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 – 02.2019)

National Forest Inventory Field Test (Deliverable 5) and Collection of emission factor / field data to test all practical elements of the system (Deliverable 7)

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Dissemination level

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Summary

- Fiji is in need of a National Forest Monitoring System (NFMS) that, among others, enables to assess the status and change of the national forest resource. As of today, no national forest monitoring program has been implemented that provides the necessary data on carbon stocks and carbon stock changes for REDD+ Measurement, Reporting and Verification (MRV).

- Three National Forest Inventories (NFIs) have been conducted in Fiji so far. None of the NFIs were optimized towards the assessment of forest carbon. Carbon in pools other than above-ground biomass (e.g., deadwood or litter) cannot be estimated from the data collected.

- A Permanent Sample Plot (PSP) program has been established in 2010. The PSP program suffers from several methodological short-comings. Currently, the data from the PSP program cannot be used to estimate average carbon stocks in Fijian forests, and, hence, the program is not able to provide the necessary data and information for REDD+ Measurement, Reporting and Verification (MRV).

- Several suggestions are made how data collection procedures for the PSP program may be improved and extended. Extensions include amendments that are suggested for the PSP program to enable the assessment of deadwood, litter, understorey biomass and disturbances.

- The suggested data collection procedures and amendments have been tested in field. The test included new techniques of data capture and transfer. For data capture and transfer, the Open Data Kit (ODK) application was used.

- PSP measurement procedures and the amendments have been tested on four PSP plots in October 2017.

Acronyms

DBH   Diameter at breast height

GHGI   Greenhouse gas inventory

MSD   Management Service Division

MRV   Measurement, Reporting and Verification

NFI   National Forest Inventory

NFMS   National Forest Monitoring System

ODK   Open Data Kit

PSP   Permanent Sample Plot (program)

QA/QC   Quality Assurance / Quality Control

UHH   University of Hamburg

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1   Introduction

Fiji is in need of a National Forest Monitoring System (NFMS) that, among others, enables to assess the status and change of the national forest resource. For national REDD+ Measurement, Reporting and Verification (MRV) and greenhouse gas inventories (GHGIs) it is of particular importance that data and information on forest carbon stocks and carbon stock changes in Natural Forest and Forest Plantations are/is available. These data may, for example, be used to derive emission factors which are used as input for the estimation of emissions from e.g., deforestation. National Forest Inventories (NFIs) are often the primary source of this type of data. However, as of today, no NFI has been fully implemented in Fiji that is able to provide the necessary data and information (i.e., data and information on forest carbon stocks) in sufficient detail.

So far, three NFIs were conducted in Fiji, the first in 1969, another in 1991 and for the last time in 2006. All three NFIs focused on the availability of commercial timber in Fiji's Natural Forest. The NFIs have been designed as one-time resource inventories, i.e., they were not implemented to monitor the forest resource over successive occasions. For REDD+ MRV and GHGI, none of the previous NFIs were optimized towards the estimation of forest carbon stocks. However, even if the assessment of forest carbon has not been the focus, the data collected may still be used to produce estimates of forest above-ground carbon stocks. Data from the last NFI 2006, for example, have been used to derive emissions factors for deforestation for Fiji's Forest Reference Level (FRL) 2006-2016. As the NFI 2006 focused on timber availability, it was, however, not possible to estimate carbon stored in pools other than above- and below-ground biomass (e.g., carbon stored in litter or deadwood). For the future another NFI is suggestion in Fiji which will be a continuous forest inventory (i.e., measurements at successive occasions to enable monitoring), instead of a one-time resource inventory. More information on the future NFI can be found in the "National Forest Monitoring System (NFMS)" document that has been recently submitted to the Ministry of Forestry (MoF) by the University of Hamburg (UHH).

In addition to the three NFIs conducted so far, a Permanent Sample Plot (PSP) program was initiated in 2010. The primary purpose of the program was to derive estimate of annual allowable cuts in Fiji's forests but not to estimate forest carbon. The initial aim of the PSP program was (and still is) to support the sustainable management of Natural Forests in Fiji. In total 84 PSP plots were established in the forest. Plots have been remeasured in 2012, 2014, 2016 and lastly in 2018. Currently, Fiji plans to use the data collected during the PSP program for REDD+ monitoring. However, the PSP program – as it is currently implemented and maintained – will be able to fulfill this goal if not substantial changes are not made to the program.

The primary aim of the document at hand is to provide guidance for the planning phase of an NFI that will be implemented in the near future. Therefore, we first provide a critical review of past and ongoing assessments (NFI 2006 and the PSP program). Several short-comings were identified for the previous assessments. They are described in detail to ensure that they will be avoided in a future NFI.

There is strong will in Fiji to maintain the PSP program, because financial resources are secured for the years to come. Moreover, it is intended that the PSP program will be integrated into a future NFI (see NFMS document). In this document, PSP data collection procedures are described in detail. Improvements to current measurement procedures are listed and described. Moreover, amendments (e.g., litter, deadwood, understorey biomass and the assessments of disturbances) are suggested in order to enable the assessment of carbon pools other than above-ground biomass. Measurement procedures, including the amendments, have been tested in the field. The test also included state-of-the-art techniques for electronic data capture, transfer and storage. The Open Data Kit (ODK), available on portable electronic devices, was used which transfers data collected on the PSP plots to the NFMS database established at the Ministry of Forestry via the world wide web.

The consultancy team (UHH) faced several challenges during the review of past and ongoing assessments. In general, documentation is very poor. For the PSP program, for example, UHH did not get access to any written documentation of what was planned for the program and how the program was implemented. We faced similar problems regarding the NFI 2006. A Standard Operating Procedure document exists, but it falls short in describing what was done in the necessary detail. For the NFI 2006 and the PSP program, UHH relied on evaluating the data collected, field visits and, most importantly, on personal communication with people that were/are actively engaged in NFI and PSP data collection. However, most of the staff responsible for the development of the assessments were not available. Because of the unavailability of the documents related to NFI and PSP, a systematic assessment of the program was not be possible. Information so far found were sporadic. The documentation should include all steps of the assessment – from the planning phase to the final dissemination of results.

