6 | 181,00 | 109 | 0,398 |
| 141_S | REWA | 141BST5 | 236,00 | 149 | 0,369 |
| 57_O | REWA | 57BOT1 | 1144,00 | 642 | 0,439 |
| 141_S | REWA | 141BST3 | 380,00 | 240 | 0,368 |
| 141_S | REWA | 141BST4 | 246,00 | 156 | 0,366 |
| 141_S | REWA | 141BST2 | 268,00 | 174 | 0,351 |
| 57_O | REWA | 57BOT13 | 124,00 | 70 | 0,435 |
| 57_O | REWA | 57BOT7 | 493,00 | 284 | 0,424 |
| 57_O | REWA | 57BOT6 | 553,00 | 319 | 0,423 |
| 30_I | REWA | 30IT4 | 192,00 | 103 | 0,464 |
| 57_O | REWA | 57BOT12 | 182,00 | 105 | 0,423 |
| 57_O | REWA | 57BOT8 | 384,00 | 223 | 0,419 |
| 57_O | REWA | 57BOT9 | 334,00 | 194 | 0,419 |
| 57_O | REWA | 57BOT2 | 605,00 | 355 | 0,413 |
| 30_I | REWA | 30IT5 | 161,00 | 83 | 0,484 |

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|---|---|---|---|---|---|
| 57_O | REWA | 57BOT4 | 905,00 | 532 | 0,412 |
| 57_O | REWA | 57BOT5 | 362,00 | 216 | 0,403 |
| 30_I | REWA | 30IT6 | 114,00 | 58 | 0,491 |
| 57_O | REWA | 57BOT11 | 282,00 | 169 | 0,401 |
| 57_O | REWA | 57BOT3 | 466,00 | 281 | 0,397 |
| 30_I | REWA | 30IT7 | 152,00 | 81 | 0,467 |
| 57_O | REWA | 57BOT10 | 430,00 | 260 | 0,395 |
| 57_P | REWA | 57BPT0 | 1050,00 | 548 | 0,478 |
| 57_P | REWA | 57BPT16 | 84,00 | 45 | 0,464 |
| 57_P | REWA | 57BPT13 | 168,00 | 93 | 0,446 |
| 57_P | REWA | 57BPT15 | 175,00 | 97 | 0,446 |
| 57_P | REWA | 57BPT14 | 287,00 | 163 | 0,432 |
| 57_P | REWA | 57BPT9 | 397,00 | 227 | 0,428 |
| 57_P | REWA | 57BPT10 | 306,00 | 176 | 0,425 |
| 57_P | REWA | 57BPT8 | 366,00 | 212 | 0,421 |
| 57_P | REWA | 57BPT5 | 678,00 | 394 | 0,419 |
| 57_P | REWA | 57BPT7 | 423,00 | 246 | 0,418 |
| 57_P | REWA | 57BPT3 | 589,00 | 343 | 0,418 |
| 57_P | REWA | 57BPT11 | 230,00 | 134 | 0,417 |
| 57_P | REWA | 57BPT6 | 369,00 | 215 | 0,417 |
| 57_P | REWA | 57BPT2 | 726,00 | 425 | 0,415 |
| 57_P | REWA | 57BPT12 | 208,00 | 122 | 0,413 |
| 57_P | REWA | 57BPT4 | 619,00 | 369 | 0,404 |
| 57_P | REWA | 57BPT1 | 576,00 | 349 | 0,394 |
| 80_B | Ba | 80B'EB4+7+8 | 381,00 | 229 | 0,399 |
| 80_B | Ba | 80B'EB2+3+5 | 1008,00 | 636 | 0,369 |
| 80_B | Ba | 80B'EB1 | 784,00 | 500 | 0,362 |
| 80_B | Ba | 80B'EB6 | 934,00 | 609 | 0,348 |
| 17_B | Ba | 17B'KB9+10 | 25,00 | 13 | 0,480 |
| 17_B | Ba | 17B'KB8 | 34,00 | 19 | 0,441 |
| 17_B | Ba | 17B'K2B1 | 23,00 | 13 | 0,435 |
| 17_B | Ba | 17B'KB7 | 60,00 | 34 | 0,433 |
| 17_B | Ba | 17B'K2B4 | 81,00 | 46 | 0,432 |
| 17_B | Ba | 17B'KB5 | 211,00 | 121 | 0,427 |
| 17_B | Ba | 17B'K2B3 | 47,00 | 27 | 0,426 |
| 17_B | Ba | 17B'K2B2 | 40,00 | 23 | 0,425 |
| 17_B | Ba | 17B'KB6 | 137,00 | 79 | 0,423 |
| 17_B | Ba | 17B'KB4 | 260,00 | 151 | 0,419 |
| 17_B | Ba | 17B'K2B5 | 172,00 | 100 | 0,419 |
| 17_K | Ba | 17B'KL2 | 474,00 | 174 | 0,633 |
| 17_K | Ba | 17B'KL1 | 547,00 | 210 | 0,616 |
| 17_B | Ba | 17B'K2B6 | 601,00 | 365 | 0,393 |
| 17_B | Ba | 17B'K2B8 | 698,00 | 427 | 0,388 |
| 17_B | Ba | 17B'KB1 | 546,00 | 340 | 0,377 |
| 17_B | Ba | 17B'KB2 | 252,00 | 158 | 0,373 |
| 17_B | Ba | 17B'K2B7 | 885,00 | 555 | 0,373 |
| 17_B | Ba | 17B'K2B9 | 754,00 | 485 | 0,357 |
| 17_B | Ba | 17B'KB3 | 241,00 | 157 | 0,349 |
| 17_B | Ba | 17B`K2R1 | 67,00 | 23 | 0,657 |
| 17_B | Ba | 17B`K2R2 | 188,00 | 77 | 0,590 |
| 17_B | Ba | 17B`K2T1 | 277,00 | 161 | 0,419 |
| 17_B | Ba | 17B`KT1 | 279,00 | 165 | 0,409 |
| 17_B | Ba | 17B`KT2 | 877,00 | 528 | 0,398 |
| 17_B | Ba | 17B`KT3 | 677,00 | 418 | 0,383 |
| 17_B | Ba | 17B`K2T2 | 1212,00 | 766 | 0,368 |
| 80_B | Ba | 80B'ET1 | 501,00 | 316 | 0,369 |

# Height, DBH; Crown dimension; Canopy cover

| Location | Plot | H_base [°] | H_1branch [°] | H_1 branch [m] | D_for_ Height [m] | H_total [°] | H_crown_ middle [m] | Crown_middle to_H_total[m] | H_total [m] | D_to_ PlotC [m] | DBU [m] | DBH [m] | BRRU [m] | DBR [m] | H_BRR [m] | Angle [°] | X [m] | Y [m] | Crownr_N [m] | Crownr_O [m] | Crownr_S [m] | Crownr_W [m] | Crown_canopy cover [m2] | Crown_ volume [m3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rewa | 190A | | 15 | 4,48 | 10 | 50 | 9,10 | 4,62 | 13,72 | 10 | 1,51 | 0,48 | 1,73 | 0,55 | 0,61 | 104 | 9,70296 | -2,41922 | 4,2 | 3,9 | 3,9 | 7,1 | 77,33815715 | 357,23 |
| Rewa | 190A | | 10 | 3,56 | 10 | 55 | 9,82 | 6,26 | 16,08 | 10 | 1,21 | 0,39 | 1,54 | 0,49 | 0,74 | 155 | 4,22618 | -9,06308 | 2,6 | 3,7 | 3,3 | 3 | 31,68296191 | 198,31 |
| Rewa | 190A | | 20 | 5,59 | 10,4 | 50 | 9,89 | 4,30 | 14,19 | 10,4 | 1,11 | 0,35 | 1,26 | 0,40 | 0,66 | 174 | 1,0871 | -10,343 | 2 | 2,4 | 2,6 | 2,5 | 17,88351618 | 76,98 |
| Rewa | 190B | -2,6 | 2 | 1,90 | 3 | 59 | 4,35 | 2,44 | 6,79 | 3 | 0,48 | 0,15 | 0,6 | 0,19 | 0,39 | 220 | -2,29813 | -1,92836 | 1,4 | 1 | 1,13 | 1,1 | 4,277985256 | 10,46 |
| Rewa | 190B | -2,5 | 2,5 | 1,94 | 3,3 | 60 | 4,73 | 2,79 | 7,52 | 3,3 | 0,56 | 0,18 | 0,63 | 0,20 | 0,3 | 265 | -0,28761 | -3,28744 | 1,2 | 1 | 0,9 | 1,03 | 3,385772943 | 9,43 |
| Rewa | 190B | -2,5 | 0 | 1,80 | 3,1 | 65 | 5,12 | 3,32 | 8,45 | 3,1 | 0,39 | 0,12 | 0,44 | 0,14 | 0,2 | 320 | -1,99264 | 2,37474 | 1,7 | 1,8 | 1,4 | 1,4 | 7,893251542 | 26,24 |
| Rewa | 190C | -10 | 0 | 1,80 | 9,7 | 38 | 5,59 | 3,79 | 9,38 | 9,7 | 1,1 | 0,35 | 1,22 | 0,39 | 0,5 | 15 | 9,36948 | 2,51054 | 2 | 1,7 | 1,5 | 1,9 | 10,01382658 | 37,94 |
| Rewa | 190C | -2,5 | 10 | 2,40 | 3,4 | 60 | 5,04 | 2,64 | 7,69 | 3,4 | 0,74 | 0,24 | 0,75 | 0,24 | 0,17 | 300 | -2,94449 | 1,7 | 3,4 | 1,9 | 0 | 1,9 | 14,74977751 | 39,01 |
| Rewa | 190C | -8 | 2 | 2,02 | 6,34 | 44 | 4,97 | 2,95 | 7,92 | 6,34 | 0,89 | 0,28 | 0,8 | 0,25 | 0,3 | 315 | -4,48306 | 4,48306 | 0 | 0 | 3,3 | 2 | 11,69457865 | 34,51 |
| Rewa | 190D | -2,5 | 40 | 4,49 | 3,2 | 73 | 8,38 | 3,89 | 12,27 | 3,2 | 0,9 | 0,29 | 0,87 | 0,28 | 0,6 | 130 | 2,45134 | -2,05692 | 1,6 | 2,1 | 3,6 | 1,8 | 18,19767545 | 70,80 |
| Rewa | 190D | -2,8 | 0 | 1,80 | 2,7 | 50 | 3,41 | 1,61 | 5,02 | 2,7 | 0,67 | 0,21 | 0,58 | 0,18 | 0,3 | 190 | -2,65898 | -0,46885 | 7,7 | 0 | 0 | 0 | 46,56625711 | 74,92 |
| Rewa | 190D | -2,2 | 30 | 3,24 | 2,5 | 70 | 5,96 | 2,71 | 8,67 | 2,5 | 0,89 | 0,28 | 1 | 0,32 | 0,6 | 230 | -1,60697 | -1,91511 | 3,2 | 2 | 2,6 | 3,1 | 24,04103778 | 65,22 |
| Rewa | 240E | -20 | -10 | 0,88 | 5,2 | 42 | 4,18 | 3,30 | 7,48 | 5,2 | 0,31 | 0,10 | 0,55 | 0,18 | 0,27 | 0 | 5,2 | 0 | 0,7 | 1 | 2,9 | 2,1 | 11,23904772 | 37,08 |
| Rewa | 240E | -30 | 0 | 1,80 | 3,3 | 45 | 3,95 | 2,15 | 6,10 | 3,3 | 0,44 | 0,14 | 0,45 | 0,14 | 0,32 | 20 | 3,10099 | 1,12867 | 1,9 | 3,8 | 1,7 | 1,7 | 18,71603823 | 40,24 |
| Rewa | 240E | -20 | 0 | 1,80 | 4,9 | 55 | 5,80 | 4,00 | 9,80 | 4,9 | 1,78 | 0,57 | 2,08 | 0,66 | 0,67 | 50 | 3,14966 | 3,75362 | 5,3 | 6 | 4 | 6,1 | 92,12720457 | 368,41 |
| Rewa | 240F | -11 | 3 | 2,48 | 13 | 29 | 5,74 | 3,26 | 9,01 | 17,15 | 0,76 | 0,24 | 0,89 | 0,28 | 0,34 | 170 | 2,97807 | -16,8895 | 5,1 | 2,2 | 2,5 | 1,8 | 31,68296191 | 103,36 |
| Rewa | 240F | -8 | 5 | 2,76 | 11 | 20 | 4,28 | 1,52 | 5,80 | 13,85 | 0,5 | 0,16 | 0,61 | 0,19 | 0,31 | 190 | -13,6396 | -2,40503 | 2,33 | -1,5 | 1,3 | 3,19 | 15,3506071 | 23,34 |
| Rewa | 240F | -6 | 8 | 3,63 | 13 | 21 | 5,21 | 1,58 | 6,79 | 14,35 | 0,632 | 0,20 | 0,58 | 0,18 | 0,25 | 217 | -11,4604 | -8,63605 | 0,55 | 2 | 1,5 | 1,3 | 6,473644362 | 10,24 |
| Rewa | 240G | -10 | 10 | 3,21 | 8 | 40 | 5,86 | 2,65 | 8,51 | 14,07 | 0,48 | 0,15 | 0,66 | 0,21 | 0,17 | 0 | 14,07 | 0 | 3,15 | 0,6 | 0,45 | 2,4 | 12,75879316 | 33,82 |
| Rewa | 240H | -10 | 10 | 3,56 | 10 | 30 | 5,57 | 2,01 | 7,57 | 1,36 | 0,58 | 0,18 | 0,83 | 0,26 | 0,39 | 210 | -1,17779 | -0,68 | 3,5 | 3,3 | 2,4 | 1,6 | 24,70862622 | 49,54 |
| Rewa | 240H | -20 | 10 | 3,56 | 10 | 40 | 6,88 | 3,31 | 10,19 | 3,7 | 0,24 | 0,08 | 0,34 | 0,11 | 0,16 | 225 | -2,6163 | -2,6163 | 2,1 | 0,5 | 0,75 | 1,65 | 6,239988408 | 20,68 |
| Rewa | 240H | -19 | 25 | 6,46 | 10 | 49 | 9,88 | 3,42 | 13,30 | 3,3 | 0,38 | 0,12 | 0,58 | 0,18 | 0,23 | 230 | -2,1212 | -2,52795 | 1,7 | 3,3 | 1,92 | 1 | 14,50347664 | 49,61 |
| Rewa | 240H | -15 | 22 | 5,84 | 10 | 47 | 9,18 | 3,34 | 12,52 | 5,1 | 0,53 | 0,17 | 0,69 | 0,22 | 0,22 | 233 | -3,06926 | -4,07304 | 2,1 | 1,65 | 1,48 | 2,08 | 10,72013515 | 35,82 |
| Rewa | 240H | -30 | 0 | 1,80 | 10 | 29 | 4,57 | 2,77 | 7,34 | 1,06 | 0,17 | 0,05 | 0,23 | 0,07 | 0,12 | 270 | -6,5E-17 | -1,06 | 1,4 | 0,4 | 1,1 | 1,6 | 4,625995182 | 12,82 |
| Rewa | 30I | -12 | 6 | 2,85 | 10 | 34 | 5,70 | 2,85 | 8,55 | 6 | 0,93 | 0,30 | 0,95 | 0,30 | 0,44 | 150 | 3 | -5,19615 | 3,2 | 1,7 | 4,2 | 4,6 | 40,78572663 | 116,12 |
| Rewa | 30I | -11 | | 1,96 | 10 | 24 | 4,11 | 2,15 | 6,25 | 5,8 | 0,36 | 0,11 | 0,54 | 0,17 | 0,25 | 270 | -3,6E-16 | -5,8 | 4,4 | 0,45 | 0,5 | 0,85 | 16,12815129 | 34,61 |
| Rewa | 30I | -10 | 10 | 3,56 | 10 | 32 | 5,81 | 2,24 | 8,05 | 5,5 | 0,67 | 0,21 | 0,76 | 0,24 | 0,5 | 280 | -5,41644 | 0,95506 | 1,8 | 0 | 2 | 4,7 | 23,03572813 | 51,66 |
| Rewa | 57M | -6 | | 1,18 | 16 | 31 | 6,30 | 5,12 | 11,41 | 9 | 1,62 | 0,52 | 1,57 | 0,50 | 0,28 | 232 | -5,54095 | -7,0921 | 3,2 | 0 | 1,6 | 3,8 | 21,39424597 | 109,47 |
| Rewa | 57M | -5 | 1 | 2,15 | 20 | 37 | 9,51 | 7,36 | 16,87 | 11,6 | 1,78 | 0,57 | 2,29 | 0,73 | 0,6 | 242 | -5,44587 | -10,2422 | 9,6 | 4,7 | 3,7 | 0 | 100,483841 | 739,66 |
| Rewa | 57M | -7 | -2 | 1,35 | 6 | 21 | 2,73 | 1,38 | 4,10 | 8,8 | 1,08 | 0,34 | 1,14 | 0,36 | 0,18 | 245 | -3,71904 | -7,97551 | 6,2 | 3,5 | 4,4 | 2,2 | 58,81846846 | 80,97 |
| Rewa | 57M | -6 | 12 | 6,05 | 20 | 37 | 11,46 | 5,41 | 16,87 | 10 | 1,63 | 0,52 | 1,77 | 0,56 | 0,85 | 274 | -9,97564 | 0,69756 | 4 | 4,3 | 2 | 4,7 | 47,57942074 | 257,40 |
| Rewa | 57M | -8 | -1 | 0,84 | 19 | 32 | 7,26 | 6,42 | 13,67 | 8,15 | 1,57 | 0,50 | 1,48 | 0,47 | 0,2 | 277 | -8,08925 | 0,99324 | 5,6 | 5,1 | 2,7 | 3,9 | 62,72975131 | 402,49 |
| Rewa | 57M | -6 | -2 | 1,66 | 24 | 28 | 8,11 | 6,45 | 14,56 | 8,1 | 0,45 | 0,14 | 0,61 | 0,19 | 0,27 | 297 | -7,21715 | 3,67732 | 5,4 | 3,45 | 0 | 3,5 | 41,87153959 | 270,09 |
| Rewa | 57N | -8 | 11 | 4,25 | 12,6 | 33 | 7,12 | 2,87 | 9,98 | 4,7 | 0,6 | 0,19 | 0,71 | 0,23 | | 110 | 4,41656 | -1,60749 | 4,9 | 1,4 | 2,2 | 3,1 | 31,74579376 | 91,00 |
| Rewa | 57N | -10 | 10 | 3,56 | 10 | 36 | 6,31 | 2,75 | 9,07 | 4,5 | 0,61 | 0,19 | 0,68 | 0,22 | 0,32 | 115 | 4,07839 | -1,90178 | 3,1 | 3,4 | 0 | 1,9 | 19,46216649 | 53,54 |
| Rewa | 57N | -10 | 0 | 2,20 | 10 | 37 | 5,77 | 3,57 | 9,34 | 3,17 | 0,66 | 0,21 | 0,66 | 0,21 | 0,31 | 183 | -3,16566 | -0,1659 | 2,7 | 1,2 | 1,4 | 3 | 15,46448984 | 55,17 |
| Rewa | 57N | -8 | 3 | 2,27 | 9 | 38 | 5,55 | 3,28 | 8,83 | 6,6 | 0,75 | 0,24 | 0,94 | 0,30 | 0,6 | 184 | -6,58392 | -0,46039 | 1,9 | 2 | 3,7 | 5,6 | 41,35906728 | 135,66 |
| Rewa | 57N | -5 | 1 | 2,04 | 14 | 41 | 8,01 | 5,96 | 13,97 | 11 | 0,84 | 0,27 | 1,02 | 0,32 | 0,55 | 195 | -10,6252 | -2,84701 | 4 | 4,3 | 2,1 | 1,2 | 31,68296191 | 188,92 |
| Rewa | 57N | -11 | 3 | 2,32 | 10 | 46 | 7,24 | 4,92 | 12,16 | 2,85 | 1,03 | 0,33 | 1,19 | 0,38 | 0,76 | 308 | -2,24583 | 1,75464 | 2,7 | 0 | 3,9 | 7,6 | 63,03605659 | 309,86 |
| Rewa | 57O | -6 | 8 | 2,45 | 14 | 28 | 5,85 | 3,40 | 9,24 | 8,3 | 0,42 | 0,13 | 0,53 | 0,17 | 0,5 | 92 | 8,29494 | -0,28967 | 2,7 | 1,75 | 2,7 | 1,6 | 15,8670064 | 53,90 |
| Rewa | 57O | -8 | 0 | 0,90 | 13 | 28 | 4,81 | 3,91 | 8,71 | 8,2 | 0,46 | 0,15 | 0,54 | 0,17 | 0,55 | 190 | -8,07542 | -1,42392 | 3,3 | 2,2 | 4,15 | 3,6 | 36,05959318 | 140,85 |
| Rewa | 57O | -7 | 15 | 5,28 | 13 | 31 | 7,45 | 2,16 | 9,61 | 10,3 | 0,38 | 0,12 | 0,5 | 0,16 | 0,25 | 289 | -9,73884 | 3,35335 | 1,5 | 0,7 | 0,7 | 5 | 22,17179015 | 47,98 |
| Rewa | 57O | -8 | 5 | 3,09 | 14,8 | 29 | 6,55 | 3,45 | 10,00 | 7,2 | 0,46 | 0,15 | 0,5 | 0,16 | 0,4 | 290 | -6,76579 | 2,46255 | 1,6 | 1,6 | 4,3 | 4,5 | 34,44756345 | 119,00 |
| Rewa | 57O | -8 | 4 | 0,60 | 12 | 31 | 4,81 | 4,21 | 9,01 | 5,15 | 0,48 | 0,15 | 0,8 | 0,25 | 0,45 | 309 | -4,0023 | 3,241 | 3,55 | 2,6 | 2,1 | 2,6 | 23,98016942 | 100,84 |
| Rewa | 57O | -9 | 3 | 1,35 | 11,6 | 30 | 4,92 | 3,57 | 8,50 | 8,9 | 0,38 | 0,12 | 0,47 | 0,15 | 0,28 | 333 | -4,04052 | 7,92996 | 2,9 | 2,85 | 2,2 | 2,4 | 21,30981567 | 76,15 |
| Rewa | 57P | -6 | 20 | 7,62 | 16 | 40 | 11,42 | 3,80 | 15,23 | 9,1 | 0,56 | 0,18 | 0,71 | 0,23 | 0,38 | 35 | 7,45428 | 5,21955 | 0 | 0 | 2,5 | 7,25 | 46,19122948 | 175,57 |
| Rewa | 57P | -8 | 2 | 2,15 | 10 | 37 | 5,74 | 3,59 | 9,34 | 8,5 | 0,82 | 0,26 | 1 | 0,32 | | 48 | 5,68761 | 6,31673 | 9,1 | 4,1 | 1,1 | 1,55 | 81,0786159 | 291,33 |
| Rewa | 57P | -4 | 10 | 4,97 | 18 | 37 | 10,17 | 5,20 | 15,36 | 5,4 | 1,45 | 0,46 | 1,84 | 0,59 | 0,4 | 50 | 3,47105 | 4,13664 | 6,3 | 6,9 | 5,5 | 4,1 | 105,5260972 | 548,21 |
| Rewa | 57P | -5 | 5 | 3,02 | 14 | 35 | 7,31 | 4,29 | 11,60 | 7,8 | 0,73 | 0,23 | 0,98 | 0,31 | 0,41 | 78 | 1,62171 | 7,62955 | 2 | 3,75 | 2,15 | 1,5 | 19,5839032 | 84,00 |
| Rewa | 57P | -8 | 12 | 4,14 | 11 | 43 | 8,10 | 3,96 | 12,06 | 5,75 | 0,55 | 0,18 | 0,66 | 0,21 | 0,34 | 79 | 1,09715 | 5,64436 | 2,5 | 2,1 | 2,7 | 4,05 | 26,98039041 | 106,84 |
| Rewa | 57P | -5 | 4 | 3,27 | 21 | 34 | 9,62 | 6,35 | 15,96 | 7,65 | 0,76 | 0,24 | 1,01 | 0,32 | 0,46 | 146 | 4,27783 | -6,34214 | 3,6 | 5,15 | 4,4 | 1,8 | 48,75948148 | 309,53 |
| Rewa | 141Q | -5 | 18 | 8,30 | 20 | 33 | 11,54 | 3,24 | 14,79 | 4,2 | 1,1 | 0,35 | 1,34 | 0,43 | 0,73 | 45 | 2,96985 | 2,96985 | 0 | 0 | 6,9 | 6,85 | 74,24565188 | 240,92 |
| Rewa | 141Q | -6 | 12 | 6,26 | 21 | 25 | 8,93 | 2,66 | 11,59 | 3,8 | 0,52 | 0,17 | 0,68 | 0,22 | 0,57 | 85 | 0,33119 | 3,78554 | 1,35 | 1,7 | 5,7 | 1,9 | 32,05406254 | 85,40 |

# Gross Density

| Plot | Location | Sample no. | Volume_M1 [cm³] | Volume_M2 [cm³] | Volume_S [cm³] | Desnsity_M1 [g/cm³] | Density_M2 [g/cm³] | Density_S [g/cm³] |
|---|---|---|---|---|---|---|---|---|
| 80_B | Ba | 80B'EB4+7+8 | 234 | 223 | | 0,98 | 1,03 | |
| 80_B | Ba | 80B'EB2+3+5 | 770 | 753 | | 0,83 | 0,84 | |
| 80_B | Ba | 80B'EB1 | 613 | 599 | | 0,82 | 0,83 | |
| 80_B | Ba | 80B'EB6 | 732 | 718 | | 0,83 | 0,85 | |
| 17_B | Ba | 17B'KB9+10 | 23 | 22 | | 0,57 | 0,59 | |
| 17_B | Ba | 17B'KB8 | 33 | 31 | 32,29 | 0,58 | 0,61 | 0,59 |
| 17_B | Ba | 17B'K2B1 | 15 | 13 | | 0,87 | 1,00 | |
| 17_B | Ba | 17B'KB7 | 50 | 50 | 59,41 | 0,68 | 0,68 | 0,57 |
| 17_B | Ba | 17B'K2B4 | 58 | 56 | | 0,79 | 0,82 | |
| 17_B | Ba | 17B'KB5 | 168 | 164 | 193,79 | 0,72 | 0,74 | 0,62 |
| 17_B | Ba | 17B'K2B3 | 26 | 28 | | 1,04 | 0,96 | |
| 17_B | Ba | 17B'K2B2 | 27 | 25 | | 0,85 | 0,92 | |
| 17_B | Ba | 17B'KB6 | 103 | 100 | 119,47 | 0,77 | 0,79 | 0,66 |
| 17_B | Ba | 17B'KB4 | 210 | 207 | 239,96 | 0,72 | 0,73 | 0,63 |
| 17_B | Ba | 17B'K2B5 | 139 | 135 | | 0,72 | 0,74 | |
| 17_B | Ba | 17B'K2B6 | 513 | 506 | | 0,71 | 0,72 | |
| 17_B | Ba | 17B'K2B8 | 620 | 608 | | 0,69 | 0,70 | |
| 17_B | Ba | 17B'KB1 | 478 | 467 | 472,86 | 0,71 | 0,73 | 0,72 |
| 17_B | Ba | 17B'KB2 | 208 | 203 | 237,46 | 0,76 | 0,78 | 0,67 |
| 17_B | Ba | 17B'K2B7 | 776 | 760 | | 0,72 | 0,73 | |
| 17_B | Ba | 17B'K2B9 | 615 | 599 | | 0,79 | 0,81 | |
| 17_B | Ba | 17B'KB3 | 200 | 195 | 225,07 | 0,79 | 0,81 | 0,70 |
| 17_B | Ba | 17B`K2R1 | 84 | 81 | 89,63 | 0,27 | 0,28 | 0,26 |
| 17_B | Ba | 17B`K2R2 | 214 | 204 | 225,73 | 0,36 | 0,38 | 0,34 |
| 17_B | Ba | 17B`K2T1 | 227 | 225 | 200,48 | 0,71 | 0,72 | 0,80 |
| 17_B | Ba | 17B`KT1 | 222 | 217 | 220,06 | 0,74 | 0,76 | 0,75 |
| 17_B | Ba | 17B`KT2 | 715 | 705 | 771,28 | 0,74 | 0,75 | 0,68 |
| 17_B | Ba | 17B`KT3 | 481 | 467 | | 0,87 | 0,90 | |
| 17_B | Ba | 17B`K2T2 | 1027 | 1018 | 1046,80 | 0,75 | 0,75 | 0,73 |
| 80_B | Ba | 80B'ET1 | 287 | 280 | | 1,10 | 1,13 | |

# Kiln dry density

| Plot | Location | Sample no. | Volume_M1 [cm³] | Volume_M2 [cm³] | Volume_S [cm³] | Desnsity_M1 [g/cm³] | Density_M2 [g/cm³] |
|---|---|---|---|---|---|---|---|
| 141_S | REWA | 141BS1 | 211 | 201 | | 0,76 | 0,80 |
| 141_S | REWA | 141BS2 | 125 | 120 | | 1,04 | 1,08 |
| 141_S | REWA | 141BS3 | 111 | 106 | | 1,08 | 1,13 |
| 141_S | REWA | 141BS4 | 128 | 123 | | 1,04 | 1,08 |
| 141_S | REWA | 141BS5 | 94 | 89 | | 1,07 | 1,13 |
| 141_S | REWA | 141BS6 | 109 | 105 | | 1,08 | 1,12 |
| 190_B | REWA | 190BAB16 | 62 | 58 | | 0,98 | 1,05 |
| 190_B | REWA | 190BAB15 | 61 | 58 | | 1,13 | 1,19 |
| 190_B | REWA | 190BAB14 | 122 | 119 | | 0,98 | 1,00 |
| 190_B | REWA | 190BAB12 | 198 | 194 | | 0,98 | 1,00 |
| 190_B | REWA | 190BAB4 | 277 | 269 | | 0,85 | 0,87 |
| 190_B | REWA | 190BAB17 | 56 | 54 | | 1,18 | 1,22 |
| 190_B | REWA | 190BAB1 | 167 | 162 | | 0,92 | 0,94 |
| 190_B | REWA | 190BAB13 | 172 | 168 | | 0,97 | 0,99 |
| 190_B | REWA | 190BAB7 | 219 | 213 | | 0,97 | 1,00 |
| 190_B | REWA | 190BAB8 | 370 | 360 | | 0,81 | 0,84 |
| 190_B | REWA | 190BAB5 | 182 | 176 | | 0,96 | 0,99 |
| 190_B | REWA | 190BAB9 | 362 | 348 | | 1,04 | 1,08 |
| 190_B | REWA | 190BAB11 | 110 | 106 | | 1,04 | 1,08 |
| 190_B | REWA | 190BAB10 | 156 | 150 | | 0,96 | 0,99 |
| 190_B | REWA | 190BAB3 | 393 | 384 | | 1,10 | 1,13 |
| 190_B | REWA | 190BAB2 | 516 | 497 | | 0,34 | 0,36 |
| 190_B | REWA | 190BAB6 | 101 | 98 | | 1,14 | 1,17 |
| 141_B | REWA | 141BRB5 | 139 | 132 | | 1,04 | 1,09 |
| 141_B | REWA | 141BRB6 | 74 | 69 | | 1,12 | 1,20 |
| 141_B | REWA | 141BRB3x | 155 | 150 | | 1,00 | 1,03 |
| 141_B | REWA | 141BRB4 | 192 | 188 | | 0,98 | 1,00 |
| 141_B | REWA | 141BRB1x | 261 | 253 | | 0,93 | 0,96 |
| 141_B | REWA | 141BRB2x | 171 | 165 | | 0,98 | 1,01 |
| 141_B | REWA | 141BRB4x | 175 | 172 | | 0,77 | 0,78 |
| 141_B | REWA | 141BRB3 | 227 | 222 | | 0,98 | 1,00 |
| 141_B | REWA | 141BRB2 | 169 | 164 | | 1,02 | 1,05 |
| 141_B | REWA | 141BRB1 | 292 | 283 | | 0,96 | 0,99 |
| 240_B | REWA | 240BEB1+2+3+4 | 177 | 170 | | 0,89 | 0,92 |
| 190_R | REWA | 190BAR1 | 185 | 181 | | 1,17 | 1,19 |
| 240_B | REWA | 240BEB5to10 | 198 | 183 | | 0,83 | 0,90 |
| 141_T | REWA | 141BRT4 | 567 | 549 | | 0,91 | 0,94 |
| 141_T | REWA | 141BRT1 | 1312 | 1282 | | 0,81 | 0,83 |
| 141_T | REWA | 141BRT6 | 281 | 275 | | 1,11 | 1,14 |
| 141_T | REWA | 141BRT2 | 905 | 876 | | 0,86 | 0,88 |
| 141_T | REWA | 141BRT7 | 341 | 330 | | 1,01 | 1,04 |
| 141_T | REWA | 141BRT5 | 467 | 449 | | 1,06 | 1,10 |
| 141_T | REWA | 141BRT3 | 523 | 511 | | 0,93 | 0,95 |
| 190_T | REWA | 190BAT3 | 303 | 297 | | 0,84 | 0,86 |
| 190_T | REWA | 190BAT2 | 218 | 212 | | 1,35 | 1,39 |
| 190_T | REWA | 190BAT1 | 280 | 272 | | 0,99 | 1,01 |
| 240_T | REWA | 240BFT3 | 368 | 357 | | 0,90 | 0,93 |
| 240_T | REWA | 240BFT1 | 291 | 275 | | 1,11 | 1,17 |
| 240_T | REWA | 240BFT4 | 361 | 348 | | 1,06 | 1,09 |
| 240_T | REWA | 240BFT5 | 268 | 254 | | 1,16 | 1,23 |
| 240_T | REWA | 240BFT2 | 224 | 214 | | 1,17 | 1,22 |

## Weighed in segments

| Plots | Total [kg] | Trunk [kg] | Brench [kg] | Leaves [kg] |
|---|---|---|---|---|
| 190A | 1937 | 1169 | 662 | 105 |
| 240F | 158 | 99 | 37 | 22* |
| 240H | 301 | 133 | 120 | 48 |
| 57N | 205 | 134 | 42 | 29 |
| 57O | 209 | 130 | 44 | 35 |
| 57P | 203 | 134 | 37 | 31 |
| 141R | 237 | 144 | 47 | 46 |
| 141S1 | 72 | 45 | 17 | 10* |
| 141S2 | 69 | 49 | 11 | 10 |
| 80'E | 166 | 41 | 117 | 8 |
| 17'K1 | 174 | 46 | 103 | 25 |
| 17'K3 | 141 | 24 | 98 | 19 |

*calculated with the percentage from Table 3

# Extrapolation DSM Bruguiera gymnorrhiza Rewa delta

| Plot | Tree | u [%] | C [%] | AGB green [kg/plot] | Mean [kg/plot] SD | AGB kiln dry [kg/plot] | Mean [kg/plot] SD | C. content [kg/plot] | Mean [kg/plot SD | C. content [kg/ha] | Mean [kg/ha] SD | AGB green [kg/ha] | Mean [kg/ha] SD | AGB kiln dry [kg/ha] | Mean [kg/ha] SD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 190_A | R. selala | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190_B | R. stylosa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 190_C | R. stylosa | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 190_D | R. selala | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 240_E | B. gymnorrhiza | 0,4 | 0,49 | 46,4 | 74,84 | 27,84 | 44,90 | 14,27 | 23,016 | 15856,41 | 25573,59 | 51555,50 | 83149,92 | 30933,30 | 49889,95 |
| 240_F | R. stylosa | 0 | 0 | 0 | 104,56 | 0 | 62,74 | 0 | 32,158 | 0 | 35731,32 | 0 | 116176,76 | 0 | 69706,06 |
| 240_G | R. stylosa | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 240_H | B. gymnorrhiza | 0,4 | 0,49 | 252,94 | | 151,764 | | 77,79 | | 86437,94 | | 281044,16 | | 168626,50 | |
| 30_I | B. gymnorrhiza | 0,4 | 0,49 | 77,16 | 19,29 | 46,296 | 11,57 | 23,73 | 5,933 | 26368,12 | 6592,03 | 85733,25 | 21433,31 | 51439,95 | 12859,99 |
| 30_J | 0 | 0 | 0 | 0 | 33,41 | 0 | 20,05 | 0 | 10,276 | 0 | 11417,73 | 0 | 37123,59 | 0 | 22274,15 |
| 30_K | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 30_L | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 57_M | R. selala | 0 | 0 | 0 | 10,55 | 0 | 6,33 | 0 | 3,246 | 0 | 3606,14 | 0 | 11724,99 | 0 | 7034,99 |
| 57_N | B. gymnorrhiza | 0,4 | 0,49 | 42,21 | 18,28 | 25,326 | 10,97 | 12,98 | 5,62 | 14424,55 | 6246,01 | 46899,95 | 20308,28 | 28139,97 | 12184,97 |
| 57_O | B. gymnorrhiza | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 57_P | B. gymnorrhiza | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |
| 141_Q | B. gymnorrhiza | 0,4 | 0,49 | 1051,3 | 381,58 | 630,78 | 228,95 | 323,34 | 117,36 | 359265,90 | 130399,83 | 1168116,45 | 423981,76 | 700869,87 | 254389,05 |
| 141_R | B. gymnorrhiza | 0,4 | 0,49 | 258,51 | 398,91 | 155,11 | 239,35 | 79,51 | 122,69 | 88341,40 | 136321,81 | 287233,05 | 443236,47 | 172339,83 | 265941,88 |
| 141_S | B. gymnorrhiza | 0,4 | 0,49 | 216,52 | | 129,91 | | 66,59 | | 73992,03 | | 240577,54 | | 144346,52 | |
| 141_T | R. selala | 0 | 0 | 0 | | 0 | | 0 | | 0 | | 0 | | 0 | |

| AGB mean green [Mg/ha] | SD AGB green | SE AGB green | Ci below value | Ci above value |
|---|---|---|---|---|
| 108,06 | 160,55 | 71,80 | -35,55 | 251,66 |
| **Mean_dry [Mg/ha]** | **SD_w_dry** | **SE_w_dry** | | |
| 64,83 | 96,33 | 43,08 | -21,33 | 151,00 |
| **Mean_C [Mg/ha]** | **SD_C** | **SE_C** | | |
| 33,23 | 49,38 | 22,08 | -10,93 | 77,40 |

deadwood

## Extrapolation DSM Bruguiera gymnorrhiza & Rhizophora spp. Rewa delta

| Plot | Tree | u | C | AGB green | Mean [kg/plot] | AGB kiln dry | Mean [kg/plot] | C. content | Mean [kg/plot] | C. content | Mean [kg/ha] | AGB green | Mean [kg/ha] | AGB kiln dry | Mean [kg/ha] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | [%] | [%] | [kg/plot] | SD | [kg/plot] | SD | [kg/plot] | SD | [kg/ha] | SD | [kg/ha] | SD | [kg/ha] | SD |
| 190_A | R. selala | 0,40 | 0,47 | 588,01 | 472,88 | 350,81 | 273,59 | 185,12 | 144,32 | 205689,49 | 160350,95 | 653343,79 | 525424,47 | 389784,91 | 303985,68 |
| 190_B | R. stylosa | 0,45 | 0,47 | 380,05 | 77,91 | 210,70 | 53,99 | 111,08 | 28,54 | 123423,09 | 31714,51 | 422277,36 | 86563,84 | 234110,57 | 59993,39 |
| 190_C | R. stylosa; R. samoensis | 0,45 | 0,47 | 428,89 | | 237,78 | | 125,36 | | 139284,12 | | 476543,97 | | 264195,98 | |
| 190_D | R. selala | 0,40 | 0,47 | 494,58 | | 295,07 | | 155,71 | | 173007,11 | | 549532,78 | | 327851,26 | |
| 240_E | R. stylosa; B. gymnorrhiza | 0,45 | 0,47 | 79,02 | 190,71 | 43,81 | 105,73 | 23,10 | 55,74 | 25662,13 | 61934,00 | 87799,91 | 211899,79 | 48676,27 | 117477,24 |
| 240_F | R. stylosa | 0,45 | 0,47 | 176,84 | 79,17 | 98,04 | 43,89 | 51,69 | 23,14 | 57429,65 | 25711,89 | 196488,69 | 87970,16 | 108933,33 | 48770,66 |
| 240_G | R. stylosa | 0,45 | 0,47 | 205,93 | | 114,17 | | 60,19 | | 66876,77 | | 228810,88 | | 126852,75 | |
| 240_H | R. stylosa; B. gymnorrhiza | 0,45 | 0,47 | 301,05 | | 166,90 | | 87,99 | | 97767,46 | | 334499,67 | | 185446,61 | |
| 30_I | B. gymnorrhiza | 0,40 | 0,49 | 77,16 | 19,29 | 46,30 | 11,57 | 23,73 | 5,93 | 26368,12 | 6592,03 | 85733,25 | 21433,31 | 51439,95 | 12859,99 |
| 30_J | 0 | 0,00 | 0,00 | 0,00 | 33,41 | 0,00 | 20,05 | 0,00 | 10,28 | 0,00 | 11417,73 | 0,00 | 37123,59 | 0,00 | 22274,15 |
| 30_K | 0 | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | |
| 30_L | 0 | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | |
| 57_M | R. selala | 0,40 | 0,47 | 745,51 | 196,93 | 447,31 | 118,16 | 236,04 | 62,26 | 262270,16 | 69173,68 | 828343,62 | 218810,89 | 497006,17 | 131286,54 |
| 57_N | B. gymnorrhiza | 0,40 | 0,49 | 42,21 | 317,19 | 25,33 | 190,31 | 12,98 | 100,48 | 14424,55 | 111639,72 | 46899,95 | 352434,36 | 28139,97 | 211460,62 |
| 57_O | B. gymnorrhiza | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | |
| 57_P | B. gymnorrhiza | 0,00 | 0,00 | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | | 0,00 | |
| 141_Q | R. selala; B. gymnorrhiza | 0,40 | 0,49 | 1101,50 | 452,97 | 660,90 | 271,78 | 338,78 | 139,85 | 376417,47 | 155385,86 | 1223883,06 | 503295,57 | 734329,84 | 301977,34 |
| 141_R | B. gymnorrhiza | 0,40 | 0,49 | 258,51 | 374,72 | 155,11 | 224,83 | 79,51 | 114,94 | 88341,40 | 127715,19 | 287233,05 | 416359,43 | 172339,83 | 249815,66 |
| 141_S | B. gymnorrhiza | 0,40 | 0,49 | 216,52 | | 129,91 | | 66,59 | | 73992,03 | | 240577,54 | | 144346,52 | |
| 141_T | R. selala | 0,40 | 0,47 | 235,34 | | 141,20 | | 74,51 | | 82792,53 | | 261488,63 | | 156893,18 | |

| AGB mean green [Mg/ha] | SD AGB green | SE AGB green | Ci below value | Ci above value |
|---|---|---|---|---|
| 296,17 | 191,85 | 85,80 | 124,58 | 467,77 |
| Mean_dry [Mg/ha] | SD_w_dry | SE_w_dry | | |
| 173,52 | 113,37 | 50,70 | 72,12 | 274,91 |
| Mean_C [Mg/ha] | SD_C | SE_C | | |
| 90,69 | 58,99 | 26,38 | 37,92 | 143,45 |

