PANDA MITI KIBIASHARA
PRIVATE FORESTRY PROGRAMME

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FOREST PLANTATION MAPPING OF THE SOUTHERN HIGHLANDS

United Republic of Tanzania
MINISTRY OF NATURAL RESOURCES AND TOURISM
Forestry and Beekeeping

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Final report

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United Republic of Tanzania
MINISTRY OF NATURAL RESOURCES AND TOURISM
Forestry and Beekeeping Division

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Forest Plantation Mapping of the Southern Highlands

Final report

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ABBREVIATIONS

DEM	Digital elevation model
FAO	Food and Agriculture Organization of the United Nations
FBD	Forestry and Beekeeping Division
FDT	Forestry Development Trust
GEE	Google Earth Engine
GIS	Geographic information system
MNRT	Ministry of Natural Resources and Tourism
NAFORMA	National Forest Monitoring and Assessment of Tanzania
NDVI	Normalized Difference Vegetation Index
PFP	Private Forestry Programme
SHI	Sao Hill Industries
SRTM	Shuttle Radar Topography Mission
SUSLAND	Sustainability, scale relations and structure-function-benefit chains in the landscape systems of the Tanzanian Southern Highlands
TANWAT	Tanganyika Wattle Company
TFS	Tanzania Forest Service
TGA	Tree growers’ association
UDSM	University of Dar es Salaam
UTU	University of Turku
QGIS	Quantum GIS, an open Source GIS Software

EXECUTIVE SUMMARY

The Private Forestry Programme (PFP) operates over a large geographical area of the Southern Highlands in Tanzania. Knowledge about the existing forest plantations in that area could serve as an important baseline for future plantation management and development (PFP, 2015). Unfortunately, while the area has a substantial number of commercial and privately operated forest plantations, it is unclear what the geographical extent of forest coverage is, how many plantation forests lie in each district of the Southern Highlands, how large a proportion of them are privately run, and other key information is missing. The lack of spatially explicit information about forest plantations has made it challenging to engage in strategic forest management planning. Clearly, there is a dire need for maps and statistics forest plantation to support the efforts of the project. Having more geospatial information about current forest plantations would support plantation management, the monitoring of changes, the planning of future investments and the allocation of new land areas for planting.

To help meet this need, the Food and Agriculture Organization of the United Nations (FAO) and the University of Turku (UTU) conducted a plantation mapping study of the Southern Highlands during between June 2016 and December 2016 under the framework of the FAO-Finland Forestry Programme. The area mapped included the operating areas of the PFP and the Forestry Development Trust (FDT, 2016) as well as areas of interest identified by the SUSLAND project (UTU, 2016). Other partners of this study included the University of Dar es Salaam (USDM), the Ministry of Natural Resources and Tourism (MNRT), and Tanzania Forest Service (TFS).

The mapping was conducted at two levels. For level 1, tentative plantation and forest maps were created. For level 2, the accuracy of the maps was improved by collecting a large sample data set of plantation attributes. Level 2a included mapping the plantation cover over the whole study area at the spatial resolution of 30 m, and level 2b focused on mapping the plantations on three small pilot areas at a higher spatial resolution (10 m). When that work was complete, the accuracy of the mapping was assessed. The satellite imagery and GIS data sets used at both levels of work were Landsat-8 OLI mosaic, ALOS Palsar, Sentinel-1, Sentinel-2, SRTM DEM and Hansen Global Forest Change mapped land surface data.

In order to collect a large training sample of forest plantations from high-resolution satellite images using Open Foris Collect Earth, an intensive data-collection event, Mapathon, was organised at the USDM Department of Geography HEI-GIS lab in October 2016. Fourteen volunteers, all students of GIS/remote-sensing, and eight forest land cover experts worked for about a week to collect over 7,000 sample points in the area. The survey attributes were based on the NAFORMA land-cover classes (MNRT, 2015) but they were adjusted for the interpretation of high-resolution imagery. Maps of specific plantation attributes (species, age class and density class) were produced for the forest plantation land-cover class. During level 2 work, different image classifiers were tested; Random forest classifier proved to be the most accurate.

Using imagery mainly from the period between 2013 and 2015, the FAO-UTU study created baseline information about the geographical extent of the forest plantations in the Southern Highlands. In December 2016, the findings were compiled into a technical report issued jointly by the FAO and the UTU in December (Mankinen, Koskinen, Käyhkö, & Pekkarinen, 2016). The UTU continued to gather data and to produce this report, which contains the results of the original FAO-UTU study, refined statistical results, regional and district-level maps, and key statistics about the forest plantations in the Southern Highlands. This report allows the PFP and its key stakeholders to compare relative plantation intensity across the Southern Highlands and between different districts. This report also contains practical guidelines describing how the mapping work was done, and thus enables repeating the process in order to monitor changes. All the work was done using open source data, tools and software to foster methodological sustainability.