2 A review of the NFI 2006 and Fiji's Permanent Sample Plot (PSP) program

This section provides a detailed review of the NFI 2006 and PSP program methodology. As mentioned above, the evaluation of the methodology is largely based on preliminary data analysis, field visits and personal communication with people involved in the assessments. The review of the methodologies is structure around the following components (many more components may be considered; only the most important ones are listed below):

- Main objective(s) of the assessment:
  - o Relevant questions: why was the assessment initiated and implemented? What information should the assessment deliver (and to whom)?
- Population of interest:
  - o Relevant questions: for which object/subject should the information be produced? The entire land-mass, forested areas or a particular forest type? How are the borders of the population defined (and by whom)?
- Sampling design:

- o Relevant questions: how to distribute sample points/plots before data collection starts? Simple random sampling, systematic sampling, or stratified sampling? Or a combination? How many sample points/plots?
- Response (plot) design:
  - o Relevant questions: how to locate sample points in the field? What is the design of the sample plots? Nested cluster plots or a single plot? Circles or squares? How is the design linked to the objective of the assessment? Should plots/trees be permanently marked? What should be recorded on the plot and the trees?
- Analysis design:
  - o Relevant questions: how are the data analyzed (and by whom)? Which estimators will be used? Which software? How will the results be presented?

The following additional components may be considered:

- Documentation (who is responsible? How can the documentation be accessed?)
- Data capture, transfer and maintenance (how are the data captured? How are the data transferred to the database? Who is maintaining the database?)
- Dissemination of results (how are the results made available and to whom?)

2.1 Objectives

- Fiji's National Forest Inventory 2006
  - o The main objective of the NFI 2006 was to estimate the availability of commercial timber in Fiji's Natural Forest. This primary objective is reflected in what tree attributes have been recorded during the NFI 2006. For example, commercial tree height was measured on trees, but not total tree height. However, the data can be used to estimate average carbon stocks in Natural Forest[1], but the NFI was not designed to serve this goal. It is expected that the objective of a future NFI will also include the estimation of carbon stocks. This requires that more plot and tree attributes will be recorded in the future.
- Fiji's Permanent Sample Plot program
  - o The main objective of Fiji's PSP program was to obtain data to estimate annual allowable cuts in Fijian forests to support the implementation of sustainable forest management. The data is to be used as input in forest growth models. The PSP program is managed by Management Service Division (MSD) of the Ministry of Forestry. The objectives of the PSP program have been extended recently. Now, the PSP program should also provide data that can be used to estimate carbon stocks and emission factors in Fiji's Natural Forest. That is, the PSP program is intended to quantify the forest resource and serve as an important source of information for

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[1] More information on how carbon stocks were estimated from the NFI 2006 data can be found in the document "Fiji's Forest reference Level" submitted by UHH within this consultancy.

2.2   Population of interest

- Fiji's National Forest Inventory 2006
  - The population of interest for the NFI 2006 was defined by a forest cover map that was constructed using satellite imagery acquired in 2000/2001 (Landsat). The map covers Fiji's seven largest islands. The outer islands are not included. The forest cover map depicted two forest classes: closed forest and open forest. Both classes together defined the population of interest. The plantation lease area of Fiji Pine Limited and Fiji Hardwood Corporation Limited, as well as mangrove were not included.

    Use of a forest cover map to define the population of interest is a justifiable approach for a one-time forest resource assessment like the NFI 2006. However, the approach is not useful if measurements are to be taken at successive occasions, e.g., the same sample plots are revisited in a continuous forest inventory. The forest area in a country like Fiji changes over time. If the same definition of the population is used in later assessments (i.e., same plots), there may be a miss-match of what has been forest in the past and what is forest today. That is, in future assessments the original population of interest (based on the forest cover map) may not represent the population about which information is desired at later stages. In most countries that operate NFIs since many years (e.g., Norway, Germany, or the United States of America), it's usually not the forest area that defines the population, but the entire land-mass.

- Fiji's Permanent Sample Plot program
  - The population of interest for the PSP program has not been properly defined. The population of interest can only be guessed from where sample plots have been placed (see sampling design below). The systematic sample grid of the PSP program covers all of the three largest islands Viti Levu, Vanua Levu and Taveuni. It is, therefore, likely that the entire land mass of these three islands define the population of interest.

2.3   Sampling design

- Fiji's Forest Inventory 2006
  - Stratified simple random sampling was used for the NFI 2006. The mapped classes closed and open forest served as strata. Simple random sampling is very uncommon for NFIs. Usually systematic sampling is applied in forest assessments. Moreover, it is not entirely clear how sample points have been selected. A test of complete spatial randomness of NFI 2006 sample points (Ripley's K-function) revealed that sample points are not randomly distributed. One suspicious sentence can be found in the NFI Standard Operating Procedure. It says: "[o]nce the areas on the map being

stratified by forest types, plots are then distributed to each stratified areas and the plots to be measured will be randomly picked from all sets of plots". It seems that the final NFI 2006 plots have been selected from some larger set of plots. No information is available how the large set was selected and how a subset was selected from the large set of sample points.

For the NFI 2006, trees on in total 1023 plots were recorded. There is no single plot in the NFI dataset that does not have trees. This is again suspicious, as one would expect, that at least some plots are not located in forest (the forest cover map was certainly not free of errors). Either "empty" plots were removed from the NFI dataset, or plots were shifted from non-forest to forest. In both cases the sample design is flawed (e.g., sampling weights become unknown and a standard statistical analysis cannot be performed) and cannot be considered statistically sound.

For a future NFI a systematic sample grid covering the land mass of the entire country is recommended (i.e., not only in forest). The NFI sample grid may be aligned to the PSP sample grid (see NFMS document for more information).

- Fiji's Permanent Sample Plot program
  - For the PSP program a systematic grid that covers the three islands Viti Levu, Vanua Levu and Taveuni was used (see Figure 1). The grid spacing (i.e., the shortest distance between two neighboring plots) is 12km in Viti Levu and 13km on Vanua Levu and Taveuni. This poses challenges for data analysis, because the sampling weights (i.e., how much area is represented by one plot) will be different between the islands.

    Systematic sampling covering the entire land mass is very uncommon for PSP programs. Usually stratified sampling within forest areas is used – often with many strata. PSP plots are usually visibly marked to prevent that the plot is disturbed by e.g., cutting trees. Moreover, it is usually not the aim of a PSP program to quantify the resource (e.g., obtaining an estimate of the average carbon stock per hectare). The primary purpose of most PSP programs is to provide input for growth models or to monitor long-term ecosystem dynamics. The strata for PSP programs typically cover only those forest types for which an estimate of the annual allowable cut is desired.

    For the PSP program it was planned to establish in total 100 plots. However, only 84 were established in the field in 2010. The remaining 16 plots were not in forest. There might be some plots that were not located in forest in 2010 but in e.g., 2016. However, these plots have not been added.