# Extrapolation KTDSM Bruguiera gymnorrhiza Rewa delta

| REWA | Distance to PlotCentre | Weight Trunk | Weight Trunk & Branches | Rmd | al | Efl | Biomass Trunk | Biomass Trunk & Branches | Biomass Trunk &Braches Kiln dry | C. Content |
|---|---|---|---|---|---|---|---|---|---|---|
| Plot | [m] | [kg] | [kg] | [m] | [m²] | | [kg/ha] | [kg/ha] | [kg/ha] | [kg/ha] |
| 190A | 10,00 | 871,24 | 1117,24 | | | | | | | |
| 190A | 10,00 | 1157,37 | 1484,16 | | | | | | | |
| 190A | 10,40 | 647,14 | 829,87 | 10,20 | 326,85 | 30,59 | 62065,42 | 79589,78 | 47658,36 | 24429,67 |
| 190B | 3,00 | 57,91 | 74,27 | | | | | | | |
| 190B | 3,10 | 47,55 | 60,97 | | | | | | | |
| 190B | 3,30 | 87,22 | 111,84 | 3,20 | 32,17 | 310,85 | 32782,28 | 42038,45 | 25172,62 | 12903,49 |
| 190C | 3,40 | 155,80 | 199,79 | | | | | | | |
| 190C | 6,34 | 232,21 | 297,78 | | | | | | | |
| 190C | 9,70 | 419,91 | 538,48 | 8,02 | 202,07 | 49,49 | 19202,11 | 24623,88 | 14744,78 | 7558,17 |
| 190D | 2,50 | 254,08 | 325,82 | | | | | | | |
| 190D | 2,70 | 83,35 | 106,88 | | | | | | | |
| 190D | 3,20 | 367,67 | 471,48 | 2,95 | 27,34 | 365,77 | 123422,18 | 158270,80 | 94772,55 | 48580,41 |
| 240E | 3,30 | 43,70 | 56,04 | | | | | | | |
| 240E | 4,90 | 1148,73 | 1473,07 | | | | | | | |
| 240E | 5,20 | 26,61 | 34,12 | 5,05 | 80,12 | 124,82 | 148833,07 | 190856,52 | 114284,88 | 58582,43 |
| 240F | 13,85 | 53,69 | 68,85 | | | | | | | |
| 240F | 14,35 | 100,36 | 128,70 | | | | | | | |
| 240F | 17,15 | 192,49 | 246,84 | 15,75 | 779,31 | 12,83 | 1976,74 | 2534,87 | 1517,88 | 778,07 |
| 240G | 14,07 | 72,58 | 93,07 | | | | | | | |
| 240H | 1,06 | 7,85 | 10,07 | | | | | | | |
| 240H | 1,36 | 94,27 | 120,89 | | | | | | | |
| 240H | 3,30 | 71,09 | 91,16 | | | | | | | |
| 240H | 3,70 | 21,72 | 27,85 | | | | | | | |
| 240H | 5,10 | 130,17 | 166,93 | 4,40 | 60,82 | 164,42 | 32050,38 | 41099,90 | 24610,62 | 12615,40 |
| 30I | 5,50 | 133,70 | 171,45 | | | | | | | |
| 30I | 5,80 | 29,98 | 38,45 | | | | | | | |
| 30I | 6,00 | 273,48 | 350,70 | 5,90 | 109,36 | 91,44 | 14967,21 | 19193,25 | 11492,92 | 5891,27 |
| 57M | 8,10 | 109,11 | 139,92 | | | | | | | |
| 57M | 8,15 | 1247,07 | 1599,18 | | | | | | | |
| 57M | 8,80 | 177,10 | 227,10 | | | | | | | |
| 57M | 9,00 | 1108,41 | 1421,38 | | | | | | | |
| 57M | 10,00 | 1658,67 | 2127,01 | | | | | | | |
| 57M | 11,60 | 1978,00 | 2536,49 | 10,80 | 366,44 | 27,29 | 117356,72 | 150492,74 | 90115,05 | 46192,98 |
| 57N | 2,85 | 477,18 | 611,91 | | | | | | | |
| 57N | 3,17 | 150,48 | 192,96 | | | | | | | |
| 57N | 4,50 | 124,82 | 160,07 | | | | | | | |
| 57N | 4,70 | 132,98 | 170,53 | | | | | | | |
| 57N | 6,60 | 183,82 | 235,73 | | | | | | | |
| 57N | 11,00 | 364,75 | 467,74 | 8,80 | 243,28 | 41,10 | 43951,96 | 56361,92 | 33749,52 | 17300,00 |
| 57O | 5,15 | 76,82 | 98,51 | | | | | | | |
| 57O | 7,20 | 78,33 | 100,45 | | | | | | | |
| 57O | 8,20 | 68,22 | 87,48 | | | | | | | |
| 57O | 8,30 | 60,34 | 77,38 | | | | | | | |
| 57O | 8,90 | 45,40 | 58,22 | | | | | | | |
| 57O | 10,30 | 51,36 | 65,86 | 9,60 | 289,53 | 34,54 | 11366,95 | 14576,44 | 8728,37 | 4474,16 |
| 57P | 5,40 | 1195,32 | 1532,82 | | | | | | | |
| 57P | 5,75 | 134,97 | 173,08 | | | | | | | |
| 57P | 7,65 | 341,22 | 437,56 | | | | | | | |
| 57P | 7,80 | 228,80 | 293,40 | | | | | | | |
| 57P | 8,50 | 232,28 | 297,86 | | | | | | | |
| 57P | 9,10 | 176,68 | 226,57 | 8,80 | 243,28 | 41,10 | 87657,70 | 112408,11 | 67309,98 | 34503,09 |
| 141Q | 0,95 | 1089,87 | 1397,60 | | | | | | | |
| 141Q | 2,90 | 601,79 | 771,70 | | | | | | | |
| 141Q | 3,80 | 115,99 | 148,74 | | | | | | | |
| 141Q | 4,20 | 662,13 | 849,08 | | | | | | | |
| 141Q | 4,55 | 166,93 | 214,07 | | | | | | | |
| 141Q | 4,85 | 148,75 | 190,75 | 4,70 | 69,40 | 144,10 | 379942,01 | 487219,76 | 291747,19 | 149549,61 |
| 141R | 0,80 | 144,05 | 184,72 | | | | | | | |
| 141R | 1,64 | 62,10 | 79,63 | | | | | | | |
| 141R | 3,20 | 2528,84 | 3242,86 | | | | | | | |
| 141R | 6,55 | 1046,63 | 1342,14 | | | | | | | |
| 141R | 8,55 | 1328,55 | 1703,68 | | | | | | | |
| 141R | 9,10 | 521,99 | 669,37 | 8,83 | 244,67 | 40,87 | 208860,32 | 267832,65 | 160378,19 | 82209,86 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 141S | 1,23 | 36,81 | 47,20 | | | | | | | |
| 141S | 1,36 | 32,21 | 41,30 | | | | | | | |
| 141S | 5,73 | 90,37 | 115,88 | | | | | | | |
| 141S | 6,15 | 70,87 | 90,88 | | | | | | | |
| 141S | 6,80 | 1669,97 | 2141,49 | | | | | | | |
| 141S | 8,90 | 7294,99 | 9354,75 | | | | | | | |
| 141S | 9,20 | 1368,98 | 1755,52 | | | | | | | |
| 141S | 10,25 | 10263,37 | 13161,27 | 9,73 | 297,12 | 33,66 | 355555,43 | 455947,55 | 273021,39 | 139950,77 |
| 141T | 1,15 | 56,58 | 72,55 | | | | | | | |
| 141T | 1,60 | 255,33 | 327,42 | | | | | | | |
| 141T | 2,50 | 122,76 | 157,42 | | | | | | | |
| 141T | 2,80 | 167,31 | 214,55 | | | | | | | |
| 141T | 3,22 | 171,97 | 220,53 | | | | | | | |
| 141T | 5,30 | 92,16 | 118,18 | 4,26 | 57,01 | 175,40 | 135750,59 | 174080,16 | 104239,20 | 53433,01 |

# Extrapolation KTDSM Bruguiera gymnorrhiza Ba delta

| BA<br>Plot | Distance to PlotCentre<br>[m] | Weight Trunk<br>[kg] | Weight Trunk & Branches<br>[kg] | Rmd<br>[m] | al<br>[m²] | Efl | Biomass Trunk<br>[kg/ha] | Biomass Trunk & Branches<br>[kg/ha] | Biomass Trunk &Braches Kiln dry<br>[kg/ha] | C. Content<br>[kg/ha] |
|---|---|---|---|---|---|---|---|---|---|---|
| 80'E | 19,90 | 152,52 | 195,59 | | | | | | | |
| 80'E | 24,80 | 67,02 | 85,95 | 22,35 | 1569,30 | 6,37 | 971,91 | 1246,33 | 746,30 | 382,56 |
| 17'K | 2,95 | 53,05 | 68,03 | | | | | | | |
| 17'K | 6,10 | 68,29 | 87,58 | | | | | | | |
| 17'K | 6,50 | 28,74 | 36,85 | | | | | | | |
| 17'K | 9,40 | 99,30 | 127,34 | | | | | | | |
| 17'K | 14,75 | 179,30 | 229,93 | | | | | | | |
| 17'K | 15,20 | 53,53 | 68,64 | 14,98 | 704,50 | 14,19 | 6084,86 | 7802,94 | 4672,40 | 2395,07 |

## Analysis of Variance

Significant codes:
0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

**Water content for Tracts starting from Waterfront:**

| | All Segments | Trunk | Branches |
|---|---|---|---|
| | P | P | P |
| Location | 0.61803 | 0.4586 | 0.001001 ** |
| Plot | 0.01173 * | 9.935e-07 *** | 1.321e-11 *** |
| | | With interdependency | |
| Plot/ Location | 0.07118 . | 0.3923 | 0.0213578 * |
| Location/ Plot | 0.07118 . | 0.3923 | 0.02136 * |

**Water content for all Tracts:**

| | All Segments | Trunk | Branches |
|---|---|---|---|
| | P | P | P |
| Location | 0.79528 | 0.3379 | 0.002226 ** |
| Plot | 0.01596 * | 9.158e-08 *** | 5.334e-13 *** |
| | | With interdependency | |
| Plot/ Location | 0.05799 . | 0.3643 | 0.012954 * |
| Location/ Plot | 0.05799 . | 0.3643 | 0.01295 * |

**Analysis of Variance for DBH:**

| | Tracts starting from Waterfront | All Tracts |
|---|---|---|
| | P | P |
| Location | 0.3809 | 0.5091 |
| Plot | 0.1398 | 0.1636 |
| | With interdependency | |
| Plot/ Location | 0.8126 | 0.8080 |
| Location/ Plot | 0.8126 | 0.8080 |

**Analysis of Variance for Volume:**

| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 0.2864 | 0.3267 |
| Plot | 0.1901 | 0.4429 |
| | With interdependency | |
| Plot/ Location | 0.9019 | 0.8964 |
| Location/ Plot | 0.9019 | 0.8964 |

**Analysis of Variance for Height:**

| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 5.449e-07 *** | 7.814e-07 *** |
| Plot | 0.8937 | 0.1732 |
| | With interdependency | |
| Plot/ Location | 0.9650 | 0.9638 |
| Location/ Plot | 0.96496 | 0.96376 |

**Analysis of Variance for crown volume:**

| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 0.07275 . | 0.09309 . |
| Plot | 0.65164 | 0.63488 |
| | With interdependency | |
| Plot/ Location | 0.9602 | 0.95818 |
| Location/ Plot | 0.9602 | 0.9582 |

**Analysis of Variance for crown canopy cover:**

| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 0.02525 * | 0.03701 * |
| Plot | 0.70819 | 0.47586 |
| | With interdependency | |
| Plot/ Location | 0.80920 | 0.8029 |
| Location/ Plot | 0.80920 | 0.80294 |

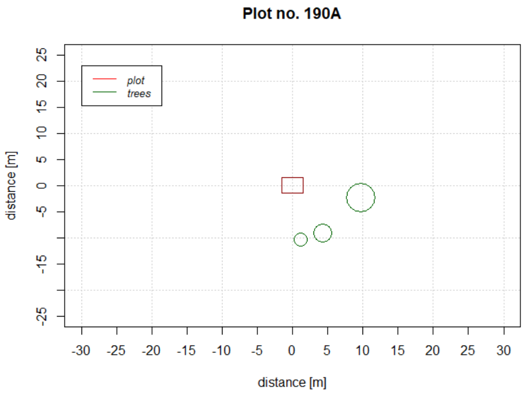
**Analysis of Variance for the diameter of Buttress roots:**

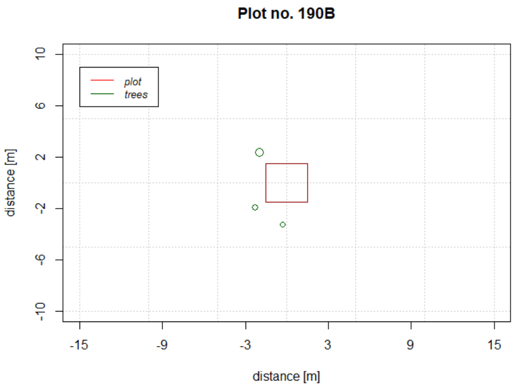
| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 0.0297 * | 0.04614 * |
| Plot | 0.2644 | 0.26239 |
| | With interdependency | |
| Plot/ Location | 0.84678 | 0.84438 |
| Location/ Plot | 0.84678 | 0.84438 |

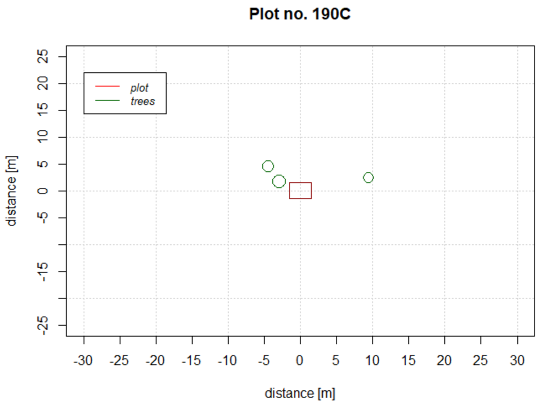
**Analysis of Variance for weight wood of cut down trees:**

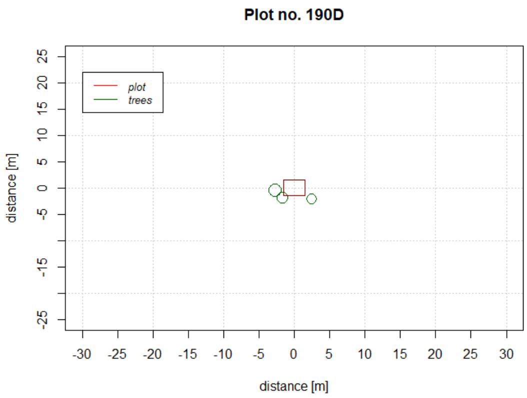
| | Tracts starting from Waterfront | All tracts |
|---|---|---|
| | P | P |
| Location | 0.4488 | 0.5117 |
| Plot | 0.1379 | 0.2621 |
| | With interdependency | |
| Plot | 7.443e-05 *** | 0.0001659 *** |
| Location | 7.547e-05 *** | 7.547e-05 *** |
| Plot/ Location | 2.628e-05 *** | 2.628e-05 *** |
| Plot | 4.163e-05 *** | 9.031e-05 *** |
| Location | 0.001302 ** | 0.002304 ** |
| Location/ Plot | 2.628e-05 *** | 2.628e-05 *** |

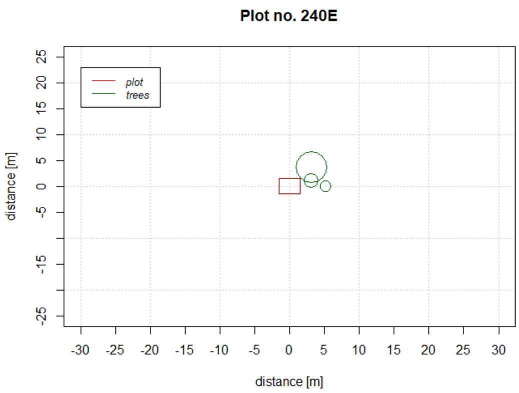
# Maps of geographical arrangement a canopy crown cover

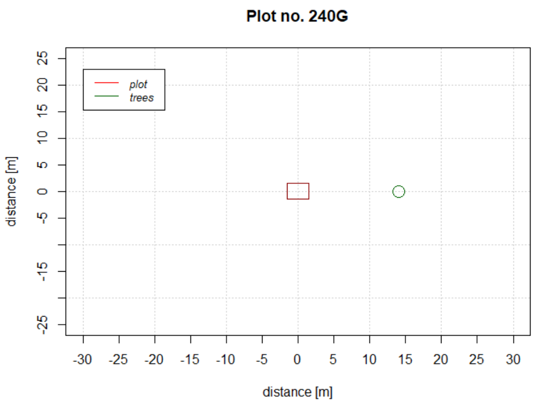


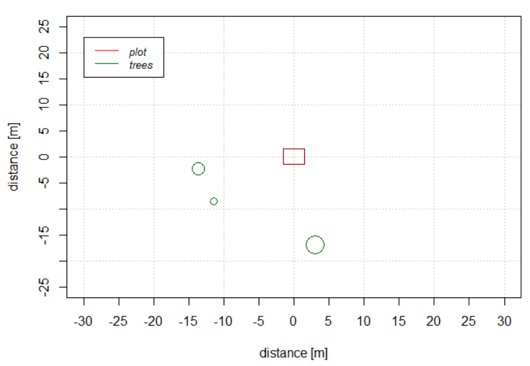



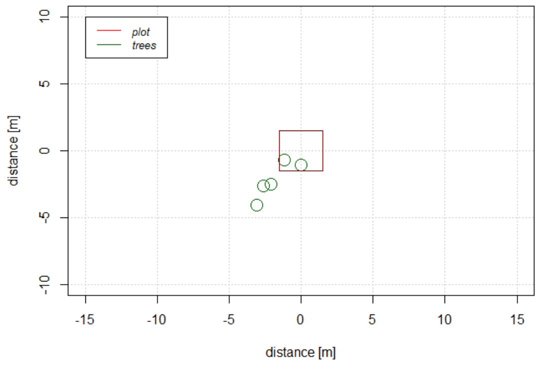



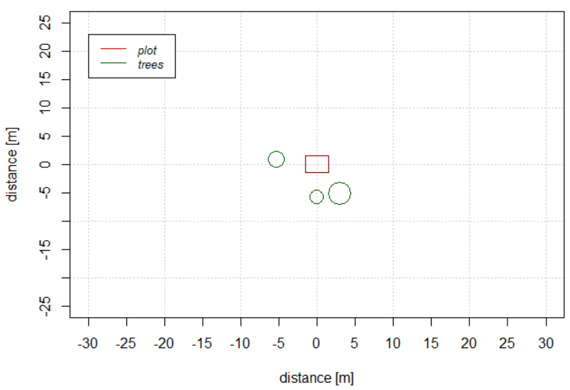
Plot no. 240F



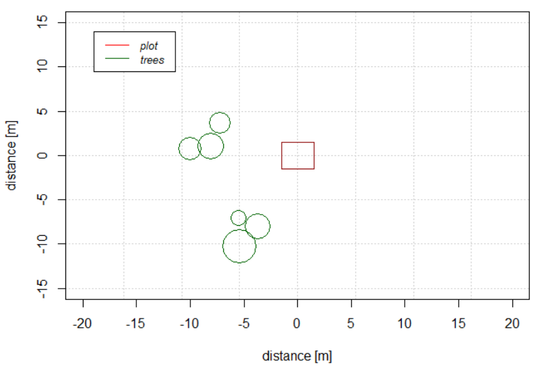

Plot no. 240H



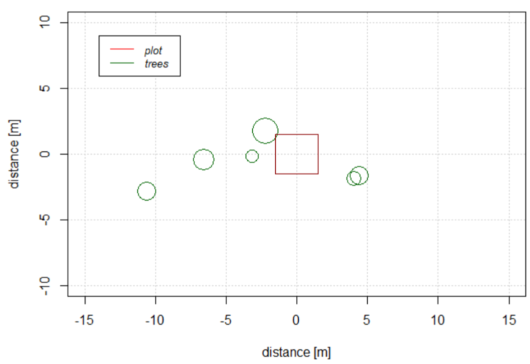

Plot no. 30I



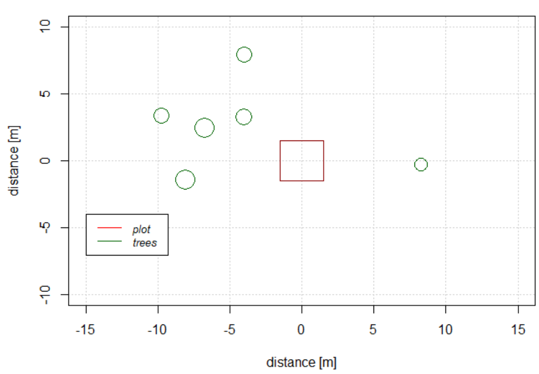

Plot no. 57M



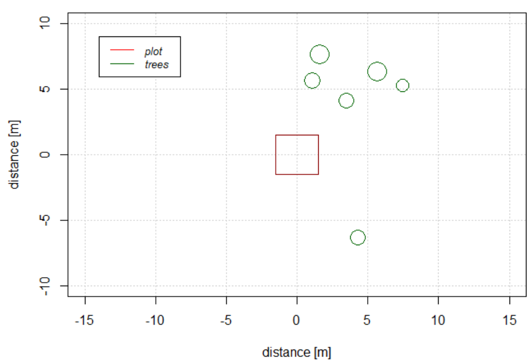

Plot no. 57N



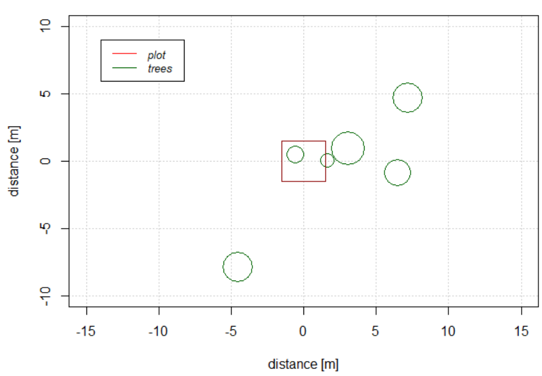
# Appendix



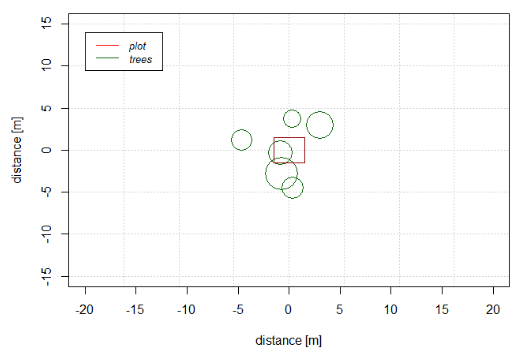

Plot no. 57O



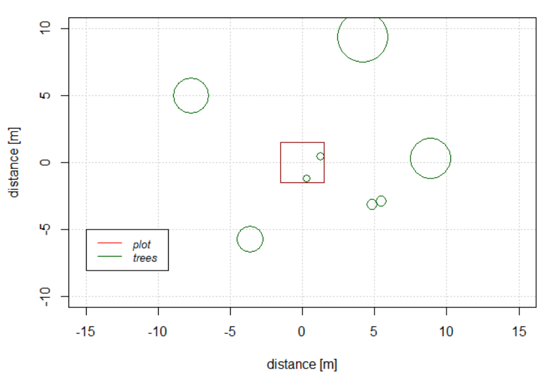

Plot no. 57P



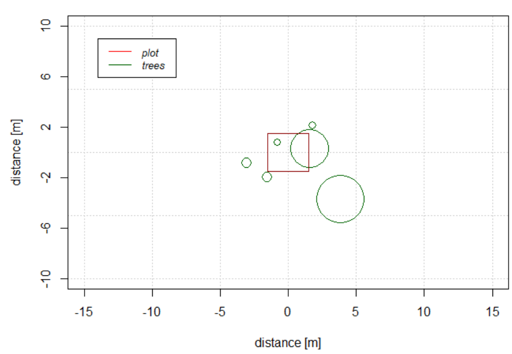

Plot no. 141R



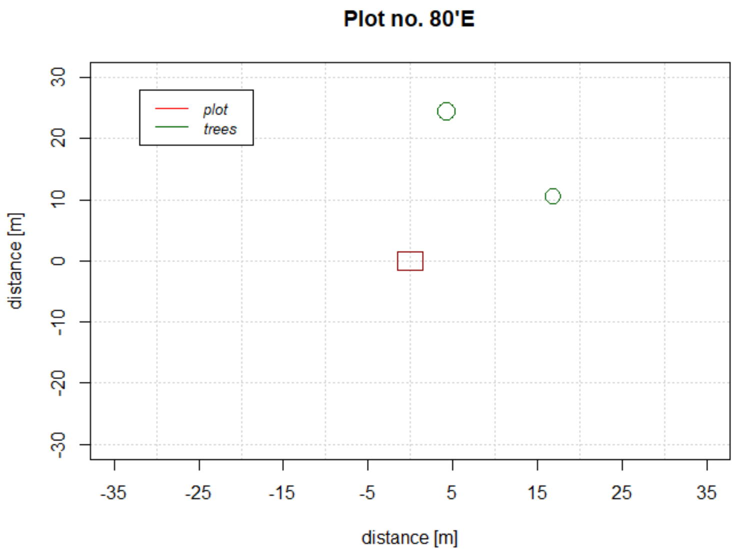

Plot no. 141Q

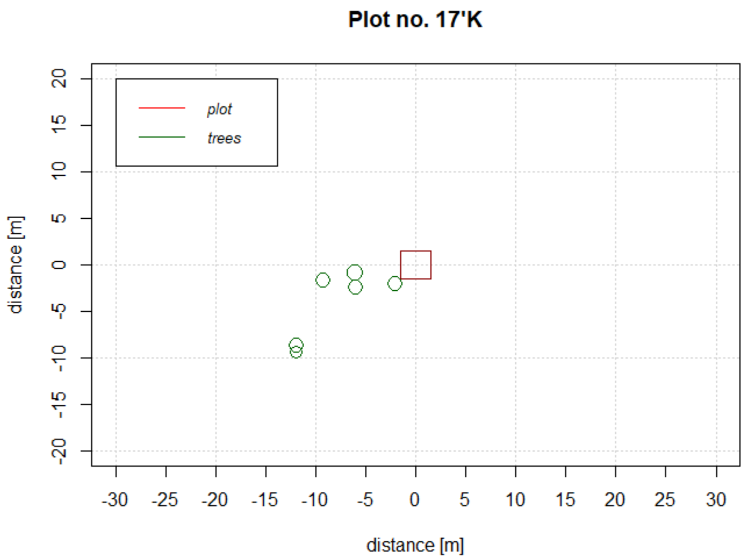



Plot no. 141S




Plot no. 141T


Plot no. 80'E
plot
trees
distance [m]
30
20
10
0
-10
-20
-30
-35
-25
-15
-5
5
15
25
35
distance [m]


Plot no. 17'K
plot
trees
distance [m]
20
15
10
5
0
-5
-10
-15
-20
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
distance [m]

## Field from DSM

| | |
|---|---|
| **Date** | |
| **Transect No.** | |
| **Plot no.** | |

| **Trunk (kg)** | **Branches (kg)** | **Leaves (kg)** | **Notes:** |
|---|---|---|---|
| | | | |
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## Field from KTDSM

Date
Plot No.
Distance to tree for hight [m]

| Tree No. | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Base [°] | | | | | | | |
| Height first Brench [°] | | | | | | | |
| Height total [°] | | | | | | | |
| Distance Plot Center [m] | | | | | | | |
| CBH [m] | | | | | | | |
| CBRH [m] | | | | | | | |
| Hight Butress Roots [m] | | | | | | | |
| Angle/ Kompass [°] | | | | | | | |
| Crown Radius [°] | N | | | | | | |
| | E | | | | | | |
| | S | | | | | | |
| | W | | | | | | |
| | **Notes:** | | | | | | |
| | | | | | | | |

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Fakultät für Mathematik, Informatik und Naturwissenschaften

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Zentrum Holzwirtschaft
Fachbereich Biologie
Fakultät für Mathematik, Informatik und Naturwissenschaften

## Consent form

Kandidat/in: Burkhart Ludwig Brielmaier
Studienabschluss: M. Sc. Holzwirtschaft
Thema: Methodology development of a tree volume function applicable to *Bruguiera gymnorrhiza* located in the mangrove forest of Fiji

**Sperrvermerk:** Die Arbeit wird in Bezug auf die Einsichtnahme Dritter bzw. die Ausleihe

☐ gesperrt ☐ nicht gesperrt.

Die Sperre gilt ab dem Datum der Abgabe für die Dauer von ☐ Jahren.

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☐ ja ☐ nein.

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☐ nicht einverstanden ☐ einverstanden.

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**Establishment of a Reference Level (FRL) for forest land and development of a System for Monitoring, Reporting and Verifying (MRV) carbon emission reductions from forests in FIJI**

**(04.2017 – 07.2018)**

# Methodology Development for FRL


**Lead organisation for this deliverable**: University of Hamburg

**Contributor name(s)**: Dr. Philip Mundhenk,

Prof Dr Michael Köhl, Dr Narendra Chand, Dr Prem Raj Neupane

# 1 Abbreviations

| | |
|---|---|
| AD | Activity data |
| AGB | Above-ground biomass |
| AI | Aridity Index |
| A.s.l. | Above sea level (m) |
| BGB | Below-ground biomass |
| $CO_2e$ | Carbon dioxide equivalents |
| COP | Conference of the Parties to the UNFCCC |
| E | Environmental stress factor |
| EF | Emission factor |
| FAO | Food and Agriculture Organization of the United Nations |
| FCPF | Forest Carbon Partnership Facility of thehe World Bank |
| FHCL | Fiji Hardwood Corporation Limited |
| FPL | Fiji Pine Limited |
| FREL/FRL | Forest Reference Emission Level/Forest Reference Level |
| GFOI | Global Forest Observation Initiative |
| ha | Hectare(s) |
| IPCC | Intergovernmental Panel on Climate Change |
| LDF | Logging damage factor |
| LIF | Logging infrastructure factor |
| MC | Monte Carlo |
| Mg | Megagram |
| NFI | National Forest Inventory |
| PSP | Permanent Sample Plot |
| R | Root to shoot ratio |
| REDD+ | Reducing Emissions from Deforestation and Forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries |

| | |
|---|---|
| SRTM | Shuttle Radar Topography Mission |
| TB | Total biomass |
| TC | Total carbon |
| TEF | Total (timber) emission factor |
| UNFCCC | Unied Nations Framework Convention on Climate change |
| WD | Wood density |

## CONTENT

# 2 Background

## 2.1 Aim

The goal of the Forest Reference Level (FRL) construction for Fiji is to estimate net historical forest-related emissions or removals for the period 2006 to 2016. The FRL will serve as a baseline against which future forest-related emissions or removals will be compared. For the FRL, the 17th session of the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC) (Decision 12/CP.17) requests countries to express emissions in metric tonnes of carbon dioxide equivalent ($tCO_2e$) per year. In this document, we propose a set of methodological approaches that we recommend as tools to estimate historical forest-related emissions in Fiji. To ensure consistency among historical, current and future estimates of emissions, the methodology proposed in this document is linked directly to the choice of methods that may be considered for future assessments. However, UNFCCC (Decision 12/CP.17, par. 10) "stresses the usefulness of adopting a stepwise approach, enabling countries to improve their FREL/FRL[1] over time by incorporating better data [and] improved methodology […]" (FAO, 2015a).

## 2.2 Scope and scale

### 2.2.1 REDD+ activities

The following three REDD+ activities will be included in Fiji's FRL**,** as outlined in Fiji's National REDD+ Policy [MPI, 2011] and the Emission Reductions Programme Idea Note [ER-PIN, 2016]:

a. reducing emissions from deforestation;
b. reducing emissions from forest degradation; and
c. enhancement of forest carbon stocks via afforestation and reforestation.

For Fiji's FRL, these three activities translate to the following sources and sinks of Greenhouse Gases (GHGs): a) emissions from deforestation, b) emissions from forest degradation, and c) removals from afforestation and reforestation.

### 2.2.2 Pools

Of the five forest carbon pools identified by IPCC (2003a, 2006), above-ground biomass (AGB) and below-ground biomass (BGB) will be included in Fiji's FRL construction. As of today, the contribution of the different carbon pools to total forest related emissions or removals is unknown in Fiji and, hence, no informed statement about their significance can be made. The decision which pools to include was guided by FCPF's REDD+ Decision Support Toolbox (FCPF-DST), expert judgements, data availability and implications for future emission reduction estimates.

As significant pools, FCPF-DST identified (i) AGB, (ii) BGB and (iii) Soil Organic Carbon (SOC). For Fiji, no data are available for litter and dead wood in FCPF-DST. SOC is excluded from

[1] Although the UNFCCC did not explicitly specify the difference between a Forest Reference Emission Level (FREL) and an Forest Reference Level (FRL), a common understanding is that the FRL includes both, activities that reduce emissions and increase removals, while an FREL only includes activities that reduce emissions.

the FRL mainly for two reasons. Firstly, no national estimates of SOC stocks are available in Fiji.Secondly, knowledge on conversions of IPCC land-use categories (e.g., Forest Land to Grassland, Forest Land to Cropland, or Grassland to Forest Land) are required to estimate emissions/removals in SOC after land-use conversion. These data are currently not available in Fiji, because only conversions from Forest Land to Non-Forest Land and vice versa aree mapped for the FRL. IPCC [2003b] and IPCC [2006] do not provide default Emission Factors (EFs) for the conversion from Forest Land to Non-Forest Land, as the latter is not considered an IPCC land-use category. FCPF [2016, Indicator 4.2.ii] stipulates that “Carbon pools [...] may be excluded if: The ER Program can demonstrate that excluding such Carbon Pools [...] would underestimate total emission reductions”. By excluding SOC, future potential emission reductions will be underestimated.

Litter and Dead Wood are considered insignificant. Excluding Litter and Dead Wood will cause an underestimation of future emission reductions.

*Table 1 Justification for the inclusion and exclusion of carbon pools.*

| Pool | Included | Justification |
|---|---|---|
| AGB | Yes | AGB is included in the FRL. |
| BGB | Yes | BGB is included in the FRL. |
| SOC | No | SOC is not included in the FRL. The exlusion of SOC will cause an underestimate of future emission reductions. |
| Litter | No | Litter is not included in the FRL. The exlusion of Litter will cause an underestimate of future emission reductions. |
| Dead Wood | No | Dead Wood is not included in the FRL. Excluding Dead Wood will cause an underestimate of future emission reductions. |

### 2.2.3 Gases

The Agriculture, Forestry and Other Land Use (AFOLU) sector cover mainly three types of GHGs, namely carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) (IPCC, 2006). Emissions of $N_2O$ may be caused by biomass burning or any forest management practice that increases the availability of inorganic nitrogen in soils. However, unless lands have had a heavy application of nitrogen fertilizer, forest-related emissions of $N_2O$ do not usually represent a key category (GFOI, 2016).

Similar to $N_2O$, $CH_4$ is released to the atmosphere when biomass is burned. In Fiji, man-made and wild fires are not uncommon (Trines, 2012), but national records on the cause, extent, and intensity are currently not available. The Burned Area Products from the Moderate-resolution Imaging Spectroradiometer (MODIS) was used to assess where burned areas were located between 2006 and 2016. An overlay of the forest cover maps of 2006 and 2012 produced by the Geoscience Division of the Pacific Community (SPC-GSD) and the MODIS Burned Area Products revealed that most of the burned areas were recorded in non-forested areas, mostly in grasslands. Fires that spread into forested areas were mostly located in pine plantations. AGB and BGB in pine stands are usually only significantly affected by fires if they are young (e.g., have been planted recently). However, these stands store only small amounts of carbon. Because of the lack of data on $CH_4$ and the supposedly minor contribution of non-$CO_2$ emissions to total emissions, only $CO_2$ will be considered during FRL construction.

*Table 2 Justification for the inclusion and exclusion of GHG gases.*

| Gas | Included | Justification |
|---|---|---|
| $CO_2$ | Yes | Carbon dioxide ($CO_2$) is inlcuded in the FRL. |
| $CH_4$ | No | Methane ($CH_4$) is not included in the FRL. Burning of biomass in forests is considered negligible as man-made fires rarely significantly affect above- and below-ground biomass. Exclusion of CH 4 will cause an underestimation of future emission reductions. |
| $N_2O$ | No | Nitrous oxide ($N_2O$) is not included in the FRL as forest management practices currently employed do not include heavy application of nitrogen fertilizer. Exclusion of $N_2O$ will cause an underestimation of future emission reductions. |

### 2.2.4 Scale

The FRL accounting area (i.e., the area for which the FRL is established) is subnational, including Fiji's three largest islands: Viti Levu, Vanua Levu and Taveuni. The accounting area covers about 89% of Fiji's forest area. A map of the FRL accounting area is shown in Figure 1.