KEY FINDINGS

The total estimated plantation area in the Southern Highlands was 207,000 ha and the overall estimated accuracy of the map produced was 91.5%. It is likely that the actual total area is higher than that mapped since the mapping techniques were not able to capture all recently established and very small forest plantations.

More than 70% of the plantation area was located outside the large government and company-owned plantations, a fact suggesting the significant potential of smallholder woodlots. The majority of the forest plantations within the study area were located in Njombe (89,843 ha) and Iringa (85,919 ha) regions. The districts with the largest plantation areas were Mufindi (52,558 ha), Makete (27,696 ha) and Njombe Urban (25,882 ha).

Pine, which was found to comprise 66% of plantations, was the most commonly planted species; eucalyptus (19%) and wattle (15%) followed. The accuracy of the figures for eucalyptus and wattle is in question, however, as it was difficult to separate the two during training data collection and automated classification. In terms of age, most plantations (59%) fell in the category ‘growing’ (3–8 years old), and the proportion in the ‘mature’ class (>8 years) was significantly higher on company-owned (51%) than privately owned plantations (28%). Estimates of the proportions of young plantations (0–3 years) are not valid due to methodological uncertainties.

Accuracy was improved using two rounds of mapping, where the result was refined and a larger data set was used for classification in the second stage. Using a set of 2,135 sample points collected by an expert team with Collect Earth, the estimated accuracy of the level 2 plantation map was 91.5%, a slight improvement over the 89.6% accuracy of the level 1 map.

While large monoculture plantations were mapped easily, the heterogeneity of the study area landscape and plantations posed a challenge: small patchy plantations and very young woodlots may be missed in image classification. Planted trees can also easily be misclassified as natural forest.

1. INTRODUCTION

1.1 Private Forestry Programme and the needs for plantation mapping

The Private Forestry Programme (PFP) operates over a large geographical area of the Southern Highlands in Tanzania. Knowledge about the existing forest plantations in that area could serve as an important baseline for future plantation management and development (PFP, 2015). Unfortunately, while the area has a substantial number of commercial and privately operated forest plantations, it is unclear what the geographical extent of forest coverage is, how many plantation forests lie in each district of the Southern Highlands, how large a proportion of them are privately run, and other key information is missing. The lack of spatially explicit information about forest plantations has made it challenging to engage in strategic forest management planning. Clearly, there is a dire need for maps and statistics forest plantation to support the efforts of the project. Having more geospatial information about current forest plantations would support plantation management, the monitoring of changes, the planning of future investments and the allocation of new land areas for planting.

The estimated forest plantation area across Tanzania varies from around 200,000 to 550,000 hectares (Ngaga, 2011; MNRT, 2015; FAO, 2015), with most of the planted area situated in the Southern Highlands. The large variation in the estimates is mostly due to the difficulty of estimating the coverage of private smallholder plantations, which are constantly expanding (Akida & Blomley, 2007; Ngaga, 2011). Mapping the constantly changing smallholder plantations is thus a challenge. Having spatially explicit information is of great importance to the PFP if it is to be able to meet its objectives, to support private plantation establishment and promote sustainable private forestry (PFP, 2015).