    During field visits field crew members reported that some plots have been shifted from non-forest to forest (i.e., no plot was established at the original location). This practice was applied when the original coordinates (i.e., the coordinates of the original sample grid) were in non-forest, but a forest patch could be found nearby. The plot was than shifted to the nearby forest patch. Which plots have been shifted is not known (no information can be found in the PSP dataset). The procedure of

shifting plots has far reaching consequences for the data analysis and for what the PSP plots can be used. When plots are shifted the population to which they refer becomes unknown (i.e., it does not match the initial population, that is, the and-mass of Fiji). Inclusion probabilities of plots, and, hence, sampling weights, become unknown, too. In consequence, statements can only be made about the plots, but not for the population they should represent.

For future assessments it is extremely important that once the population is defined and a random sample has been selected, plots are not shifted or dropped from the dataset. If this strict rule is not followed, the implemented sample design is not statistically sound anymore, and standard statistical analysis procedures cannot be used.
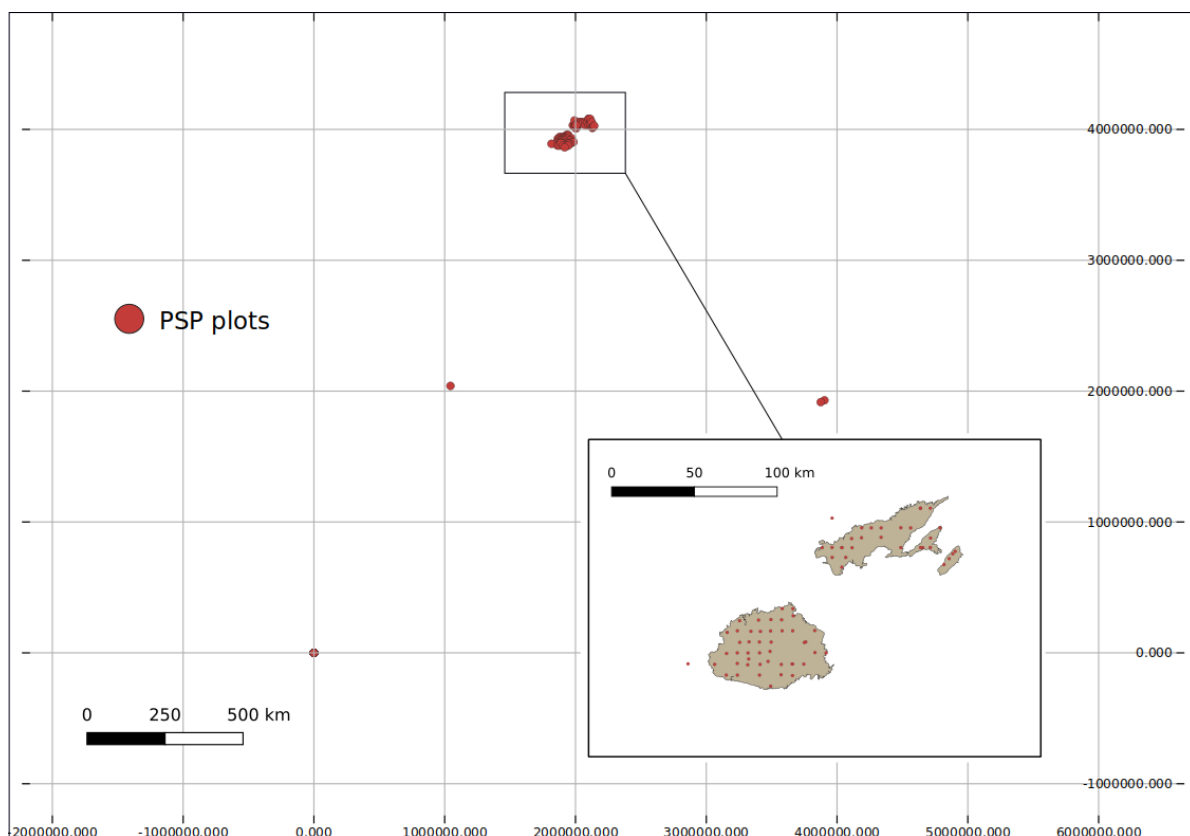
Figure 1 PSP plot locations (coordinates were taken from the PSP dataset). Several plots are not located on land and many plots do not align with the grid. Coordinate Reference System: Fiji Map Grid 1986. Axis in meters.

2.4   Response design

- Fiji's National Forest Inventory 2006
  - o Nested cluster plots with five circular sub-plots were used for the NFI 2006 (see Figure 2). Cluster plots are very common in NFIs and have the advantage that they are able to reduce the negative effect of spatial auto-correlation on estimates of

precision. However, the distance between adjacent cluster sub-plots is rather small in the NFI 2006 plot design (40m). For future assessments it is recommended to increase the distance between sub-plots and probably drop the center cluster sub-plot (see NFMS document).

On the sub-plots it is important to account for slope (i.e., slope correction). These techniques have probably not been applied during the NFI 2006.

NFI 2006 plots have not been marked and, hence, they cannot be relocated. It is common for NFIs (and obligatory for continuous forest inventories) to permanently mark plots. However, this should be done in a way that these plots can only be relocated by field crew members to avoid potential treatment bias on visibly marked plots.
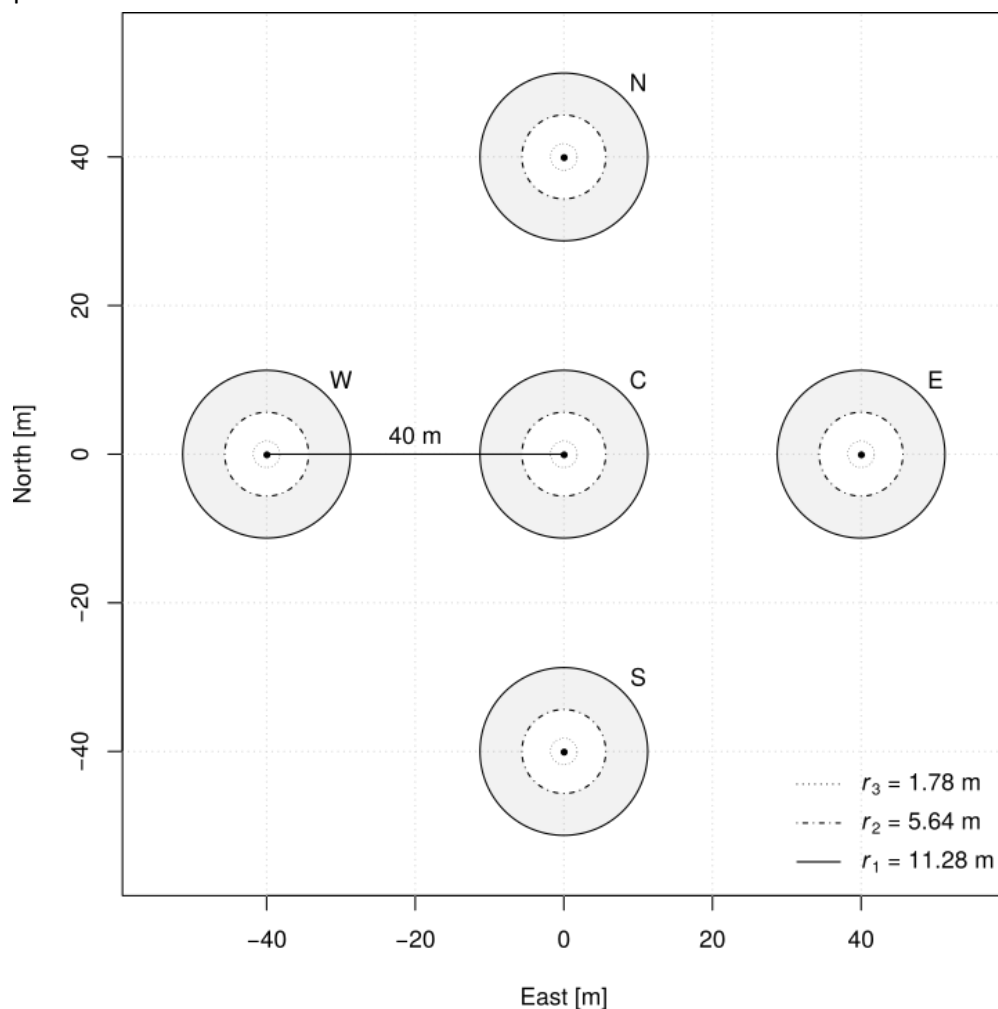