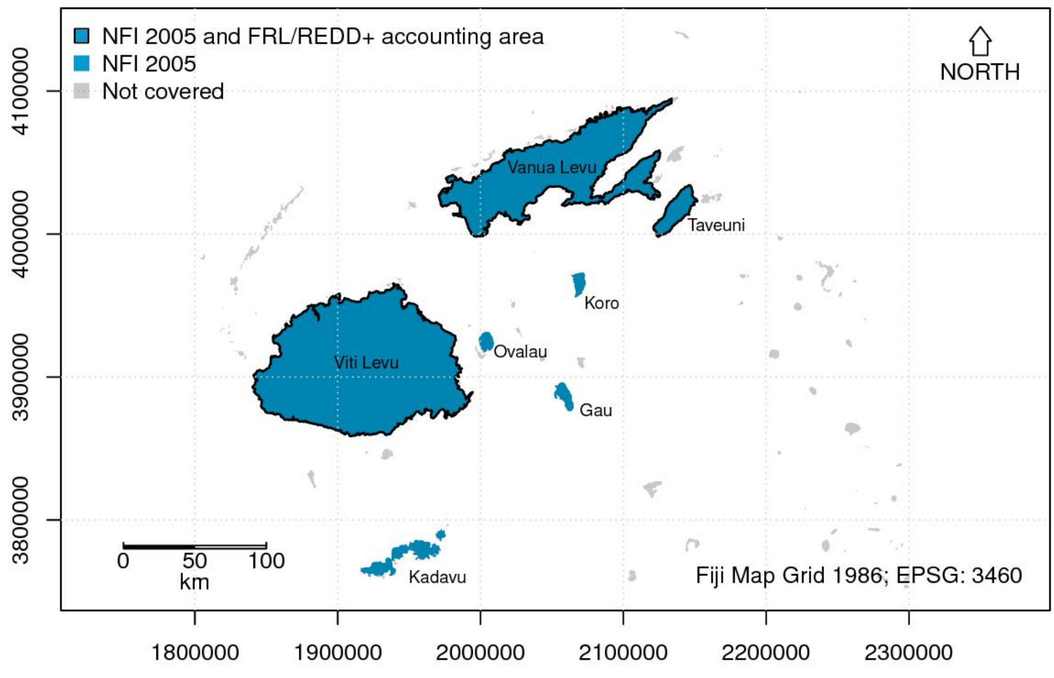


*Figure 1 Map of Fiji. In blue: areas covered by the National Forest Inventory (NFI) 2005; blue with black outline: areas included for the Forest Reference Level (FRL) construction and the NFI 2005.*

## 2.3 Definitions of forest, deforestation and forest degradation

### 2.3.1 Forest definition

The term 'forest' has not yet been formally defined in Fiji. For its national REDD+Policy (MPI, 2011), Fiji adopted the forest definition provided in FAO (2006):

"Land spanning more than 0.5 hectares with trees higher than five metres and a canopy cover of more than 10 percent, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agriculture or urban use. Forest is determined both by the presence of trees and the absence of other predominant land uses. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10 percent and a tree height of five metres are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate. Includes: areas with bamboo and palms, provided that height and canopy cover criteria are met; forest roads, fire breaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of scientific, historical, cultural or spiritual interest; windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 hectares and width of more than 20 metres; plantations primarily used for forestry or protected purposes [...]. Excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens" (MPI, 2011).

### 2.3.2 Definition of classes of forests: deforestation, forest degradation, forestation, plantation and forest enhancement

For Fiji's FRL, the IPCC land-use category 'Forest Land' was disaggregated into two sub-categories ('Natural Forest' and 'Forest Plantation'). Each sub-category holds two forest strata: the sub-category 'Natural Forest' contains the strata 'Lowland forest' and 'Upland forest' and the sub-category 'Forest Plantation' contains the strata 'Softwood plantation' and 'Hardwood plantation' (Table 23).

The boundary between 'Lowland forest' and 'Upland forest' was drawn at 600 m above sea level (a.s.l.). 'Lowland forest' is located below 600 m a.s.l. and 'Upland forest' equal or above 600 m a.s.l. This threshold value was set based on findings of Mueller-Dombois & Fosberg [1998], who identified structural and floristical changes below and above the threshold. A preliminary analysis of the NFI 2006 data revealed significant differences in average carbon stocks [t $ha^{-1}$] between the two strata.

Mangrove forests are not included in the FRL. As of today, no national estimates of carbon stocks in mangrove forests are available in Fiji. For mangrove only Tier 1 methods could, therefore, be employed (i.e., default carbon stocks $ha^{-1}$), which may not be sufficient to meet FCPF's Methodology Framework (MF) requirements [FCPF, 2016]. A test inventory was recently conducted in Fiji's mangrove forests but the analysis of the data has not yet been finalized. Moreover, the primary purpose of conducting the test inventory was to assess how to efficiently set up an inventory within Fiji's mangrove forests. Once estimates of carbon stocks and associated Emission Factors (EFs) are available, mangrove may be included in an updated FRL.

The strata 'Softwood plantations' and 'Hardwood plantations' within the sub-category 'Forest Plantations' cover the areas leased by Fiji Pine Limited (FPL) and Fiji Hardwood Corporation Limited (FHCL), respectively. Softwood plantations are almost exclusively stocked with pine trees (*Pinus* [*Pinus*] *caribaea* Morelet). Hardwood plantations are mostly stocked with broadleaf mahogany (*Swietenia macrophylla* King). The sub-category 'Forest Plantations' does not include areas outside the plantation lease areas of FP and FHCL that are planted with e.g., pine or mahogany. These planted areas belong to the sub-category 'Natural Forest'. Hence, land that is classified as 'Natural Forest' cannot be converted to 'Forest Plantation' and vice versa. This distinction was made because it was not possible to distinguish between natural (native) forests and planted forests using the available remotely sensed data. However, the boundaries of the plantation lease areas could be clearly demarcated (i.e., polygon vector files of the lease areas are available). Note that the sub-category 'Natural Forest' should not be confused with "native" or "primary" forest as the sub-category "Natural Forest" includes forests that evolve from natural regeneration (of native species), as well as areas planted with introduced species.

The stratification of forests used for the FRL differs from the one given in Fiji's Country Report to FAO's Global Forest Resources Assessment (FRA) [FRA-Fiji, 2015]. The stratification provided in the FRA is based on forest cover maps produced by the Geoscience Division of the Pacific Community (SPC-GSD). To differentiate between closed and open natural forest unsupervised classification techniques were used. However, no rigorous accuracy assessment [Olofsson et al., 2014] has been conducted on these maps, and their quality remains unknown. For the FRL, the available remotely-sensed data did not allow to reliably distinguish between e.g., closed and open forest.

*Table 3 IPCC land-use categories, sub-categories and forest strata used for Fiji's FRL.*

| IPCC category | Sub-category | Stratum | Description |
|---|---|---|---|
| Forest Land | Natural Forest | Lowland forest | The stratum 'Lowland forest' includes all areas classified as forest that are located <600 m a.s.l. It includes primary (native) forest, human modified forests as well as areas planted with native or introduced tree species. It does not include forest in plantation lease areas and areas classified as mangrove forest. |
| | | Upland forest | The stratum 'Upland forest' includes all areas classified as forest that are located ≥600 m a.s.l. It includes primary (native) forest, human modified forests as well as areas planted with native or introduced tree species. It does not include forest in plantation lease areas and areas classified as mangrove forest. |
| | Forest Plantation | Softwood plantation | The stratum `Softwood plantation' includes all areas leased by Fiji Pine Limited (FPL) between 2006 and 2016. The boundary of the lease area of FP is available as a vector (polygon) file. Areas not currently stocked with trees (crown cover percent is zero) but which are situated within FP's lease area are |

| | | | |
|---|---|---|---|
| | | | classified as forest |
| | | Hardwood plantation | The stratum `Hardwood plantation' includes all areas leased by Fiji Hardwood Corporation Limited (FHCL) between 2006 and 2016. The boundary of the lease area of FHCL is available as a vector (polygon) file. Areas not currently stocked with trees (crown cover percent is zero) but which are situated within FHCL's lease area are classified as forest. |
| Non-Forest Land | | Non-forest | The land-use category `Non-Forest Land' includes all areas not classified as `Forest Land'. For the FRL, areas classified as mangrove forest are included in the land-use category `Non-Forest Land'. Note that `Non-Forest Land' is not an IPCC land-use category. For the FRL, the land-use category `Non-Forest Land' includes all IPCC land-use categories, i.e., `Grassland', `Cropland', `Wetlands', `Settlements' and `Other Land', except the category `Forest Land'. |

The UNFCCC defined deforestation (Decision 16/CMP.1) as "the direct, human-induced conversion of forested land to non-forested land". For the FRL, deforestation was defined as the conversion of land classified as 'Natural Forest' to land classified as non-forest. Deforestation can only occur in the sub-category 'Natural Forest' and cannot occur in the sub-category 'Forest Plantation'. Areas within the plantation lease area that are not currently stocked with trees are still considered as forest (i.e., "temporarily unstocked" as defined in Fiji's forest definition). Hence, areas belonging to the sub-category 'Forest Plantation' that are cleared, i.e., all trees are removed, will not be considered as deforestation.

The IPCC report on "Definitions and Methodological Options to Inventory Emissions from Direct Human-Induced Degradation of Forests and Devegetation of Other Vegetation Types" [IPCC, 2003a] suggests the following characterization of the term "forest degradation": "A direct, human-induced, long-term loss (persisting for X years or more) or at least Y % of forest carbon stocks [and forest values] since time T and not qualifying as deforestation." The term "forest degradation" is not defined in Fiji and no quantitative threshold values are in use that allow to assess forest degradation either in the field or by remotely sensed data. For the FRL, emissions from forest degradation are estimated using proxy data, namely logging statistics. No data on forest degradation caused by wood fuel collection are available in Fiji and the FCPF-DST. However, emissions from wood fuel are considered insignificant (ER-PIN, 2016).

# 3 Methodological framework to estimate emissions by sources and removals by sinks

## 3.1 General approach

For the FRL construction we consider four sources of emissions/removals: (i) emissions from deforestation in natural forests, (ii) emissions from logging in natural forests (i.e., degradation), (iii) emissions and removals in forest plantations, and (iv) removals from afforestation in areas that have not been forested at the beginning of the reference period (i.e., 2006). These four sources link to the three REDD+ activities reducing emissions from deforestation, reducing emissions from forest degradation and enhancement of carbon stocks. For the FRL (i) to (iv) will be combined and net emissions (or removals) will be estimated, i.e.,

Net emissions/removals = Emissions (from (i), (ii) and (iii)} – Removals {from (iii) and (iv)}.

As described in the previous section deforestation occurs only in natural forest. Afforestation occurs in areas that were not forested in 2006 and are not located in areas designated as plantation areas, i.e., lease areas of FPL and FHCL. To estimate emissions from deforestation the gain-loss method will be applied (see Section 3.3.1). For the gain-loss method the average carbon stock per hectare needs to be estimated. This estimate is called the emission factor (EF). In order to estimate emissions from deforestation, the carbon stock estimate is multiplied by the area of forest loss (in hectares) during the reference period 2006 -2016. Removals from afforestation are estimated in a similar way. Net emissions are estimated as shown above. To estimate areas of forest loss and gain, the Geoscience Division of the Pacific Communities (SPC-GSD), located in Suva, Fiji Islands produces a forest map that depicts areas of forest change between 2006-2012 and 2012-2016. The change map is based on an overlay of a forest cover map from 2006 to 2012 for the first period and from 2012 to 2016 for the second period.

Plantation areas and areas that were logged will be excluded from mapping, because areas harvested will be taken from logging statistics of FPL and FHCL. For the estimation of emissions/removals from deforestation/afforestation a single estimate for the entire reference period will be available. This estimate will be annualized by dividing total emissions by (2012 - 2006) = 6 years and (2016 – 2012) = 5 years. *The forest change maps are still not available to the consultancy team!*

Emissions from logging in natural forest (i.e., forest degradation) are estimated using national logging statistics. These statistics provide annual data on the volume logged and the area where the logging took place within the reference period. Logged volumes will be converted to $CO_2e$ and will be treated as committed (i.e., direct) emissions, even if the carbon is stored in wood products and not directly emitted to the atmosphere. Emissions from logging do not only result from the extracted timber itself but also from logging residues (e.g., tree stumps and crowns left as logging residiues in gap from felled tree in the forest), damage to nearby trees (i.e., incidental damage) and construction of logging infrastructure (e.g., log-landings or skid trails). To account for these additional sources of emissions, the carbon logged will be multiplied by a Logging Emission Factor (LEF). The LEF will be taken from a study that was conducted in Fiji (see Haas (2015)) and LEF estimates from other tropical countries. Emissions from logging in natural forests will be estimated on an annual basis, since logged volumes are recorded annually. *Data on logged volumes and areas harvested were provided by Divisional Forest Offices, but serious flaws in the data were detected and no updated data were provided to the consultancy team so far!*

Emissions and removals from plantations (pine and mahogany) will be estimated using data that are available at Fiji Pine Limited and Fiji Hardwood Corporation Limited. *These data are partly available to the consultancy team, but serious flaws in the data were detected and no updated data are yet available!* To estimate emissions from plantations, the volumes harvested per year will be converted to $CO_2$e, such that average annual emissions can be estimated. Removals will be estimated by multiplying the areas planted in a year, by estimates of growth extracted from yield functions that are available for FPL and FHCL. In a similar way, the removals from plantation areas that were neither harvested nor planted between 2006-2012 and 2012-2016 will be computed.

Figure 2 shows the three sources of forest-related emissions that are considered for the FRL construction in Fiji. For each of the three components the uncertainty attached to the emission estimate will be estimated using either readily available estimators (i.e., formulas), or, if the estimation procedures are more complex (e.g., Tier 2 and Tier 3), Monte Carlo (MC) simulations will be conducted. The final result of the FRL construction will be a single annualized $CO_2$e emission/removal estimate for the period 2006 to 2016, including an estimate of precision. Annual estimates of the two periods 2006-2012 and 2012-2016 will be combined by computing a weighted historical average. *These estimates can only be produced, if the (existing) data are made available to the consultancy team!*

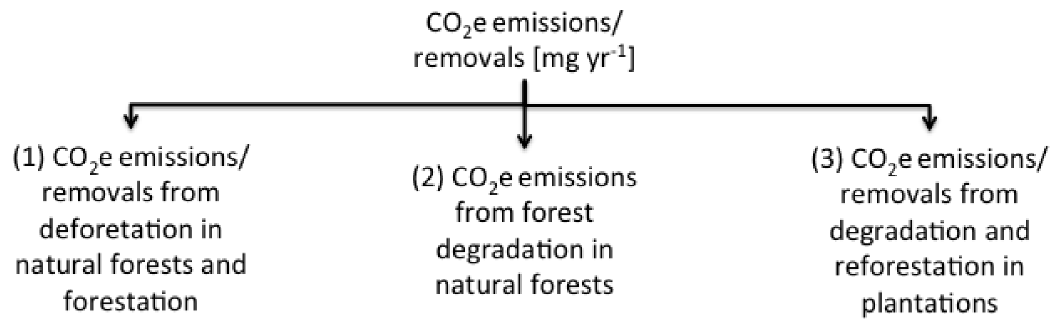


*Figure 2 The figure shows the three sources of forest-related emissions that are considered for the FRL construction in Fiji. The three sources render different sets of data fort the assessment of Activity Data (AD) and Emission Factors (EFs) necessary (Table 4). For each of the three components the uncertainty attached to the emission estimate.*

## 3.2 Data sources

Several sources of data and information are used for the FRL construction. A brief overview is provided in the following compilation:

| | |
|---|---|
| NFI 2005 | Data from Fiji's third National Forest Inventory (NFI) 2005. The NFI data are the primary source to estimate emission factors (EF) in Fiji's natural forests (excluding mangrove forests). |
| PSP | Data from Fiji's Permanent Sample Plot (PSP) program. Data from the first PSP round (2010) is used to derive diameter-height models, which are used as input to derive emission factors. |
| SRTM | Elevation (model) data from the Shuttle Radar Topography Mission. The SRTM data are used to derive emission factors for different elevation levels (domains/strata). |

| | |
|---|---|
| Aridity Index (AI) | A global raster map that is used to select default root:shoot ratios (R) to derive estimates of below-ground biomass (BGB). The raster is available on the web. |
| ESF | A global raster of the environmental stress factor (ESF). The ESF is used to predict above-ground biomass (AGB) of single trees as input to derive emission factors for natural forests. The ESF raster map is available on the web. |
| Wood Density Database | Database of estimates of wood specific gravity for tropical tree species. Used as input to predict single tree AGB. |
| Satellite imagery | Satellite data (mostly Landsat) to create forest cover and forest cover change maps and to obtain Activity Data (AD) for the reference period (including data procurement for the accuracy assessment, i.e., the reference or validation dataset). |
| Vector data | Georeferenced vector data, used to derive emissions from forest degradation in natural forests (excluding mangrove) and planted forests. The vector data are also used to exclude logged areas from deforestation mapping. |
| Logging statistics | National statistics of wood volumes removed from natural forests. Used to derive emissions from forest degradation in natural forests. |
| Plantation | Data from pine and mahogany plantations managed by Fiji Pine Limited and Fiji Hardwood Corporation Limited. The data are used to derive emissions from forest degradation and removals from reforestation in plantations. |
| Auxiliary information | Data and information from several (local) study reports, research articles and the IPCC guidance and guidelines documents [IPCC, 2003b, 2006]. |

## 3.3 Emissions from deforestation and removals from forestation

### 3.3.1 General approach

In its “Good Practice Guidance” (IPCC, 2003b) and “2006 Guidelines” (IPCC, 2006) the IPCC distinguishes between two methods to estimate GHG emissions and removals: the stock change method and the gain-loss method. For the stock change method (called the stock difference method in IPCC (2006)) net annual emissions are estimated from the difference in total carbon stocks at two points in time, divided by the number of intervening years. Carbon stocks are estimated from repeated field measurements from national forest inventories (NFIs); remotely sensed data may be used as auxiliary data to improve the efficiency of the estimation. For the gain-loss method net annual emissions are estimated as the sum of gains and losses in the different carbon pools. The gain-loss method requires the estimation of emission or removal factors (EF)[2] and activity data (AD). AD are data on the extent of human activity causing emissions and removals, and are often data on areas or areas of change (e.g., a change from Forest Land to another land use category, or change from Non-Forest Land to Forest Land in case of removals) (GFOI, 2016). EF are emissions or removals per unit activity. For the gain-loss method, total net carbon emissions or removals are estimated as the product of estimated AD and their associated EF estimates:

Net carbon emissions/removals = AD x EF

For the FRL construction in Fiji, the gain-loss method will be applied for the estimation of emissions from deforestation in natural forest (excluding mangrove forests). The data sources used for estimating emissions from deforestation/afforestation, forest degradation, and emissions/removals from degradation and reforestation in plantations are presented in Table 4.

*Table 4: Data sources for estimating emissions from deforestation/afforestation, forest degradation, and emissions/removals from degradation and reforestation in plantations*

| Sources of $CO_2$e emissions/ removals | AD | EF | Uncertainty assessment |
|---|---|---|---|
| Deforestation | Remote sensing[1] | NFI 2005 | Monte Carlo (MC)[5], Accuracy assessment |
| Afforestation | Remote sensing[1] | NFI 2005 | MC, Accuracy assessment |
| Forest remaining forest | Remote sensing[1] | NFI 2005 | MC, Accuracy assessment |
| Degradation | Logging areas[2] | Volume logged[3] | MC |
| Emissions/ removals from plantations | Plantation area[4] | Changes of per year growing stock[4] | MC |

[1)] Excluding logging areas and plantation areas

[2)] obtained from Harvested Area Reporting (HAR)

[3)] obtained from Timber Revenue System (TRS) database

[4)] provided by Fiji Pine Ltd. and Fiji Hardwood Corporation Ltd.

[5)] Monte Carlo methods

[2] The acronym EF includes emissions as well as removals.

### 3.3.2 Emission factors

The primary source to derive emission factors for natural forest is data from Fiji's NFI 2005. For the NFI 2005, attributes of trees were recorded on in total $n$ = 1023 fixed area cluster plots. Data collection started in 2006 and was finalized in late 2007. A stratified simple random sampling design was employed, where the strata were closed and open forest. The map that was used for stratification was derived by visual interpretation of Landsat imagery that was acquired between 2000 and 2002.

To derive emission factors from the NFI 2005 data several steps were necessary. First, the above-ground biomass of individual trees needed to be predicted. This is commonly done by applying allometric models that relate easy to measure tree attributes (e.g., diameter at breast height [DBH], species and total tree height) to the AGB of an individual tree. Up until now, no country-specific allometric models are currently available in Fiji that allow for a nation-wide application. Therefore, two candidate models were selected that have been published in Chave et al. (2014). Equation 7 in Chave et al. (2014) requires as input the DBH, the wood specific gravity and a so-called environmental stress factor. The DBH was measured during the NFI 2005. Wood densities were extracted from available literature resources and global databases (Zanne et al., 2009). The environmental stress factor $E$ — which serves as a substitute for height measurements — is available in the form of a global raster map. As the geographic positions of NFI cluster plots were known, the value of $E$ was extracted at each plot location and was attached to the trees located on the respective plot. The AGB was predicted for all trees recorded during the NFI 2005, using Chave et al.'s (2014) Euqation 7.

The second model, Equation 4 in Chave et al. (2014), requires the DBH, wood density and measured total tree height as input to predict the AGB of an individual tree. Total tree height was not measured during the NFI 2005, however. To predict the heights of trees, data from Fiji's Permanent Sample Plot (PSP) program was used. During the first round of the PSP program (2010), the DBH, species and height was measured on trees located on 86 fixed area sample plots. In total more than 9000 trees were recorded and for more than 5000 of them records of the DBH, species and tree height were available. These data were used to derive a diameter-height model, which was then applied to the NFI 2005 dataset. Once tree heights were predicted using the PSP height model, Equation 4 in Chave et al. (2014) was used to predict the AGB of all NFI trees.

When the AGB predictions of the two models were compared, large deviances were observed. Therefore, a third AGB model was considered. This "adjusted" allometric model was derived by refitting Chave et al. (2014)'s Equation 4 to a subset of the data Chave et al. (2014) used to derive the allometric model. The subset was chosen such that the diameter-height relationship was similar to the relationship found for the PSP data. The model was used to predict the AGB of all trees recorded during the NFI 2005. Although a pan-tropical dataset was used to derive the AGB model for Fiji, locally available data were used to adjust the model, and, hence, we consider this approach as being Tier 2 (see IPCC (2006))

After the AGB was predicted for individual trees, AGB was aggregated at the cluster plot level and expanded to per hectare values, i.e., $n$ = 1023 predictions of AGB [t $ha^{-1}$] were available. These plot level predictions were used as input to compute estimates of below-ground biomass (BGB) at the plot level.

To derive BGB, default root:shoot ratios (R) found in IPCC(2006) were used. IPCC(2006) provide ratios for different ecological zones and Fiji falls entirely into the "Tropical rain forest" zone. However, with respect to rainfall, the mountainous topography in Fiji, combined with the southeast trade winds, produce a pronounced windward-leeward effect (ranging from about 3000 mm rainfall per year, or more at higher elevations, to about 1800 mm per year, or less in sheltered positions) (Mueller-Dombois & Fosberg, 1998). For a more detailed zoning, the following three zones were considered: "Tropical rain forest" (≤3 months dry during winter), "Tropical moist deciduous forest" (3-5 months dry during winter) and "Tropical mountain systems" (altitudes approximately > 1000 m with local variations). The decision which R to apply was guided by the aridity index (AI; Zomer et al., (2008)) and altitude at plot location. Plots located ≥ 600 m above sea level (a.s.l.) were classified as "Tropical mountain systems" (see Mueller-Dombois & Fosberg (1998; page 121)). To differentiate between tropical rain- and tropical moist deciduous forest (among plots that were located < 600 m a.s.l.), different thresholds of the AI were considered. Table 5 shows which R was used for the NFI 2005 plots.

*Table 5 Root:shoot ratios (R) used to compute values of BGB = AGB _ R [t]. Adopted from Table 4.4 in IPCC [2006, Chapter 4].*

| **Ecological zone** | **Altitude [m]** | **AI**[3] | **AGB [t ha$^{-1}$]** | **R**[4] |
|---|---|---|---|---|
| **Tropical rainforest** | <600 m a.s.l.[5] | ≥2 | | 0.37 |
| **Tropical moist deciduous forest** | <600 m a.s.l. | <2 | ≥125 | 0.24 |
| | | <2 | <125 | 0.20 |
| **Tropical mountain systems** | ≥600 m a.s.l. | | | 0.27 |

Once AGB and BGB were available at the plot level, total biomass (TB) was predicted for each NFI 2005 cluster plot as TB = AGB + BGB. Afterwards, TB was converted to total carbon (TC) and TC = TB x 0.47 was converted to carbon dioxide equivalents ($CO_2e$ = TC x 44/12). Table 6 shows the conversion factors which were applied. All estimates were based on the adjusted allometric model. For FRL construction the adjusted model will be chosen, because we assumed, that this model lead to the supposedly smallest bias (i.e, the smallest systematic difference between the predicted and unknown "true" AGB [Mg] of an individual tree). Moreover, using the adjusted model will reduce the risk of overestimating potential future emission reductions.

*Table 6 Conversion factors used to estimate below-ground biomass, total biomass, total carbon and carbon dioxide.*

| Name | Abbreviation | Unit | Conversion |
|---|---|---|---|
| Above-ground biomass | AGB | t ha$^{-1}$ | |
| Below-ground biomass | BGB | t ha$^{-1}$ | BGB = AGB x R |
| Total biomass | TB | t ha$^{-1}$ | TB = AGB + BGB |

[3] AI = Aridity Index

[4] R = root to shoot ratio

[5] A.s.l. = above sea level

| | | | |
|---|---|---|---|
| Total carbon | TC | t $ha^{-1}$ | TC = TB x 0.47 |
| Carbon dioxide equivalent | $CO_2e$ | t $ha^{-1}$ | $CO_2e$ = TC x 44/12 = TC x 3.667 |

Estimators that are commonly applied for stratified simple random sampling designs were used to predict average $CO_2e$ [t $ha^{-1}$] for the two strata "closed forest" and "open forest" and several domains (i.e., subpopulations that may cut across strata). The estimators are found in Särndal et al. (1992). The analysis revealed that no significant differences in $CO_2e$ [t $ha^{-1}$] were found between closed and open forest, most likely because the differentiation of closed and open forest using unsupervised classification was poor.

Estimates were computed by only considering those plots that fell into the FRL accounting. Average $CO_2e$ [t $ha^{-1}$] was also estimated for different elevation levels: lowland (plots below 600 m above sea level) and upland (plots equal or above 600 m above sea level). $CO_2e$ [t $ha^{-1}$] differed significantly between the two domains. We, therefore, recommend applying different emission factors for the two domains "Lowland forest" and "Upland forest". A finer "stratification" (or breakdown into domains) may not be favorable from a statistical point of view, because this splitting may increase variances of $CO_2e$ [t $ha^{-1}$] estimates within the domains.

Variances of emission factor estimates were computed in two different ways. First, variances were estimated assuming that the plot level $CO_2e$ [t $ha^{-1}$] predictions are free of error (i.e., ignoring the uncertainty that results from using an allometric model). Closed form estimators (i.e., formulas) exist, that can be applied to estimate the variance of population, strata and domain means and totals. To account for the uncertainty in the adjusted allometric model, a Monte Carlo (MC) simulation will be conducted in which random errors are added to different components of the model. For the simulation, the following random errors will be added:

- Random error in wood density estimates (error randomly drawn from a Normal distribution with mean zero and a standard deviation that is estimated from the variability in wood density estimates).
- Random error in predicted heights (error randomly drawn from a Normal distribution defined by the distribution of residuals of the height model).
- Error from the refitted allometric model (error from a Normal distribution defined by the residual distribution of the refitted model).

These errors will be added to individual tree level AGB predictions. Afterwards plot level AGB will be aggregated (as described above). In total 10,000 runs will be conducted (i.e., AGB is predicted for each plot 10,000 times). In a next step, a random error is added to the root:shoot ration R. Parameters for the error distribution will be taken from Table 4.4 in IPCC (2006). To account for sampling error, bootstrap samples will be taken from simulated plot data [$CO_2e$ t $ha^{-1}$]. The final estimation error will be computed by taking the standard deviation of 10,000 bootstrap estimates of the target parameter $CO_2e$ [t $ha^{-1}$].

### 3.3.3 Activity data

Land cover change information provides the basis for estimating emissions and removals from human activity (activity data - AD). The procurement and analysis of AD should follow IPCC good practice guidelines that advocate neither over- nor under-estimating GHG emissions or removals and reducing uncertainties as far as is practicable (IPCC 2006, GFOI

2003, 2016). To estimate accurate and consistent AD for Fiji, a forest area change assessment and an accuracy assessment have been carried out.

The following 4 steps (Figure 3) best describe the overall methodology adopted for accuracy assessment of forest change. This approach is based on IPCC good practice guidelines and is recommended by Olofsson et al. (2014) and the Global Forest Observation Initiative (GFOI, 2016; section 5.1.5.).

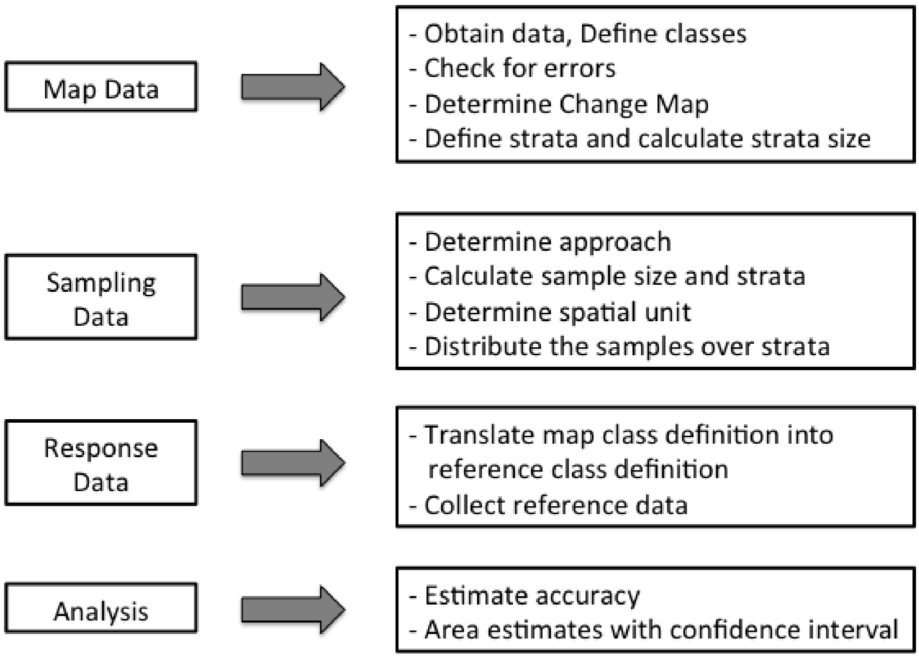


*Figure 3 Methodology for forest change accuracy assessment.*

Activity data used for FRL construction for Fiji will be taken from a land cover change assessment conducted between the years 2006-2012 and 2012-2016. The focus of change assessment is primarily on changes between forest and non-forest categories including the strata Lowland and Upland forest. Landsat Thematic Mapper (TM) data downloaded from the United States Geological Survey (USGS) Global Visualization Viewer (GloVis) were used to obtain land cover data. In addition, geospatial information of the Fiji Ministry of Lands and Mineral Resources, Lands Department, river system and Shuttle Radar Topographic Mission (SRTM) Digital Elevation Model (DEM) with 30 m and 90 m resolutions were used as supplementary data. Land cover data for 2006, 2012 and 2016 as well as the change detection map have been prepared by the Pacific Community (SPC), Geoscience Division.

A specific problem for the South Pacific region is the limited availability of historical satellite data, which is partly due to persistent cloud cover, non-regular recording of satellite imagery due to the lack of receiving stations and inadequate data access infrastructure in the region. Therefore, the assessment of accuracy of forest change could not be done through comparing map data with greater quality reference data. Instead a sampling approach was applied that implemented an independent second image interpretation of Landsat TM data (i.e., assessing the accuracy of a map using independent reference data). The comparison of reference (i.e. independent interpretation) and map data (i.e. interpretation by SPC-Geoscience) allowed for bias-corrected area estimates with associated confidence intervals (GOFC-GOLD 2016).

#### 3.3.3.1 Methodology for land cover interpretation

Map data refers to the input maps used for forest change assessment. Considering the requirement of historical data for FRL construction, a review of existing cloud-free satellite imagery for the years 2006, 2012 and 2016 was conducted. The following criteria were adopted based on expert consultation for selecting the appropriate satellite scenes for map source:

- Historical coverage,
- Wall-to-wall coverage,
- Cloud-free coverage,
- Derived from same sensor configuration,
- Consistent in scale and spatial extent,
- Proven accuracy measures, and
- Well accepted by the FRL team and REDD+ SC Fiji.

Landsat TM scenes were found that meet the above mentioned criteria. The data preparation included an atmospheric correction of the image data and a geometric correction with reference to the Lands Department river system. The corrected satellite imagery for 2006 and 2016 was embedded in a GIS, and two GIS backdrops were produced:

-True color composite (RGB: red, green, blue), see Figure 4
-False color composite (blue, green, near infrared), see Figure 5

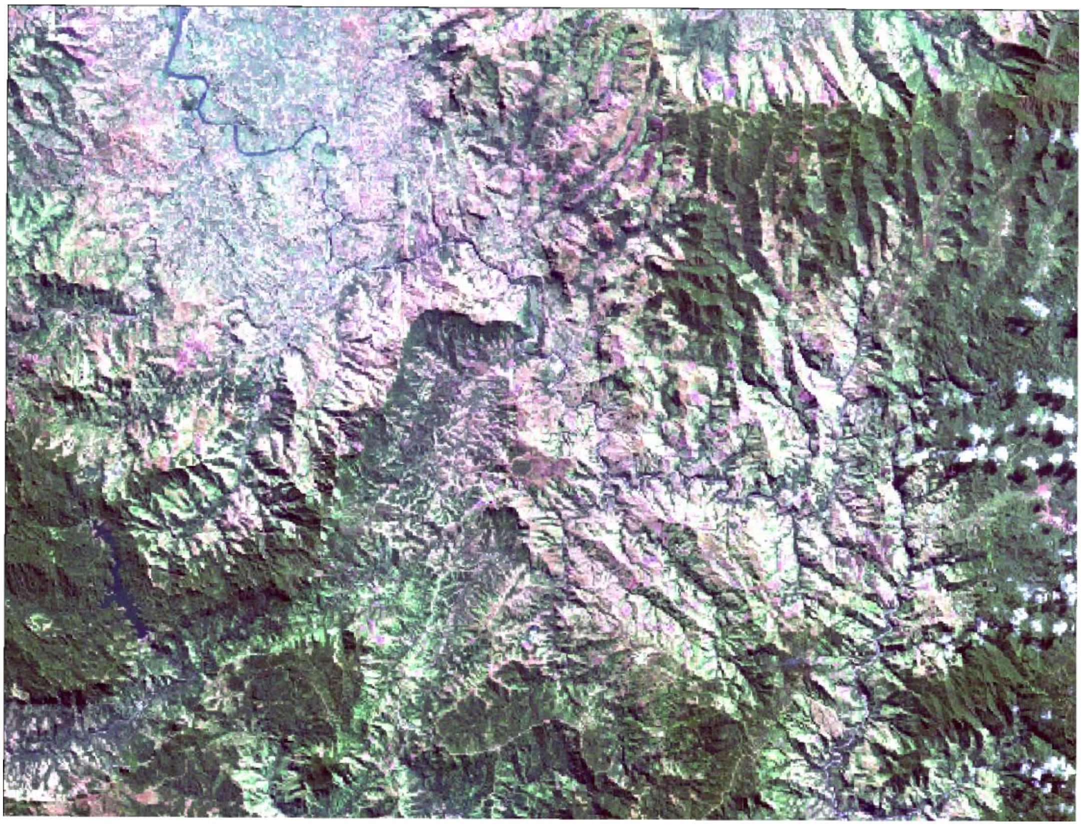

*Figure 4 True color composite – close-up (RGB: red, green, blue).*

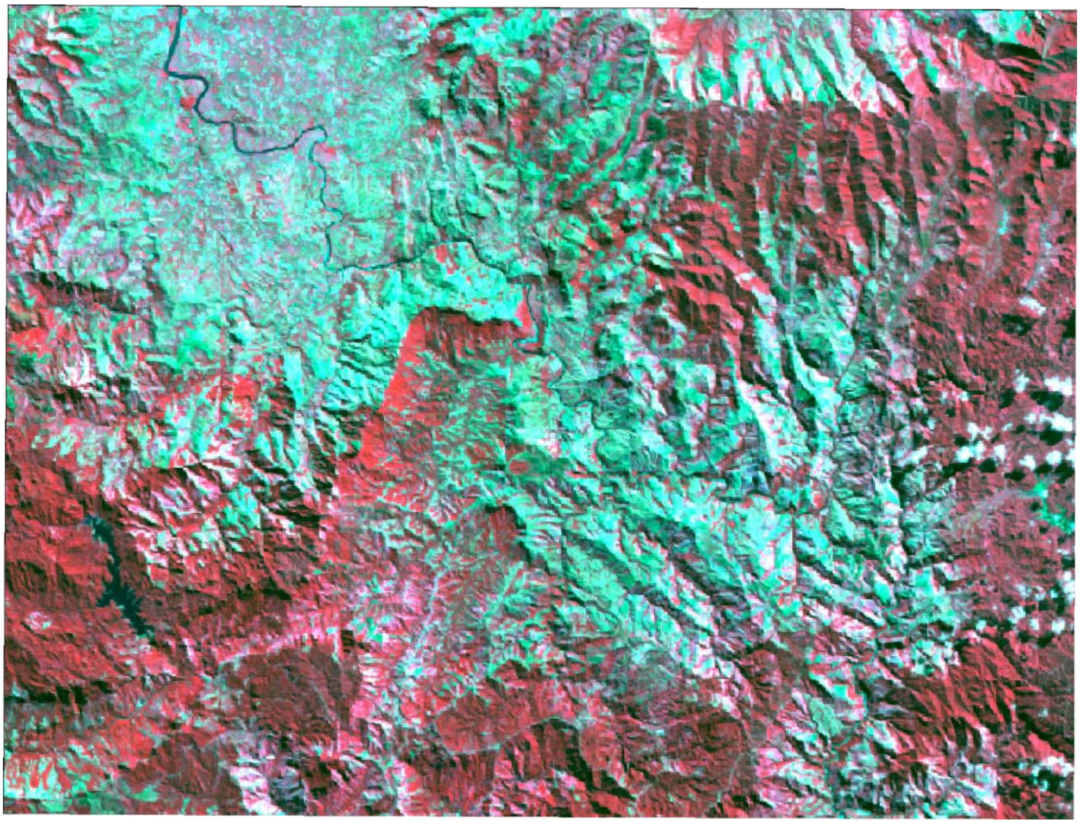

*Figure 5 False color composite – close-up (blue, green, near infrared).*

In 2007 forest polygons have been digitized from Landsat TM imagery that contain the boundaries between forest and non-forest areas. The GIS-data of 2006, 2012 and 2016 were overlaid with those polygons. Subsequently the 2007 polygons were adjusted for the 2006, 2012 and 2016 situation. The resulting forest boundaries for 2006, 2012 and 2016 were combined with auxiliary raster data (i.e. water, forest plantations) and converted to thematic raster maps. The classes assigned to each pixel follow the classification system shown in Table 7 Land cover classification.

*Table 7 Land cover classification.*

| Class | Code |
|---|---|
| 1 | Forest |
| 2 | Mangrove |
| 3 | Pine plantation |
| 4 | Mahogany plantation |
| 5 | Coconut plantation |
| 6 | Water body |
| 7 | Non-forest |

In order to be consistent with the definition of the REDD+ accounting area and the overall approaches to estimate (1) emissions in natural forests, (2) emission from logging in natural forests, and (3) emissions and removals from management of plantations; the forest area displayed in the 2006, 2012 and 2016 raster data had to be adjusted. Therefore, water bodies (class 6), plantation areas (classes 3 and 4), coconut plantations (class 5) and mangroves (class 2) were excluded. Plantation areas were excluded because, emission and removals will be estimated differently using data provided by FPL and FHCL.

Figure 6 summarizes the workflow for the land-use interpretation and subsequent land-use change assessment.