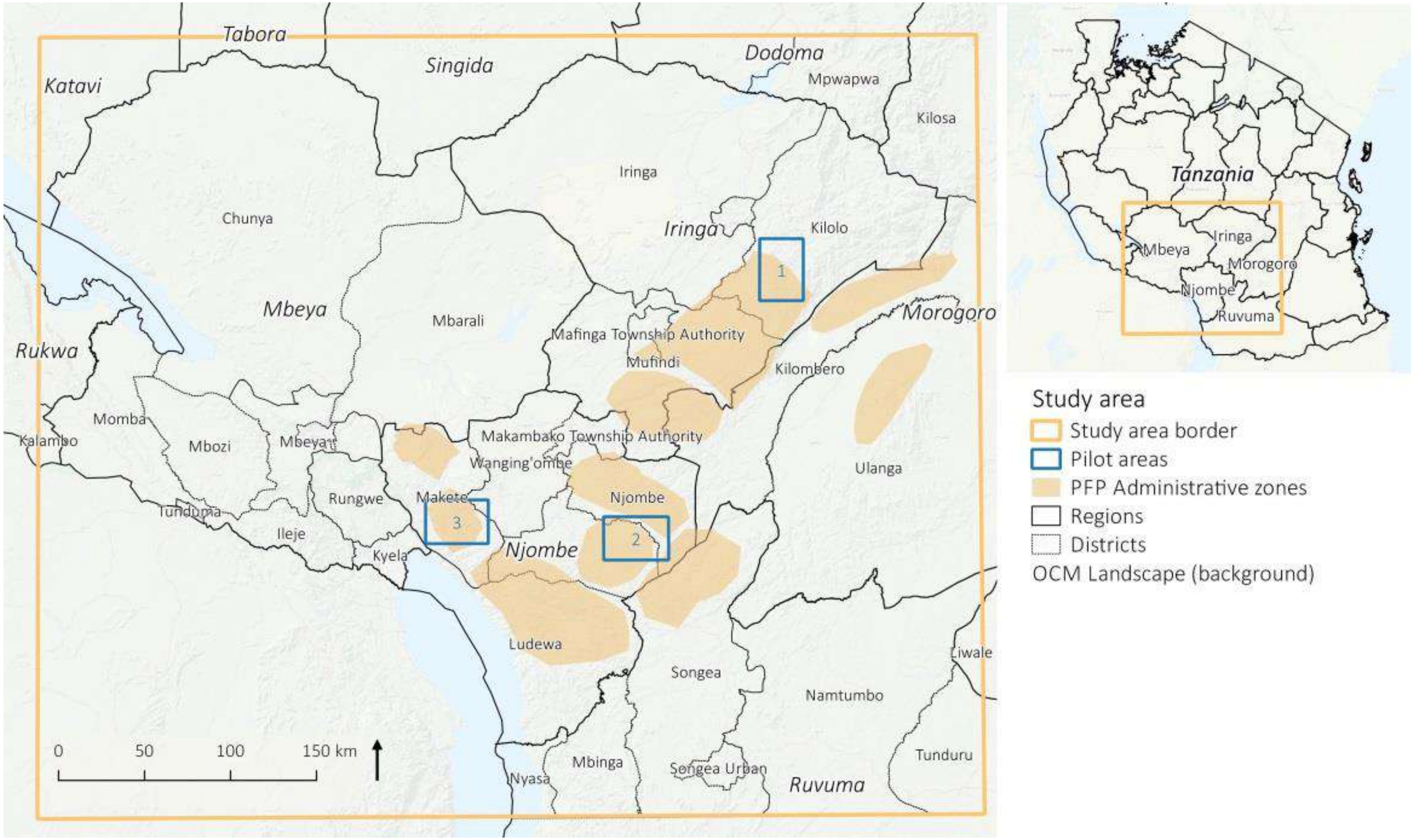
The Food and Agriculture Organization of the United Nations (FAO) and the University of Turku (UTU) conducted a plantation mapping study of the Southern Highlands between June and December 2016 to create baseline information about the geographical extent of the forest plantations in the Southern Highlands. This information was compiled into a joint technical report by the FAO and the UTU in December 2016 (Mankinen, Koskinen, Käyhkö, & Pekkarinen, 2016). The PFP and the UTU continued working on the findings to establish this document, which presents a more consistent and up-to-date report. It contains the results of the original FAO-UTU study, refined statistical results, regional and district-level maps and key statistics about the forest plantations. It allows readers to compare relative plantation intensity across the Southern Highlands and between different districts. It also includes practical guidelines to mapping, thereby enabling future forest plantation mapping to be carried out in order to monitor changes. The FAO and the UTU did all their work using open source data, tools and software to make such future efforts doable.

1.2 Study area

The entire area of the Southern Highlands was mapped. With altitudes ranging from 1,300 masl to 2,000 masl, sufficient annual rainfall and mild temperatures, the Southern Highlands is a prominent location for forest industry in Tanzania. Some of the biggest industrial-scale forest plantations, covering tens of thousands of hectares, such as the government-owned Sao Hill Industries (SHI) and company-owned Tanzania Wattle Company (TANWAT) are located in the Southern Highlands. Sao Hill alone produces 85% of the total wood supply of Tanzanian government plantations (FBD, 2010). There are also a significant number of smallholder plantations in the area, all run with low-intensity manual management and down to a couple of acres in size (Penttilä, 2016). According to Ngaga (2011), pines (*Pinus patula*, *Pinus elliottii* and *Pinus caribaea*) are the dominant species planted in Tanzania as a whole as well as in the Southern Highlands alone. Other species frequently planted are eucalyptus (*Eucalyptus spp*.), wattle (*Acacia mearnsii*), and, in some areas, teak (*Tectona grandis*). Wood is used for timber as well as poles, firewood and charcoal production.