Figure 2 Design of a cluster plot of the National Forest Inventory (NFI) 2006.

- Fiji's Permanent Sample Plot Program
  - The PSP sample plot consists of a large 50x50m plot. At the northern and southern corner of the 50x50m PSP plot, 20x20m sub-plots were established (see Figure 3 and Figure 4). At the northern tip of the southern 20x20m sub-plot and at the southern

tip of the northern 20x20m subplot, circles of 3m radius have been installed. On the large plot attributes on all trees >=25cm DBH were recorded, on the two 20x20m sub-plots attributes were recorded on trees >=10cm to <25cm DBH. On the circular sub-plots attributes on trees were recorded that had >=3cm and <1cm DBH.

The plot design of the PSP plots may be considered useful for the primary purpose of the program (i.e., the development of forest growth models). However, to quantify the forest resource the PSP plot design is less useful. While for resource inventories the goal is to capture as much of the local variability as possible (therefore cluster plots are often used), for PSP plots the goal is the opposite. PSP plots should be sufficiently large but as homogeneous as possible. This is an important prerequisite for forest growth models. Hence, there is no one-size-fits-all plot design for resource inventories and PSP plots.

PSP plots and trees have been permanently marked with colored paint. This is generally recommended for PSP plots to ensure that they are not disturbed by humans. However, for resource inventories and continuous forest inventories this is not good practice because plots may be treated differently from the surrounding forest (i.e., treatment bias). If the goal is to quantify the resource and changes of the resource, plots should be treated as any other forest area. Hence, plots should not be visibly marked.

At the first PSP assessment in 2010 each tree received a number which was painted on the tree. Large trees, for example, got a yellow number. Trees in 20x20m sub-plots received a red number. If a tree exceeded the threshold diameter of the 20x20m subplot (i.e., reached 25cm DBH) in a subsequent assessment (e.g., 2014), it received a new yellow number (the old red number was removed). This is unfortunate since it becomes impossible to trace individual trees over time, because the same tree may have different numbers over time. Growth modelling could, therefore, only be performed on an area basis (e.g., per hectare), but not at the tree level (e.g., diameter increment of individual trees).

Unfortunately, the original PSP plot design has been occasionally changed during data collection. If no, or only few trees were found in the northern and southern 20x20m sub-plots, the sub-plots were shifted towards an east-west orientation. In consequence area-based attributes (e.g., biomass per hectare) cannot be estimated, because all estimates will be upward "biased". Shifting the sub-plots back to the original orientation may be problematic, if they got already disturbed.

In Section 4.3 additional attributes to be recorded on the PSP plots are suggested to cover other forest carbon pools. It would also be very beneficial if stem coordinates of trees are recorded (e.g., by recording the azimuth and the distance to a reference point).

Regarding the response design, the PSP data collected is of rather little use mostly because:

- Plots have been shifted from non-forest to forest.

- ▪ Sub-plots have been occasionally shifted from north-south to east-west direction.
        - ▪ Individual trees cannot be traced over time.
    - o To improve the PSP program, it is recommended to shift plots back to their original location, to establish sub-plots at the correct location and to develop a new tree numbering system that allows to trace trees over time.
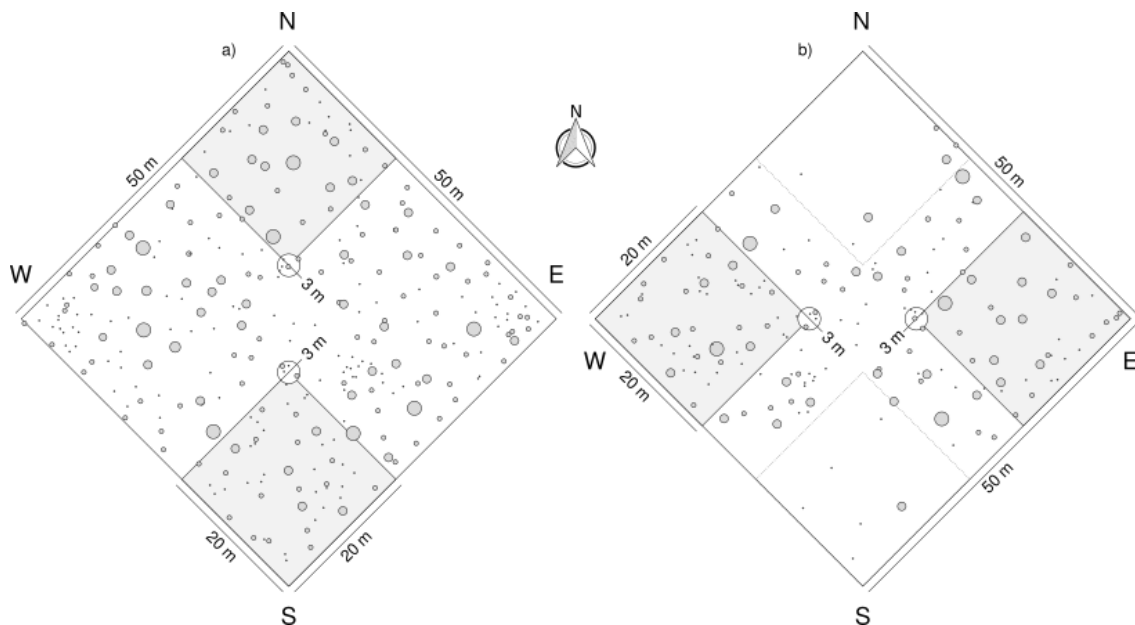

Figure 3 Correct implementation of the PSP plot design (20x20m in north-south orientation; left) and wrong implementation (right).