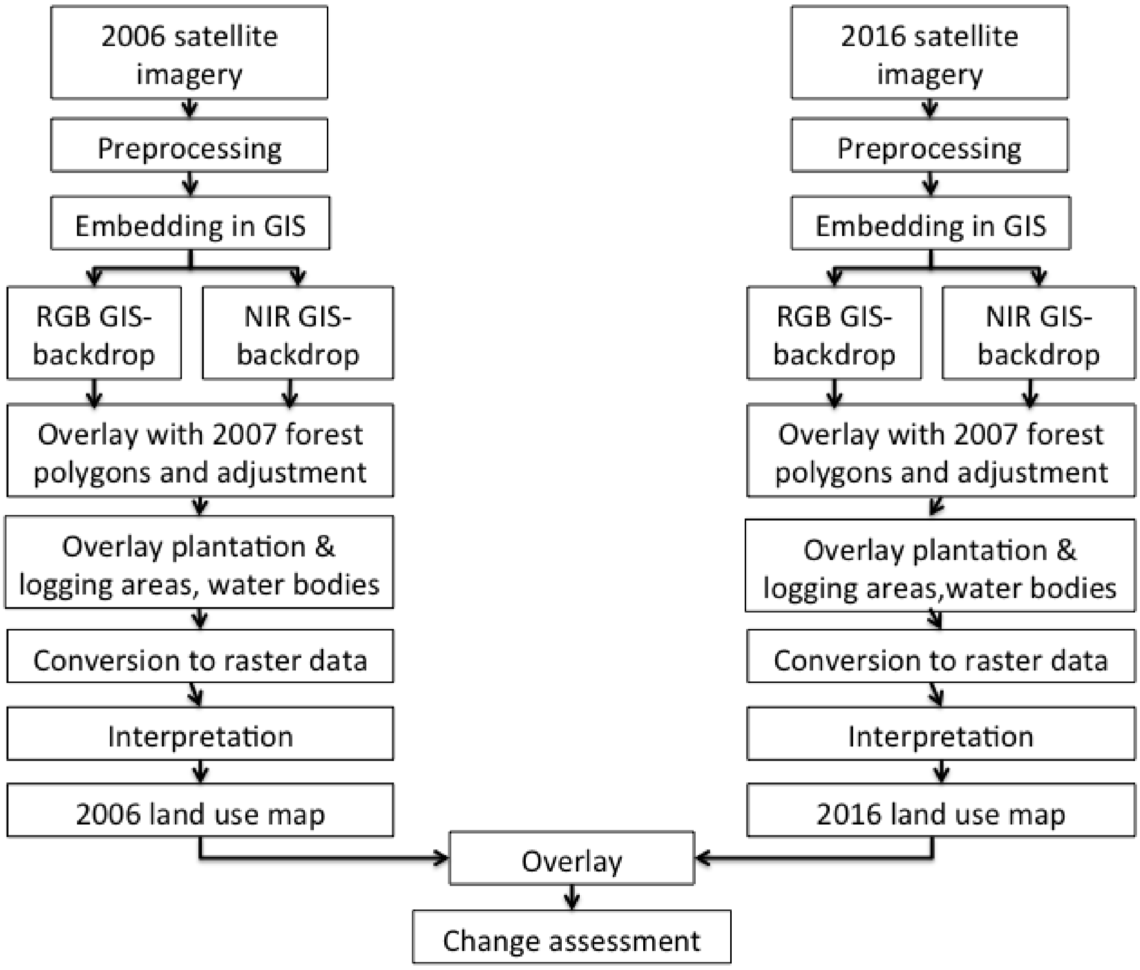


*Figure 6 Workflow showing land-use interpretation and land-use change assessment.*

#### *3.3.3.2 Land-use change assessment*

In a final step, the resulting raster data for 2006, 2012 and 2016 are overlaid and six area change classes (i.e. forest remaining forest, land converted to Forest Land, Forest Land converted to non-forest Land for both strata Lowland and Upland forest) are calculated for each pixel (Figure 7). The raster data are cut into map sheets and the respective area changes are calculated. In addition, each pixel will be classified as being located over or below 600m a.s.l., utilizing the SRTM digital terrain model. The use of the biophysical factors (correlation between elevation and biomass/carbon density) as a basis for stratification of forest cover will increase the accuracy and precision of the measuring and monitoring forest carbon.

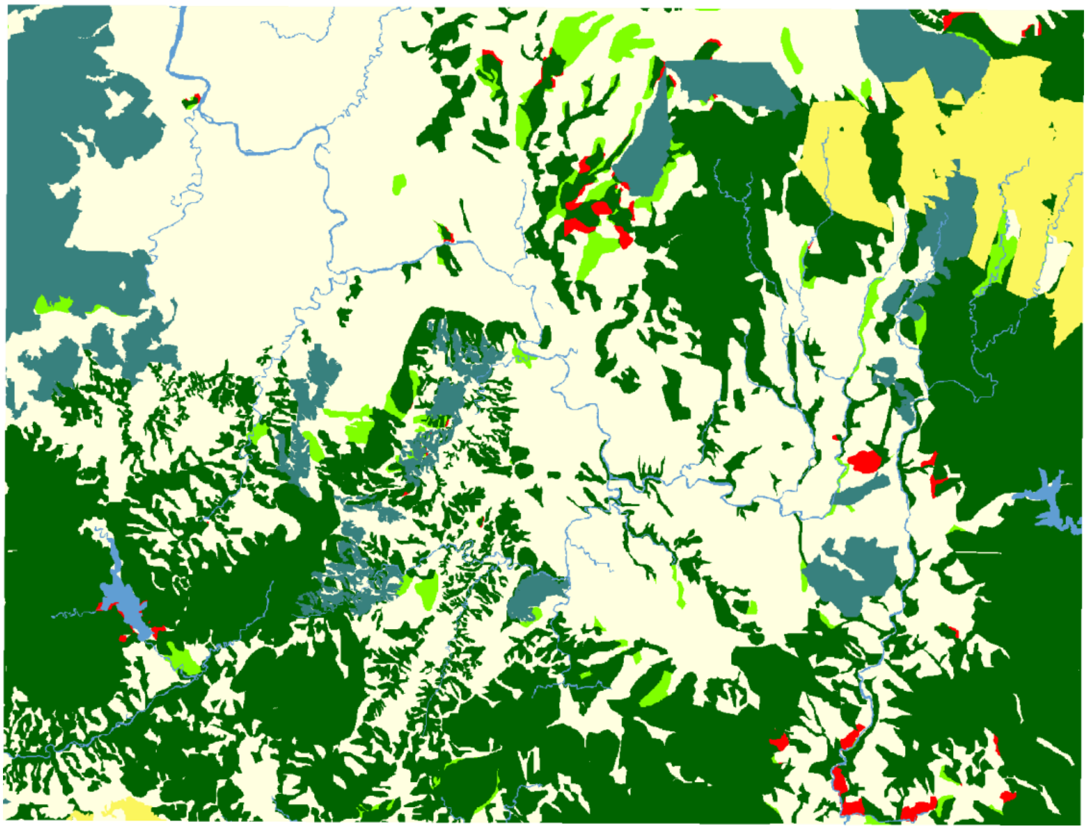

*Figure 7 Land-use change map – green: forest remaining as forest, red: forest loss, light green: forest gain, blue: water bodies, white: non-forest remaining as non-forest.*

The following statistics (Table 8) will be provided to show the distribution of change area and stable forest and non-forest areas across the REDD+ accounting area. See Chapter 0 for the respective estimation procedures.

*Table 8 Forest area change across strata.*

| Strata | Forest loss area | | Forest gain area | | Stable forest area | | Stable non-forest area | |
|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % |
| >600m a.s.l. | | | | | | | | |
| ≤600m a.s.l. | | | | | | | | |
| Grand total | | | | | | | | |

#### 3.3.3.3 Accuracy assessment[6]

An accuracy assessment of the land-cover change map using simple random sampling design will be conducted. A critical step in accuracy assessment is the selection of a suitable source for reference data. For 2006 no satellite imagery with higher resolution than the utilized Landsat TM data is available. The sample points of the NFI 2005 are not suitable as reference, as they are located in forest areas only and would thus introduce a considerable bias in the accuracy assessment. This holds especially true, as the NFI data include no in-situ information on non-forest areas, i.e. non-forest areas interpreted as forests cannot be detected. Therefore, Landsat TM data are to be used (as independent reference data) for verification and accuracy assessment. Thus, the same data source (i.e. Landsat TM) is used for interpretation and verification, which renders the conduction of the accuracy assessment (i.e., the collection of reference data) by an independent third body necessary.

Stratified random sampling will be chosen as it is a practical design that satisfies the basic accuracy assessment objectives for most of the desirable design criteria (Olofsson et al., 2014) and it helps the country to conform with the IPCC good practice principle of removing bias and reporting uncertainties transparently (GFOI, 2016). Within the strata the sampling points will be distributed by random. The number of sample plots is determined based on a standard sampling design method suggested by Olofsson, et al. (2014).

The accuracy assessment has two key objectives of the analysis: 1) accuracy assessment of the change classification, and 2) estimation of area of change. The error or confusion matrix (hereafter noted as the error matrix) plays a central role in meeting both the accuracy assessment and area estimation objectives (Olofsson et al., 2014; Congalton & Green, 2009). The error matrix is a simple cross-tabulation of the samples of classes interpreted and allocates the classification of the remotely sensed data against the reference data. Table 9 presents the error matrix to be derived. Error matrices will be constructed for both periods 2006-2012 and 2012-2016.

*Table 9 Example of an error matrix for the first period.*

| 2006-2012 | | Reference data | | | | | |
|---|---|---|---|---|---|---|---|
| | | Forest loss | Forest gain | Stable forest | Stable non-forest | Total samples in map classes | Users's accuracy |
| Map data | Forest loss | | | | | | |
| | Forest gain | | | | | | |
| | Stable forest | | | | | | |
| | Stable non-forest | | | | | | |

[6] The presentation follows Olofsson et al., 2014

| | | | | | | |
|---|---|---|---|---|---|---|
| Total reference samples per class | | | | | | |
| Producer's accuracy | | | | | | |

From the error matrix the following accuracy parameters can be derived:

*Overall accuracy*:

$O = \sum_{j=1}^{q} p_{jj}$ ....................(eq. 1)

*User's accuracy* of class *i* (i.e. the proportion of the area mapped as class *i* that has reference class *i*), $U_i$, or its complementary measure, commission error of class *i*,

$U_i = p_{ii}/p_i$ ....................(eq. 2)

*Commission error* = $1\text{-}p_{ii}/p_i$

*Producer's accuracy* of class *j* (the proportion of the area of reference class *j* that is mapped as class *j*), $P_j$, or its complementary measure omission error of class *j*

$P_j = p_{jj}/p_j$ ....................(eq. 3)

*Omission error* of class *j*, $1 – p_{ii}/p_i$

where

$p_{ij}$ = proportion of area for the population that has map class *i* and reference class *j*, = $N_{ij}/N$

$q$ = number of classes

$N$ = total number of pixels

$N_{ij}$ = number of pixels that has mapped class i and reference class *j*

As no full tally but a sample of pixels used as reference points is available, the proportions are obtained as sample estimates. Therefore, the values for $p_{ii}$, $p_{jj}$ and $p_i$ in equations 1 to 3 are to be replaced by the sample estimates $\hat{p}_{ii}$, $\hat{p}_{jj}$, and $\hat{p}_i$. For equal probability sampling designs (e.g., systematic sampling) and for stratified random sampling in which the strata correspond to the map classes,

$\hat{p}_{ij} = W_i \frac{n_{ij}}{n_{i.}}$ ....................(eq. 4)

where $W_i$ is the proportion of pixels mapped as class *i*, $W_i = n_k/n$.

The error matrix has to be constructed utilizing the estimated proportions. The sampling variability associated with the accuracy estimates is quantified by the respective sampling errors. Those are obtained for the estimated overall accuracy, $\hat{O}$, by

$\hat{V}(\hat{O}) = \sum_{i=1}^{q} \frac{W_i^2 \hat{U}_i (1-\hat{U}_i)}{n_i - 1}$ ....................(eq. 5)

for the estimated users's accuracy for class *i*, $\hat{U}_i$, by

$\hat{V}(\hat{U}_i) = \frac{\hat{U}_i (1-\hat{U}_i)}{n_i - 1}$ ....................(eq. 6)

and for the estimated producer's accuracy for class *j*, $\hat{P}_j$, by

$\hat{V}(\hat{P}_j) = \frac{1}{\hat{N}_{.j}^2} \left[ \frac{N_{j.}^2 (1-\hat{P}_j)^2 \hat{U}_j (1-\hat{U}_j)}{n_{j.}} + \hat{P}_j^2 \sum_{i \neq j}^{q} N_{i.}^2 \frac{n_{ij}}{n_{i.}} \left(1 - \frac{n_{ij}}{n_{i.}}\right) / (n_{i.} - 1) \right]$ ....................(eq. 7) where

$$\hat{N}_{.j} = \sum_{i=1}^{q} \frac{N_{i.}}{n_{i.}} n_{ij}$$

is the estimated marginal total number of pixels of reference class *j*, and $N_{i.}$, is the marginal total of map class *i* and $n_i$.

95% confidence intervals are estimated as $\hat{Y} \pm 1.96\sqrt{\hat{V}(\hat{Y})}$, where $\hat{Y}$ is replaced by $\hat{O}$, $\hat{P}_i$, and $\hat{U}_i$.

The analyses shown above will result in accuracy measures for the land-use interpretation as follows:

*Table 10 Error matrix for the first period 2006-2012.*

| 2006-2012 | | Reference data | | | | | |
|---|---|---|---|---|---|---|---|
| | | Forest loss | Forest gain | Stable forest | Stable non-forest | Proportion according to map | Users's accuracy |
| Map data | Forest loss | $\hat{p}_{11}$ | $\hat{p}_{12}$ | $\hat{p}_{13}$ | $\hat{p}_{14}$ | $\hat{p}_{1.}$ | $\hat{U}_1, \hat{V}(\hat{U}_1)$, 95% CI |
| | Forest gain | $\hat{p}_{21}$ | $\hat{p}_{22}$ | $\hat{p}_{23}$ | $\hat{p}_{24}$ | $\hat{p}_{2.}$ | $\hat{U}_2, \hat{V}(\hat{U}_2)$, 95% CI |
| | Stable forest | $\hat{p}_{31}$ | $\hat{p}_{32}$ | $\hat{p}_{33}$ | $\hat{p}_{34}$ | $\hat{p}_{3.}$ | $\hat{U}_3, \hat{V}(\hat{U}_3)$, 95% CI |
| | Stable non-forest | $\hat{p}_{41}$ | $\hat{p}_{42}$ | $\hat{p}_{43}$ | $\hat{p}_{44}$ | $\hat{p}_{4.}$ | $\hat{U}_4, \hat{V}(\hat{U}_4)$, 95% CI |
| Proportion according to reference | | $\hat{p}_{.1}$ | $\hat{p}_{.2}$ | $\hat{p}_{.3}$ | $\hat{p}_{.4}$ | | |
| Estimated producer's accuracy | | $\hat{P}_1$ $\hat{V}(\hat{P}_1)$ 95%CI | $\hat{P}_2$ $\hat{V}(\hat{P}_2)$ 95%CI | $\hat{P}_3$ $\hat{V}(\hat{P}_3)$ 95%CI | $\hat{P}_4$ $\hat{V}(\hat{P}_4)$ 95%CI | | |
| Estimated overall accuracy | | $\hat{O}, \hat{V}(\hat{O})$, 95% CI | | | | | |

#### 3.3.3.4 Area estimation

The area of class *i*, $A_i$, within the entire inventory area, *A*, is generally given by the proportion of the sub-area, *p*, multiplied by the total inventory area, i.e. $A_i = p_i * A$. The error matrix can be used to calculate sub-areas. However, two alternatives for $p_i$ are presented by the error matrix:

- The estimated proportion $p_{.k}$, which is given by the reference data. As this proportion is based on a sample, it is subject to sample variability.
- The proportion $p_{k.}$, which is obtained from the map and based on the number of pixels falling in class *k*. $p_{k.}$ has no associated sampling variance, but is subject to classification errors.

The two proportions $p_{k.}$ and $p_{.k}$ will not be equal. Therefore, a decision has to be made, which of the two proportions is to be used for the calculation of sub-areas (note: sub-areas are forest loss, forest gain, stable forest, stable non-forest). The bias attributable to reference data is smaller than the bias attributable to map classification error. Therefore, $p_{.k}$ is superior in quality, and reference data should be used for area estimates. However, this renders the inclusion of the associated sampling variances for estimating the related uncertainties necessary.

A direct estimator for the proportion of area of class k based on reference data is

$$\hat{p}_{.k} = \sum_{i=1}^{q} \hat{p}_{ik} \quad \text{(eq. 8)}$$

which is under stratified random or systematic sampling

$$\hat{p}_{.k} = \sum_{i=1}^{q} W_i \frac{n_{ik}}{n_{i.}} \quad \text{(eq. 9)}$$

where $W_i$ is the area proportion of map class *i* and $\hat{p}_{ik} = W_i(\frac{n_{ik}}{n_{i.}})$. This estimator is a poststratified estimator for simple random and systematic sampling, and it is the direct stratified estimator of $p_{\cdot k}$ for stratified random sampling when the map classes are the strata. The variance of $\hat{p}_{.k}$ is estimated by

$$\hat{V}(\hat{p}_{.k}) = \sum_{i=1}^{q} W_i^2 \frac{\frac{n_{ik}}{n_i}\left(1-\frac{n_{ik}}{n_{i.}}\right)}{n_i - 1} = \sum_{i=1}^{q} \frac{W_i \hat{p}_{ik} - \hat{p}_{ik}^2}{n_i - 1} \quad \text{(eq. 10)}$$

where $n_{ik}$ is the sample count at cell (i,k) in the error matrix and the summation is over the q classes. The 95% confidence interval for $\hat{p}_{.k}$ is obtained by $\hat{p}_{.k} \pm 1.96\sqrt{\hat{V}}(\hat{p}_{.k})$. The estimated area of class k, $\hat{A}_k$, is using the estimated proportion of the reference data, $\hat{p}_{.k}$,

$$\hat{A}_k = A * \hat{p}_{.k} \quad \text{(eq. 11)}$$

with standard error

$$\hat{S}(\hat{A}_k) = A * \sqrt{\hat{V}(\hat{p}_{.k})} \quad \text{(eq. 12)}$$

and the approximate confidence interval

$$\hat{A}_k \pm 1.96\, \hat{S}(\hat{A}_k) \quad \text{(eq. 13)}$$

### 3.3.4 Combing activity data and emission factors

Area estimates and estimated emission factors will be combined to estimate total emissions from deforestation in natural forests.

Total emissions [$tCO_2e$ ] = AD [ha] x EF [$tCO_2e$ $ha^{-1}$] ........ (eq. 14)

The variance of total emissions will be computed by combining the estimated standard error of the area estimate with the estimated standard error of the emission factor (derived from the Monte Carlo simulation; see Section 3.3.2). In this second Monte Carlo, simulation area estimates will be randomly drawn from the empirical error distribution of the area estimate and will be multiplied by an emission factor estimate that is randomly drawn from the empirical error distribution of the emission estimate. The simulation will have 10,000 runs. The standard deviation of 10,000 total emission estimates will be the standard error of total emissions.

## 3.4 Emissions from forest degradation

According to the Fijian definition of forest, degradation may occur in both, natural forests and forest plantations. For the FRL, emissions from forest degradation are the emissions that result from selective logging. The applied satellite-based land-use classification method does not further separate forests in open and closed forests. Therefore, the assessment of areas subject to degradation from available image classification is technically not feasible. Therefore, an alternative approach for the estimation of emissions from forest degradation has to be applied.

### 3.4.1 Quantification of emissions from logging

As forest degradation involves selective logging, the harvested areas were used as a proxy for quantifying the emissions from forest degradation. In Fiji official logging statistics are available which record all timber harvesting realized in concessions under a "Right license". Two different data repositories are used to archive harvesting information:

(1) **Timber Revenue System Database (TRS)**: Harvested volume is obtained by the measurement of logs in the field and transferred to the TRS. The information contained in the TRS includes concession number, timber volume logged and year of logging. The area of the concession license is not available in the TRS.

**(2) Harvested Area Reporting (HAR)**: The HAR contains GPS measurements of the areas logged. The measurements are provided by local foresters. Areas are available as shape files.

The information on harvested timber volume provides the base for the assessment of emissions from forest degradation. From the TRS the total harvested volume can be calculated for the years 2006 to 2016. As the total harvested volume is known no further consideration of the logged area is required. However, the logged area is to be excluded from the forest change mapping in order to avoid double counting (e.g., an area that was logged may cause emissions from forest degradation and emissions from deforestation, i.e., emissions are counted twice). This will be realized by merging the shape files of the HAR with the land-use map of SPC and clipping out the harvested areas from the land-use map.

The harvested volume will be converted into $CO_2$e by multiplying the volume with the wood density to obtain the biomass, by multiplying the biomass with a factor of 0.47 to get the carbon content and by expanding the carbon content by a factor of 44/12 to get the emissions in $CO_2$e. As information on volumes per tree species is not available the average wood density of commercial species will be derived from species lists used for the PSP and NFI taking into account species distribution and species specific gravity.

Harvested wood products (sometimes considered as an additional carbon pools) will not be considered for the FRL construction and the extracted volume will be regarded as direct emissions. Besides emissions due to the timber volume removed from the forest two additional sources of emissions have to be considered

(1) damaged biomass in the process of logging; represents the carbon in the aboveground and belowground biomass of the stump and top of the timber tree felled and left as dead wood in the forest, trees incidentally killed or severely damaged (i.e. uprooted or snapped), and large branches broken off from surviving trees during tree felling, and

(2) damaged biomass resulting from infrastructure construction necessary for logging.

Following a proposal from Pearson et al. (2014), these two sources can be transferred into a logging damage factor (LDF) and an infrastructure damage factor (LIF) which can be combined to the total emission factor (TEF),

TEF = LDF + LIF ........ (eq. 15)

Haas (2015) studied the carbon emissions caused by logging in Fiji and derived respective emission factors for selective (TEF=0.89) and conventional logging (TEF=1.05). Those factors are below factors reported for the Republic of Congo, Indonesia, or Brazil (Pearson et al., 2014). According to Hass (2015) this is caused by the logging intensities, which are higher in Fiji than in other tropical regions studied, and by including the BGB. The total emissions, E, are calculated via

E=(TEF*carbon logged)+carbon logged ........ (eq. 16)

The TEF developed by Haas (2015) and Pearson et al. (2014) do no show substantial differences. Therefore it was decided to take the average of both. In further applications the TEF has to be impoved.

### 3.4.2 Uncertainty assessment for emissions from logging

Logging areas and logging volumes are assessed as full tallies and thus not subject to sampling variability. The uncertainty assessment will thus only address the uncertainty associated with transferring timber volumes into carbon content and associated $CO_2$e emissions, i.e. the selection of the wood density and the TEF.

To estimate the uncertainty attached to the emissions from logging, another Monte Carlo simulation will be conducted. In the simulation, random draws of TEF and wood density will be selected from a Gaussian distribution and emissions from logging will be recalculated 10,000 times. The parameters of the distribution (mean and variance), from which the random numbers are drawn during each simulation run, will be derived from Haas (2015) and Pearson et al. (2014). The (relative) standard error of the logging emission estimate will be the standard deviation of the simulated 10,000 emission estimates.

## 3.5 Emissions and removals from management of plantations

Emissions and removals from plantations (pine and mahogany) will be estimated using data that are made available by Fiji Pine Limited and Fiji Hardwood Corporation Limited.

Plantations in the scope of establishing the FRL are those areas managed by Fiji Pine Limited and Fiji Hardwood Corporation Limited (i.e., subcategory “Plantation Forest”). They are generally even-aged, single species stands that originate from planting. The total area of plantations managed under both companies is roughly 142.000 ha (Fiji Pine Ltd.: 85.500 ha, Fiji Hardwood Corporation Ltd.: 56.500 ha). Out of the total area under lease by Fiji Pine Ltd. (85.000 ha) only 23960 ha were stocked in 2016. From the remaining 61.000 ha, roughly 24.000 ha could potentially be stocked, the rest is not available for replanting, as it is located in rocky areas, areas stocked by native species, or high conservation areas. *The data provided by FPL and FHCL is (partly) available, but serious flaws have been detected, e.g., no harvesting of FPL in 2012!*

The estimation of the total emissions and removals from plantations will take into account three different categories:

- Removals from growth of remaining stand,
- Removals from areas planted within 2006 and 2016, and
- Emissions from areas cut between 2006 and 2016.

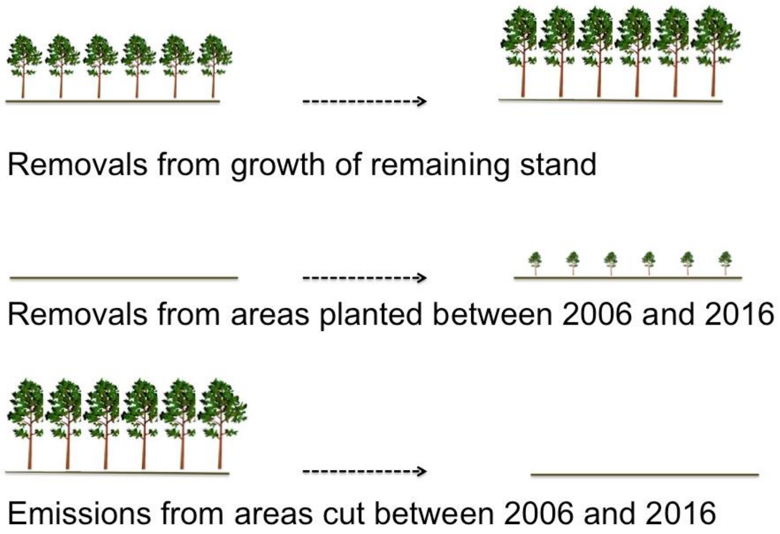


*Figure 8 Emissions and removals from plantations.*

### 3.5.1 Removals from growth of remaining stand

Removals from tree growth in remaining stands is calculated separately for the remaining stands of Fiji Pine Ltd. and Fiji Hardwood Corporation Ltd. Remaining stand is a term used for plantation areas that are continuously stocked during the entire period from 2006 to 2016. The area of the remaining stand, $A_{rs}$, is obtained by

$A_{rs} = A_t - A_u - A_L - A_P$ ........ (eq. 17)

where

$A_t$ = total plantation area under lease

$A_u$ = plantation area under lease but unstocked

$A_L$ = plantation area logged between 2006 and 2016

$A_P$ = plantation area planted between 2006 and 2016

Emission/removal factors can be calculated (1) by growth functions giving the current volume of a stand as a function of stand age, or (2) via the mean annual increment as the ratio between harvested volume and stand age. Carbon stock values per hectare and stand age have been presented by Payton and Weaver (2011) for pine and mahogany. Figure 9 presents the carbon stock values from Payton and Weaver (2011) and the two respective carbon stocks derived from logging records of Fiji Hardwood Corp. Ltd. As the sources of the Payton and Weaver's (2011) carbon stock values remain unclear and in order to provide conservative and consistent estimates, it was decided not to consider further those estimates. In consequence, mean annual increment as derived from logging records will be used for the calculation of removals of the remaining stands in plantation areas.

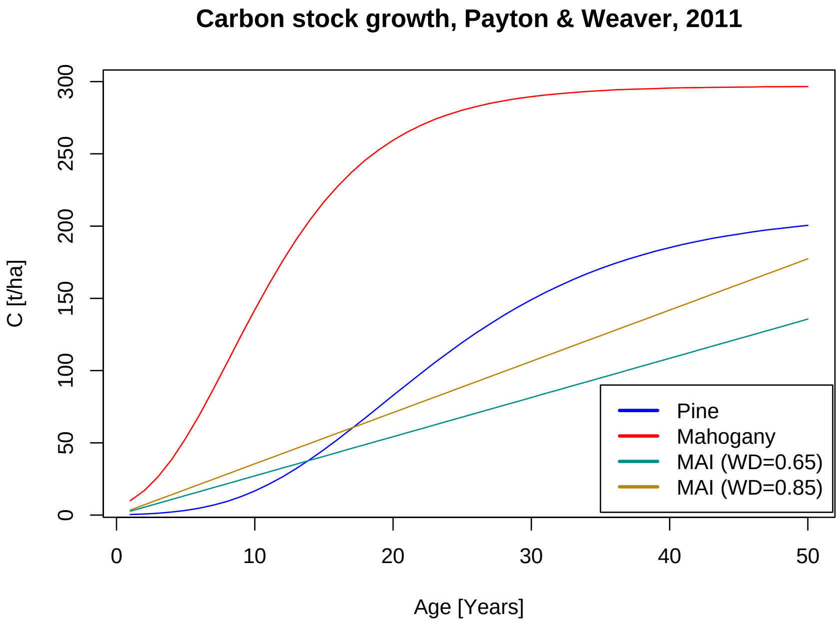


*Figure 9: Carbon stock over age according to Payton and Weaver (2011) and mean annual increment (MAI) for mahogany provided by Fiji Hardwood Corporation.*

The mean annual increment (MAI) is

$$MAI = F_L \sum_{i=1}^{n} \frac{V_{Li}}{(Year_{Li} - Year_{Pi}) * A_{Li}} \quad \text{(eq. 18)}$$

where

$MAI$ = Mean annual increment in [$m^3$/ha]

$V_{Li}$ = logged volume on stand *i*

$Year_{Li}$ = year when stand *i* was logged

$Year_{Pi}$ = year when stand *i* was planted

$A_{Li}$ = logged area of stand *i*

$F_L$ = factor to correct for logging losses

$n$ = number of logged stands between 2006 and 2016

The factor $F_L$ is introduced factor to account for logging losses, which remain on the plantations.

In the next step the *MAI* is converted to per hectare biomass growth, $i_B$, by applying a biomass expansion factor, BEF to obtain *AGB*, and a root:shoot ratio to obtain *BGB*

$$i_B = AGB + BGB = (MAI * \text{BEF}) * (1+\text{R}) \quad \text{(eq. 19)}$$

Per hectare biomass growth is multiplied by the total area of remaining stands (i.e. between 2006 and 2016), $A_{rs}$, in order to obtain the total removals due to tree growth in plantation areas, $E_{rs}$.

$E_{rs} = A_{rs} * i_B$ ........ (eq. 20)

From the $E_{rS}$ values removals in terms of C and $CO_2$e can be calculated.

$E_{rs}$ and associated $CO_2$e are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from the remaining stands.

### 3.5.2 Removals from areas planted within 2006 and 2016

Replanting of plantation area was realized in any of the years between 2006 and 2016. As the areas replanted in individual years differ as well as the growth rates at different stand ages the year of planting of individual stands has to be taken into account when estimating removals from replanting. This is realized by multiplying the areas replanted in a distinct year $i$, $A_{Pi}$, with the annual growth rate in the years following the plantation year until 2016, $i_{vi}$. Thus, the total volume growth of areas planted between 2006 and 2016, $V_{Ptot}$, is

$V_{Ptot} = \sum_{i=2006}^{2016} A_{Pi} \sum_{j=1}^{2016-i} i_{vj}$ ........ (eq. 21)

$V_{Ptot}$ is converted into total biomass following the procedure given in 2.5.1, and subsequently C and $CO_2$e are calculated.

$V_{Ptot}$ and associated $CO_2$e removals from planting are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from areas planted.

### 3.5.3 Emissions from areas cut between 2006 and 2016

From the records of Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd, the volume harvested in the period 2006 to 2016 can be obtained. The total harvested volume is expanded to *AGB* by means of the biomass expansion factor, BEF, and the respective wood density for pine, mahogany and other relevant species. Applying the root-shoot ratio the *BGB* is obtained. The sum of *AGB* and *BGB* gives the total biomass removed by logging, $B_L$. Transferring the total biomass into total C and $CO_2$e gives the total emissions from logging activities.

$V_L = \sum_{i=2006}^{2016} V_{Li}$ ........ (eq. 22)

$B_L = AGB_L + BGB_L = (V_L * BEF) * (1+R)$ ........ (eq. 23)

where

$V_L$ = total volume logged

$V_{Li}$ = volume logged in year i, i={2006,...,2016}

$AGB_L$ = above ground biomass logged

$BGB_L$ = below ground biomass logged

$B_L$ and associated $CO_2$e from logging activities are to be calculated separately for areas under management by Fiji Pine Ltd. and Fiji Hardwood Corp. Ltd. and added to obtain the total removals from the remaining stands.

### 3.5.4 Total emissions/ removals from plantation areas

Emissions/ removals (1) growth of remaining stand, (2) areas planted, and areas cut between 2006 and 2016 have to be combined in order to achieve the total emissions/ removals from plantation management. Table 11 summarizes the necessary calculations. The 95%-CI are obtained from the uncertainty analysis.

*Table 11 Calculation of ermissions/ removals from plantation areas.*

| Source | | Fiji Pine Ltd. $CO_2e$ [t $ha^{-1}a^{-1}$] | Fiji Hardwood Corp. Ltd. $CO_2e$ [t $ha^{-1}a^{-1}$] |
|---|---|---|---|
| Remaining stand | Total | | |
| | 95% CI | | |
| Plated areas | Total | | |
| | 95% CI | | |
| Logged areas | Total | | |
| | 95% CI | | |
| Total | Total | | |
| | 95% CI | | |
| Grand total | Grand total | | |
| | 95% CI | | |

### 3.5.5 Uncertainty analysis

The plantation areas are obtained from terrestrial surveying and available in mapped format. As they are subject to negligible measurement errors only, no uncertainty assessment for the plantation areas will be carried out. Harvesting is generally realized as clear cut resulting in temporarily unstocked areas. Those unstocked areas are considered as plantation area, for what reason clearcutting does not result in deforestation. To remain consistent *plantation areas have to be removed from the land use map* to avoid double counting.

Uncertainty analysis will address the errors associated with emission factors. In the calculation of biomass values uncertainty is introduced by assumptions on wood densities, WD, and root:shoot ratios, R. Logging volumes are measurements and thus not subject to uncertainties. In estimating the growth of the remaining stand and planted areas assumptions have to made concerning tree growth, which introduce uncertainty.

An MC simulation will be conducted to assess the uncertainty attached to emission/removal estimates from plantations. That is, 10,000 simulation runs were random error is added to values of wood density, root:shoot ratios, and estimates of growth (i.e., MAI).

# 4 Estimation of Forest Reference Level (FRL)

The estimation of the FRL is based on historical data, which are available for 2006-2007 (EF from NFI) as well as 2006, 2012 and 2016 (AD from satellite imagery). For plantations and logging areas annual data are available for the period 2006 to 2016. The data are representative for the accounting area. From these data historical emissions and removals will be derived. The emissions and removals are averaged. Given the length of the reference period the time available for the average is representative of current conditions. There is no systematic variation in the data. Therefore, the prerequisites for using the historical average are satisfied.

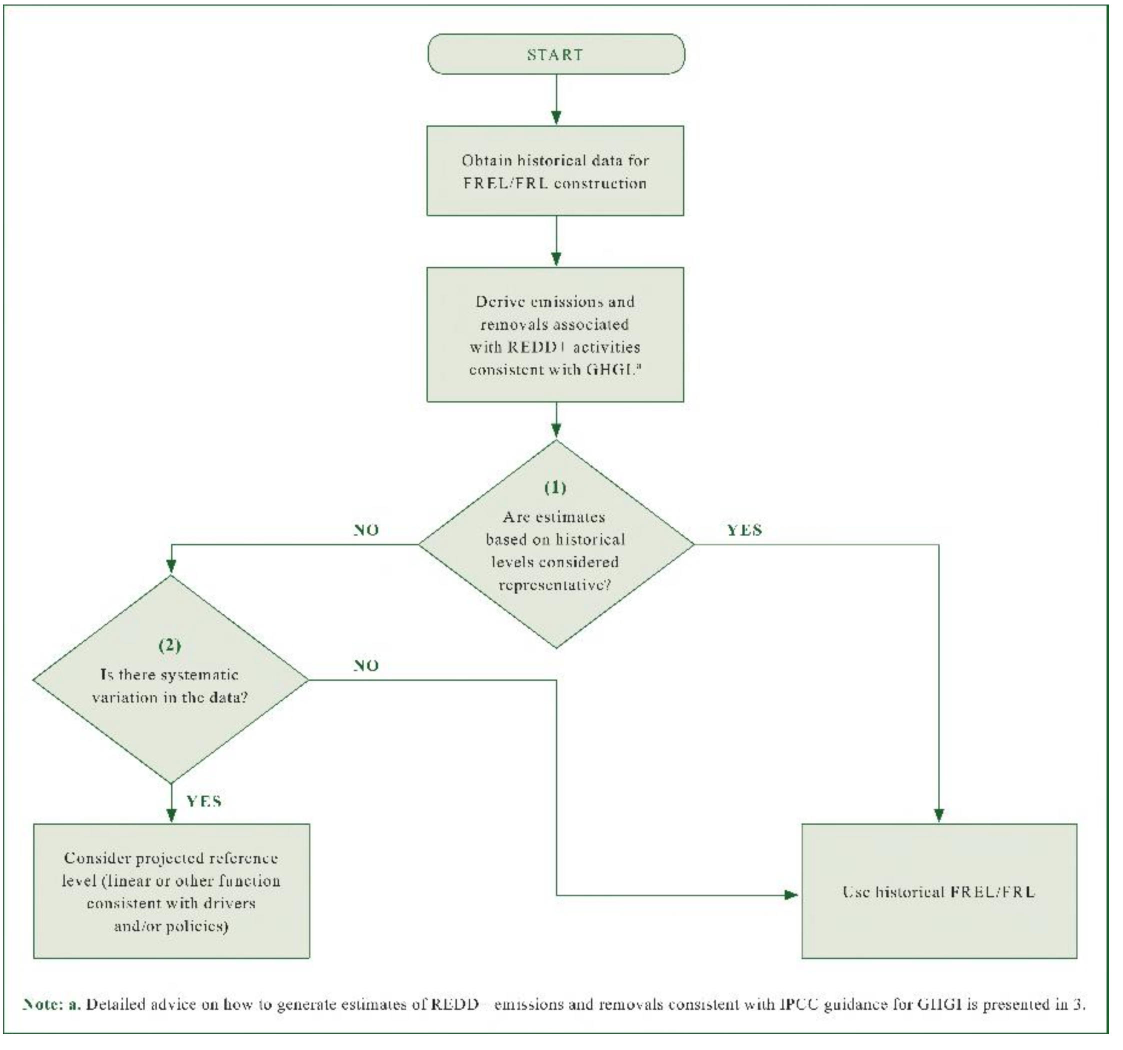


*Figure 10 Use of historical data for developing FREL/FRLs (GFOI, 2016)*

## 4.1 Historical emissions/removals

In the first place emissions and removals are calculated for three subclasses:

- Emissions from deforestation and afforestation (using NFI data and remote sensing imagery)
- Emissions from forest degradation (using logging records as proxies)
- Emissions from plantations
- Removals from plantations

The emissions/removals will be combined as shown in Table 13. The values that will be presented in the second column will include estimates of variance (i.e., the lower and upper 95% confidence limits).

*Table 11 Example of a table showing results of the estimated emissions by subgroup.*

| Subgroup | Emissions/removals $CO_2e$ [t $ha^{-1}a^{-1}$] | Comment |
|---|---|---|
| Emissions from deforestation and afforestation in natural forests (see 2.3) | | Data sources: NFI 2005 and land-use change classification 2006-2016<br>Gain-loss method<br>Emissions = AD *EF |
| Emissions from logging in natural forests (see 2.4) | | Total logged volume 2006 to 2016 |
| Emissions and removals from management of plantations (see 2.5) | | Total emissions/removals from plantations |
| Total historic emissions/removals | Σ | |

## 4.2 Updating frequency

In line with the UNFCCC decision 12/CP. 17,paragraph 10, Fiji's FRL estimation follows a stepwise approach, aiming to improve FRL accuracy overtime by incorporating better data, improved methodologies and, when appropriate, additional pools. Fiji will therefore follow a periodic cycle in updating its FRL, ensuring consistency with the NFI. In addition, Fiji will make efforts to enhance capacity to estimate emissions/removals from mangrove forests and forest degradation. These efforts will be applied particularly during the period 2018-2023 so that additional knowledge can be acquired for the modification of FRL scope and methodologies. Specific areas for future improvement are presented in the following section.

## 4.3 Future improvements

Specific areas for improvement of the FRL have been identified, on which Fiji is advised to continue investigation, data collection and testing of methodologies, dependent on available resources. These are the following:

- Replace the indirect assessment of forest degradation through logging concession data by cost-effective direct measurements of forest degradation by advanced remote sensing technologies, which allow for consistent and sufficiently accurate monitoring of closed and open forest cover over time.

- Fully include the activity forest carbon stock enhancement on forest land remaining forest land. This would allow Fiji to report on the important results of improved forest management achieved in the country.
- Improve the allometric functions for the estimation of above-ground biomass.
- Include measurements for the assessment of the carbon pools litter, dead wood and soil organic carbon.
- Develop and implement a NFI concept that allows for representative, reliable and consistent assessment of current values and changes of forest biomass and carbon stock.

Develop and implement methods for utilizing improved remote sensing technologies for land-use change assessments and detection of forest degradation.

Implement initiatives for capacity building with respect to field assessments, remote sensing image analysis, IT-technology (incl. database management) and sampling statistics.

# 5 Compliance with IPCC Principles (of Good practice) and FCPF Carbon Fund Methodological Framework

## 5.1 Compliance with IPCC Principles

IPCC good practice guidance (IPCC, 2003b, 2006) assists countries in producing inventories that are accurate in the sense of being neither over nor underestimated as far as can be judged, and in which uncertainties are reduced as far as practical. One of the elements that contribute to the overall improvement of the inventories is that both IPCC and UNFCCC guidelines include the principles of transparency, consistency, comparability, completeness and accuracy (TCCCA) as guiding principles in preparing and reporting inventories. These principles are applicable for the FRL-construction as well.

***Transparency*** means that the assumptions and methodologies used for an inventory should be clearly explained to facilitate replication and assessment of the inventory by users of the reported information. The present FRL is transparent as all required information for its construction is given and allows for the reconstruction at any time.

***Consistency*** means that an inventory should be internally consistent in all its elements with inventories of other years. An inventory is consistent if the same methodologies are used for the base and all subsequent years and if consistent data sets are used to estimate emissions or removals from sources or sinks. The FRL in its current stage follows a step-wise approach. Data available at the time of its construction are consistently used. Future improvements need to take into account existing methodology.