The boundaries of the FAO-UTU study area and its three pilot areas in the Southern Highlands (Figure 1) formed a rectangle around the administrative regions of Iringa, Njombe and Mbeya in order to capture the operating areas of the PFP (PFP, 2015) and the Forestry Development Trust (FDT, 2016), as well as areas of interest to the SUSLAND project (UTU, 2016). Other partners in this study included the University of Dar es Salaam (UDSM), the Ministry of Natural Resources and Tourism (MNRT) and Tanzania Forest Service (TFS). The mapping activities during 2016 were carried out under the framework of the FAO-Finland Forestry Programme, which is funded by the Government of Finland. This report and the finalisation of the results into maps and statistics were funded by the PFP.

Figure 1 **Map of the study area**



2. METHODOLOGY

2.1 Overview

The FAO-UTU mapping was conducted in two levels, as presented in Figure 2 and described more specifically in the following chapters. The input data sets are presented in detail in Table 1.

In level 1, preliminary plantation and forest maps were created. In level 2, the accuracy of these maps was improved by collecting a large sample data set; plantation attributes (species, age class and density class) were also added. Level 2a included mapping plantations across the whole study area at a resolution of 30 m, and 2b the mapping of three small pilot areas at a higher spatial resolution (10 m). When level 2 was completed, the accuracies of the maps were assessed. A possible level 3 effort, field mapping and estimating biomass in the pilot areas, could be carried out but was not part of this study.