2.5   Analysis design

- Fiji's National Forest Inventory 2006
    - o To the best of the consultancy team's knowledge there exists no detailed report on the NFI 2006 results (if it exists it was not made available to the consultancy team). The SOPs that was developed before the NFI was implemented do not mention how the NFI 2006 data should be analyzed. This is surprising since the sampling and response design should go hand in hand with the analysis design. The FRL document submitted to the Ministry of Forestry provides one chapter on the analysis of the NFI 2006 data. The R code that was used for the data analysis is also available at the Ministry.
- Fiji's Permanent Sample Plot program
    - o What holds true for the NFI 2006 also holds true for the PSP program. Thus far, no comprehensive analysis of the data collected for the PSP program has been conducted. Given the various short-comings of the PSP data collection procedures, little useful information can be derived from the data. Preliminary data analysis of the PSP data also revealed several errors (e.g., impossible tree heights, misspellings

of species names, erroneous PSP plot coordinates, etc.). In order to make the PSP data more usable, intensive data cleansing is required.

2.6   Data management and documentation

- Fiji's National Forest Inventory 2006
    - o The data from the NFI 2006 is available in a Microsoft Access database (Microsoft Excel files have been extracted from the database). Recently all data have been transferred to the NFMS database (PostgreSQL) at the Ministry of Forestry which is accessible via the world wide web.

- Fiji's Permanent Sample Plot Program
    - o The PSP data are also available in a Microsoft Access database and have also been transferred to the NFMS database. INTEND GmbH, a sub-consultant of UHH, has developed the NFMS database design and also implemented a flexible system that allows to collect data on the PSP plots using handhelds (tablets with Android installed). The electronic data from the handhelds can be transferred to the NFMS data base via the world wide web.

    The Open Data Kit (ODK) software was used to enable direct data collection and transfer. ODK forms were developed in close cooperation with field crew members and staff from MSD. Intensive training was conducted by INTEND on the usage of ODK. ODK forms are defined in Microsoft Excel sheets (see the MS Excel file "fiji-mrv-psp-final_version.xlsx"). One advantage of the predefined ODK forms is that errors in data collection are reduced since for categorical variables (e.g., tree species, PSP plot number or slope facing) the user has to select the attribute from a predefined set of values. In addition, automatic data checks during data entry are performed (e.g., the maximum height of trees is restricted such that a entered height of e.g., 150m will cause an error). Finally, errors during data transfer are reduced. The use of ODK available on Tablets was tested on four PSP plots.

3   Lessons learned from NFI 2006 and PSP

- Past assessments have not been properly documented. It was a great challenge to UHH to evaluate the assessments without having access to the documentation. This had far reaching consequences for the test inventory. Because of the limited time available for the test inventory, ODK forms had to be developed before the PSP methodology (and its implementation in the field) could be fully evaluated - and before all short-comings were identified.

- For future assessments it is recommended to clearly assign responsibilities for documentation. The documentation should not only describe what should be done, but also what was actually done. For a future NFI each step, from the planning phase to the final dissemination of results, should be documented appropriately.

- The designs of the NFI 2006 and PSP program have several limitations. However, probably more importantly, the initial designs have not been properly implemented. For a future NFI it will be important to develop a well-designed quality assurance quality control (QA/QC) system to ensure that the design is implemented and maintained as intended. QA/QC strategies should also be developed to ensure high quality of data collected (see NFMS document for more details).
- The PSP data collected up until now is of little use. Currently the PSP program is neither able to fulfill its primary purpose (obtaining an estimate of annual allowable cuts), nor does it provide useful data for REDD+ MRV. The system has to be revised as suggested in order to make it successful.
- The data collected during the PSP program is of little use for the planning phase of a future NFI. For example, it is not possible to reliably estimate the required number of plots (for a specified level of precision) from the PSP data.

The different components of an assessment (e.g., sampling design, response design and analysis design) have to go hand in hand. For example, if a complex (non-standard) sampling design is developed, the estimators (i.e., formulas) that are to be used for analysis should be clearly identified and described before the sampling design is implemented. It is a poor practice to implement a design without knowing how to analyse the data.

4   Inventory field test

4.1   Goal of the inventory field test

As mentioned above, the PSP data can not be used to estimate average carbon stocks and carbon stock changes in Natural Forest. Therefore, it is still not possible to obtain estimates of emission factors from the data obtained from the program. If the PSP methodology would have been implemented correctly, the required estimates could have been computed.

The test inventory focused on (a) improvements regarding the measurement of attributes currently recorded on PSPs and (b) amendments to PSPs (i.e., lying deadwood and tree stumps, litter, understorey biomass and disturbance classes). The amendments are suggested to assess carbon stored in forest biomass pools other than above- and below-ground biomass. For the test inventory, no new plots were established. Instead existing PSP program plots were revisited and existing measurement procedures as well as amendments were tested in the field. The decision to not establish new plots (for the test inventory) was taken in close collaboration with staff from the Fiji REDD+ Unit and the Management Service Division (MSD) of the Ministry of Forestry.

- As described in the "National Forest Monitoring System (NFMS)", a future National Forest Inventory (NFI) will go hand in hand with the already implemented PSP program (e.g., PSP plot data will supplement NFI data). The design of the NFI has not yet been finally

developed. The NFMS document provides suggestions how NFI and the PSP program may be combined conceptually.

- There is a strong will in Fiji to continue the PSP program, because financial resources are secured for the years to come. It was decided by the Fiji REDD+ Unit, MSD and UHH to focus on improvements of the PSP program such that the data collected will provide a valuable source for future forest carbon monitoring. The locations of the PSP plots are already fixed. The amendments suggested for the PSP plots may be integrated into a future NFI.