***Comparability*** means that estimates of emissions and removals reported by Parties in inventories should be comparable among Parties. For this purpose, Parties should use the methodologies and formats agreed by the COP for estimating and reporting inventories. The allocation of different source/sink categories should follow the split of the IPCC Guidelines, at the level of its summary and sectoral tables. The current FRL implements the methodology given by IPCC for the LULUCF and AFOLU sector. Therefore, results are comparable with those from other Parties implementing the IPCC guidance.

***Completeness*** means that an inventory covers all sources and sinks, as well as all gases, included in the IPCC Guidelines as well as other existing relevant source/sink categories which are specific to individual Parties and, therefore, may not be included in the IPCC Guidelines. Completeness also means full geographic coverage of sources and sinks of a Party. The current FRL includes only $CO_2e$. Other GHG are not included as they play a minor role in Fiji's forests. The accounting area covers roughly 90% of Fiji's forested area. Under a step-wise approach completeness can be assumed for the FRL at its current stage.

***Accuracy*** is a relative measure of the exactness of an emission or removal estimate. Estimates should be accurate in the sense that they are systematically neither over nor under true emissions or removals, as far as can be judged, and that uncertainties are reduced as far as practicable. To promote accuracy in the available data and analysis procedures appropriate methodologies have been implemented, in accordance with the IPCC good practice guidance, to promote accuracy of the emission/ removal estimates.

## 5.2 Compliance with FCPF Carbon Fund Methodological Framework

The Forest Carbon Partnership Facility of the World Bank has published a Carbon Fund Methodological Framework (MF) that provides guidance to the development and selection of REDD+ Programs (FCPF, 2016). For the construction of a FRL the MF presents four criteria and ten indicators, which are listed and discussed below.

**Criterion 10:** The development of the Reference Level is informed by the development of a Forest Reference Emission Level or Forest Reference Level for the UNFCCC.

**Indicator 10.1:** The Reference Level is expressed in tonnes of carbon dioxide equivalent per year.

Fullfilled for Fiji's FRL. The reference level will be expressed in tonnes of $CO_2$e.

**Indicator 10.2:** The ER Program explains how the development of the Reference Level can inform or is informed by the development of a national Forest Reference Emission Level or Forest Reference Level, and explains the relationship between the Reference Level and any intended submission of a Forest Reference Emission Level or Forest Reference Level to the UNFCCC.

A national FRL will be constructed, which includes roughly 90% of the total forest area of Fiji. The same FRL-construction will be used by the ER-Program.

**Indicator 10.3:** The ER Program explains what steps are intended in order for the Reference Level to achieve consistency with the country's existing or emerging greenhouse gas inventory.

Consistency is maintained as the same forest area definition is used.

**Criterion 11:** A Reference Period is defined.

The reference period is defined. It covers the time period from 2006 to 2016.

**Indicator 11.1:** The end-date for the Reference Period is the most recent date prior to two years before the TAP starts the independent assessment of the draft ER Program Document and for which forest-cover data is available to enable IPCC Approach 3. An alternative end-date could be allowed only with convincing justification, e.g., to maintain consistency of dates with a Forest Reference Emission Level or Forest Reference Level, other relevant REDD+ programs, national communications, national ER program or climate change strategy.

The end date of the reference period is two years before the TAP starts. ER-PD will be submitted by October 2018, the first meeting of TAP will probably be in mid-2019. The reference period ends in 2016.

**Indicator 11.2:** The start-date for the Reference Period is about 10 years before the end-date. An alternative start-date could be allowed only with convincing justification as in Indicator 11.1, and is not more than 15 years before the end-date.

The start date (2006) of the reference period is ten years before the end date (2016).

**Criterion 12:** The forest definition used for the ER Program follows available guidance from UNFCCC decision 12/CP.17.

**Indicator 12.1:** The definition of forest used in the construction of the Reference Level is specified. If there is a difference between the definition of forest used in the national greenhouse gas inventory or in reporting to other international organizations (including an

Forest Reference Emission Level or Forest Reference Level to the UNFCCC) and the definition used in the construction of the Reference Level, then the ER Program explains how and why the forest definition used in the Reference Level was chosen.

The forest area definition is specified. The construction of the FRL uses the same forest definition as it was used in the Second National Communication to the UNFCCC, 2013 submitted by the Republic of Fiji .

**Criterion 13:** The Reference Level does not exceed the average annual historical emissions over the Reference Period. For a limited set of ER Programs, the Reference Level may be adjusted upward by a limited amount above average annual historical emissions. For any ER Program, the Reference Level may be adjusted downward.

**Indicator 13.1:** The Reference Level does not exceed the average annual historical emissions over the Reference Period, unless the ER Program meets the eligibility requirements in Indicator 13.2. If the available data from the National Forest Monitoring System used in the construction of the Reference Level shows a clear downward trend, this should be taken into account in the construction of the Reference Level.

The FRL does not exceed the annual historical emissions over the reference period.

**Indicator 13.2:** The Reference Level may be adjusted upward above average annual historical emissions if the ER Program can demonstrate to the satisfaction of the Carbon Fund that the following eligibility requirements are met:

i. Long-term historical deforestation has been minimal across the entirety of the country, and the country has high forest cover;

ii. National circumstances have changed such that rates of deforestation and forest degradation during the historical Reference Period likely underestimate future rates of deforestation and forest degradation during the Term of the ERPA.

No adjustments to national circumstances will be made.

**Indicator 13.3:** For countries meeting the eligibility requirements in Indicator 13.2, a Reference Level could be adjusted above the average historical emission rate over the Reference Period. Such an adjustment is credibly justified on the basis of expected emissions that would result from documented changes in ER Program circumstances, evident before the end-date of the Reference Period, but the effects of which were not fully reflected in the average annual historical emissions during the Reference Period. Proposed adjustments may be rejected for reasons including, but not limited to:

i. The basis for adjustments is not documented; or

ii. Adjustments are not quantifiable.

Not applicable, as no adjustments to national circumstances will be made.

**Indicator 13.4:** An adjustment of the Reference Level above the average annual historical emissions during the Reference Period may not exceed 0.1%/year of Carbon Stocks.

Not applicable, as no adjustments to national circumstances will be made.

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# Comparison of Forest Disturbance Datasets in Fiji [DRAFT].

Eric Bullock

January 27, 2020

## Background

This document provides preliminary results for analysis conducted in support of Fiji's National Forest Monitoring System in conjunction with the Forest Carbon Partnership Facility (FCPF). The objective of this analysis is to develop and test a methodology for monitoring forest degradation using remote sensing data. To do so, we created a preliminary dataset using the Continuous Degradation Detection (CODED) methodology. This dataset was compared to the results of analysis performed by Fiji for developing their forest reference emission level (FREL) from 2005 to 2017.

The prior dataset (hereby referred to as the "Fiji Dataset") was created using a time series of yearly cloud-free Landsat composites. Since CODED operates on the pixel level and requires all available data (as opposed to yearly composites), it was not possible to run CODED on the yearly composites. However, a simple version of the algorithm based on a simple decision tree approach (hereby referred to as "CODED-Light" or in figures "CODED-L") was run on yearly composite data. This analysis was done to simulate using the locally created composites for estimating degradation, as opposed to CODED which requires all available observations.

The Fiji dataset was created for 2005-2017 for the islands of Vanua Levu and Viti Levu, while CODED was run for 2006-2016 for Vanua Levu and Viti Levu and CODED-Light for 2006-2016 and only for Viti Levu. The Fiji dataset contains pixels that undergo forest clearings, while CODED and CODED-Light provide pixels that contain deforestation and/or degradation. Deforestation was defined as a conversion from forest to non-forest, while degradation was defined as a disturbance in a forest without a land cover conversion.

## Preliminary Results

Preliminary assessment of the datasets show a relatively strong spatial correlation (Figure 3) with variation in the years and types of disturbance (Figures 1, 2). CODED-Light found the largest area of total disturbance (Table 1), but exhibited stronger temporal relation to the Fiji dataset than did CODED (Figure 2). Both CODED and CODED-Light found more disturbances than the Fiji dataset when including degradation.

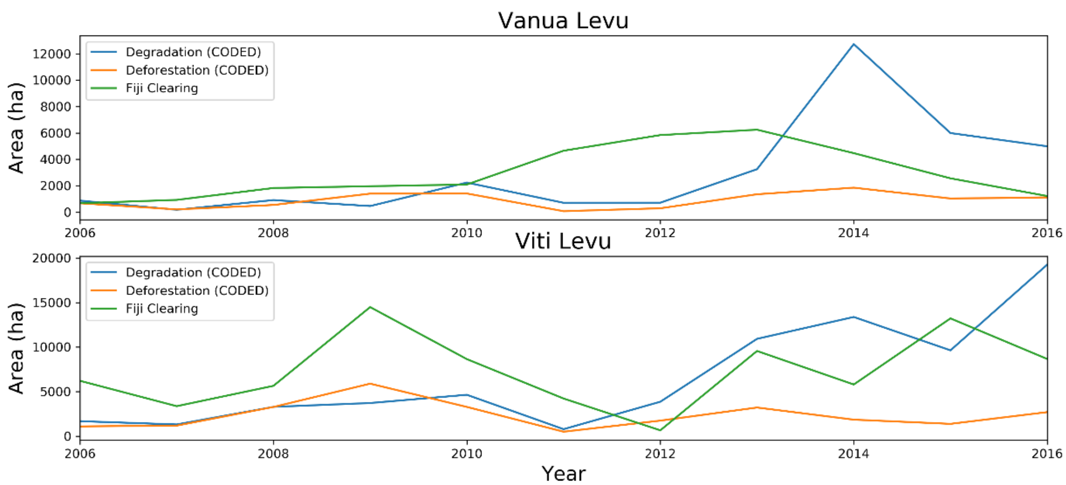


**Figure 1. Yearly mapped areas of forest disturbance for Vanua Levu and Viti Levu from 2006 to 2016 according to the Fiji dataset and results creating using the CODED methodology.**

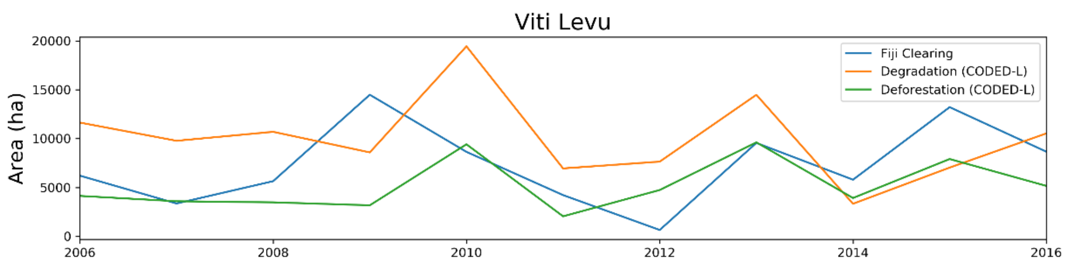


**Figure 2 Yearly mapped areas of forest disturbance for Viti Levu from 2006 to 2016 according to the Fiji dataset and results creating using the CODED-Light methodology.**

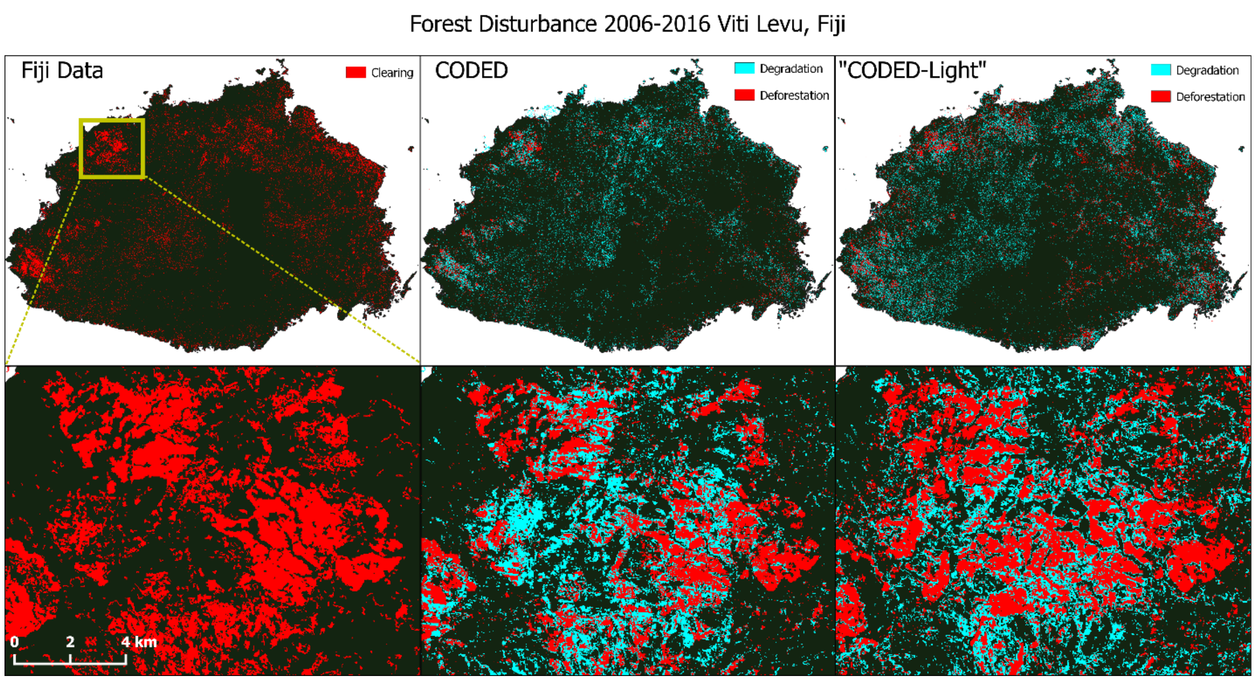

**Table 1. Total disturbance area (ha) from 2006-2016 according to the three different datasets.**

| | **Fiji** | **CODED** | | **CODED-Light** | |
|---|---|---|---|---|---|
| | Clearing | Deforestation | Degradation | Deforestation | Degradation |
| **Viti Lenu** | 80000 | 22000 | 72000 | 57000 | 110000 |
| **Vanua Levu** | 32000 | 10000 | 33000 | N/A | N/A |

**Incomplete Analysis**

In addition to mapping disturbance, an objective of this analysis is to compare field data on forest type and logging to determine whether they can be classified using the CODED methodology. This analysis, as of January 27th, 2020, is in its early stages and thus was not included in this report.

**Next steps**

This preliminary assessment found that both CODED and CODED-Light may *potentially* be affective for monitoring forest degradation and/or deforestation in Fiji. However, the following analysis is required for completion during this project:

- Incorporate feedback from local experts.
- Collection of Fiji-specific training data using field inventory data on forest types.
- Pixel-level comparison of the different datasets to evaluate biases.
- Extension of both the CODED and CODED-Light methodologies to other islands.
- Completion of an accuracy assessment that can be used to assess each of the datasets.
- Collection of reference data on disturbance types and occurrence.
- Estimation of activity data of forest degradation and deforestation.

# MINISTRY OF ECONOMY

P.O.Box 2212, Government Buildings, Suva, Fiji; Tele: (679) 330 7011, Fax: (679) 330 8654
Website: www.economy.gov.fj, Email: Economyinformation@economy.gov.fj
Ro Lalabalavu House, 370 Victoria Parade, Suva

17 February, 2020

**By Email:** eriko.hibi@fao.org

Ms. Eriko Hibi
Subregional Coordinator for the Pacific Islands
FAO Subregional Office for the Pacific Islands
Lauofo Meti's Building
4 Corners
Matautu-Uta
**APIA**

Dear Ms. Hibi

**Letter of Support for the Climate Resilient Forests, Communities and Value Chains in Fiji Project**

We refer to and thank the Food and Agriculture Organisation (**'FAO'**) for its support in developing the Climate Resilient Forests, Communities and Value Chains in Fiji Project.

The project is well aligned to Fiji's 5-Year and 20-Year National Development Plan, the Low Emissions Development Strategy 2018-2050 and the National Adaptation Plan. The project is also expected to directly contribute towards Sustainable Development Goals 12 – Responsible Production and Consumption, 13 – Climate Action, and 15 – Life on Land. It also synergises with the 30 million trees in 15 years initiative of the Fijian Government and Fiji's carbon trading ambitions.

In this regard, the Fijian Government is pleased to support the project and we look forward to working with FAO to finalise the project Concept Note, the Project Preparation Funding application and the Funding Proposal.

Kindly note that this Letter of Support is not equivalent to a No Objection Letter from the National Designation Authority (**'NDA'**). Consideration will be given to issue a No Objection Letter when the project proponents send a Project Preparation Funding Application and/or a Funding Proposal for review by the NDA.

Thank you.

Yours sincerely

**Makereta Konrote**
**Permanent Secretary for Economy**

# Fiji REDD+ Feedback and Grievance Redress Mechanism

DELIVERABLE 3

April 2018

## Design of the Feedback and Grievance Redress Mechanism (FGRM) and Reporting Forms

Rerevaka na Kalou ka doka na Tui

REDD+ FIJI

Integra

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# Acknowledgements

This FGRM Team and Integra wishes to acknowledge that this mechanism was designed in consultation with experts in the fields of REDD+ and conflict resolution from Fijian agencies, ministries, boards, nongovernmental organizations, civil society organizations, and communities.

The report was authored by Corey Nelson, Ulai Baya, Mereseini Seniloli, and Lorraine Reiher (FGRM Team) of Integra for the Fiji REDD+ Secretariat.

# Executive Summary

The "Design of the Feedback and Grievance Redress Mechanism (FGRM) and Reporting Forms" is the second phase of the Fiji Reducing Emissions from Deforestation and Forest Degradation (REDD+) Readiness FGRM consultancy that builds on the inputs from all consultations conducted under the previous research and analysis phase ("Deliverable 2: Assessment and Recommendations of Existing Issues and Structures") to develop a FGRM based on existing practice that aligns with the objectives of Fiji's REDD+ Policy, supported by the REDD+ Unit and REDD+ Secretariat, and is reinforced by the REDD+ Steering Committee (RSC) and its representative members. The design takes into consideration both formal and informal networks for redress. The design process includes strategic choices based on purpose and functionality of the FGRM, as well as integrating the mechanism into the National REDD+ Strategy.

This FGRM will be used to respond to the concerns, complaints, disputes, and any other contentious issues that will arise during the readiness and implementation phases of Fiji's National REDD+ Programme. The mechanism promotes and facilitates a two-way communication process between local landowners and LoU and the Ministry of Forestry's REDD+ Programme and serves as an effective outreach process to local communities. This FGRM will function to compliment existing structures that serve to reduce conflict on issues related to land use, land tenure, and land management whilst promoting mutually constructive relationships and building trust. In support of this mechanisms purpose the FGRM Team has also designed standard feedback and grievance redress forms (in close consultation with the Ministry of iTaukei Affairs, Ministry of Rural and Maritime Development, the National Disaster Management Office, RSC members, and project beneficiaries). The first form is to be used by iTaukei Village Headmen (*Turaga ni Koro*), supported by dictation from Village Councils (*Bose Vakoro*) to record grievances for both REDD+ readiness potential sites and implementation stages. The second form is designed for FGRM Officers (Forest Officers from the Ministry of Forest (MoF) and the REDD+ Liaison Officer (R+LO) from the REDD+ Unit) to record and report issues and grievances relating to REDD+ activities under their authority. The forms are in English and will be translated to iTaukei by the Ministry of iTaukei Affairs, once they have been finalized (following comments from the Secretariat and feedback from the stakeholder consultation training). The use of a specific "form" in coordination with other avenues of reporting is further elaborated on in this deliverable in order to propose a culturally appropriate and sustainable approach to grievance redress.

Once the REDD+ Secretariat has approved the FGRM design and subsequent forms, the FGRM team will conduct training for the above-targeted groups on the use of the forms (carried out in collaboration with the Secretariat). Feedback on the forms and the reporting and recording processes will be collected during (through open dialogue) and after the training (survey) from all participants in order to improve the process. The final forms and results of the training will then be shared in a "Training Report", in conjunction with a communications strategy for the FGRM, with the REDD+ Steering Committee. A final inclusive package (all deliverables) will be submitted to the REDD+ Unit and RSC for approval. After approval the team will present the FGRM findings, design, training report, and communications strategy at a "Validation Meeting"; soliciting inputs from stakeholders. The FGRM Team will then account for comments collected and finalize the consultation.

# 1. Introduction

This FGRM[1] design intends to construct an integrated and practical FGRM for REDD+ that is both *legally recognized* and *socially acceptable*. The proposed FGRM for REDD+ is designed for intervention as an alternative dispute resolution (ADR) mechanism at a semi-formal level of grievance redress, so as to compliment and not replace current legal/formal redress or customary/informal systems. The design is based on the outcome of the study previously conducted ("Assessment and Recommendations of Existing Issues and Structures" or D-2) that identified and analyzed legislation and policy that impacts REDD+, analyzed Fiji's existing institutional capacity and mechanisms used to respond to and resolve conflict, and identified existing and potential grievances and conflicts that may arise as a result of REDD+.

## 1.1. FINDINGS FROM PHASE 1: RESEARCH AND ANALYSIS

The results of the previous study (D-2) institutional and risk assessment, coupled with data collected from various stakeholder groups, resulted in the identification of gaps and issues in existing grievance redress mechanisms (GRM), challenges for setting up a FGRM Framework, and a series of lessons learned (see *Attachment 2*) for Fiji REDD+. The previous analysis found that there were significant gaps in grievance redress processes within formal systems that are responsible for conservation, land use, and land management issues. The GRM processes for these formal institutions were found to be either poorly established or inconsistent with how they process, manage, and address grievances; as evaluated across seven Forest Carbon Partnership Facility (FCPF) guiding principles[2]. There was also problematic disconnect between "non-legal" or traditional structures, where most land and related disputes are resolved within communities, and formalized legal structures. Existing GRMs at the formal-level were found to be inadequate to support REDD+ in their current form and informal systems did not have the legal clout, resources, or technical capacity to address grievances fully at the community-level. Potential risks identified centered primarily on issues related to benefit-sharing and land use. Without the employment of REDD+ legislation, greater specificity in current legislation regarding carbon ownership, and the design of a national land use plan for Fiji, risks will become further exacerbated.

**The findings from the study provided for three high-level recommendations:**

- Greater synergy between informal and formal systems and improved governance.
- Improved awareness and capacity building for all stakeholders on REDD+ programming and benefits.
- Accountability and free prior and informed consent.

[1] "FGRM" in this deliverable is used in reference to the specific mechanism designed to address grievances for REDD+. "GRM" is used to reference alternative/other grievance mechanisms not specific to REDD+.
[2] Derived from the UN Human Rights Council, 2011.

## 1.2. STRUCTURE AND APPROACH

The FGRM design takes into account the findings from the previous study and incorporates, where feasible[3], recommendations from that same study. This report starts with setting the scope and goal of the FGRM, after which a structure is discussed, procedures are established, implementation and operation of the FGRM is outlined, and recommendations for mainstreaming are proposed. The report concludes with a framework for improved and continual monitoring, reporting, and learning.

[3] "Feasible" in this instance references the incorporation of those recommendations that are within the scope of the FGRM. This mechanisms' ability to achieve its purpose will be dependent on the acceptance by actors in both the customary system as well as legal institutions.

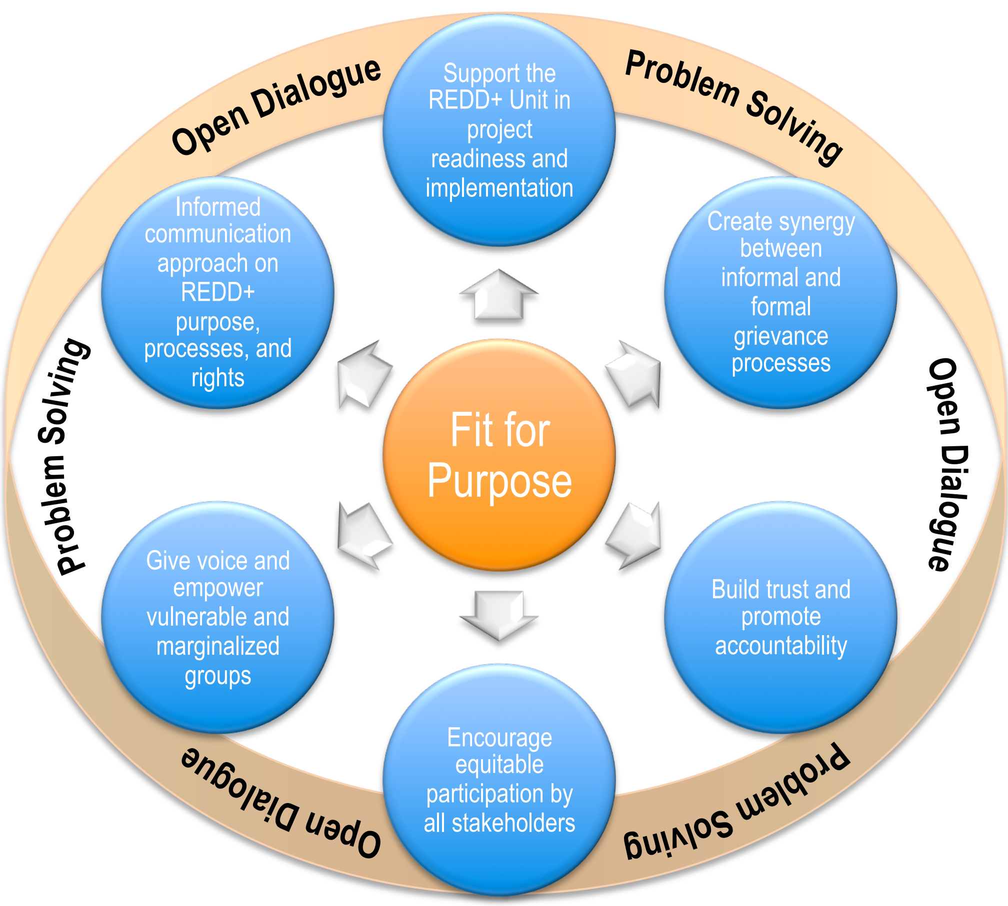
# 2. Goals, Objectives, and Scope of the FGRM

The purpose of a FGRM for REDD+ activities in Fiji is to provide a mechanism for grievances that is transparent, readily acceptable to all project beneficiaries, and provides an institutionalized and evolving process for conflict resolution resulting from REDD+ implementation. The FGRM is open to a wide range of concerns: both those based on factual data and those arising from perceptions or misperceptions. It is not the purpose of the FGRM to replace existing GRMs, rather to compliment and provide an alternative path towards resolving conflict, should customary methods be exhausted and to avoid costly and timely legal routes (e.g., institutional GRMs, court).

## 2.1. GOALS AND OBJECTIVES

**The overarching goal of the FGRM is to channel grievances through a system that is fit for purpose** (see *Figure 1*). Fit for purpose, in this instance, signifies that the focus of the mechanism is on facilitating open dialogue as a way for stakeholders to discuss grievances that are both culturally acceptable, legally enforceable, and readily accessible (given resource and logistic constraints) that results in a transparent and easily understood problem-solving process for all stakeholders involved. The FGRM is expected to primarily address "interest-based" REDD+ conflicts, meaning conflict in which groups with some form of interdependency have a difference in interests (perceived or otherwise). For example, this may be a conflict between two landowning units (LoU) regarding land use over communal areas, land boundaries in projects with multiple LoUs, or exercise of rights by a non-residential LoU.

**Figure 1. Goals and Objectives for the Fiji FGRM**



In support of the overarching goal, the FGRM has several secondary objectives:

**1. Support the REDD+ Unit in project readiness and implementation**

The FGRM will support the REDD+ Unit with improved outcomes by serving as an early warning system for budding disputes. Early identification will help the REDD+ Unit capture grievances before they expand into more complex (or even intractable) conflicts. The mechanism will resolve REDD+ related disputes in a shorter amount of time by increasing awareness of REDD+ thereby creating a more educated populace on the policies and procedures of conservation efforts under this program: (a) better informing communities of their rights, (b) improved understanding of how to identify and handle disputes by grievance officers, (c) and greater enforcement of *Free, Prior, and Informed Consent* (FPIC) processes early in readiness, mitigating conflicts in the future. The FGRM will also help communities better navigate informal and formal system processes for conflict resolution, presenting options and multiple methods to address conflict that they can self-select prior to/during engagement of the semi-formal process of the FGRM. This will help the REDD+ Unit prioritize and allocate resources for grievance redress and provide greater autonomy for resolution by forest-users. The FGRM is also low-tech and can operate in a low-resource and logistically challenging climate (i.e., Fiji) providing greater coverage for the REDD+ Unit to maintain the mechanism while providing quality resolution results.

**2. Serve as a connection point between informal and formal systems that align with the law and can be enforceable[4]**

The FGRM should be seen as the "in-between" step for stakeholders when informal disputes fail, where access to information and technical capacity is needed, and to avoid more costly, time consuming, and less effective resolutions at the formal level. The mechanism provides an ADR for those that seek resolution prior to engagement in more formal or judicial processes and when the dispute is with an institution, implementing partner, or government entity. Many forest-users (e.g., LoUs, individuals) see the formal system as unpredictable, inequitable, and non-transparent and the informal system as needing more structure and greater reliance on informed understanding regarding rights. The FGRM provides an opportunity for accountability and enforcement that builds off the customary system and offers an intermediary for the formal - creating synergy between customary and formal means of grievance redress, whilst facilitating third party interventions. Whilst the FGRM proposed is limited to all matters regarding REDD+, it is inevitable that the GRM may have to be subjected to third party timelines and its internal decision making processes. In instances where this arises, the involvement and backing of the Ministry and the RSC should be enough for special consideration for expedited closure.

**3. Build trust with government, REDD+ project implementers, and beneficiaries**

Trust is often the most decisive factor in the success or failure of any project and lack of trust and accountability were two of the top concerns expressed by forest-users and counterpart government entities that are engaged in land management. In order to build trust in the system and process, there must be more accountability in the outcomes in order for the FGRM to be seen as transparent and open. It will be important that all FGRM stakeholders are permitted to ask questions/raise concerns and the REDD+ Unit should be obligated to give them answers. This

[4] REDD+ legislation is needed along with authority by formal institutions and enforcement and empowerment.

approach will instill more trust in the process and ensure that forest-users feel more engaged in its outcomes. There must be several avenues to engage in a dispute, several options for resolution, and the Complainant must be involved and engaged throughout the process as an active participant and key decision-maker. In order to render a trustworthy mechanism that is intended to guarantee fair, objective, and impartial treatment, thorough consideration of all the parties involved will be required.

**4. Promote greater accountability by all REDD+ stakeholders**

Creating outcomes that are enforceable requires buy-in and recognition by legal and non-legal (customary) systems. As an ADR the FGRM must produce outcomes that are recognized, acceptable, and achievable within its mandated purpose. The iTaukei Land Trust Board (TLTB) acts as the primary governing body for all iTaukei land, with ancillary working support from the iTaukei Lands and Fisheries Commission (TLFC) and the iTaukei Affairs Board. As such, the FGRM must coordinate, develop, and align with current formal procedures – adding necessary missing elements such as the comprehensive application of FPIC requirements. REDD+ entities must also establish rules and procedures for handling grievances (the purpose of this report) and communicate them throughout communities to not only promote use and implications of the FGRM, but also to ensure that forest-users understand the process and policies for engagement in REDD+ programming from the onset. Part of this engagement process is also to inform communities of their obligations and responsibilities in the system as well – what they must do to properly submit a grievance, their responsibilities as stakeholders and caretakers of conservation and REDD+ recognized sites. In addition, full disclosures relating to long-term leasing of land and how it may adversely affect current levels of enjoyment, access, and exercise of rights, duties, and obligations must be discussed thoroughly as part of the FPIC process.

**5. Equitable participation as a tool for engaging stakeholders**

One of the biggest challenges the REDD+ FGRM will face is accessibility of its base forest-users (i.e., LoUs). This has been a challenge for all GRMs previously researched in Fiji because of the typically remote settings where many of the REDD+ sites are and will be located and because of limited financial means for effective engagement in the formal GRM process. More equitable participation is needed for the REDD+ FGRM to be seen as a credible option for grievance resolution. In order to overcome these barriers, the use of local facilitators, government counterparts, and multiple entry points will be needed for grievance submission and follow-up.

**6. Empower vulnerable (e.g., women, youth, elderly, disabled) peoples and marginalized groups to engage, have their voice heard, and receive equal opportunity for conflict resolution**

Vulnerable people must have an avenue to submit grievances and seek resolution outside of perceived or socially constructed systems if they so choose. The FGRM will allow for individuals, not just LoUs or agencies, to submit grievances and receive equal treatment in a process that is the same for all participants involved and incorporates multiple party perspectives in the decision-making process (equitable representation). It must also provide anonymity when asked or appropriate, be responsive, culturally appropriate, and foster open dialogue. The likely remoteness of many of these REDD+ communities can also result in marginalization because of accessibility and financial constraints. As such, these groups must be given appropriate avenues to submit complaints and receive resolution.

More marginalized forest-dependent communities can also be motivated to be more vocal in REDD+ by being given the opportunity to engage in dialogues with other forest user groups, nongovernmental organizations (NGOs), civil society organizations (CSOs), government officials in the Forestry Department, REDD+ actors, advisors, and other LoUs engaged in similar projects. This must exist in the FGRM process itself, but also in the evaluation of the FGRM once it is in use, garnering greater ownership of the process through dialogue and problem solving activities.

7. **Communication tools to inform forest-users and build capacity of governing entities on REDD+ purpose, process, and rights**

The FGRM can be used as a communication tool to improve awareness and build capacity for all stakeholders on REDD+ programming and benefits. Government counterparts, LoUs, and surrounding communities with strong REDD+ potential must be engaged through a combined education and communications campaign that delivers *consistent* messaging on REDD+ programming (e.g., ecosystems management, benefit-sharing) from all multiple actors (e.g., ministries, RSC, NGOs, CSOs) that will also alleviate confusion regarding policies, rights, and benefits for stakeholders.

Capacity training must also be augmented through the strengthening of national networks (Forest Officers and REDD+ Project Coordinators) at regional and local levels regarding information sharing. Key messages must be basic and simple vis-à-vis the rights of landowners – this entails current rights enjoyed and those that are likely to be affected, payment systems, and equitable compensation sharing mechanisms, including fair representative entities that are more appropriate to existing traditional structures.

## 2.2. SCOPE

The FGRM should purposely address the biggest challenges the REDD+ readiness process is currently facing and will potentially face in the future.

### 2.2.1 REDD+ related Grievances

The type of grievances that has to be captured by the FGRM in Fiji is related to tensions that exist from land and forest governance resources (non-REDD+) such as tenure rights, boundary disputes, administration of customary land, LoUs and investor relations, awareness of rights and access to resources (*in-direct impacts*), as well as aspects related to *direct impacts* from REDD+ program itself (e.g., benefit-sharing, conservation lease terms). REDD+ related grievances are grouped into the following thematic areas:

- **Benefit-sharing** – Distribution of benefits between different forest users, elemental property rights, and internal conflicts over power. Inequity, elite capture, and other internal power struggles are expected to increase once the money shows up.
- **Awareness of Rights and Access to Resources** – grievances and disputes of processes to acquire rights to land (FPIC) and access to other forest-based products/resources on REDD+ conservation sites.
- **Boundary Disputes –** overlap or contested land with designated REDD+ sites.

- **Sustainability and Ownership** – division of responsibility between individuals, LoUs, other forest-users, and the government over maintenance of REDD+ sites and its effective regulation and implementation.
- **REDD+/Conservation Lease Terms and Enforcement** – Length, authority, and requirements for "specialized" lease[5] terms (e.g., are they properly and appropriately conducted for customary consideration for the purposes of FPIC?).

### 2.2.2 Rollout

Ultimately, the geographic scope for the FGRM will be national because of the interconnectivity of different REDD+ landscapes (forest and mangrove) and high mobility of forest-users. The FGRM should however, gradually expand from project pilot sites to a national focus in order to provide the MoF, REDD+ Unit, and implementer-led projects with lessons learned. It is recommended that rollout of the FGRM occur in an already active national site (Emalu) as well as on an implementer-led site (Drawa), for compatibility modeling. The FGRM can be scaled once it has been piloted and evaluated in these locations and once there has been trust built with stakeholders.

### 2.2.3 Hybrid Model

Fiji has chosen to take a 'hybrid' model for REDD+ implementation, which includes payments flowing at the national, programmatic, and project-scale as specified in the National REDD+ Policy's "Fiji's Readiness Preparation Proposal" (R-PP). The FGRM proposes the inclusion of both project/implementer-led and national-led activities in a conflict resolution approach for REDD+. Implementer led activities should follow a similar process as the REDD+ FGRM in that there is strong preference for conflicts to be resolved at the informal-level, where possible. Outside of the customary system, conflicts that are on implementer-led sites should try to resolve complaints through their own GRM if possible. However, if the issue is between the implementer and a forest-user or if the forest-user wishes to use the REDD+ FGRM they should be permitted to do so, following the process as outlined in *Section 4*.

> **Overlap between project/ implementer-led and national-led GRM processes**
>
> Should a grievance be submitted to the FGRM from a forest-user located in an implementer-led site (that was unresolved through the project's GRM or by informal means) then the dispute will be submitted directly to the R+LO for possible mediation, as a first step. If the R+LO is unable to help the Complainant and parties reach a resolution then the grievance will continue to follow the process, elevating to the next step of a third party evaluation, until a resolution is reached.

It will be important for the scope of the FGRM to be inclusive and not divisive between REDD+ participants so as to not create confusion on when they can engage in the FGRM, who is handling the grievances and resolutions, who is accountable, and what outcomes they might expect. Outcomes need to be in alignment or else conflict may arise from the preference or perceived benefit of using one GRM over another and creditability of the mechanisms will be impacted. While it is useful for individual projects to have their own dedicated GRM (as is the

[5] It is the FGRM team's understanding that there are specialized conservation leases for REDD+ sites, however we were not permitted access to these contracts and as such can not provide details or opinions regarding potential issues that may arise regarding the terms. The team was informed of some of the challenges regarding these leases from consultations with representatives from the DBFCC and Live and Learn.

case in the Drawa Block Forest Community Cooperative or "DBFCC") multiple projects in a country can centralize certain FGRM functions to reduce costs and enhance overall effectiveness.

Possible point of synergy between the multiple GRMs with the REDD+ FGRM include:

- The REDD+ FGRM will host an internet-based grievance monitoring system with a centralized database that is accessible by all REDD+ projects, national and implementer-led. This database can be used as a repository for all grievances related to REDD+ and will aid the REDD+ FGRM Team in tracking disputes within and outside the national system as they relate to REDD+.

- All projects should replicate a common system to acknowledge the receipt of users' grievances and keep them updated on the progress of investigations. To the extent that there is any inconsistency, all implementer-led projects will be asked to align their GRM processes with the national FGRM and to use similar forms (see *Attachment 3*). Keeping a uniform system in place will alleviate confusion on behalf of forest-users and a shared system for reporting and monitoring or grievances on all REDD+ sites.

- Consistent communication and coordination between all REDD+ activities can manifest in using the R+LO as a hub for any issues and concerns that may arise from mainstreaming of grievance processes. As part of this coordination, implementer-led activities should initiate a monthly check-in with the R+LO to discuss pertinent issues, challenges, or opportunities for improved FGRM processes. All REDD+ grievances should be entered into the central database of recorded REDD+ grievances, managed by the R+LO. When a REDD+ grievance is entered in the database it should note whether the grievance was initiated and initially recorded as a FGRM grievance or a GRM grievance (as part of an implementer-led project.) Recording all REDD+ grievances in one database should help centralize valuable data and create a system where precedents can be accessed in one place.

### 2.2.4 Economies of Scale

As the FGRM is new there will be limited understanding of the process initially and it will be important to allow the mechanism to grow organically as awareness increases. Putting in place a system that is too comprehensive when understanding and experience is limited will be neither effective nor sustainable. Therefore, it is best to start with a FGRM that is focused on a few issues and is simplistic in how it receives and resolves conflicts for REDD+. After the FGRM becomes more entrenched and has established credibility it will be easier to scale-up and encourage the government to provide additional resources (human and fiscal) towards conflict resolution processes.

## 2.3. PRINCIPLES

The FGRM takes into account the unique operating context of REDD+. For example, the size of the management unit; types of services delivered; beneficiary's needs; and technical, financial, and human resource constraints. Well-designed FGRMs can provide a wide range of benefits, such as curbing corruption, identifying exploitation, collecting qualitative and quantitative data that can be used to improve operational processes and performance, empowering vulnerable and marginalized populations, enhancing projects legitimacy amongst all stakeholders, and providing greater accountability that will ultimately result in better project outcomes.

In order to capture grievances at the local, regional, and national-levels the FGRM is designed based on 10 core principles (see *Table 1*) – establishing a quality standard for the mechanism. These principles are derived from relevant international and national laws, standards and criteria on rights and grievance redress, and the social and legal/regulatory conflict analysis from the previously conducted study (D-2), as well as criteria from the Task Order Request (TOR).

### Table 1. Core Principles of the FGRM

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| 1 | The FGRM must build awareness and capacity of all REDD+ beneficiaries and participants | Communication and education are critical components for the success of any FGRM and REDD+. Without clear communication channels and access to knowledge there will be an overflow of awareness-related grievances.<br><br>Information regarding obligations, policies and procedures, rights, and safeguards must be accessible and clearly understood by all REDD+ participants. Therefore the FGRM should include a component for strengthening awareness of stakeholders so they can effectively engage in REDD+ through open dialogue and problem solving. | **Local-level** through education of communities in the disclosure of REDD+ policies, procedures, and safeguard documents (paper and web-based) and access to resource groups, such as NGOs and CSOs, for information and support regarding rights and options for resolution.<br><br>**Project-level** through better-educated Forest Officers and REDD+ Project Coordinators on conflict resolution during readiness and implementation, as well as identification and possible prevention of REDD+ related risks.<br><br>**National-level** through applied and consistent use of FPIC in REDD+ readiness and better-informed government representatives (outside of the REDD+ Unit) in REDD+ policies and procedures. | • Access to information that enables forest-users to feel more involved and informed regarding REDD+ policies, procedures, and regulations.<br>• FPIC would reflect REDD+ parameters so communities are better informed on programming and expectations.<br>• Access to specialists in REDD+ (NGOs, CSOs, legal resource groups) that can help with education and conflict resolution at the local-level and offer mediation with tools and techniques for workable solutions at the national-level.<br>• Focus on FPIC prior to REDD+ activity, which will help align perceptions and misperceptions with actual policies and procedures – managing forest-user expectations.<br>• Technical expertise offered as part of the readiness process through engagement with NGOs can result in assistance in the development of proposals to secure funding for alternative livelihoods, improved negotiations regarding lease terms, and improved understanding of benefits from REDD+ which will help communities become self-sufficient.<br>• LoUs are up-to-date on legislative development (i.e., amendments or introduction of new laws) that may affect their legal position in reference to land management and REDD+ creating more informed forest users. |
| 2 | The FGRM must clearly detail REDD+'s performance based system and enforcement implications | Forest-users do not understand REDD+'s performance-based system or the parameters around its enforcement. There is confusion in communities regarding the benefits of preserving eco-system services and laws around the protection of native | **Local-level** through education and communication regarding the use of forest products, protected species, and regulations for REDD+ sites so they are informed participants in the program. | • Forest-users will understand legislation governing conservation and REDD+ designated land and regulation of activities that may place them in violation of polices.<br>• Provision of a feasible platform for Access Benefit Sharing (ABS) Agreement in terms of future plant genetics uses, ownership and equity. |

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| | | trees. Communities have also expressed concern that they may be barred from gathering forest products, as there is still confusion regarding how land that is designated as conservation (REDD+) can or cannot be used. | **Project-level** through improved adherence to REDD+ requirements for site recognition and maintenance.<br><br>**National-level** through enforcement and adherence to international and nationally enforceable laws, such as the *Protected Species Act*, and REDD+ reporting and regulatory requirements to receive carbon funds. | • FPIC will help forest-users understand how to plan for land use in REDD+ and the opportunities for alternative livelihoods on the same land as well as which and how they can use forest products.<br>• Protected species and resources may be better protected and managed and may result in enhanced conservation efforts and more opportunity for those that may need to generate revenue from their land in a compliant manner through REDD+. |
| 3 | **The FGRM must support both project- and nationally-led REDD+ activities** | It is imperative that the FGRM fosters open dialogue between project and national implementers that allows for information sharing and an alignment with all REDD+ projects in how they will work together addressing grievances.<br><br>Creating multiple GRMs that are not in alignment with the FGRM will cause confusion for all REDD+ stakeholders. Even if implementer-led activities wish to have additional processes it will be important to create a simplified and unified approach to grievance redress since similar agencies will be involved and where there is overlap. In addition, all grievances should be entered in a centralized database. | **Local-level** through education and communication on the similarities and difference between project- or national-led REDD+ activities.<br><br>**Project-level** through the determination of roles and responsibilities so there are no overlaps, clear agreements, and mutual understanding of the processes and how to address issues regardless of the implementing entity.<br><br>**National-level** through engagement with existing and future implementer-led initiatives to make sure that their GRMs are in alignment with the national FGRM. | • Mitigate against duplicative grievances being processed at both the project and national level.<br>• Knowledge base for grievances impacts on project vs. national-led activities and opportunity for improved FGRM.<br>• Unified approach to grievance redress that can also help alleviate the burden on the REDD+ unit, by having implementers try to address grievances where possible without the aid of the REDD+ Unit.<br>• Unified approach keeps costs outlay for grieving parties given the two systems the FGRM has to consider. |
| 4 | **The FGRM must operate independently of all parties to promote transparency and enforce accountability** | In order to deter fraud, corruption, and mitigate risks, the FGRM must operate independently of all interested parties in order to guarantee fair, objective, and impartial treatment in each case. There must be oversight and checks and balances provided from the beginning to ensure a fair process that | **Local-level** through improved relationships with the government given the existing distrust between forest-users and certain institutions.<br><br>**Project-level** through the application of high-level decision-making, multiple actors' perspectives equally weighted | • Advocate for resolution at the informal and semi-formal level by all participants.<br>• In line with its aim to maintain impartiality in its treatment of all matters before it, this process does not preclude any party opting for avenues outside the FGRM.<br>• Prevent grievances from escalating to the formal-level or judiciary/court. |

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| | | allows for multiple perspectives, interpretations, and opportunities for innovation problem solving.<br><br>The FGRM must also be inclusive of multiple parties in decision-making processes, especially for complex and multi-issue grievances. It is imperative that cooperation exists at between government counterparts and REDD+ and that enforcement processes are taken into consideration. | and heard, and enforcement of contractual outcomes by all stakeholders involved.<br><br>**National-level** through the support of the use of third party mediators, encouragement to resolve grievances at the informal and semi-formal level whenever possible, and collaboration and more open approach to resolving grievances with other government institutions/bodies. | • Multi-party FGRM to overcome power disparities, permits different views of the dispute, and promotes cooperation.<br>• Third party mediation with the government when needed from REDD+ stakeholders (REDD+ Unit, NGO, CSO, legal resource group) that can advocate on behalf of the forest-user.<br>• Performance reviews for Forest Officers and REDD+ Project Coordinators will address their role in the FGRM, which will promote greater accountability and improved processes for reporting, recording, and monitoring grievances. |
| 5 | **The FGRM must be built on existing informal and formal structures for addressing grievances** | The FGRM will have to rely on two existing systems, informal and formal, in order to facilitate a more easily acceptable and familiar grievance resolution process. The FGRM will serve as an "in-between" step, encouraging resolution where possible at the informal-level (low cost, quick resolution, seen as fair and transparent) and preventing where possible the escalation to the formal-level (costly, delayed resolution time, lower transparency).<br><br>The FGRM needs to be responsive to the needs of project beneficiaries, addressing and resolving grievances that arise from REDD+ activities whilst simultaneously aligning with existing legal structures. | **Local-level** through a more structured informal process that offers improved tools for documentation and conflict resolution.<br><br>**Project-level** through an improved recording and reporting process with more information flowing from the local-level and ability to monitoring impacts.<br><br>**National-level** through improved alignment with legal structures and greater recognition of semi-formal ADR to help facilitate grievance processes. | • Credibility is built by taking into account and respecting cultural context and local customs as well as the recognition of similar processes at the formal-level, allowing for greater buy-in on resolutions.<br>• Enhance cost effectiveness and resource allocation at both the project and national-level.<br>• More transparent processes for all parties involved, which leads to fewer people perceiving the system as ineffective.<br>• Trans-disciplinary perspectives being incorporated in the decision-making process from multiple angles allows for several opportunities to resolve grievances at an earlier stage. |
| 6 | **The FGRM must have several submission channels that can address multi-party/ multi-issue complaints** | Allowing multiple points of entry creates equitable participation of all forest-users, particularly the inclusion of more remote, poor, vulnerable, and marginalized groups. | **Local-level** through the acceptance of a wide range of concerns – both those based in factual data and those arising from perceptions or misperceptions – from a wide range of forest-users. | • Potential barriers for accessing the FGRM are removed (literacy, remoteness, financial barriers, lack of communication access via internet or mobile means) |

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| | | | **Project-level** through an improved ability to resolve less complex grievances in an informed manner and knowledge of when to elevate as needed.<br><br>**National-level** through a more inclusive process for identifying and addressing grievances that will ultimately ensure for a more sustainable REDD+ Programme for Fiji. | • More informed REDD+ stakeholders that are also more invested in a program that is sustainable. |
| 7 | **The FGRM must be simple and flexible in its design to allow for mutual learning and adaption of processes** | Encourage monitoring and evaluating of the FGRM itself to learn and adapt strategies as necessary during REDD+ implementation. The FGRM must also be simple and user-friendly to encourage use from all stakeholders. | **Local-level** through integration of feedback into processes and learning at the informal-level for improved grievance resolution and information collection.<br><br>**Project-level** through overall improved FGRM performance that allows for monitoring and tracking for reporting requirements as well as opportunities to recognize grievance patterns and possibly mitigate grievances earlier.<br><br>**National-level** through adaption to policies, regulations, and laws regarding conservation and REDD+ and improved communication of existing rules and legislation. | • Simple and friendly procedure encourages use and adaption of the system into current processes and less confusion clogging up the pipeline.<br>• Improve performance of FGRM creates greater efficiency moving forward.<br>• User-friendly assurance for LoUs to patronize, building trust. |
| 8 | **The FGRM must promote fact-finding and resolution that accounts for both local and technical expertise** | Minimize the influence of any one actor on the decision-making process and accounts for both technical knowledge of REDD+ and conservation as well as local expertise knowledgeable about the land and environmental conditions. | **Local-level** through representation and recognition of expertise that is bolstered by additional technical data for a more informed and holistic approach towards resolution. | • Improved training for FGRM staff is responsible for handling and management of REDD+ related grievances.<br>• Development of marketing and communication materials that are more targeted for REDD+ staff, counterparts, and beneficiaries. |

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| | | | **Project-level** through joint decision-making processes that allow for multiple perspectives on an issue(s).<br><br>**National-level** through a more robust and grounded monitoring and tracking program for REDD+ where multiple perspectives are weighed on complex issues. | • More informed experts at both the local, national, and international-level on procedures and processes for conflict resolution and forensic investigations.<br>• Early buy-in from all stakeholders in the decision-making process leads to swifter and more agreeable outcomes for all.<br>• More grievances reach resolution at the informal-level or are resolved based on established prior protocols, enabled by continual learning. |
| **9** | **The FGRM must support and promote equitable benefit sharing** | The FGRM must remain objective in the distribution of benefits from REDD+ programming and provide an opportunity for forest-users to submit grievances where monetary payments are seen as inequitable or unfair.<br><br>The FGRM should seek the use of uniform entities that are legally acceptable, but less onerous to encourage its use among LoUs. | **Local-level** through improved understanding of how benefit-sharing works and how to address problems they perceive are in the system.<br><br>**Project-level** through direct distribution of benefits to all intended beneficiaries in an efficient and equitable process that is continuously monitored.<br><br>**National-level** through meeting reporting requirements for REDD+, improved livelihoods for all communities engaged, and better protected conservation areas that result in proper resource allocation enriching surrounding environment ecology, and equitable and sustainable outcomes. | • Fewer disputes related to access and distribution of benefits once money starts to roll in.<br>• Self-regulation by community members in the distribution of benefits and how and where to spot inequities in the system.<br>• Expectations are managed as forest-users are more informed of benefit sharing mechanisms, resulting in fewer grievances submitted.<br>• Conditions for use of economic gains for REDD+ are prioritized toward projects that have community considerations. |
| **10** | **The FGRM must be inclusive and encourage engagement and input on the FGRM process from stakeholders** | The FGRM should be accessible to all, regardless of gender, ability, location, or access to resources. An effective FGRM will make sure to engage all possible stakeholders in the process to create a holistic and comprehensive approach to conflict resolution. | **Local-level** through systems that encourage feedback and implementation of recommendations.<br><br>**Project-level** through improved conflict resolution approaches that integrate community perspectives to deliver outcomes that are sustainable. | • Buy-in and trust are generated through a mutually beneficial process of feedback generation.<br>• REDD+ programs are more successful and beneficial to all stakeholders involved because of a shared sense of responsibility.<br>• Issues are mitigated for earlier in the process because of a continuous feedback loop. |

| Nº | Principle | Description | Visibility | Improved Grievance Process |
|---|---|---|---|---|
| | | Trust is the foundation for use of the FGRM and as such it must ask for feedback from users regarding its processes and procedures and be adaptable to the needs of its stakeholders. | **National-level** through improved FGRM procedures and processes that can be distilled through improvements in training, communication, and outreach for more effective REDD+ outcomes. | |

# 3. Design of the FGRM

The FGRM will serve as a conduit for soliciting inquiries, welcoming feedback, and increasing not only community participation in REDD+ but overall awareness of its policies, procedures, and rules, as well as educating and informing forest-users of their rights. It is important that a detailed explanation of the FGRM structure, processes, and subsequent roles and responsibilities for beneficiaries, government entities, and supporting mediators is outlined and communicated in order to steer REDD+ implementation towards success. As such, the following section should be considered a "blueprint" for the design of the FGRM that should be revisited and refined over the lifetime of the mechanism.

## 3.1. STRUCTURE

The proposed FGRM for Fiji's REDD+ Programme is structured as a quasi-judicial body, meaning that it is "judicial in character", but not within functions established under legislation. The FGRM will serve as a public administrative body endowed with the power to conduct investigations into disputes and/or infractions of rules and regulations, conduct hearings, and make decisions related to REDD+ activities that are supported by informal and formal structures. Linkages must be established from the bottom up and the FGRM cannot exist separate and isolated from the broader network. If the ultimate outcome of the FGRM is to be a contractual agreement, in which parties have binding obligations under Fijian law, then enforcement and coordination are paramount and consideration must be given to the ramifications if contractual obligations are not honored (see *Section 3.1.2.3* for more information regarding enforcement).

Consideration should also be given to section 5(2) of the Native Land Trust Act (Cap. 134), now known as the iTaukei Land Trust Act which provides that "All instruments purporting to transfer, charge or encumber any native land or any estate or interest therein to which the consent of the Board has not been first given shall be null and void." It is arguable that if party wishes to negotiate a contract as the outcome of the FGRM, which encumbers iTaukei land, then the consent of the TLTB should first be obtained. Arguably the word "encumber" may only relate to a legal instrument, such as a mortgage, which burdens a title with a debt or legal claim. In practice, it is preferable that the FRGM is a timely means of resolving a grievance and that a contract negotiated as a solution should not require TLTB's prior consent.

### 3.1.1 Proposed Dispute Resolution Structure

The mechanism is designed to engage in disputes at the informal-level as a mediating force and to a lesser extent at the formal-level as a facilitator and negotiator for institutional conflicts (e.g., conflicts regarding FPIC, lease terms, rights-based processes, benefits-sharing) offering a win-win solution for beneficiaries. Within the proposed grievance structure, there are three options to address conflicts that are REDD+ related.

**Option 1: Informal dispute resolution.** This is the most preferred venue for dispute resolution. All beneficiaries consulted favor this approach both for its simplicity and transparency, as for its low cost (essentially free) and ultimately time effectiveness. Challenges include the lack of a written record and difficulty with enforcing decisions that are made (morally binding but difficult to enforce without recourse to the courts.). The absence of a written record affects continual learning and precludes the establishment of a precedent bank. Findings from community consultations supported a process for documentation of grievances at the local-level to support continual learning and to help the communities decide when a grievance should be elevated. Communities will be able to record their grievances and provide greater legitimacy and transparency to the process through the institutionalization of written forms and recorded decisions. As part of the FGRM a form has been designed and will be vetted by the REDD+ Secretariat and representative beneficiaries as a tool to receive and record grievances (see *Attachment 3*). A copy will be given to all parties involved in the dispute and can be used as documentation support should the grievance be elevated, remain unresolved, become recurrent, or to detect a pattern or discern a grievance as a symptom of a larger more complex issue.

**Option 2: Semi-formal or alternative dispute resolution (REDD+).** Should the informal dispute approach be insufficient in delivering a resolution, Complainants may submit their REDD+ grievance to the FGRM. As part of a semi-formal approach, the FGRM is designed to serve as a mediating force in disputes; acting on behalf of forest-users, while providing expertise in all phases in conflict resolution. The aim of the semi-formal structure is to provide an avenue for Complainants that is based on open dialogue between parties, builds upon customary approaches for resolution, and complements current legal/formal redress systems to find solutions that are amenable. This ADR allows for outside mediation support aimed at helping communities throughout the design, leasing, and implementation process of REDD+ to establish a more legitimate and accountable system built on mutual trust. This approach also encourages the engagement of additional actors (NGOs, CSOs, legal resource groups, academia, etc.) to help inform and improve community's understanding regarding human rights, and environmental and resource law, which will ultimately help manage expectations of forest-users as well as mitigate potential conflicts early in the process. This was widely supported by communities consulted as they desired greater awareness of their rights and more resources to support them regarding REDD+ polices, processes, and procedures. Distinctive to this approach is the use of third and multi-party perspectives in the decision-making process to alleviate bias, and a modality to loop disputants back into the informal dispute resolution mechanism whenever appropriate.

**Option 3: Formal or judicial dispute resolution.** If the semi-formal approach is ineffective or unable to transform a particular conflict, disputants are able to advance their grievance to the formal system via the courts. Disputes handled in the formal system deal with issues such as tenure rights, boundary disputes, administration of customary land in regard to leases, land use, and investor relations. Mediation within the formal system is available in cases where the parties are open to mediation. Generally, mediation is optional and is organized and funded by the parties. In some cases, a judge or magistrate may recommend mediation but it is not compulsory, per se, in all cases.

### 3.1.2 FGRM as a Tool for a Semi-formal Approach to REDD+ Grievance Redress

The FGRM will function as a tool for a semi-formal approach to conflict resolution for Fiji's REDD+ Programme. The REDD+ Secretariat, under the MoF, will be the entity responsible for managing all grievances and the process for resolution resulting from national REDD+ activities under its purview. The FGRM is designed to support decision-making at the informal level, as needed, to operate independently at the semi-informal level, and to serve as a resource for the formal level.

#### 3.1.2.1. FGRM Staffing Structure

It is highly recommended that two positions be created under the REDD+ Unit to support an effective, efficient, and independent grievance redress process. It is not recommended to tack additional responsibilities onto existing staff as these positions are both full-time and require expertise in conflict resolution and grievance management. Forestry Officers can be tasked at the local-level for cost savings and for efficiency, but will need technical support and oversight from trained conflict resolution and management specialists. A brief snapshot of the staffing required to support the FGRM is included in *Table 2* below and a more detailed breakout of roles and responsibilities for each step of the FGRM process is included in *Section 4*.

**Table 2. FGRM Staffing Structure Overview**

| Roles and Responsibilities | | | | |
|---|---|---|---|---|
| **Responsibility Progression** | **FGRM Representative** | **Reporting** | **Possible Role(s)** | **Responsibility** |
| ↓ | **iTaukei Village Headmen** | N/A (Informal GRM process where the grievance is resolved in the customary system.) | Mediator, Facilitator, Decision-maker | • Ensure that the Village Council records all REDD+ related grievance decisions<br>• Maintain and keep village record and makes it available for sighting if, for example, required for Independent Assessment Group (IAG) purposes |
| | ***Roko Tui* (Roko)** | iTaukei Affairs Board who in turn reports to iTaukei Ministry of Affairs | Facilitator, Mediator | • Facilitate in the submission of grievances to Forest Officers<br>• Help potential Complainants to the FGRM determine eligibility of their grievance prior to formal submission<br>• If a complaint is screened and deemed ineligible by R+LO then they serve as the new POC for Complainant during referral process. |
| | **Forest Officer** | REDD+ Liaison Officer (R+LO) | Mediator, Facilitator, Investigator, Decision-maker | • Receive, record, and filter REDD+ related grievances (primary on the ground point of contact (POC))<br>• Provide education and increase awareness of communities on REDD+ policies and procedures<br>• Resolve minor issues and conflicts as appropriate<br>• Conduct preliminary investigation and supports additional fact-finding as directed<br>• Communicate progress of grievance with Complainant<br>• Update REDD+ Grievance database and flag issues for R+LO |
| | **REDD+ Liaison Officer (R+LO)** | Grievance Director | Mediator, Facilitator, Manager, Decision-maker | • Receive, record, and filter REDD+ related grievances (Secondary POC based in Suva)<br>• Provide education and increase awareness of communities on REDD+ policies and procedures<br>• Oversight of Forest Officers (to include review of any locally enforced decisions)<br>• Screen for grievance eligibility and/or determine authority responsible<br>• Communicate progress of grievance with Complainant<br>• Convene and manage Independent Assessment Group (IAG)<br>• Update and manage REDD+ Grievance database, ensuring quality control, tracking, and monitoring |

**Roles and Responsibilities**

| Responsibility Progression | FGRM Representative | Reporting | Possible Role(s) | Responsibility |
|---|---|---|---|---|
| | **Independent Assessment Group (IAG)** | REDD+ Liaison Officer (R+LO) | Mediator, Facilitator, Investigator | • Provide an unbiased an impartial investigation<br>• Conduct consultations with all parties involved<br>• Produce a summary of findings and recommended approach for conflict resolution<br>• More complex matters and only convened as needed |
| | **REDD+ Grievance Director** | Secretariat | Mediator, Facilitator, Negotiator | • Coordinate with other institutional entities on designated authority for grievance redress<br>• Negotiate on behalf on REDD+ Unit on grievances that are with institutional or government entities<br>• Drafts MOU<br>• Check process compliance |
| | **REDD+ Secretariat** | Permanent Secretary, Ministry of Forest (MoF) | Mediator, Facilitator | • Liaison to the RSC and facilitates the Board Review Process for grievance redress<br>• Meet with the REDD+ Grievance Director monthly to review unresolved or complex grievances (may require additional use of resources) |
| | **REDD+ Steering Committee (RSC)** | REDD+ Secretariat<br>(Oversight provided by REDD+ Secretariat) | Mediator, Facilitator, Decision-maker | • External Review Board for multi-issue, multi-party, and complex issues.<br>• Determine if additional forensic research/investigation is needed for resolution.<br>• Only convened when needed |

#### DEDICATED STAFF AND RESOURCE GAPS

Fiji's FGRM will need its own independent grievance officers to avoid bias from other institutions or agencies that may be engaged in conflicts that are educated and trained in conflict resolution processes. At the onset it will be important for the FGRM to entrust someone with the responsibility of coordinating and managing grievances and someone to serve as a key negotiator for REDD+ grievances that are cross-jurisdictional in nature.

It will be critical that the REDD+ Unit make two strategic hires (during Phase 1 of the FGRM, see *Section 5.1*) – a REDD+ Grievance Director and a R+LO. These key positions are required to secure against government bias or interference, provide technical guidance and oversight for Forest Officers, liaison with other REDD+ adjacent institutions, and serve as the central point for the grievance management (database and daily operations). To support on-the-ground grievance measures, it is recommended, to permit and coordinate with the MoF to empower its Forestry Officers to serve as community-level grievance officers in a part-time capacity, building off of the roles that they are currently supporting for addressing minor disputes related to land and forest management. In this capacity these Officers will require additional training in REDD+ policies, procedures, and processes in addition to conflict resolution. On an as needed basis, when a dispute requires greater scrutiny and investigation from third party evaluators, the REDD+ Unit will also need to allocate financing to support the Independent Assessment Groups (IAG).

### *3.1.2.2. Governance Structure*

The lifecycle of a grievance begins with its preferred resolution at the informal-level within the community's customary resolution systems. A grievance, if unresolved, then moves formally into the REDD+ FGRM as a semi-formal level for possible resolution. A bottom-up approach will be used for grievance redress, looping back whenever possible to the informal system. If unsuccessful at the semi-formal FGRM level then the grievance can be referred out and closed out. They progression of a grievance through the redress process is further detailed below and in *Figure 2*.

#### LOCAL-LEVEL

At the local-level the REDD+ Unit will engage Forest Officers[6] as case managers, responsible for the uptake of all grievances and preliminary fact-finding and decision-making (as appropriate). Officers will be trained in how to receive and record complaints (in person, over the phone, email, or mail) and will serve as the "on the ground" point of contact for the FGRM. Officers are responsible for recording all grievances received (without filtering for REDD+ related) using the designated form (see *Attachment 3*) and uploading the grievance into a central register/database. The Officer will also provide information and serve as a resource to all community members on the FGRM process (procedures, timeline, etc.) and will make sure that the Complainant is informed of these steps during updates. The Officer will then discuss the situation with the Complainant (encouraging open dialogue and joint problem solving, which could help resolve the grievance directly), collect any relevant documentation, explore possible

[6] There needs to be adherence to a gender-balanced approach to the selection of Forest Officers and the REDD+ Secretariat and Grievance Director should work with the MoF to review its in-house gender policies and merit.

options for a resolution if it cannot be reached at this level, and provide an overview of next steps and resources (support groups). For complex grievances the Officer will elevate the case to the R+LO, who may request additional fact-finding is conducted by the Forest Officer to determine the grievance's eligibility under the FGRM. If the Forest Officer is a party to the dispute the Complainant can submit their grievance directly to the R+LO.

#### REDD+ UNIT

The R+LO is responsible for all daily operations of the FGRM – which includes oversight of decisions made by Forest Officers regarding REDD+ related issues, maintaining the database, monitoring timelines, and reporting. The R+LO is a trained specialist in conflict resolution and is the key person responsible for communicating the progress of an eligible case to the Complainant(s). Complaints can be submitted directly to Forest Officers (in person) or through indirect means (phone, email, mail). Once a grievance has been recorded and logged into the database (if not resolved by the Forest Officer or through mediation from a support group) it is processed for eligibility in the FGRM. The R+LO conducts the screening, following a predetermined set of criteria, and either (a) determines a case eligible, (b) requests additional information, or (c) determines a case ineligible and refers it to the Roko (or authorized representative) for a process to determine the appropriate authority. If a case is eligible and cannot be resolved by the R+LO, and the Complainant does not want/cannot get the grievance resolved in the informal system, then the R+LO (with support from the Grievance Director) will convene an IAG that is comprised of technical experts that have the appropriate skill-set to address the grievance type. The IAG will conduct consultations with all parties and once the investigation is concluded will submit a report that includes their findings and recommended resolution approach to the R+LO.

#### NATIONAL-LEVEL

The REDD+ Grievance Director reports directly to the REDD+ Secretariat and provides oversight to the R+LO. The Director is responsible for managing relationships with institutional counterparts that will be involved in REDD+ activities (i.e., TLTB, TLFC, Ministry of iTaukei Affairs) – to include possible parties to conflict or jurisdiction considerations. The Director will be trained in conflict resolution and will have an advanced degree ideally in forestry or environmental law. The Director is responsible for the auditing of grievances and evaluating decisions made by Officers and the R+LO (if contentious). The Director can convene the RSC as an independent review board for the highest level of grievance redress. This provides not only a multi-sector and multi-party perspective, but allows for a consensus on resolution that is transparent, collaborative, and unbiased. For example, if a grievance includes an institution such as the TLTB as a party, their representation on the RSC allows them the opportunity to add value to the resolution, a measure to control any abuse of power, and an ability to integrate the board's resolution back into their institutional GRMs for possible restructuring. If a grievance submitted is criminal in nature and outside the boundaries of the FGRM the Director will refer the matter to the police in consultation with the iTaukei Village Headmen.

#### *3.1.2.3. Considerations*

The semi-formal FGRM is intended to work primarily as an effective stand-alone mechanism and, where necessary, as a bridge between informal and formal dispute resolution systems. In order for the FGRM to be accepted and effective, there must be commitment and collaboration between key stakeholders and agreements in place that support a spirit of cooperation and accountability between parties.

### ENFORCEMENT

In order for the FGRM to be effective and adhered to there must be institutional support from REDD+ counterparts, agencies, and implementer-led projects. As there is still no REDD+ legislation in place, it is strongly recommended that the REDD+ Grievance Director, with support from the REDD+ Secretariat draft and negotiate the terms for Memorandums of Understanding (MOUs) with key institutional partners (e.g., TLTB, TLFC, Ministry of iTaukei Affairs) and implementer-led project administrators on how grievances related to REDD+ will be handled between the disparate entities, how coordination will occur, how to handle referrals, and how each will respect the outcomes of the FGRM process.

All MOUs with respective REDD+ related sector agencies should specify clear roles and responsibilities, the duration of the relationship, and the limitations and exclusions in the performance of their duties and functions under this specific arrangement. This will not require amendments to sector specific legislation, but will require that internal GRM guidelines and procedures developed by each agency are needed and it is understood where overlaps exist. It will also be important to identify "trigger" points at which various options will be activated internally (what type of grievance will trigger what type of response and by whom). This will need to be detailed and outlined with clear steps from receipt through resolution of referral. By instituting MOUs the FGRM becomes more legitimized and the resulting contractual obligations/resolutions are given a means of legality and enforcement.

It is significant to note that enforcement of the contracts would result in involvement of the courts, which would be costly, time consuming, and adversarial. For contracts where the amount in question does not exceed FJD15,000, a claim would originate in the Magistrates Court but for contracts where the amount is above that threshold, a claim would originate in the High Court. It is preferable that the parties are engaged in the negotiation process, carefully negotiate and are committed to upholding the terms of a MOU.

### ACCOUNTABILITY

These MOUs are by their very nature are an expression of goodwill and consensus between parties. Given the constituent elements covered under the FGRM – its substance and procedures – is by design a compromised contraption, accountability with regards to compliance could be afforded to it through an independent semi-formal body, such as a Tribunal.

If there is a breach of contract, rather than proceeding to immediately file a court action to enforce the contract, it is further recommended that (as an interim step) a specialist "Land and Resource Tribunal" is established. Further consultation and research would be required and the scope of the legislation would need to be determined. For example, in Queensland, the jurisdiction of the *Land and Resources Tribunal* extends to mining issues and indigenous cultural heritage applications. From a Fiji perspective, a specialist tribunal could be established to hear matters relating to land and resource issues, including REDD+ grievances (after FGRM processes are exhausted.) The benefits of a tribunal are that they relate to a specialized field; tend to be less costly, less adversarial, and less formal than the court system; and decisions tend to be made more quickly.

There may be overlap with current legislation that established the *iTaukei Lands Appeals Tribunal*, which makes rulings on cases on appeal from the TLFC relating to decisions on land ownership, fishing rights, and customary chiefly titles.[7] New or related legislation that concerns land and resources issues may have wider jurisdiction to cover foreshore and land-related issues including mangroves, mining and mineral resources, forestry, REDD+ issues, and cultural heritage issues relating to all kinds of land title (not restricted to iTaukei land). A decision of the *iTaukei Lands Appeals Tribunal* is conclusive and there is no right of appeal to a court. If a *Land and Resources Tribunal* is established in Fiji, it is recommended that there is a right of appeal for matters over FJD200,000 to the High Court, as such cases may deal with substantial issues that may need to be reviewed. For other cases, it is recommended that they are resolved at the LoU level as a right of appeal may raise issues that include proceedings being cost prohibitive and exacerbating.

## URGENT GRIEVANCES

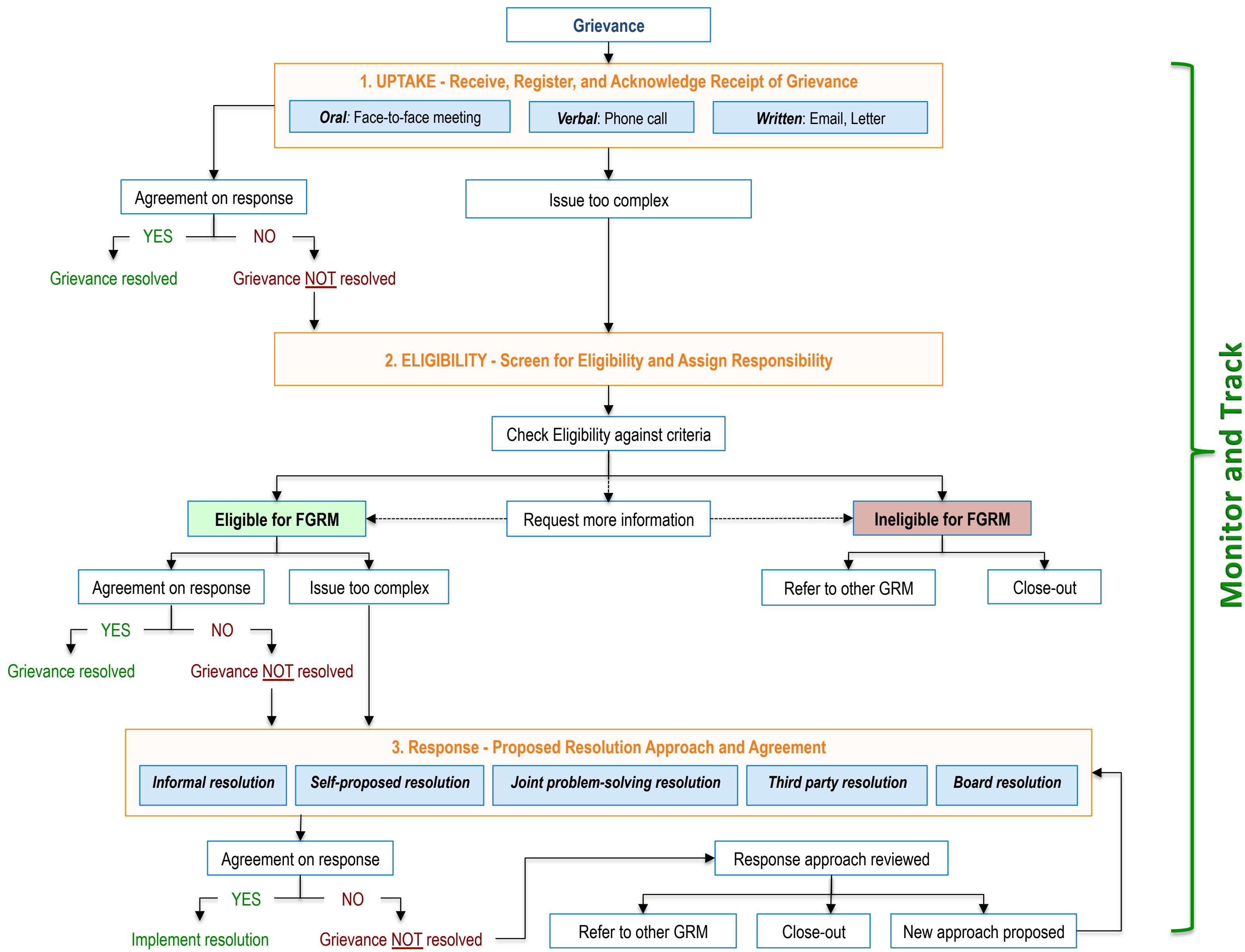
There is an open door policy for the FGRM, where Complainants have multiple methods for submitting a grievance and two formal points of entry (Forest Officer and R+LO). This is designed to ensure that everyone has equal access to the mechanism and to avoid the prioritization or politicization of one dispute over another. There are instances however, where a grievance may need to be resolved faster, based on urgency or a particular situation. As part of the grievance process, the R+LO will be responsible for flagging any disputes where there is a potential grievance threat or risk posed to the project or people in an affected area. In these instances the grievance will be immediately elevated to the Grievance Director and the REDD+ Secretariat will be notified.

## COMMUNICATION AND AWARENESS

Communicating FGRM steps, timelines, documentation requirements, access to and awareness of the FGRM begin prior to submission of a grievance with accessible information and communication from REDD+ during readiness and the use of FPIC. This is reinforced by Forest Officers during the grievance uptake process and continues through the communication of timelines, next steps by the R+LO.

[7] http://www.itaukeiaffairs.gov.fj/index.php/divisions/itaukei-lands-and-fisheries-commission

**Figure 2. Process of a Grievance**



# 4. Procedures and Processes of the FGRM

This section details the steps required taking a grievance from submission through resolution. The FGRM is designed to address primary components for the redress of grievances, in order to reach a resolution that is based on open dialogue and joint problem solving. Any individual, community, or agency can submit a grievance, if they believe they have been or will be harmed as part of the implementation of a REDD+ activity.

## 4.1. PROCEDURES

The proposed FGRM process is broken down into the following primary components:

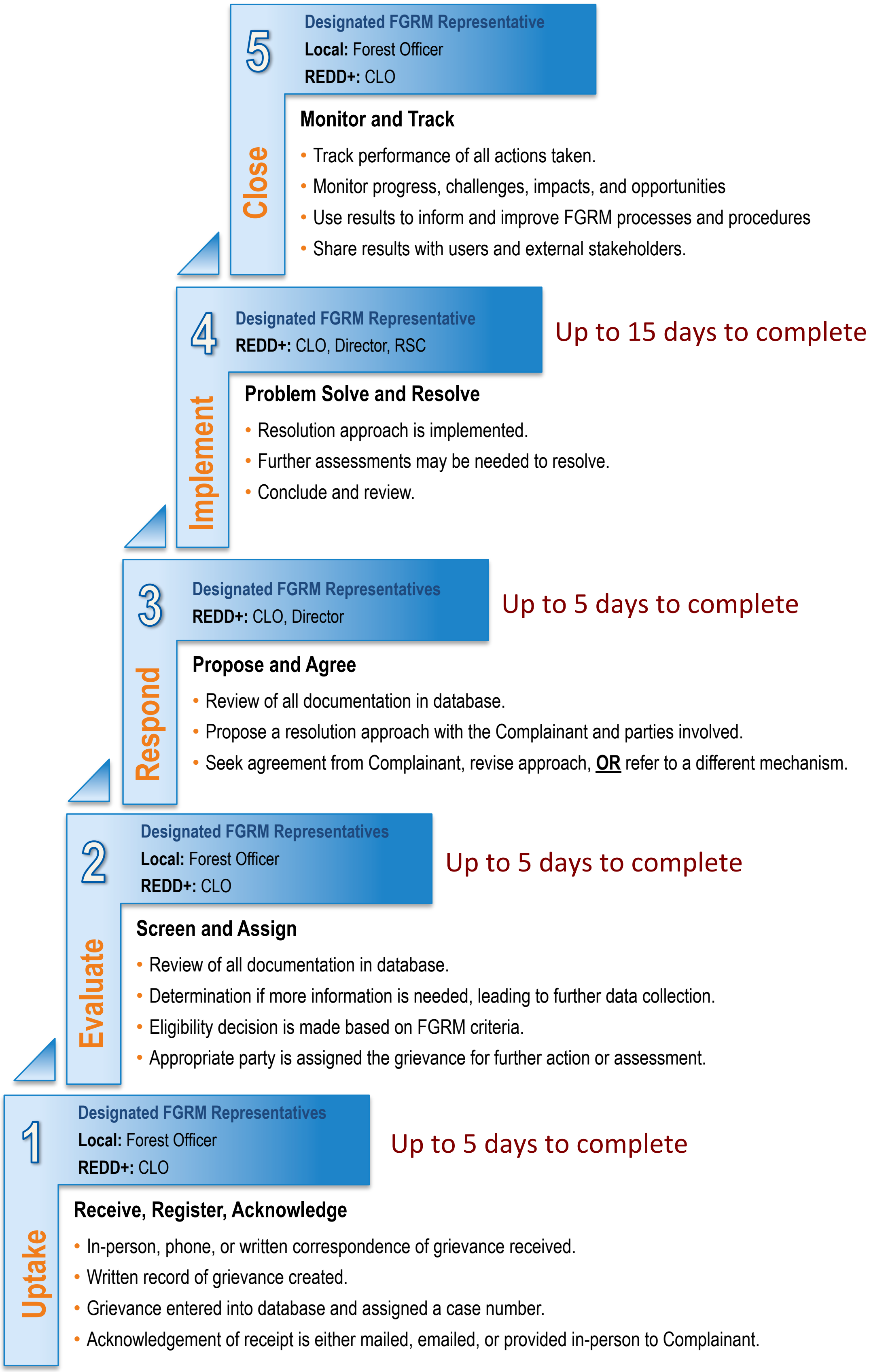
- Ways to receive, register, assess, and respond to grievances
- Method for screening REDD+ related grievances from other conflicts/GRMs
- Select grievance resolution approaches
- Implementation of the resolution
- Design of a means to track and monitor grievances
- Review and refine the design

From the time that a grievance is received until a decision is reached on the dispute (resolution or not) is an estimated 30-45 working days[8]. The grievance, once received, follows a systematic process that consists of five steps (see *Figure 3*). Each step proposes a phase timeline to help FGRM designate officers and institutions manage expectations of the user, as well as to help facilitate a smoother grievance process and identify where breakdowns may be occurring along the pipeline (which my result in the need for additional resource allocation, a revisited process, etc.). These estimates may bleed, shrink, and/or happen concurrently depending on the complexity of the issue at hand and the resources required. The breakouts for each step should be viewed as guidance, with the completion of all components of a step being accomplished in a reasonable amount of time as proposed in *Figure 3*. The FGRM process itself must be inclusive and participatory, as well as responsive, respectful, and predictable – clearly laid out in the expected timetable for key process milestones. It is critical that the FGRM involves a variety of stakeholders from multiple parties to ensure that there is transparency of process and independence of decision-making where multiple perspectives are weighed equally. Inclusive engagement also ensures the preservation of open dialogue amongst different stakeholders to promote joint problem solving and a workable resolution that will be upheld, promoted, and pragmatic. Designed in a modular fashion (with fewer uptake locations, compliant-receive channels, dual languages, etc.) the FGRM can be scaled-up gradually as additional resources are mobilized.