The goal of the test inventory was to evaluate PSP data collection procedures, taking into account those attributes that are currently recorded on PSP plots. Moreover, during the test inventory possibilities for electronic data capture (using the open source Open Data Kit [ODK]) were implemented and evaluated. In addition, amendments to the data collected on PSP plots were tested. This included a test of performing the measurements in the field as well as capturing the data using ODK. The following amendments were tested:

Collection of data on

- Litter
- Deadwood (lying and stumps)
- Understorey biomass
- Assessment of plot disturbances

All measurements were tested on four PSP plots. The data collected were captured using ODK. In the preceding sections it was mentioned several times that the data from the PSP program can currently not be used to derive emission factors for REDD+ MRV. However, the test of the implementation of the amendments still provides useful information, as these amendments can easily be integrated into a future NFI irrespective of the short-comings of the PSP design and implementation.
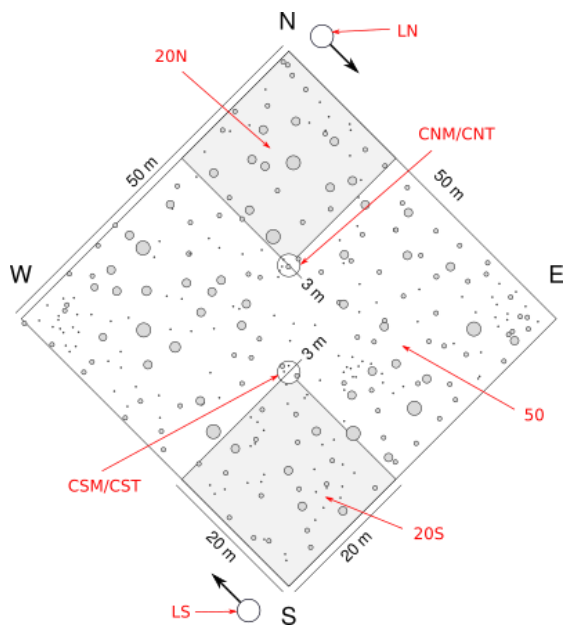
Figure 4 PSP plot showing the main 50x50m plot (50), the 20x20m sub-plots (20N and 20S), the 3m radius circular sub-plots (CSM/CST and CNM/CNT), and the north and south litter plots (LS and LN). (CSM = circle south measurement; CNM = circle north measurement; CST = circle south tree; CNT = circle north tree). See text for details.

Figure 5 Marking of PSP plots with poles (red for the 20x20m sub-plots; left) and numbering of trees with paint (right).

4.2   Attributes recorded on PSP plots

Several plot and tree attributes are recorded on the PSP plots (see list below). A PSP field manual was not made available to the consultancy team. As no written field manual was made available to UHH, the list of attributes to be measured (see below) is based on personal communication with field team members during field visits. A complete list of all plot and tree records can be found in the Microsoft Excel file "fiji-mrv-psp-final_version.xlsx" (ODK definition).

Attributes measured on PSP plots

- Plot attributes
    - Plot ID
    - Inventory round (e.g., 2010, 2012, …, 2018)
    - Plot coordinates (geographic coordinates)
    - Measurement date

- o Island, Division, Province, District, Mataqali
- o Land-use (natural forest, pine plantation, hardwood plantation, mangrove)
- o Forest type (closed or open forest)
- o Altitude (in meters)
- o Slope facing (N, NW, NE, S, SW, SE, W, E)
- o Slope (in degrees)
- o Canopy cover (in percent)
- o Ground cover (in percent)
- o Leader of field team
- o Field team members
- o Remarks
- Tree attributes
  - o Plot type (50x50, 20x20N, 20x20S, CNM [circle north measurement], CSM [circle south measurement])
  - o Tree number
  - o Tree species
  - o Diameter at breast height (DBH)
  - o Height of end of buttress
  - o Height of first branch
  - o Crown radius
  - o Tree height
  - o Tree status (dead or alive), if dead: decay class
  - o Presence of liana
  - o Presence of epiphytes
  - o Remarks

4.3   Amendments

The following additional attributes were recorded:

- Deadwood laying
- Deadwood stumps
- Litter
- Understorey biomass
- Disturbances

4.4   Measurement procedures for the amendments

Lying deadwood

- On the 50x50m plot deadwood is recorded if the mid diameter is >=25cm. On the 20x20m sub-plots, lying deadwood with mid diameter =>10cm and <25cm is recorded. On the circular plots, deadwood with mid diameter >=5cm and <10cm is recorded. Only the part of

the deadwood that is located in the respective plot is recorded (e.g., if a tree stem crosses the plot border only the part within the plot area is recorded).

- Lying deadwood is measured in compartments (Figure 6). A compartment is defined by two knots, one at the larger (thicker) and one at the smaller (thinner) end. On each compartment, three diameters are measured (larger and smaller end and mid of the compartment). At each measurement point, two diameters are recorded. First, the maximum diameter and, second, a diameter perpendicular to the first (maximum diameter). The diameter at the smaller end is the larger diameter of a subsequent compartment (if it exists). In case of stem deformation, the mid diameter is measured above and below the deformation and the average is calculated. To calculate the volume of the compartment, Newton's formula is used.
- For each compartment the decay class is recorded:
  - Decay class code 1: not rotten or decomposing
  - Decay class code 2: cavity formed less than half of cross section rotten
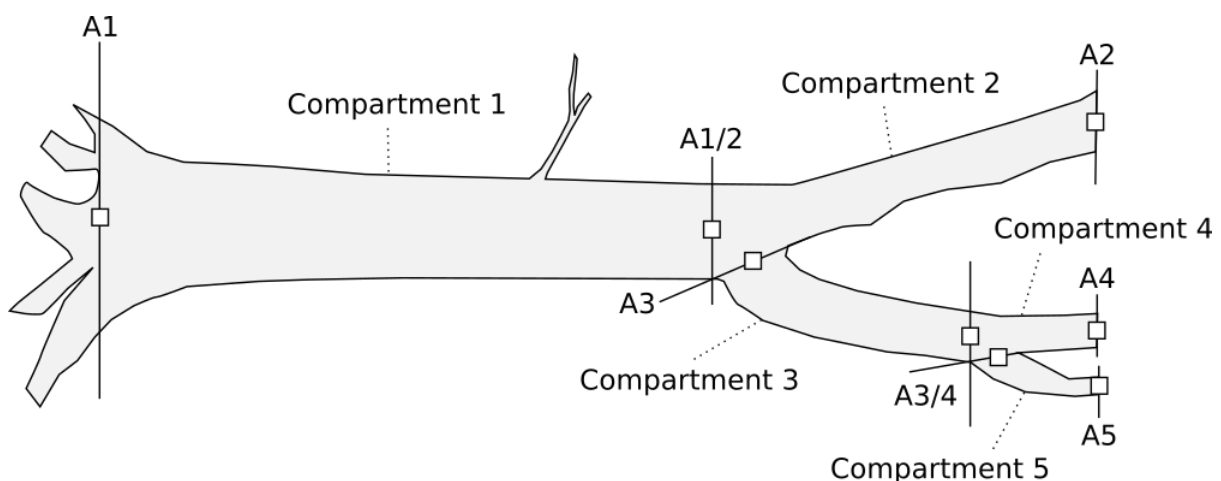 - Decay class code 3: more than half of cross section rotten

Figure 6 Measurement on lying deadwood. Measurements are taken compartment wise.

Deadwood stumps

- Stumps are recorded on the 50x50m plot if the diameter at the tip of the stump is >=25cm. Stumps are recorded if the midpoint of the stump's cross section is located within the 50x50m plot.
- If trees are not buttressed, the following measurements are taken
  - Height of the stump [cm]
  - First diameter at tip of stump (maximum diameter) [cm]
  - Second diameter at tip of stump (perpendicular to first tip diameter) [cm]
  - First diameter at base (maximum diameter) [cm]
  - Second diameter at base (perpendicular to first base diameter) [cm]
- In case of buttressed trees, two alternatives were tested:

- o Alternative 1: the same measurements are taken as for non-buttressed trees and the fact that the tree is buttressed is noted in the field form.
- o Alternative 2: The following measurements are taken:
  - Height of stump [cm]
  - Length of buttress at tip of stump [cm]
  - Thickness of buttress at tip measured at half of length of tip [cm]
  - Length of buttress at base of stump [cm]
  - Thickness of buttress at base measured at half of length of base [cm]
- o Buttresses of stumps are measured each with stump height and upper length and thickness (at 90% of stump height and half upper length of buttress) and with length and thickness at base (at 10% of stump height and half lower length of buttress).
- o The decay class of stumps, buttressed or not, is recorded using the same decay class codes as for lying deadwood.
- o Testing Alternative 2 in the field turned out to be difficult. Large deviations were observed if the same stump was measured by different field team members. For the future terrestrial laser scanning may be considered a viable alternative to assess the volume of buttressed tree stumps.
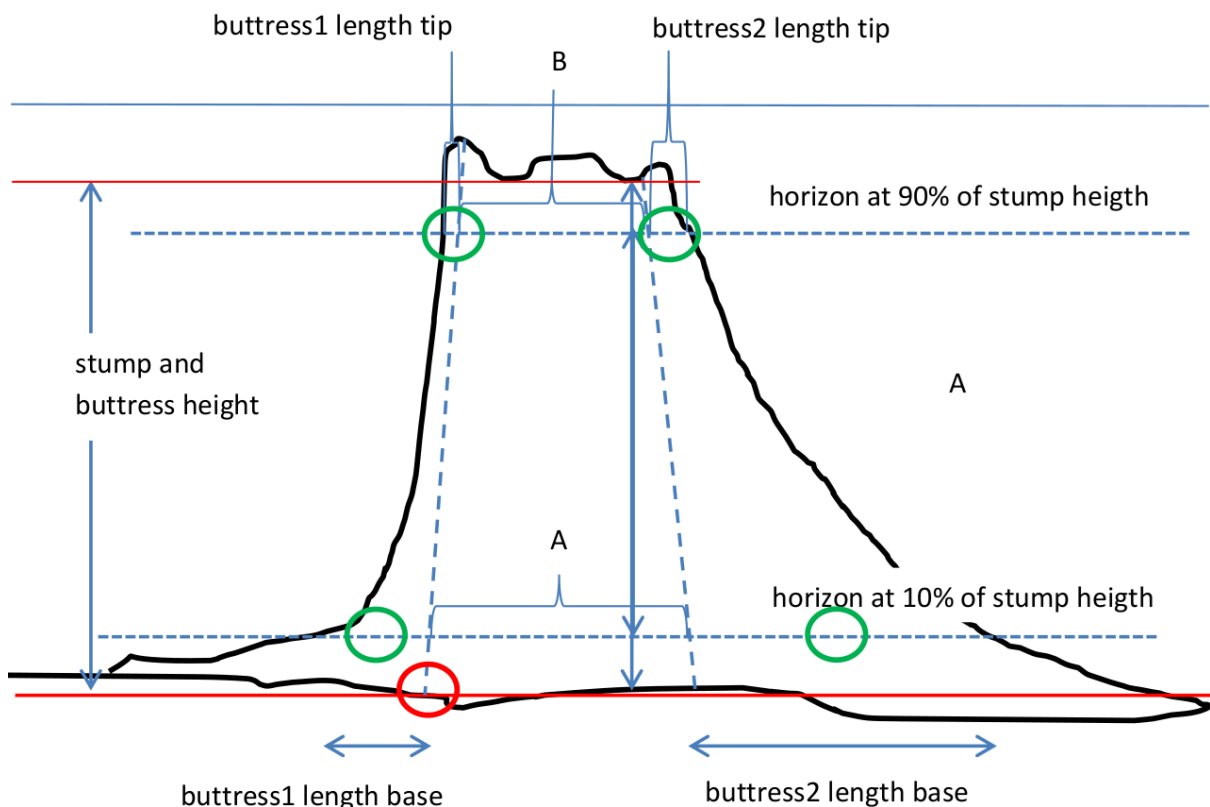

Figure 7 Buttressed tree stump. A: diameter at base of stump; B diameter at tip of stump; tip is measured at 90%, base is measured at 10% of the stump height which is measured between red baseline (red circle marks the crossing of upper humus layer limit and uphill limit of stump) and top

line in red at lower border of larger gaps (at least 10% of diameter at tip) to upper end of stump; buttress lengths are measured at same heights diameters at base and tip are; buttress thickness is measured at half of buttress length (marked with green circles).

Litter

- Litter consist of leaves and twigs or branches with mid diameter <5cm lying on the ground. Litter is to be sampled at two circular plots with horizontal radius 30cm. Circles are located at the outer edge of the 20x20m plots (i.e., outside the main plot area; LN for the north and LS for the south litter plots in Figure 4). As litter was recorded after destructive harvesting (see below), the circle has to be shifted by some distance during each measurement round. The shifting is done by 1m along the outer edge of the 50x50m plot in clockwise direction.

- All litter above the humus layer found on the circles is weighted in grams using a portable scale. A lab-sample (e.g., 100 grams put in a plastic bag) is taken to assess the carbon (and possibly nutrient) content of litter. Litter bags have to be labelled appropriately such that the lab-sample can be linked to the plot. During the test inventory litter plots have been established and the methodology was tested. However, litter was not weighted in a lab.

Understorey biomass

- Understorey vegetation includes all living biomass <3cm diameter. Understorey vegetation is destructively sampled at the same location as litter (i.e., circles with 30cm horizontal radius). The weight of the destructive sample is weighted (in grams) using a portable scale. Similar to litter a lab-sample is extracted for further analysis.