Effort should be made to improve dispute resolution processes at the community-level prior to engaging in an ADR mechanism whenever possible – opting for resolution where communities have ownership first, and then providing additional support and technical skills (e.g., information on legal rights and additional resources) through the intervention of third parties (e.g., CSO, NGO, RSC) to help facilitate resolutions before resorting to judicial.

[8] The amount of days was determined by examination of other comparable GRM timeframes in Fiji and by a review of similar FGRMs in REDD+ related context in low-resource, logistically challenging nation states.

**Figure 3. FGRM Process**



## 4.2. PROCESS

The design and operation of the FGRM considers cultural differences, such as communities' preferences for direct or indirect negotiation; attitudes toward competition, cooperation, and conflict; the desire to preserve relationships among complainants; authority, social rank, and status; ways of understanding and interpreting the world; concepts of time management; attitudes toward third parties; and the broader social and institutional environment.

*Complaints should be viewed as positive indications of stakeholder engagement*

1

### UPTAKE – RECEIVE, REGISTER, AND ACKNOWLEDGE RECEIPT OF GRIEVANCE

#### Receiving Grievances

The first step of the FGRM process occurs when a grievance is being tendered. This step is designed to be simple, convenient, and familiar to forest-users, taking into account cultural preferences for communication as well as illiteracy barriers and, if desired, anonymity. The submission, or uptake, of a grievance is comparable to other GRMs in Fiji so as to build on existing practice and familiarity of users that wish to engage in the mechanism for REDD+.

| Process for Receiving Grievances | Timeframe |
| --- | --- |
| • Forest Officer or R+LO receives grievance from Complainant. | NA |
| **Ideal turnaround (number of days to complete process)** | **NA** |

In order to promote accessibility there are multiple methods available to submit a grievance, all of which encourage open dialogue and options for face-to-face and verbal communication; being greatly important for trust building and maintenance of relationships. This FGRM proposes the following methods for submission of a grievance, building on existing practice, technological capabilities of forest-users, and resources available:

- **Oral:** Face-to-face meetings
- **Verbal:** Phone call
- **Written:** Email, letter

Grievances can be submitted directly to a Forest Officer or R+LO, through the aforementioned means. These Officers will also be responsible for broader training and awareness on the FGRM and will be able to address queries during uptake as well as providing additional information to help inform the Complainant of their rights, the FGRM process, and access to additional resources available to them.

Other on-the-ground grievance submission options, such as a suggestion box, have been tested and proven to be a less effective means of communication in Fiji[9]. This option did not align with cultural norms (oral communication) or support lower literacy levels in communities, nor did it allow for increased awareness, open dialogue, or access to information that forest-users voiced as important (during consultations) when submitting their grievance. This interaction is important at this early stage of the FGRM in order for Complainants to be able to expand on the details of their case; develop a relationship with grievance officers, thereby building trust and accountability; and improve their knowledge of REDD+ rules, processes, procedures; and to manage expectations or answer questions. SMS and website submissions are options that may be viable in the future, but mobile technology and internet connectivity are still issues for remote communities in Fiji that are, and will likely be, the primary audiences for REDD+ programming.

### Recording Grievances

A transparent grievance receipt and registration system allows forest-users a means to register complaints and confirm they have been received. There will be two stages at which a grievance will be recorded – the first is written documentation via a complaint registration form (see *Attachment 3*) and the second is electronically when it is entered into an online database. All recording instruments will follow a common protocol for data collection and be entered into a centralized database for logging and tracking grievances. This process will not only promote transparency and accountability, but it will also enable continuous learning and provide a means to quality control data. The information from this database may also be used to contribute to national-level reporting on the social and environmental sustainability aspects of REDD+ through the safeguard information system (SIS).

> *Maintaining a relatively low-barrier for entry promotes quicker turnaround and ensures users have their issues considered – promoting credibility of the FGRM while building trust and fairness of process.*

During this stage Forest Officers and the R+LO reinforce and validate that affected stakeholders understand what the FGRM is, when and how it is used, and provide additional information on REDD+ policies and procedures. This interaction provides an opportunity for communication and awareness, as well as feedback. Officers are also responsible for providing timely communication back to the Complainant on the status of their case (with estimated timelines, points of contact, etc. – see *Attachment 4*) as well as a copy of their registration documentation.

| Process for Recording Grievances | Timeframe |
|---|---|
| • Forest Officer or R+LO records grievance on paper form in person or transcribes from phone, email, or mail communication (**this step can be bypassed by directly inputting the information in the database*). | 1-3 working days |
| • Forest Officer or R+LO inputs grievance into centralized database based on documentation collected and completed dispute resolution report and a case number is assigned. | 1-2 working days |

[9] This was tested at the DBFCC site and has also been attempted at Forest Department outposts with limited success.

| Process for Recording Grievances | Timeframe |
|---|---|
| • A copy of the resolution report (hard and/or electronic) is sent to Complainant as confirmation of receipt – either in person (for in-person recorded grievances) or through mail or email once a case number has been assigned. | 1-2 working days |
| **Ideal turnaround (number of days to complete process)** | **5 working days** |

A copy of the written complaint registration form is either made at the moment of registration (in-person grievance submission) or mailed and emailed to ensure that documentation has been shared with the Complainant and confirmation of receipt is given. Officers are required to sign hard copies and, if electronically submitted via email, a confirmation of receipt will automatically be generated following submission. There will be a designated email for grievance uptake and the R+LO will manage the inbox. The database will be coded by case number for ease of reference and can act as a way to provide anonymity as needed/requested. A grievance officer must input all data into the database directly, ensuring that all grievances are reviewed prior to entry of the FGRM registry.

In addition to the form itself a timeline that also provides a description of the process is to be shared with each Complainant. For in-person submissions this process should happen fairly quickly, as the Officer receives the complaint, records the grievance, logs/scans the grievance information into the database, generates a copy of the signed report, and informs the Complainant of the procedure for assessing eligibility and next steps.

Even if a complaint is resolved "on the spot" and informally through support by the Forest Officer, there is an opportunity to record these grievances as they encourage responsiveness and ensure that repeated or low-level grievances are being noted in the system for any pattern recognition that may be avoided by further awareness or communications efforts. It also allows for the R+LO to monitor decisions being made at the local-level as a check and balance.

If the grievance is to be registered on behalf of an individual or group of individuals (e.g., an NGO on behalf of a LoU) the Complainant will need to identify the entity and provide some documentation to establish authority to act on behalf of the group. The FGRM Officer will take reasonable steps to verify this authority (the Roko can act as a resource to help determine if the Complaint(s) are authorized to submit the grievance), which may involve searches of registers held by the TLFC, including the Native Register of Land (NRL) also known as the *Vola ni Kawa Bula* (VKB.) The VKB is the official register of iTaukei landowners in Fiji and the register is currently being computerized. The R+LO may also consult with the Grievance Director and determine whether it is appropriate for a grievance to be made on behalf of a group (such as a LoU) or whether it is more appropriate that a grievance be made on behalf of a named group of individuals. In the case of a complaint by a group, individual names and details of all complainants should be recorded.

**Responsibility of the Complainant**

It will be the responsibility of the Complainant to keep their contact information up–to-date in order to receive communications on their grievance status. All Complainants have 10 days to update their information (which can include an alternate) following a change of contact or risk having their grievance marked as "incomplete".

### A Common Protocol

Information obtained via recording forms and the open dialogue process are designed to not only disclose the grievance and parties involved, but to determine REDD+ attributes – distinguishing REDD+ from non-REDD+ related grievances. The forms allow for a wide range of concerns to be reported, both those based on factual data and those arising from perceptions or misperceptions. These characteristics help track and monitor, as well assist in pattern recognition and trigger identification, allowing for more targeted communication and awareness campaigns.

There are two formal ways to communicate information to the Complainant once a grievance has been received and entered into the database – mail and email – to ensure multiple awareness points. Informally, the Complainant can request information regarding their case in person or over the phone from either the Forest Officer or R+LO based on the information in the database. All decisions and information will be recorded in the database, easily exported to a letter or email transmittal to the Complainant.

### Resource and Support Groups

Resource and support groups can be NGOs, CSOs, legal, academic, or other designated interest group that act on behalf of or in accompaniment to the Complainant. Forest-users wishing to enter a grievance may experience issues with submissions or feel uncertain about engagement for a multitude of reasons, which may include a remoteness issue, group complaint submission, perceived bias, resource constraint, or lack of understanding about the FGRM process. These groups can provide assistance at the informal and semi-formal levels through facilitation and mediation support, preparation and submission of grievances, and improved understanding of FGRM processes and resolution approaches and forest-users rights. These groups can also help potentially resolve grievances stemming from a lack of or misinformation or understanding at the local-level, preventing unnecessary grievances from being submitted to the FGRM directly. If a group is assisting in the submission of a grievance then this should be recorded.

## 2 EVALUATE – SCREEN FOR ELIGIBILITY AND ASSIGN RESPONSIBILITY

At this stage the grievance has been entered into the database and assigned a case number. The grievance is then screened, based on a few simple criteria that do not involve judging the substantive merit of the complaint to determine its eligibility of the FGRM.

| Process for Screening for Eligibility | Timeframe |
|---|---|
| • Once a case number has been assigned the R+LO will review all documentation provided for the complaint. | 1-2 working days |
| • If the information provided is sufficient the R+LO will screen the case and make a determination on its eligibility for the FGRM and communicate that decision to the Complainant (via mail and email) and update the database. | 1-2 working days |
| • If the information is **not** sufficient the R+LO will request that additional evidence be collected. | 2-5 working days |
| • Once eligibility is determined a relevant authority will be assigned. | 1 working day |
| **Ideal turnaround (number of days to complete process)** | **5 working days** |

### Screening for Eligibility

This step is not a commitment to any specific form of redress; instead it is intended only to determine if the complaint aligns with a set of pre-determined criteria for inclusion in the FGRM for REDD+. These criteria filter grievances based on what types of issues can be handled through the FGRM, which issues should be referred to other institutions/departments (i.e., TLTB, TLFC, Land Bank), and what may not be eligible for a response.

To prevent conflict of interest or bias in judging eligibility all decisions made by a Forest Officer will be audited by the R+LO. The R+LO provides oversight for and conducts eligibility screenings. Should a Complainant be dissatisfied regarding the results of a screening they can appeal the R+LO's decision and request a review by the Director for inclusion. The Director's decision on eligibility is final, however should the Director be a party to the dispute, only then can the case be elevated to a review by the RSC.

There are five broad criteria to be used when reviewing eligibility of a dispute (see *Table 3*). Additionally, included on the complaint registration form (see *Attachment 3*), is a checklist/grievance evaluation that can guide the FGRM Officer's determination on the "Nature of the Complaint" as auxiliary criteria.

**Table 3. Screening for REDD+ FGRM Eligibility**

| Grievance Eligibility Assessment Criteria |
|---|
| 1. Does the complaint indicate that a REDD+ activity has caused a negative economic, social, or environmental impact on the Complainant, or has the potential to cause such an impact?<br>2. Does the complaint specify what kind of impact has occurred, or may occur, and how the REDD+ activity has caused or may cause the impact?<br>3. Does the complaint indicate that those filing the complaint are the ones who have been impacted, or are at risk of being impacted; or those filing the complaint are representing the impacted/potentially impacted stakeholders at their request?<br>4. Can the FGRM handle the dispute in terms of complexity, multiple parties, and legality?<br>5. Does the complaint fall within the scope of issues that the FGRM is authorized to address? |

Often Complainants do not provide substantive enough information, so the Officer must make every effort to truly comprehend a grievance before making a determination on its eligibility or resolution. If there is not enough evidence provided to make a determination using the criteria listed above then the R+LO should decide if it is possible for the Forest Officer to collect additional information or if they need to follow up with the Complainant directly (see *Table 4*).

**Table 4. Ineligible Complaints Eligibility**

| Ineligible Complaints Criteria |
|---|
| **Ineligible complaints may include:**<br>• The Complainant is non-communicative and does not provide enough information or respond to requests for information<br>• The Complainant is not authorized to file the complaint on behalf of a group. The complaint should be refilled in individual names rather than in a group name<br>• The complaint is not REDD+ project-related<br>• The nature of the issue is outside the mandate of the FGRM<br>• The issue is on an implementer-led REDD+ activity and not a national project and the Complainant has not tried to resolve the issue with the project first |

Although some cases may appear without merit or unlinked to on-going activities the potential issues underlying the complaint may still need to be explored as they could indicate some underlying concern or stemming concern with a REDD+ activity (e.g., lack of trust). In such cases it is advisable to continue with the case and conduct additional investigation and obtain further information (if necessary) before determining if a complaint is inadmissible – doing so will likely increase trust by forest-users in the FGRM.

*It is advisable that there be wide-ranging discussion and that all relevant information is obtained before a complaint is rejected.*

An explanation will be provided to the Complainant following any illegible decision-made, as well as justification for the decision. Criteria will be distributed to other sector appropriate government departments and institutional boards so they may also screen their grievances; should they receive a REDD+ related dispute that needs to be referred or brought to the attention of the REDD+ Grievance Director.

It is important to note that the Complainant does not have to participate in the REDD+ program in order to file a grievance with the FGRM. This is because the impacts of the REDD+ activities may be felt by communities outside or on the peripheries of REDD+ sites, as was noted in the previously conducted Risk Assessment (D-2).

### Assign Responsibility

Complainants should be referred to the most appropriate institution, agency, implementing partner, or individual relevant to the issue raised in the complaint. If during the screening process a complaint is deemed ineligible due to it being non-REDD+ related in nature and a referral is required, then the R+LO would denote that decision in the database and flag this response to the Director. The Director will then review and the Complainant will be made aware of the decision to transfer the complaint to the appropriate authority and be given a new POC – *Roko Tui*. The Roko (or authorized representative such as the Assistant Roko) will then follow current protocol and submit a report to the iTaukei Affairs Board, who will then work with the Roko to determine which is the appropriate GRM to refer the complaint. The Complainant can decide whether to pursue the case through the referred mechanism or loop back to the informal system if desired.

The same process will be followed when receiving REDD+ related grievances as referrals from outside institutions or agencies. The Director will be responsible for reviewing and accepting a referred grievance and then submitting the case to the R+LO if accepted into the FGRM to follow up with the candidate for case information.

The process of assigning cases will be more transparent if a list of conditions is generated to support referrals and processes so that there is consistency in application for similar cases and not seen as arbitrary.

## 3 RESPOND – PROPOSED RESOLUTION APPROACH AND AGREEMENT

If the complaint is deemed eligible for the FGRM during the screening and it cannot be resolved through a relatively simple action at the local-level by the Forest Officer or the R+LO then the grievance is considered complex enough to require additional investigation and engagement with the Complainant and other stakeholders to determine how best to respond. This is also the stage of the FGRM at which a grievance from an implementer-led activity can be submitted.

| Process for Formulating a Response | Timeframe |
|---|---|
| • Selection of a proposed resolution approach by an Officer of the FGRM. | 1-2 working days |
| • Formulate and deliver a response on the proposed resolution approach. | 2-3 working days |
| **Ideal turnaround (number of days to complete process)** | **5 working days** |

### Proposed Resolution Approach

There are three primary responses for complaints: (1) direct action to resolve the complaint, (2) further assessment and evaluation needed, and (3) not eligible for FGRM. Many complaints can be resolved through direct and relatively straight forward action on the part of the Forest Officer or R+LO. In other cases further information is needed involving multiple stakeholders and unbiased investigators engaged in a process of joint fact-finding, open dialogue, and facilitation/negotiation/problem solving to resolve the complaint. The FGRM is designed to offer a range of grievance resolution approaches to accommodate differences in cultural preference and to account for simple versus complex issues (see *Table 5*).

*Rather than resorting to a purely unilateral "investigate, decide, and announce" strategy, engage more directly with the Complainant in the assessment process. Deciding together should be the centerpiece of the FGRM*

The R+LO serves as the primary point of communication to all stakeholders involved and is responsible for communicating timelines, decisions, and next steps. The identification and selection of a proposed resolution approach is done in conjunction with the Complainant and stakeholders and is facilitated by the R+LO.

**The following are five options for resolution approaches:**

**Option 1: Informal Resolution – The community decides.** In this option the response is to use the customary/traditional/informal system process to resolve the grievance. This is the most favorable option because of the higher value placed on maintaining relationships, utmost level of transparency, and greatest accessibility and predictability. As a result, decisions at this level often receive greater support and buy-in from all parties to the dispute. This system capitalizes on traditional means of conflict resolution that is mostly oral and is decided under leadership of the iTaukei Village Headman. This option (under the proposed FGRM) will now include the Village Council serving in a dictation role; recording all grievances, decision-making processes, and resolutions to improve continual learning and to provide a written record of dispute resolution (requested during the consultation period).

The Roko currently must formally endorse and witness the resolution for the Provincial Council. It is now recommended for the FGRM that the Roko act as formalization agent, whereby an agreement is formally documented and witnessed by the Provincial Office through the Roko, creating a more formalized and committed structure.

**Option 2: Self-Proposed Resolution – An Officer of the FGRM decides.** Forest Officers may be able decide on a resolution for minor, straight forward, or simple disputes, but it would be more appropriate to have the R+LO engaged if the dispute includes elements or issues regarding more specifics of the policies and procedures of the REDD+ program, where dialogue and information sharing may result in quick resolution. This resolution approach may also resolve the dispute by being able to loop the conflict back to an informal means of redress.

**Option 3: Joint Problem-Solving Resolution – An Officer of the FGRM acts as a mediator.** In implementer-led disputes a Forest Officer can act as a mediator (after receiving training). In this capacity the Officer can provide information to help facilitate decision-making on REDD+ policies and procedures. The Officer's goal is to positively influence the mediation process but avoid interfering in a decision-making role. The Forest Officer can confer with the R+LO. This option should allow for resolution in an informal setting as a next step.

**Option 4: Third Party Resolution – Facilitation offered through a third party assessment (IAG).** It is strongly recommended that parties attempt to resolve conflict using Options 1-3 prior to engaging in this approach. Should the parties' efforts fail, or if the dispute proves too complex, then this approach allows for a more comprehensive assessment and stakeholder engagement process. Under this option an IAG is convened (and managed) by the R+LO; comprised of subject matter representatives not involved in the dispute with expertise in conflict resolution. Together, the IAG investigates and proposes a resolution with the Complainant and parties involved. They play a moderating force and bring together all parties in an effort to break down the issues, improve communication, and provide recommendations for either resolution or settlement. This approach is a collaborative process that seeks to clarify underlying issues and incorporate multiple perspectives that do not have a vested interest in the outcome. The Complainant(s) and other affected stakeholder should come together to discuss the proposed resolution with the IAG and mold it into an acceptable process for both parties. This could result in a move back to the informal system.

**Option 5: Board Resolution – External review board decides.** When an issue is too complex (e.g., multi-parties, multi-issues, reoccurring problems, discrepancies in data or institutional constraints) and when voluntary agreement is not possible this approach allows for an external body to serve in a decision-making role. Under this approach the RSC serves as a review board and decision-making entity with a majority vote. The RSC may request that additional information be collected, that a new IAG is formed (where there is concern regarding bias, corruption, or lapse in technical judgment by one or more members), or make an evaluation based on the information collected to date. The REDD+ Secretariat and the REDD+ Grievance Director oversee the RSC board review process. This approach allows for checks and balances within the FGRM so that a resolution is always dependent on a multi-party team and not solely dependent on the determination of a single member or Officer.

**Table 5. Resolution Approaches**

| Decision-makers | Grievance type | Dispute Examples | Resolution Approach |
|---|---|---|---|
| **iTaukei Village Headmen proposes resolution** | Family or internal *Tokatoka* (sub-clan) or *Mataqali* (clan) issues | • Site maintenance issues within community by members<br>• Benefit sharing and equitable distribution of monetary returns relating to forestry | Informal Resolution |
| **FGRM Officer proposes resolution** | Obvious solutions, simple, informational or queries | • Timelines issues with grievances in FGRM<br>• Understanding of REDD+ in general and access to information. | Self-proposed Resolution, Informal Resolution |
| **FGRM Officers and Stakeholders jointly propose resolution** | Complex conflicts between two local stakeholders over one issue | • Dispute over land/forest use between two LoUs | Joint Problem-solving Resolution, IAG Resolution, Informal Resolution |
| | Complex conflicts between multiple parties that focuses on trust | • Benefit-sharing<br>• Lack of FPIC | Joint Problem-solving Resolution, IAG Resolution, Informal Resolution |
| | Complex conflicts about policies, procedures, facts or data | • Who has access to forest resources and what resources on REDD+ site(s).<br>• Disagreement by community and REDD+ on details of project implementation | IAG Resolution, RSC Resolution |
| | Reoccurring dispute | • Land use impacts on conservation plots. | IAG Resolution, RSC Resolution |
| | Conflicts between multiple parties and local stakeholders | • Conservation / REDD+ lease issues with TLTB or Land Bank and LoU(s) | IAG Resolution, RSC Resolution |

## Seek Agreement

Selection of a resolution approach must be done in consultation with the Complainant. Parties to the complaint should be willing to accept the outcome of the proposed resolution, if they are committed to the approach and act in accordance with the resolution. At the outset, if both parties are not committed to negotiating and honoring an ADR, they may move the grievance to a more formal means of redress (e.g. the courts). Consideration should be given to the limited resources available for ADR and parties should be advised not to venture down a ADR route if there is little commitment to the process and eventual resolution.

At any stage of the FGRM, Complainants may also be feeling slightly overwhelmed and wish to loop back to the informal system for resolution. This loop-back, allows the Complainant the flexibility to step out of the FGRM if they wish.

If there is no agreement on the proposed response then the FGRM Officer(s) should consider whether to revise the approach or refer the complaint elsewhere. It is advisable to review the proposed approach with the Complainant to see if there are any modifications available.

**Communication and Outcomes**

The Forest Officer and the R+LO communicate with the Complainant throughout the FGRM process in order to ensure that they understand the case in detail. Formal documentation (with the exception of in-person hard copies of the complaint registration form if submitted to a Forest Officer) are all provided and managed by the R+LO. Once a proposed resolution approach has been selected the R+LO will mail and/or email the Complainant and parties involved in the dispute and update the database to include the initial response. In this communication the R+LO will include information on the rationale for the approach selected, the response, each parties' view, outline the Complainant's choices, and outline next steps. Choices can include an agreement to proceed, request for a review of the eligibility decision or referral if transferred, further dialogue on a proposed action (phone call from R+LO), or face-to-face meeting with the R+LO and parties to discuss further and all decisions are to be recorded in the database.

**Exceptions**

If a dispute is determined to exhibit a risk of serious harm or rights' violations then the case should be fast tracked to the Grievance Director and the REDD+ Secretariat will be notified. The R+LO will immediately notify Complainant via email, mail, and phone (if necessary) in an expeditious manner of next steps.

## 4 IMPLEMENT – PROBLEM SOLVE AND RESOLVE GRIEVANCE

If the Complainant agrees to the proposed approach the response can be implemented, collaboratively. For informal, self-proposed, or joint problem-solving resolutions the approach and closeout of the grievance is completed according to the community. All self-proposed and joint problem-solving results should be uploaded to the database and communication on the resolution mailed/emailed to the Complainant. More complex issues that employ the third party or board review resolution, which are more formal in nature, are further elaborated below.

| Process for Implementing a Response | Timeframe |
|---|---|
| • **IF** – R+LO convenes an Independent Assessment Group (IAG) to conduct further assessment work and evaluate the grievance. | 8-10 working days |
| • **IF** – IAG is unsuccessful in their evaluation, the issue is considered too complex, or the Complainant seeks an appeal, the grievance is elevated to determination by a majority vote of the RSC – who may ask for additional information or a new IAG. | 5 working days |
| **Ideal turnaround (number of days to complete process)** | **15 working days** |

### Further Assess and Evaluate

If the proposed resolution requires a larger investigation then the R+LO will convene a REDD+ IAG. This team's purpose is to gather information on the case – key issues and concerns – helping to determine whether and how the complaint might be resolved. The IAG will consist of three team members and may be comprised of NGO, CSO, private sector, academic, conflict resolution and other subject matter experts as are relevant to the dispute. The REDD+ Secretariat and Grievance Director will approve IAG appointments through a roster (see requirements in *Attachment 5*) in collaboration with the Complainant (agreeing on selection criteria and process).

Experts that are selected to join the IAG will be required to sign a *Non-disclosure Agreement and No Conflict Statement* (this can be drafted by the REDD+ Secretariat). The R+LO will manage the IAG process and provide guidance to the team, remaining a neutral player. The Director will review and approve the outcome or ask for more details.

**Methodology and Approach**

During the investigation the IAG will first review all documentation collected on the dispute and prepare an *Evaluation Plan* (see *Table 6*). The plan will outline gaps in information collected, process for consultations, and plan for execution of the assessment. The R+LO will review and have the Director approve of the plan before initiation. The IAG will then contact the Complainant and other relevant parties to the dispute to acquire first-hand information and to better understand the tenets of the issue(s). Involving the Complainant early in the process acknowledges voice, increases mutual understanding of the problem, and brings the parties together in a more collaborative way. The IAG can also discuss with the Complainant which process they find suitable for resolution.

**Table 6. Screening for REDD+ FGRM Eligibility**

| Evaluation Plan Research Guidance |
|---|
| **Review all documentation and seek to clarify:**<br>• Issues and events that have led to the complaint.<br>• Stakeholder involved and at what points/events.<br>• All stakeholders' views, interests, and concerns on relevant issues.<br>• Interest by all stakeholders in achieving a collaborative process for resolution (joint fact-finding, open dialogue, negotiation).<br>• How stakeholders will be represented and what their decision-making authority will be.<br>• Work plan and timeline need to work on issues.<br>• What resources are needed (human, fiscal, material) and who will contribute them. |

Next, the IAG will categorize the complaint in terms of its seriousness (high, medium, low) based on the potential impact to both the REDD+ Programme and the community. Issues to consider include: (1) the gravity or seriousness of the allegation, (2) the potential impact on an individual or group's welfare and safety, (3) potential impact on the environment, (4) risks posed, whether current or future, and (5) impact of the seriousness of the allegation on the processing timeline. In addition, consideration should be given to "who needs to know what" in the REDD+ Unit, MoF, other institutions and agencies, and potentially whether there is cause for referable action to authorities (i.e., the police for criminally related matters).

**Communication and Resolution**

During this assessment it may be discovered that not all stakeholders are willing or able to participate or commit to outcomes. Whether or not the process is collaborative the IAG needs to communicate the assessment findings to the stakeholders and the Complainant with a recommended action on how to proceed.

The IAG will ultimately propose a resolution approach for the case and presents their findings to the R+LO. The response should consider the Complainant's views about the process for resolution as well as provide a specific remedy. It may offer a proposed approach for how to settle the dispute or offer a preliminary settlement. The R+LO will review the report, ask for additional information/clarification where needed, and submit to the Director for final approval. The R+LO is responsible for communicating and coordinating with the Complainant on the results of the evaluation and proposed resolution.

### Board Review

For the most complex grievances that involve multi-party, multi-issue complaints, where a determination could not be made or voluntary resolution agreed to, the Grievance Director may convene a special session of the RSC to serve in the capacity of a third party evaluator – board review. Each representative group on the RSC may participate (or abstain should they be in a potential conflict of interest in relation to the dispute). Members will be able to review the information and analysis collected to date and either request more information, determine referral to an outside GRM or agency as appropriate, or decide with a simple majority vote. The REDD+ Secretariat and the Grievance Director will oversee the process, but they are not allowed a role in the decision-making process. Criteria lists and guidance will be given to each voting member as part of a packet and their determination is then to be transmitted to the Director. This step is important to ensure that the appropriate key decision-makers on the Committee are respondents, not junior representatives.

### Appeals Process

> *Every step of the FGRM should be open to collaboration, weaving traditional and customary approaches into a more structured process.*

If the Complainant is not satisfied with a resolution outcome – either because there is a perception of bias, corruption, or the dispute remains unresolved – then an appeal can be lodged. A Complainant may lodge an appeal in writing to the R+LO within 10 working days of the date on which a decision is provided to the Complainant. The appeal should contain the grounds of appeal and a requested outcome. All appeal processes are done in collaboration with the Complainant and the Complainant has the option at any point in the FGRM process to return to the informal system for resolution. To avoid any conflict of interest parties hearing or investigating the appeal should not have been involved in the initial investigated complaint.

The process for an appeal, for each proposed resolution option is included below:

- **Informal resolution appeal** – The dispute can be elevated to formally enter the FGRM structure through submission to a FGRM Officer.
- **Self-proposed resolution appeal** – If a decision made by the Forest Officer is appealed, it goes directly to the R+LO for review and resolution. If decision made by the R+LO is appealed, it goes directly to the Grievance Director for review and resolution
- **Joint problem-solving resolution appeal** – If the Forest Officer or R+LO is unable to serve as a mediator or it is clear that the case is too complex or cannot be resolved through facilitation and mediation at this level, then an appeal can be made to conduct a

third party assessment[10]. Early engagement will help generate trust on both sides that the appeals process will be impartial and fair.

- **Third party resolution appeal** – If the results of the IAG are not accepted by the Complainant then an appeal can be made to elevate the case to a board review.
- **Board review resolution appeal** – If third-party recourse is still not acceptable or possible, the Complainant still has access to available juridical procedures or referral to a different GRM without fear of retribution or retaliation.

### Outcomes

The outcome for any resolution will result in a contractual agreement between all parties to the dispute. The contract will contain terms that are particular to the grievance in question and the parties will need to negotiate contractual terms suited to their particular situation and needs. For example, a contract may contain terms relating to benefit-sharing or to a land use dispute. Certain clauses in the contract are likely to be standard (such as the jurisdiction being Fiji), but generally each contract would need to be drafted to capture the parties' requirements relevant to each particular case.

## 5 CLOSE – MONITOR AND TRACK RESULTS

In order for the FGRM to function effectively grievances need to be tracked and monitored as they proceed through every step of the system. Tracking and documentation accomplishes several goals in alignment with the UN-REDD/FCPF Guiding Principles that include transparency, accessibility, predictability, engagement and dialogue, legitimacy, equity, rights-compatibility, and enabling continuous learning.

As the FGRM is put into place the REDD+ Unit's Grievance Director should be responsible for monitoring and tracking all of the data that is being gathered in the centralized database and discussing progress of the FGRM with users and external stakeholders as part of a commitment to joint learning and continuous improvement.

| Process for Monitoring and Tracking | Timeframe |
|---|---|
| • Process for monitoring and tracking should cover the duration of the grievance redress. | NA |
| **Ideal turnaround (number of days to complete process)** | **NA** |

As part of a resource-conscious FGRM monitoring and tracking program, the Director should host monthly meetings with the R+LO to review the status of grievances in the database, ensuring that the severity of complaints is being recorded according to specific criteria and elevated as appropriate, the timely resolution of complaints is occurring, and communication

[10] This external appeals approach helps to alleviate the concern that REDD+ is not serving as de facto judge and jury on disputes, especially where they may be party to the dispute.

protocols are being followed. This monthly check-in should also be used as an opportunity to identify any emerging patterns and document any learning that can be used to later assess the effectiveness of the FGRM or address any systemic issues that may require changes in policies or performance. Feedback should then be trickled down to Forest Officers and REDD+ Project Coordinators (responsible for monitoring in their sites). The Director will also provide status updates at RSC meetings for any feedback from representative members.

*The FGRM is not a rigid structure, but a blueprint that can be adjusted and should be continually revisited.*

The R+LO is the database manager and is responsible for maintaining compliance and overseeing the quality of inputs from Forest Officer. The R+LO is also responsible for alerting the Director of any budding issues or resource needs. All responses should be recorded in the database on a routine basis and include a record of settlements and outcomes of resolutions and any challenges faced during implementation or in negotiations- this information will help with auditing.

Forest Officers and REDD+ Project Coordinators should continue to monitor cases following resolution in order to address any identifying new issues that may result from data collection from an investigation or the implemented resolution.

### Closeout

Closing a case is both a formal way to account for the response to a particular grievance, and a critically important moment for ensuring that key information and lessons learned are captured. Once a case has been resolved through any of the means listed above, it is noted in the database and used for process improvement. During this phase a survey tool could be used to gather feedback from participants in the case.

# 5. Operation of the FGRM

This section offers procedures for successful implementation and operationalization of the FGRM. The goal is to introduce the FGRM and promote piloting at Fiji's only national REDD+ sites (Emalu) and establish coordination with an implementer-led REDD+ project site (DBFCC), refining the mechanism before rolling it out. In order to ensure successful implementation the FGRM will require three key actions: (1) the development of technical support system for grievances, and (2) training for designated FGRM officers that will be administrating, supporting, and managing the system, and (3) a communications and outreach plan that educates members about the system and their role in it[11]. As the REDD+ Programme in Fiji is still in its Readiness phase, the focus for the pilot FGRM should be on the only nationally recognized program in Emalu in coordination with an implementer-led REDD+ project. In support of a hybrid approach, the recommendation is to work with the DBFCC and Live and Learn to find points of convergence between grievances redress systems.

The FGRM should be fully operational within 18 months if it is structured as proposed and the proper human, technical, and financial resources are allocated. The operationalization of the FGRM consists of 3 phases: (1) Establishing the Infrastructure, (2) Initiating the FGRM, and (3) Mainstreaming the FGRM, which can overlap in the implementation of activities.

## 5.1. PHASE 1. ESTABLISHING THE INFRASTRUCTURE

This first phase is focused on rapid start-up of the systems needed to support the infrastructure of the FGRM – this includes communication of the FGRM, coordination with stakeholders, hiring and training of staff, and the establishment of roles and responsibilities.

### 5.1.1 Steps (2-4 months)

- Develop a policies and procedures handbook (*FGRM Operational Manual and Guidelines*) that details the FGRM making it available and accessible to all staff that will be directly involved in the mechanism, as well as available to outside agencies.
- Develop Terms of Reference (TOR) for both the REDD+ Grievance Director and R+LO and hire (see *Attachment 6*).
- Develop and institute additional job requirements for the Forest Officers and REDD+ Project Coordinators, communicating these new responsibilities and provide the opportunity to address any concerns or questions about expand roles.
- Establish MOUs with REDD+ agency and supporting institutions that detail the process for referrals, mediation, and enforcement.
- Train Village Councils and iTaukei Village Headmen on how to complete informal dispute resolution reports and the benefits of written documentation for problem-solving and continual learning (incorporate feedback to improve forms).

[11] A Training Report and Communication Plans plan will be developed in separate documents, but an overview will be provided in this section.

- Train Forestry Officers on conflict resolution theories and tools, policies and procedures of REDD+, how to record and report grievances on the form (incorporate feedback to improve forms).
- Train REDD+ Coordinators on monitoring.
- Inform resource and supports groups of FGM policies and procedures and their possible engagement in the mechanism, to include possible roles and responsibilities.
- Explore options for development of centralized grievance database and begin design.
- Establish a roster of experts for the IAG based on TOR requirements (see *Attachment 5*)
- Train RSC members on board review vote, to include their roles and responsibilities.
- Ministry of iTaukei Affairs translates grievance forms and timeline information.

## 5.2. PHASE 2. INITIATING THE FGRM

This second phase focuses on community awareness about the FGRM and the establishment of a centralized online database for grievance registration and tracking and monitoring.

### 5.2.1 Steps (6-8 months)

- Raise awareness for all forest-users on the FGRM and simultaneously on REDD+ policies and procedures for reinforcement through the development of targeted material in both English and iTaukei formats– video, web, paper materials, and through meet-and-greets.
- Introduce the FGRM designated staff to REDD+ communities through in person meet-and-greet (Q&A), marketing materials, and on the web – making sure that communities understand the roles and responsibilities of staff.
- Launch the grievance registry system.
- Train all FGRM Officers on data collection techniques and data input, as well as the process for information sharing.
- Establish monthly check-ins with implementer-led REDD+ activities.
- Activate the email protocol for grievance acceptance.

#### *5.2.1.1. Communicate to Build Awareness*

Led by the REDD+ Communications Officer, with support from the Grievance Director and R+LO, a communications strategy will be approved to stimulate demand for the FGRM. Messaging will be targeted to key groups of forest users, resource and support groups and relevant institutional stakeholders. Forest Officers, REDD+ Project Coordinators, and resource and support groups will play a large role in awareness building at the local-level. This will involve establishing a personal connection with stakeholders to foster buy-in, using an incentive-based system. As part of this campaign it will also be important to identify any risks or fears that forest-users may have regarding use of the system and finding out what else they might need to voice a complaint or participate in the process (e.g., training, mentoring, resource materials).

#### 5.2.1.2. Database

A centralized database will be developed and hosted on the MoF server, accessible by the REDD+ Unit and managed by the R+LO. The database will be accessible by all FGRM staff (Forest Officers, REDD+ Project Coordinators, R+LO, Grievance Director) and implementer-led REDD+ activities and will be the primary system used to record, track, and monitor REDD+ related grievances in Fiji.

The system should be a simple, easy to use, excel-based/logbook-based registration and monitoring database that can be converted into a real-time web-based database as resources, technological capabilities, and the amount of grievances increase over time.

All grievances that are submitted, regardless of merit or eligibility, are to be entered into the database, in addition to all decisions and steps taken during the resolution process. There will be a simplified form to codify information and assigned case numbers. Scans of photos and documents can be saved in the system as well. Information can be exported for reporting purposes and to generate status letters (emailed or mailed) to inform Complainants of the progress of their case[12].

Permissions and levels of access will be determined by the Grievance Director so as to protect sensitive information or the manipulation or corruption of data. For example, implementer-led projects will only have visibility to a certain level of data and will only be able to edit their own inputs in the system.

**Each grievance file, at a minimum will contain:**

- Date of receipt
- Date written acknowledgement was given/sent
- Date/nature of all communications or meetings with Complainant and other stakeholders
- Any previous attempts to resolve the grievance (supporting content can be uploaded)
- Date and record for any proposed resolution approach (who suggested the approach)
- Date of acceptance or rejection by Complainant (if objections were raised)
- Current status of case and next steps (including who is the person responsible)
- Notes regarding implementation of proposed resolution (any issues experienced)
- Contract details, to include what has been agreed to, who the parties are and their responsibilities, timeline for closeout, and signatures
- Date of transfer/referral to outside GRM (include person responsible) or judicial system.

[12] It would be prudent to create an electronic filing system to secure all templates, forms, and guidance on the FGRM accessible to all FGRM staff – managed by the R+LO.

- Conclusions and recommendations arising from monitoring and follow-up.

Current GRMs are not employing centralized online databases, which have contributed to poor quality of resolutions; limited communication, transparency, and collaboration with Complainants; lost and incomplete case files; low accountability; and inconsistency in resolutions. Accurate case documentation using an electronic and centralized database is essential for public accountability, organizational learning, and resource planning. This database also contributes to the maintenance of benefit-sharing and safeguards aspects of Fiji's monitoring activities for REDD+. The system for case management must incorporate both an online and accessible database in conjunction with a streamlined written documentation process (for more remote and low/no bandwidth communities).

## 5.3. PHASE 3. MAINSTREAMING THE FGRM

This third phase focuses on mainstreaming the FGRM and addressing any barriers or feedback received for process improvement.

### 5.3.1 Steps (4-6 months)

- Resource needs assessment to review resource constraints and/or training opportunities.
- Gaps assessment to identify any challenges or patterns experienced.
- Legal challenges to accountability and enforcement of the outcomes from the FGRM.

#### *5.3.1.1. Legal Challenges*

Overall Fiji's existing REDD+ Policy provides guidance for the facilitation of REDD+, but as it is, it remains largely a statement of intent, not supported by legislation. The absence of legislation means that enforcement will be problematic without the option of legal sanctions, especially in the definitional ambit of its operations in relation to other existing laws and regulations within the resource and development sectors. There are three primary areas of concern that must be addressed in order for the FGRM to function and be enforceable:

1. **Carbon Ownership:** At the time of writing this report, there is no clear articulation at the national-level, nor there is any legislative development in progress to treatise the question of carbon. Most specifically, how carbon is going to be treated as property. As this exercise is driven by commercial rhetoric of carbon trading, it is a reasonable expectation that measures should be put in place for carbon to be quantified, valued, registered, and traded. Thus, the question of ownership must be addressed as it is expected that LoUs will want answers and this issue will result in conflicts that the FGRM will not be able to address.