Disturbances

- Disturbances which are observed at the Permanent Sample Plots (50x50m) are described for their occurrence and in case of observation also by a textual description or an estimate on the strength of the impact of the disturbance. Textual and quantitative observations are documented according to the scheme of observation (yes/no) and a more detailed description of the disturbance or a quantification of the impact in terms of strength classes "weak", "medium", or "strong" or e.g. the percentage of affected area. The disturbances classes can be selected:
    o Invasive species (including the species name)
    o Fuelwood harvesting (classes "weak", "medium", or "strong")
    o Encroachment (percentage of area affected)
    o Fire (percentage of area affected)
    o Natural disaster (e.g., cyclone, landslide, flood, lightning)
    o Livestock (textual description)
    o Resin tapping (classes "weak", "medium", or "strong")
    o Wild pigs (classes "weak", "medium", or "strong")
    o Climbers
    o Other disturbances (textual description; used if none of the above applies)

4.5 Open Data Kit (ODK) submission

Data collection procedures and data submissions using ODK were tested during a field test on four PSP plots (see next section). During field visits it was tested if data collection procedures can be implemented in the field (i.e., if all measurements can be conducted as planned), if the data can be entered into to the handhelds (using ODK), and if automatic data validity checks implemented in the ODK forms work as intended. Field crew members and database managers were trained in working with ODK by INTEND GmbH and UHH.

The ODK forms are defined in a Microsoft Excel file (see file "fiji-mrv-psp-final_version.xlsx"). The content of the Excel file was developed by PSP field crew members, INTEND GmbH and UHH. The Excel file has three sheets: survey, choices and settings. The sheet "settings" provides information on the form document ID, the version number of the field form document and a title.

Some attributes recorded on the PSP plots and trees can be selected from only a predefined set of possible values. For example, the attribute "Province" of a plot can only be selected from the list of Provinces. The same holds true for e.g., tree status. The only two possible values for tree status are "dead" or "alive". The sheet "choices" list those values from which one has to be selected. If there are changes in the set of possible values, they have to be added to the sheet.

The sheet "survey" defines ODK fields that have to be filled during field data collection (e.g., tree attributes such as the diameter at breast height [DBH], the tree height, or the crown radius). Fields can be added or dropped easily. The "survey" and "choices" sheets are interlinked. Hence, the choice that can be taken for a certain tree attribute may be restricted by the choices provided in the "choices" sheet. For ratio scaled attributes (e.g., tree height), the choices are restricted to lie within a predefined interval, i.e., greater or equal to 1m and not larger than 60m. Using ODK field forms has the advantage that data entry errors are reduced compared to "pen-and-paper" field forms.

Once the data are recorded using ODK on handhelds, they can be transferred to the NFMS PostgreSQL database. The database is managed by two trained database managers at the Ministry of Forestry. Unfortunately, not all database capabilities could be tested during the training sessions, because one database administrator was not available during the training and the other got (unexpectedly) temporarily suspended from his assignment.

5 Field test

Data collection procedures were tested on four PSP plots (plot number 1, 5, 48 and 49). It was initially planned to visit more plots, however, after visiting a first test plot it turned out that more time than initially anticipated was necessary for the tests.

The first PSP test plot served as a first check if measurement procedures can be implemented as intended (including the amendments). The plot was located close to the MSD office in Colo-i-Suva (PSP plot no. 48). The three other plots were selected in order to cover different forest types during the test inventory: one plots was located in a natural forest stand at low altitude in the wet zone of

Viti Levu (PSP plot 49), another plot was situated in a hardwood plantation (PSP plot 5), and a third plot was located close to the city of Ba (dry area of Viti Levu; PSP plot 1). Plot no. 1 was heavily disturbed by cyclone Winston.

5.1   Plot 48

PSP plot 48 is located close to the MSD facilities at the north-eastern corner of the Colo-i-Suva Forest Park aside Qiolevu Road. Occurrences of human interaction (stumps indicating cuttings of trees) were detected and documented. The vegetation was rather dense.

The plot was visited by five members of the PSP field crews and members of the consultancy team (Dr. Volker Mues and Dr. Prem Raj Neupane). It turned out that the plot was one of those plots were the 20x20m sub-plots (originally in north-south orientation) were shifted to east-west orientation. To ensure comparability between the measurements taken on the plot during the PSP assessments and the field test, the east-west orientation of the sub-plots was retained.

Field teams measured several tree attributes on the plot including the total tree height. Currently a height rod is used to assess the height of a tree. Measuring tree heights turned out to be difficult because of the dense vegetation (the tops of many trees could not be detected). It was noted that on many PSP plots, field crew members estimated height instead of measuring it. For the future it should be indicated in the field form whether the height was measured or estimated. Moreover, in future assessments more accurate devices (compared to the height rod) should be used. The field teams were trained in using a Haglöf Vertex IV.

5.2   Plot 49

PSP plot 49 is located close to Nausori and east of Rewa River in a plain area. The vegetation on the plot is strongly influenced by high ground water levels. Many buttressed trees were found on the plot. Plot 49 showed impacts of human activities (tree stumps and dense regeneration).

The plot was visited by five members of the PSP field crews and one member of the consultancy team (Dr. Volker Mues). The 20x20m sub-plots were correctly implemented on plot 49. All tree attributed measurements and some of the amendments (excluding deadwood) were successfully tested.

Figure 8 PSP plot 5 recorded on October 17, 2017. Renumbering of a tree can be seen in the right figure. Tree renumbering causes that individual trees cannot be traced over time.

5.3   Plot 5

Plot 5 is located within a hardwood plantation southeast of Lautoka, about 1 km south east of Tavakubu police post. Altitude above sea level was approximately 90m. The stand was burned most likely within the last two weeks before the test inventory was conducted. Therefore, not a single tree on the plot had green leaves. Several standing dead trees and large amounts of lying deadwood were found. Some of the poles that mark the corners of the 50x50m plot and the 20x20m sub-plots were missing. Attributes on 31 living and 16 dead trees were recorded.

Figure 9 PSP plot 1 showing dense advanced regeneration (left) and large amounts of lying deadwood (right).

5.4   Plot 1

Plot 1 is located about 1km south of Narewa at the northern coast of Viti Levu. The forest stand was heavily disturbed by the cyclone Winston in February 2016 and, hence, in October 2017 was covered by a dense regeneration and deadwood. The plot was classified as an open natural lowland forest with ground cover 70% and canopy cover 30%. The plot is located about 120m above sea level.

Figure 10 Participants of the capacity building workshop on the Open Data Kit (ODK).