2. **National Land Use Planning:** Fiji does not have a National Land Use Plan nor does it have in place a comprehensive national land use policy. However, there are current pieces of policy and institutional initiatives, such as the Rural Land Use Policy (2005), that are cognizant of matters pertaining to sustainable spatial planning during projects' consideration. These often vary and render conflicting responsibilities for land use management, while others overlap without clear policy guidelines. Existing agencies, whether singly or joined by circumstances, have had substantial impact on land use and land development. They are however, disjointed in delivering a comprehensive approach to consider complex

undertakings such as REDD+. If allowed to forge ahead in the absence of the above, there are bound to be long-term risks borne by LoUs as well as investors in recouping initial capital outlay, which will be unresolvable through the FGRM.

3. **Benefit Sharing**: There are currently inadequate regulatory contexts to support REDD+ programming either through legislation directly for REDD+ or contextually through the Draft Forest Bill that address key issues such as the definition of carbon property rights and benefit-sharing. Without REDD+ legislation in place and adequate laws to support benefit-sharing FGRM enforcement will be difficult, if not impossible, and accountability non-existent.

# 6. Monitoring, Reporting, and Learning

Grievance mechanisms are always a work in progress. Beyond the monitoring and tracking of individual cases, it is important to assess and refine the mechanism itself to ensure that it achieves its stated purpose and goals – *to channel grievances through a system that is fit for purpose*. Feedback from users is critical in order to determine if procedures are seen as inefficient, accessibility as problematic, or an overall lack of confidence or satisfaction exists, which ultimately dissuades community support for the mechanism.

It is necessary to monitor and evaluate the overall performance of the FGRM throughout its lifecycle. The goal is to not only improve the operational procedures of the system, but also to improve the way grievances are being handled by all users.

## 6.1. MONITORING

Monitoring involves assessing the overall progress and approach towards handling grievances in the FGRM. Building off the overarching goal of the FGRM is to enable stakeholders affected by REDD+ to receive timely feedback and appropriate responses. As such, in addition to the monthly monitoring meetings that are held between the R+LO and Grievance Director (see *Section 4, Step 5*) and the status reports given to the RSC by the Director, it is recommended that a *Grievance Advisory Committee* be formed. This committee would consist of REDD+ Project Coordinators and LoU who will monitor the performance of REDD+ activities in their communities by periodically surveying community members to determine if they understand access points and whether they are satisfied with the grievance mechanism.

## 6.2. REPORTING

The Grievance Advisory Committee members will provide strategic advice about the grievance mechanism to the Grievance Director through semi-annual community relations meetings, hosted either in person or virtually.

Specific targets need to be set and tracked by indicators. The Grievance Director (with support from the R+LO) will be responsible for monitoring and using performance indicators (quantitative and qualitative – see *Table 7* for illustrative qualitative questions) and reporting on these outputs every 6 months to the RSC, focusing on participation and effectiveness.

## 6.3. LEARNING

Learning is a combination of evaluating and building on lessons learned to improve the FGRM's design and overall effectiveness. The Grievance Director, supported by other FGRM Officers, will gather lessons learned from the process and subsequently use these to improve organizational learning and identification of systemic problems and to identify the need for any changes to policies and procedures to prevent recurrent future disputes.

As part of an on-going evaluation process it is recommended that four (4) different bodies will be utilized to ensure that inputs from multiple stakeholders are present:

1. **Case Audits** – An advocacy group that is well versed in human rights law and environmental law (such as FELA) should oversee auditing of closed complaints. The group can provide

quality control and technical guidance for consultations. It is recommended that students from universities be tapped as auditors as it will create a continuous pool of available auditors as well as build capacity and skills for students for future environmental work. A modest stipend should be provided as an incentive and/or course credit.

2. **Grievance Advisory Committee** – REDD+ Project Coordinators meet with representative LoUs periodically and will report findings with iTaukei Village Headmen to the Grievance Director quarterly. Findings should include information on perceptions of the FGRM and process. The Grievance Advisory Committee should also be in continuous communication with the R+LO outside of the quarterly reports to address any pressing issues.
3. **RSC Grievance Working Group** – This should manifest in the sharing of lessons learned and pattern identification by the Grievance Director with the Secretariat and the RSC through the delivery of a report annually that highlights key trends in emerging conflicts, grievances, dispute resolution and makes recommendations to avoid future harm /grievances and improvements to the FGRM in accordance with the FCPF Guiding Principles.
4. **Independent Audit** – Similar to TLTB's auditing principles, it is recommended that an independent audit (conducted by a party such as the University of the South Pacific's Institute of Applied Science or CROP Agency) of the FGRM be conducted every three (3) years that addresses aggregate statistics on the number and type of complaints received, actions taken, and outcomes reached and addresses any issues of and/or perceived bias or corruption.

**Table 7. Possible Questions to Target Grievance Mechanism Performance**

| Illustrative Qualitative Statements |
|---|
| **Review all documentation and seek to clarify:**<br>• How well is the system accomplishing its stated purpose, goals, and objectives?<br>• Is the system making a difference? How or how not?<br>• Does the mechanism enable Complainants to raise their concerns, engage in a fair process, and obtain a satisfactory resolution to their issues?<br>• What are the gaps? What is and what is not working?<br>• What types/categories of grievances is the system addressing?<br>• Is the mechanism easily accessible to all groups and populations affected by REDD+ activities?<br>• To what extent is the mechanism being engaged by women, youth, disabled, elderly and other vulnerable/marginalized groups?<br>• Is the mechanism easily understood by all users (officers, agencies, forest-users)? Where to go, what to do, procedures?<br>• How does the FGRM facilitate the identification of deeply rooted conflicts (e.g., persistent or reoccurring) and what actions are being taken?<br>• How well does the system provide a balance of powers between the Complainant and institutions (i.e., REDD+)?<br>• Are there adequate opportunities to engage in open dialogue and face-to-face interactions that are culturally appropriate?<br>• Does the mechanism allow and support facilitation by external and independent mediator to redress grievances?<br>• What actions would increase effectiveness of the mechanism?<br>• What demonstrable changes is the FGRM producing in REDD+ project operations, systems, and community benefits? |

### 6.3.1 Reporting Back to the Community

All reports from the Grievance Advisory Committee, RSC Grievance Working Group, and Independent Audit should be publically available, and upon request to the community in the spirit of transparency and accountability. This information can be made available through the REDD+ website and through links. This information will help clarify expectations about what the mechanism does and does not do, how the system is being improved, and will demonstrate that community feedback is being received and evaluated. By building in these regular reviews and communicating findings directly with forest-user REDD+ procedures and activities can improve their performance and development impacts on the ground.

## 6.4. IMPROVING THE FGRM

The FGRM should be flexible and adaptable to the needs of forest-users and take into consideration its implications for other institutions and agencies involved in or impacted by REDD+ activities. The information collected from the case audits, committee reports, working group, and independent audits will be used by the MoF and the REDD+ Unit to learn and report to stakeholders concerning ways to improve the FGRM's performance. Performance improvement can be done through:

- Pattern recognition and trend evaluation through the assessment of indicators;
- Data analysis of the impact of the FGRM on REDD+ implementation (operations, management, benefits to forest-users);
- Identification of systemic changes, especially to ensure that recurring grievances will not recur; and
- Identification of actions to make the GRM more effective.

Improvement of the FGRM should be a participatory process, in which the REDD+ stakeholders play an important role. The result of the findings from the case audits and committee work is a collaborative and joint fact-finding effort that will feed into the annual report produced by the RSC resulting in the compilation of lessons learned and actions for improvements. Once these recommendations for improvement are produced the Grievance Director will translate into programmatic tools (see *Table 8*).

**Table 8. Using Monitoring Data to Evaluate and Improve the FGRM**

| Feedback Improvement |
|---|
| **Example Programmatic Tools:**<br>• Development of a new indicator for tracking these emerging impacts.<br>• Adaptation of policies and procedures, as part of the operational guidelines of the FGRM.<br>• Amendment of the REDD+ stakeholder engagement or communication and outreach plan as a result of new insights.<br>• Revise approach for awareness raising activities as a result of new insights.<br>• Reflection of gender and social inclusiveness and evidence of participation of relevant stakeholders.<br>• Compliance guidelines. |

# Attachments

## ATTACHMENT 1: ACRONYM LIST

## ATTACHMENT 2: PREVIOUS STUDY FINDINGS

## ATTACHMENT 3: REPORTING FORMS

## ATTACHMENT 4: ACCOMPANYING INFORMATION

## ATTACHMENT 5: IAG SELECTION AND SOW

## ATTACHMENT 6: FGRM STAFF QUALIFICATION

# ATTACHMENT 1: ACRONYM LIST

| | |
|---|---|
| **ABS** | Access Benefit Sharing |
| **ADR** | Alternative Dispute Resolution |
| **CSO** | Civil Society Organization |
| **DBFCC** | Drawa Block Forest Community Cooperative |
| **FCPF** | Forest Carbon Partnership Facility |
| **FELA** | Fiji Environmental Law Association |
| **FGRM** | Feedback and Grievance Redress Mechanisms |
| **FICAC** | Fiji's Independent Commission Against Corruption |
| **FJD** | Fijian Dollar |
| **FPIC** | Free, Prior and Informed Consent |
| **GRM** | Grievance Redress Mechanism |
| **IAG** | Independent Assessment Group |
| **iTLTB (TLTB)** | iTaukei Land Trust Board |
| **iTLFC (TLFC)** | iTaukei Lands and Fisheries Commission |
| **LoU** | Landowning Unit |
| **MoF** | Ministry of Forest |
| **MoU** | Memorandum of Understanding |
| **NGO** | Nongovernmental Organization |
| **NRL** | Native Register of Land |
| **PBC** | Prescribed Body Corporate(s) |
| **POC** | Point of Contact |
| **Q&A** | Questions and Answers |
| **REDD+** | Reducing Emissions from Deforestation and Forest Degradation |
| **R+LO** | REDD+ Liaison Officer |
| **R-PP** | Fiji's Readiness Preparation Proposal |
| **RSC** | REDD+ Steering Committee |
| **SIS** | Safeguard Information System |
| **SMS** | Standard Messaging System |
| **TOR** | Task Order Request |
| **VKB** | *Vola ni Kawa Bula* (Native Land Register) |

# ATTACHMENT 2: PREVIOUS STUDY FINDINGS

## Gaps/Issues Identified in Related/Existing GRMs in Fiji

### KEY FINDINGS

- There currently exists a bifurcation between customary and legally supported GRMs, but there is a desire to utilize both systems by all interested parties in the resolution of conflicts.
- Traditional customary mediation processes at the village-level are currently the main channels of resolving grievances and/or disputes. Almost all issues arising out of any contestation regarding traditional boundaries and ownership issues can be solved at village level.
- There will need to be clearly mandated support and encouragement from the formal sector for the informal system to address conflicts prior to the use of ADR or formal intervention.
- Institutions should encourage dispute resolution at the informal-level as a first step because it facilitates faster resolution of issues and helps maintain peace at the village-levels, which may otherwise be strained if left to the perceived adversarial formal systems which are non-transparent, expensive, and can be divisive in the end.
- Existing GRMs are not comprehensive enough to support REDD+ programming at the informal or formal-level and semi-formal systems are not institutionalized. This will create inconsistency and accountability problems in the handling of grievances and in the management of processes and outcomes when dealing with enforcement.
- It is necessary to create a complementary route to the existing formal structure because of its weak institutional ranking. The proposed FGRM for REDD+ should be designed for intervention at semi-formal level of grievance redress, so as to build upon customary approaches and to compliment instead of replacing current legal/formal redress systems. The use of outside mediation support either by an NGO, Legal Association, or REDD+ Unit to help support communities throughout the design, leasing, and implementation process will create a more legitimate and accountable system that is trust-building and sustainable.
- Formal systems are based on current law and do not focus on preserving future relationship between disputants.
- Formal systems are slow and unpredictable in resolution processes. This has resulted in the creation of new tensions, loss of trust, and exacerbated conflict because of the lapse timeline and poor data management.
- The formal system is mostly inaccessible to forest users because they require a substantial amount of financial resources to file a case, hire a lawyer, travel to court, etc. There is also a legal literacy gap, poor understanding of complicated contracts, and a fear of going to court because of lack of knowledge and perceived bias.
- There is a gap in understanding how grievances are currently addressed by the formal sector. There must be a better communication, outreach, and awareness campaign employed in order

for iTaukei to understand their rights and the processes and procedures for how grievances will be addressed.[13]

- Decision-making on REDD+ grievances must include multiple stakeholders' perspectives and allow for the complaint to be well informed of the process. There is a need for an independent review board to provide auditory services.
- The FGRM should be designed to accommodate different communities/individuals at different levels appropriately.
- There should be a designated Grievance Officer(s) (or a clearly mandated responsibility) to handle REDD+ grievances and to ensure that the Secretariat and Steering Committee are aware of the grievances from the public and the necessary actions to improve them.

## WEAKNESSES AND CHALLENGES

- There are currently inadequate regulatory contexts to support REDD+ programming either through legislation directly for REDD+ or contextually through the Draft Forest Bill that address key issues such as the definition of carbon property rights and benefit sharing.
- Although there are GRMs in existence (at varying levels of development) under the several government agencies and institutions that currently deal with resources and land management issues, it would be proleptic to assume that existing mechanisms are "fit for purpose". As such, there is no current FGRM in place specifically capable of addressing the intended grievances and conflicts for REDD+. Given that REDD+ is a new product it will require substantial reworking of existing structures through institutional strengthening of matters concerning FPIC, substantiating of rights, and its proper understanding leading on to its valuation.
- There is disconnect between formal and informal sectors and this will create problems for enforcement.
- There is a gap in active distribution or information sharing between sectors and government on REDD+ issues.
- Inadequate funding, human resources, and equipment required for handling grievances within the public sector, resulting in poor monitoring and implementation.
- Lack in relevant skills and knowledge of how to handle and address grievances at the provincial and national-level (e.g., no specific rules written or they are in process, no training, low technical capacity).
- Convergences between jurisdictional mandates due to lack of clear legislation or regulatory guidance on grievance redress with REDD+.

[13] Although noted in previous sections that the focus of this assessment is on iTaukei as landowners, the same applies for non-iTaukei who mostly lease land or own freehold land. Their grievances are still yet to be addressed by the formal sector for example; expired land leases for those who lease land, and poor farm road conditions caused by logging trucks for those who own freehold land.

- Absence of a national land use plan has resulted in conflicts of jurisdiction between competing sectors within the same land area and over the same resources, which will inevitably also affect the implementation of REDD+ program and any proposed FGRM in the future.
- There is a concerning lack of awareness on REDD+ program, incentives, and rules by the communities involved.
- There are inadequate or absent dispute resolution clauses in leasing contracts.

# Lessons Learned and Recommendations

## AWARENESS AND CAPACITY

- Potential REDD+ sites (i.e., Serua) are aware of REDD+'s *existence* through an initial consultation by the REDD+ Unit, but there was no follow-up or clarity around objectives, rules, and policies and procedures. The low level of awareness is a serious concern for implementation and will be cause for missed expectations and understanding of the purpose of forest driven investment by communities. If REDD+ is implemented without boosting the awareness level of local users, there will be an overflow of awareness-related grievances that may express themselves through more sensitive issues of benefit sharing. Therefore, as explained previously, the design of the FGRM will allow wide enough accessibility for local users so they can have a channel of communication to talk and learn about REDD+.
- Poor understanding of ecosystem services by communities, which has resulted in several not being interested in participating in conservation/REDD+ programming. A possible solution is to educate communities during site selection and compare ecosystem services to their supermarket needs, showing the cost for loss of these services up front.
- Permit NGOs and CSOs, with relevant government departments, to conduct village awareness on REDD+ through workshops and training in conflict management in the Western, Northern, Central and Easter Divisions. Priority should be given to those villages that have potential REDD+ sites. The use of effective educational media, such as videos, in both vernacular languages and English is imperative.
- Fiji's REDD+ Program launched a website in which policies, procedures, strategies and related documents are available (although not current). In the present situation, remote local people, especially women, poor, and marginalized groups are unaware of the specifics of the program and lack access to this information. If the REDD+ program is implemented in the current state, it will suffer from lack of support of the local peoples/communities without better communication and outreach. Therefore, disclosure of the policies, procedures, and safeguard documents at local/community level are necessary for smooth implementation of the REDD+ program in the future. These aspects must be taken into consideration in the FGRM design by building it to the local level and opening possibilities for information transfer.
- Fiji has chosen to take a 'hybrid' model for REDD+ implementation, which includes payments flowing at the national, programmatic, and project-scale as specified in the

National REDD+ Policy (R-PP.). However, in practice there have been challenges with implementation and recognition of project-scale activities. For example, the Drawa site is still not being recognized (formally approved by the government, meaning that offsetting cannot be done until the government has endorsed the project), complicating future programming that is inconsistent with current policy.

- Participation is viewed differently with the national and project-based REDD+ activities. There is perceived preference for nationally managed programs that has manifested in a concern that project-based interventions are not being integrated into the current REDD+ scheme. Common questions posted by local participants in Drawa Block show a level of distrust towards the Government as a result. It is therefore imperative that the FGRM opens communication between local level users and creates possibilities for information sharing that leads to an improved understanding of the intentions of the Government that align with all (hybrid) REDD+ projects.
- The goals and functions of GRMs are unclear to the majority of stakeholders in REDD+. A few knowledgeable people on GRM functions (forest officers, certain NGOs and interest-based organizations like FELA) were also highly educated on REDD+. It will be important to provide a full explanation of the GRM design process and subsequent roles and responsibilities for beneficiaries, government entities, and supporting mediators in the design of the FGRM to steer REDD+ towards success.
- Public awareness of the presence of GRMs within the institution, its procedural process, timelines and options of other avenues, if required for further redress need to be instituted.
- According to FCPF/UNREDD guidelines the GRM should operate independently of all interested parties in order to guarantee fair, objective, and impartial treatment to each case. Making decisions by entities having a stake in the process is thus unacceptable (this includes also the government in some specific cases) so third party mediation is recommended.
- Need for trained GRM staff that can be responsible for handling and management of REDD+ related grievances, similar to TLTB and Land Bank Units. Additional staff to pursue completion complaints, training and awareness on internal procedures, and the development materials to raise awareness for grievances and redress.
- Local users do not understand REDD+'s performance-based system. Communities are concerned that they will be barred from gathering forest products. There is a concern about whether communities will be able to comply with a new trade system for generating alternative income.

## GOVERNANCE

- Boundary distinction is critical and needs to be part of any REDD+ process during readiness for site selection. Emalu still needs its boundary to be mapped out on the ground by physical markings as neighboring provinces are encroaching into the protected area. Various LoUs also noted this in Serua under the River Fiji Conservation Project where there is not proper demarcation of ownership, which causes boundary disputes and where Fiji Pine and Harwood surpassing agreed (surveyed) plantation areas.

- Without REDD+ legislation in place and adequate laws to support benefit-sharing, GRM enforcement will be difficult if not impossible and accountability non-existent.
- There is a need for a national land use plan because of issues with competing jurisdictions and management. Even if a site is marked as a conservation site, timber is still being logged, unlawfully. Different authorities also have different rules (what is "harvesting" according to the timber companies vs. the forestry officials) and overlaps in jurisdiction can lead to community disputes
- As part of REDD+ readiness in site planning, a community land use plan should be designed (with support from the REDD+ Unit, NGOs, relevant ministries and boards, etc.) to provide communities that are participating in REDD+ means to allow for multi-sector land use that aligns with REDD+ policies whilst promoting alternative livelihood options, allowing for agriculture and timber space as needed, and for human settlements (this was done in Drawa).
- Re-examine endangered species legislation, which protects native trees that are still being logged. Conservation efforts may foster greater buy-in by communities if there is greater awareness of protected species.
- Sustainable alternative livelihood sources to support the loss of land for purposes of agriculture or timber should be sought immediately for the landowners (e.g., *yaqona*. ecotourism, bee-keeping). This must be supported with technical expertise offered as part of the readiness process through engagement with NGOs that can assist in the development of proposals to secure funding and to provide implementation support for communities to become self sufficient.
- Benefit-sharing structures need to be supported through registered legal entities account set-up and management for disbursement of funds for access to all members of LoUs; having a system in place to check that funds are being accessed.
- Distribution needs to be equitable amongst the landowners where there are differences in the membership size of LoUs, acreage, and even forest density where timber stocking will have an impact. The conflicts will come once there is actual distribution of funds.
- Updated resource inventories are needed. For example, in Drawa 18,800 tons were evaluated 10 years ago for the Block's conservation site. It would be better to assess carbon every 5 years with the renegotiation of the lease and based on the "Project Monitoring Reports" that contain assertions of the quantified ecosystem services benefits delivered by the project during the relevant (3-yearly) monitoring period. This quantitative assertion is the basis for issuing payment for ecosystem service units (e.g. carbon offsets) to the project.
- Use of different forms of management will need to be assessed in order to secure the most appropriate for communities (e.g., cooperative or trust). The number of LoUs involved is also contributory to the multitudes of interest that needs to be negotiated through TLTB. Benefit sharing expectations will also be subjected to similar tensions.
- Forest users favor submitting grievances at the local-level. Whenever this system is insufficient, stakeholders should be able to propose an alternative locally operating grievance redress system in which all parties are represented. Stakeholders agree that the most

important reason for choosing a collaborative model is because REDD+ beneficiaries should maintain ownership of the decision and, as a result, it will be have greater chance of success.

## ACCOUNTABILITY

- Nothing is recorded at the community-level GRM. There is a need and desire for a written record to offer legitimacy to the process as well as a recording of grievance and response to encourage continued learning.
- Recognition of a hybrid system to cater for western and customary structures. A need for the formal system to respect the traditional in a far more legitimate way to give weight to the GRM. This can be done through encouragement by institutions to resolve issues at the informal-level in contracts and in support of the outcomes proffered.

## FPIC

- FPIC needs to be integrated and adjusted to reflect REDD+ parameters so communities are better informed on programming and expectations.
- Consultations with key stakeholders and beneficiaries revealed a positive perception about REDD+, once they had been more informed about the process and benefits of the program – predominantly provided by members of district networks, CSOs, and NGOs active involvement in REDD+ activities. However, potential sites revealed that very few of the community level forest users have received the opportunity to participate in a REDD+ yet, so there is an information gap that needs to be addressed.
- From stakeholder consultations, the study team collected a variety of perspectives on rights, policies, and procedures under REDD+ program, but it was consistently unclear where or how grievances need to be resolved for REDD+ or who responds to them. Currently, all grievances are handled through TLTB (formal) or through intermediaries of ADR (e.g. Live & Learn). This process needs to be specific and clear and resourced appropriately to respond to a variety of risks and for different forest users as appropriate.
- Perception and transparency about timeframes need to be explicit with communities made with FPIC. Communities need to be informed of the timeline for all phases or REDD+ with quarterly reports and disbursement of information. There must be an expectation set early on regarding when funds may actually be disbursed and the steps in the process that must be meet before.
- Communities need support in the negotiation of conservation lease terms, grievance redress for REDD+ because of technical competencies, and in understanding their rights. NGOs, CSOs, and Legal Association (FELA) can be tasked to support REDD+ in providing these services to the communities to help minimize misunderstandings and conflicts and to remove bias.
- Leases must be fit for purpose and allow for the incorporation of alternative dispute resolution in clauses.

- Terms of leases need to be consistent with how distribution is offered, expectations for management (government vs. landowners) of sites, and regulations for land use so that there is not perceived favoritism.

## ATTACHMENT 3: REPORTING FORMS

REDD+ FIJI

# INFORMAL DISPUTE RESOLUTION REPORT / *iTaukei*

This is a guide for iTaukei *Turaga ni Koro*, Village Headmen, transcribed by Village Councils, to use for recording any grievances at the local-level. Should a REDD+-related grievance be submitted to the FGRM then this will be collected if available. / *iTaukei*

| **Notes / *iTaukei*** |
|---|
| **Parties to the Dispute / *iTaukei*:**<br>1. **Initiator(s) / *iTaukei*** –<br><br>**Representatives / *iTaukei*** –<br><br>2. **Respondent(s) / *iTaukei*** –<br><br>**Representatives / *iTaukei*** – |
| **Details of Dispute / *iTaukei*:**<br>*[e.g. Approximate date that dispute started, what happened in chronological order / iTaukei]* |

| |
|---|
| **Resolution or Solution Proposed / *iTaukei*:** |
| **If resolved, provide details of resolution or solution / *iTaukei*:** |
| **If unresolved, provide next steps proposed / *iTaukei*:** |
| **Signature of Parties / *iTaukei*** |
| *Print Name(s) / iTaukei:* |
| *Signature(s) / iTaukei:* |
| *Date / iTaukei:* |
| **Witness to the Agreement (Signature of Roko or authorized representative) / *iTaukei*** |
| *Print Name / iTaukei:* |
| *Signature / iTaukei:* |
| *Date / iTaukei:* |

**Case Number:** 

# COMPLAINT REGISTRATION FORM / *iTaukei*

## Fiji REDD+ PROGRAM

This form is to be completed by the designated feedback grievance and redress mechanism (FGRM) representative – Forest Officer of REDD+ Liaison Officer. / *iTaukei*.

**Section 1:** Complainant please complete as much of the information as possible or leave blank if you wish to remain anonymous (the Officer may fill this in for the Complainant. / *iTaukei*)

| **Complainant's Contact Information / *iTaukei*** | **Landowning Unit Information / *iTaukei*** |
|---|---|
| **Name / *iTaukei*:** | **Clan / *Mataqali*:** |
| **Email / *iTaukei*:** | **Sub-Clan / *Tokatoka*:** |
| **Telephone Number / *iTaukei*:** | **Family / *Vuvale*:** |
| **Address / *iTaukei*:** | |
| **Representative / *iTaukei* *** | |
| **Submitted on Behalf of (Yes or No) / *iTaukei*:**<br>**If yes, then who is Representing the Complainant(s) / *iTaukei*:**<br><br>**If yes, is there Verification of Consent and Authorization of Evidence of Representative Capacity* (must present documentation) / *iTaukei*:** | |

** Consent must be proven – LoU membership must account for 60% in order for this to be acceptable.*

**Case Number:** 

**Section 2:** The following section must be completed by the uptake Officer. / *iTaukei*

| Officer Information / *iTaukei* | Dates / *iTaukei* |
|---|---|
| Ministry and/or Department / *iTaukei*: | |
| Name / *iTaukei*: | Date Grievance Received / *iTaukei*: |
| Position Title: | Date Grievance Review Conducted / *iTaukei*: |
| Telephone Number / *iTaukei*: | |
| Email / *iTaukei*: | |

**Section 3:** Officer, please complete the following section after speaking to the Complainant. / *iTaukei*

| | |
|---|---|
| REDD+ Site Location / *iTaukei* | |
| All Parties Involved / *iTaukei* | |

**Case Number:** 

**Section 4:** Officer, *complete this section only if the complaint was addressed in the customary system of redress.* / *iTaukei*

Please ask the complainant to provide any written documentation from the Village Council and attach to this form, if appropriate, and record the complainant's answers to the questions below. / *iTaukei*

| **Record of Grievance Process / *iTaukei*** |
|---|
| **Location of the grievance / *iTaukei*:** |
| **Date of the grievance / *iTaukei*:** |
| **What was the decision made and detail the steps taken towards resolution / *iTaukei*:** |
| **What assistance is now being requested / *iTaukei*:** |

**Case Number:** 

**Section 5:** Officer, please have the Complainant sign and date, unless they wish to remain anonymous*. / *iTaukei*

| **Signatures / *iTaukei*** | |
|---|---|
| **Complainant / *iTaukei*:** | **Uptake Officer / *iTaukei*:** |
| *Print Name / iTaukei:* | *Print Name / iTaukei:* |
| *Signature / iTaukei:* | *Signature / iTaukei:* |
| *Date / iTaukei:* | *Date / iTaukei:* |

**Officer, if the Complainant wishes to remain anonymous inform them that they will not receive communication of the progress of the complaint, unless they contact the recording Officer and ask for the case number (once it has been logged into the database).*

**Case Number:** 

**Section 6:** Officer, please check the applicable sections after speaking to the Complainant to determine if this is a REDD+-related grievance. Common examples have been provided below. / *iTaukei*.

| N° | Nature of the Complaint | *iTaukei* | REDD+ Related / *iTaukei*? |
|---|---|---|---|
| **Land Disputes for REDD+ Sites** | | | |
| **1** | Boundary description for REDD+ site is not clear and conflicts with oral evidence of community members or other LoU recorded boundaries | | |
| | Conflicting interest of (member) over engagement in land for REDD+ purposes | | |
| | Other? Please describe: | | |
| **Property Disputes** | | | |
| | Destruction of property (individual) or community asset | | |
| | Illegal logging in REDD+ site | | |
| | Other? Please describe: | | |
| **REDD+/ Conservation Lease Terms and Enforcement** | | | |
| | Lease terms for REDD+ site is not fit for purpose or is not being executed properly | | |
| | Land use plan was not put in place and or is not being followed as intended | | |
| | Disputing process of lease renewal without grant of member's consent (FPIC) | | |
| | Dispute related to (un)authorized activities allowed on customary land | | |
| | Other? Please describe: | | |
| **Environmental Impacts** | | | |
| | Activities from REDD+ are impacting the environment resulting in degradation and/or damage of surrounding areas. | | |

**Case Number:** 

| N° | Nature of the Complaint | *iTaukei* | REDD+ Related / *iTaukei*? |
|---|---|---|---|
| | Poor site maintenance of REDD+ site(s) | | |
| | Water, air, and land surface pollution | | |
| | Other? Please describe: | | |
| **Communication and Rights** | | | |
| | Disagreement by community and REDD+ on details of project implementation | | |
| | Information on REDD+ project activities and processes were/are not transparent | | |
| | Dispute regarding the extraction of forest products on REDD+ land (access to those resources and/or permissible use) | | |
| | Restriction of spaces to cultivate due to REDD+ project | | |
| | Lack of drinking water related to the project | | |
| | Other? Please describe: | | |
| **Benefit-sharing** | | | |
| | Unequal distribution of benefits | | |
| | Timeline for distribution and access to funds is not being followed | | |
| | Compensation issues | | |
| | Other? Please describe: | | |
| **Social Inclusion** | | | |
| | Isolated or not included in decision-making regarding REDD+ activities or site management | | |
| | Perceived discrimination or bias from REDD+ staff, government, or representatives | | |
| | Access and/or requests for information | | |
| | Other? Please describe: | | |

**Case Number:** [ ]

| Nº | Nature of the Complaint | *iTaukei* | REDD+ Related / *iTaukei*? |
|---|---|---|---|
| | | | |
| **REDD+ Institutions and Staff** | | | |
| | Inappropriate staff behavior on site | | |
| | Nonresponsive to previous grievances submitted | | |
| | Previous resolution not enforced or has proven inadequate to resolve conflict | | |
| | Other? Please describe: | | |

| |
|---|
| **If complaint does not fit into one of the categories above, but the complaint is likely REDD+ related please, briefly describe and then speak with the R+LO / *iTaukei*** |
| **If complaint is determined NOT to be REDD+ related please, briefly describe why / *iTaukei*** |

## ATTACHMENT 4: ACCOMPANYING INFORMATION

# GRIEVANCE PROCESS TIMELINE / *iTaukei*

## Fiji REDD+ PROGRAM

Officer, please include this timeline in-person or in the email or letter to the Complainant – walk through the timeline to ensure understanding and explain that this is an average, not a guaranteed estimate of time given for each step. Complainants cannot skip ahead in the process and it is important that they understand the process is progressive. / *iTaukei*

| **Step 1. Uptake / *iTaukei*** | **Timeframe / *iTaukei*** |
|---|---|
| **Point of Contact:** Officer that recorded the grievance / *iTaukei* | |
| • Forest Officer or R+LO receives grievance from Complainant / *iTaukei* | NA |
| • Forest Officer or R+LO records grievance / *iTaukei* | 1-3 working days |
| • Forest Officer or R+LO inputs grievance into centralized database and a case number is assigned / *iTaukei* | 1-2 working days |
| • A copy of the resolution report (hard and/or electronic) is sent to Complainant as confirmation of receipt / *iTaukei* | 1-2 working days |

| **Step 2. Evaluate / *iTaukei*** | **Timeframe / *iTaukei*** |
|---|---|
| **Point of Contact:** Officer you reported the grievance to and the R+LO / *iTaukei* | |
| • R+LO will review all documentation provided for the complaint / *iTaukei* | 1-2 working days |
| • If the information provided is sufficient the R+LO will screen the case, make a determination of eligibility under the FGRM, and communicate that decision to the Complainant / *iTaukei* | 1-2 working days |
| • If the information is **not** sufficient the R+LO will request that additional evidence be collected / *iTaukei* | 2-5 working days |
| • Once eligibility is determined a relevant authority will be assigned / *iTaukei* | 1 working day |

| Step 3. Respond / *iTaukei* | Timeframe / *iTaukei* |
|---|---|
| **Point of Contact:** R+LO / *iTaukei* | |
| • Selection of a proposed resolution approach by an Officer of the FGRM / *iTaukei* | 1-2 working days |
| • Formulation and delivery of proposed resolution approach to Complainant / *iTaukei* | 2-3 working days |

| Step 4. Implement / *iTaukei* | Timeframe / *iTaukei* |
|---|---|
| **Point of Contact:** R+LO / *iTaukei* | |
| • **IF** – R+LO convenes an Independent Assessment Group (IAG) to conduct further assessment work and evaluate the grievance / *iTaukei* | 8-10 working days |
| • **IF** – IAG is unsuccessful in their evaluation, the issue is considered too complex, or the Complainant seeks an appeal, the grievance is elevated to determination by a majority vote of the RSC – who may ask for additional assessment work or a new IAG / *iTaukei* | 5 working days |

| Step 5. Close / *iTaukei* | Timeframe / *iTaukei* |
|---|---|
| **Point of Contact:** R+LO / *iTaukei* | |
| • Complainant may receive survey or other follow-up to support monitoring and closeout / *iTaukei* | • NA |

# ATTACHMENT 5: FGRM IAG SELECTION AND SCOPE OF WORK

## EDUCATION

- **Minimum** of an undergraduate degree in environmental economics, resource management, forestry, climate change, sociology, agriculture, law, human rights, agriculture, gender, or related major
- **Preferred** certification in conflict resolution

## EXPERIENCE AND SKILLS

- **Minimum:**
  - Five (5) years experience in strategic planning, program development, monitoring and evaluation, economic development, and/or cross-cultural communications
  - Conflict resolution, facilitation, or mediation experience
  - Community consultation and stakeholder engagement expertise in Fiji
  - Sufficient knowledge of REDD+ policies, procedures, and regulations
  - Excellent written and oral communication skills
  - Gender sensitized and aware of gender issues in Fiji land use management
  - Adequate knowledge of diverse culture in Fiji especially of the iTaukei
- **Preferred:**
  - Conflict resolution experience on natural resource activity
  - Understanding of GRMs in Fiji and common processes for grievance redress
  - Understanding of customary ownership issues
  - Demonstrates integrity and accountability in conduct of duties

## CONFLICT OF INTEREST

- **Required:**
  - Must be able to sign a *Non-disclosure Agreement* and *No Conflict Statement*
  - Pass a reference check

## EVALUATION AND SELECTION PROCESS

The evaluation of each candidate will be determined on the above criteria and weighted based on the submission of supporting documentation. Total scores will be used to rank each candidate and a passing score of 75% is needed to be included on the rooster for the Independent Assessment Group (IAG). The breakdown for scoring is: Education 25%, Experience and Skills 65%, and Conflict of Interest 10%. The selection of each applicant will be based on a set of selection criteria related to the specific issues in the case and in consultation with the registered Complainant.

# ATTACHMENT 6: FGRM STAFF QUALIFICATION

Recommended capacities for new FGRM Unit Team Members and additional capacities for existing officers that will support and be involved in the FGRM.

## NEW FGRM UNIT STAFF

### Grievance Director

*Level of Effort:* 100%

*Reports to:* REDD+ Secretariat

*Minimum Requirements*:

- degree in social science, forestry, agriculture, environment, and/or resource law
- experienced manager with proven capacity building expertise
- strong leadership and organizational skills
- highly developed communication skills and writing
- five (5) years of conflict resolution experience
- experience with developing policies and procedures
- monitoring and reporting experience
- negotiator that is respected by other institutions, but must not have worked for TLTB or TLFC (to avoid due bias or influence)

*Preferred Requirements*:

- advanced degree in social science, forestry and/or resource law
- conflict resolution certification
- awareness of the context of REDD+
- understanding of gender mainstreaming effort in land use in Fiji
- experience in Boardroom process and running review of Boards

### REDD+ Liaison Officer (R+LO)

*Level of Effort:* 100%

*Reports to:* Grievance Director

*Minimum Requirements*:

- degree in social science, law, forestry, agriculture, environment, resource management
- experienced manager with proven capacity building expertise

- strong leadership and organizational skills
- strong analytical and communication skills and writing
- experience in conflict resolution, including mediation and facilitation
- monitoring and evaluating experience

*Preferred Requirements:*

- understanding and awareness of the context of REDD+
- ability to maintain and manage a database

## EXISTING FGRM SUPPORT STAFF, EXPANDED RESPONSIBILITIES

### Forest Officer

*Level of Effort:* 15%

*REDD+ Coordination POC:* R+LO

*Minimum Requirements*:

- degree in forestry and/or related major
- sound REDD+ knowledge
- strong organizational and reporting skills
- effective communication skills

*Additional Skill Requirements*:

- obtain training certificate on mediation and conflict resolution
- learn database and basic computer skills

### REDD+ Project Coordinators

*Level of Effort:* 10%

*REDD+ Coordination POC:* R+LO

*Minimum Requirements*:

- sound REDD+ knowledge
- strong organizational and reporting skills
- effective communication skills

*Additional Skill Requirements*:

- obtain training certificate on mediation and conflict resolution
- monitoring and tracking for FGRM operational and process issues in communities

**Roko Tui**

*Level of Effort:* 5%

*REDD+ Coordination POC:* R+LO and Grievance Director

*Minimum Requirements*:

- sound REDD+ knowledge
- strong organizational and reporting skills
- effective communication skills

*Additional Skill Requirements*:

- obtain training certificate on mediation and conflict resolution

**MINISTRY OF FORESTRY**

**HEADQUARTERS**
Takayawa Building, Toorak Road, Suva
P. O. BOX 2218, Government Buildings
Suva, FIJI

Phone: (679) 3301611
Email: tfong@govnet.gov.fj

**Ref: FO/A/2/5-4** **Date: 08.05.2020**

The Chairperson
Facility Management Team
Forest Carbon Partnership Facility
World Bank
Washington DC
United States of America

Dear Sir,

**RE: NAKAUVADRA COMMUNITY BASED REFORESTATION PROJECT**

This is to certify that the Fiji Government is aware that the above project has been certified at Gold Level under CCB vide Certificate # SCS-GHG-000027 to comply with international best practices aiming to fulfil the donors Corporate Social Responsibility in the vicinity of their business interest in Fiji. It is clarified that the project is not a REDD+ Emission Reductions project and that it will not issue emission reductions in the future.

Therefore, the project will not be part of the national REDD+ accounting and reporting.

Sincerely,

PERMANENT SECRETARY FOR FORESTRY
FIJI

G. P. N. Baleinabuli
**Permanent Secretary**

*Statement of CCB Standards Compliance*

# Nakauvadra Community Based Reforestation Project

## Validation Scope:

The SCS Greenhouse Gas Verification Program has conducted a validation audit of the "Nakauvadra Community Based Reforestation Project", for which Conservation International is the project proponent, against the requirements of the Climate Community Biodiversity Alliance (CCBA) Project Design Standards, Version 2.0 (December 2008). SCS conducted both desk and field based assessment activities in its evaluation of the project. SCS used the client-supplied project documentation as the basis for its evaluation.

## Validation Opinion:

Based on the results of our validation activities, it is our opinion that the project meets the quality standard defined by CCBA. The "Nakauvadra Community Based Reforestation Project" conforms to the 14 Required CCB Criteria. The project also conforms to the optional Excpetional Biodiversity Benefits CCB Criteria, qualifying the project for Gold Level.

Certificate # SCS-GHG-000027
Date: October 9, 2013
Expiration Date: October 8, 2018
Project Location: Nakuavadra Range, Fiji

Christie Pollet-Young, GHG Program Manager
SCS Global Services

Robert J. Hrubes, Ph.D., Executive Vice President
SCS Global Services

SCS global SERVICES
Setting the standard for sustainability™

2000 Powell Street, Ste. 600, Emeryville, CA 94608 USA
+1.510.452.8000 main | +1.510.452.8001 fax
www.SCSglobalServices.com