Figure 2 The mapping process

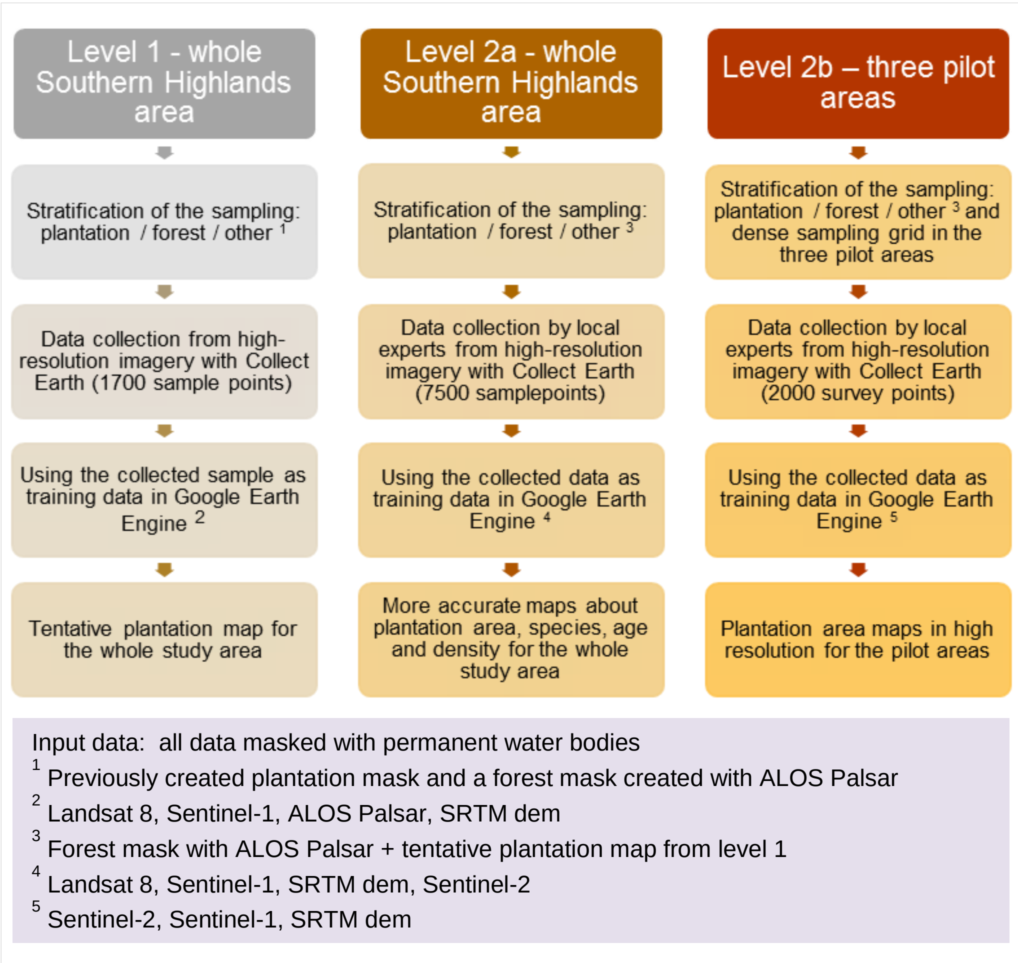


Table 1 Input data sets for the mapping

Data set	Description
Landsat 8 OLI mosaic	A cloud-free best-pixel mosaic built for two seasons in Google Earth Engine using USGS Landsat 8 calibrated top-of-atmosphere (TOA) reflectance, orthorectified scenes only. Years 2013–2015, bands 3–7, resolution 30 m.
ALOS Palsar (used in level 1 mapping only)	JAXA L-band Synthetic Aperture Radar (SAR) dataset pre-processed with the Open Foris SAR Toolkit. Acquisition year 2010. Gamma0 HH, Gamma0 HV polarizations and HH/HV ratio were used.
Sentinel-1	ESA C-band SAR dataset pre-processed with the Open Foris SAR Toolkit. Acquisition year 2015. VV and VH polarizations were used.
Sentinel-2 (used in level 2 mapping only)	A cloud-free mosaic built in Google Earth Engine using the SENTINEL-2 MultiSpectral Instrument (MSI), Level-1C products for years 2015–2016 and bands 2–4, 8 and 11. Original resolution 10–20 m.
SRTM dem	The Shuttle Radar Topography Mission (SRTM) Digital Elevation Data Version 4, original resolution 90 m (Jarvis, Reuter, Nelson, & Guevara, 2008).
Hansen Global Forest Change mapped land surface	Hansen Global Forest Change v1.0 (2000–2012) mapped land surface created with Landsat 7 ETM+ images, was used to mask out permanent water bodies (Hansen, et al., 2013). Resolution 30 m.

2.2 Preparations for data collection

2.2.1 Stratified sample in level 1

The aim of the first level of mapping was for an expert FAO/UTU team to create a tentative plantation coverage map at 30 m x 30 m resolution for the whole study area. A sample data set for this purpose was collected using visual interpretation of high-resolution imagery in Google Earth and Bing Maps with FAO Open Foris Collect Earth software (FAO, 2016). The collected data was then used as training data for image classification.

Stratified sampling was chosen as the sampling method as the plantations cover a relatively small area of the whole study area and could have otherwise been easily left out of the sample. Since plantations are easily misclassified as natural forest by automated classification, collecting more samples from forest areas was considered important. Thus, the first stage sampling was stratified into three strata: plantations, forest, and other land cover.

The tree cover mask for the forest stratum was created using ALOS HH and HV channels and their ratio because of the ability of PALSAR to capture aboveground biomass. An NDVI layer was calculated from Landsat 8 mosaic (2013–2015), and values less than 0.3 were used to mask the ALOS stack, as built-up areas can have high PALSAR backscattering values similar to those of dense forests. The NDVI value 0.3 was chosen as the masking value because built and barren areas tend to have a maximum annual NDVI of 0.3 (Defries & Townshend 1994). The image stack was clustered with the Open Foris Geospatial toolkit oft-kmeans tool (Open Foris, 2016) into 30 clusters. Those clusters which did not represent woody vegetation were ruled out by comparing them to high-resolution Google satellite images in QGIS.

The mask for the plantation stratum in the first level of mapping was based on a previously created test, an unpublished map based on NAFORMA field data and

Landsat-8 imagery (Ortmann, 2015). This test plantation mask was originally made for a small area in the Southern Highlands using the Cart classifier and two-season mosaics of Landsat-8 data in Google Earth Engine. The script was modified to cover the whole Southern Highlands study area and also modified for use also in the level 2 mapping. The tree and plantation masks were overlaid on top of the study area bounding box raster and finally masked with the permanent water bodies of the Global Forest Change 2000–2014 dataset (Hansen, et al., 2013). Everything outside the forest and plantation mask areas was considered to belong in the ‘other land cover’ stratum.

The sampling design was created in R Studio using the Open Foris Accuracy Assessment app (Open Foris, 2016) which allows for the stratification of a sample based on the user’s raster image and other sampling criteria (equal, proportional, or adjusted number of sampling points per pixel count in class). An adjusted number of sampling points (963 in total) was used to ensure that more points would fall on actual plantations. The distribution of sample points was as follows: 150 in the plantation stratum, 361 in the forest stratum, and 452 in the other stratum (Figure 3). After the data was collected, 700 hand-drawn points were added to the sample (section 2.3.1 Data collection in level 1).

2.2.2 Stratified sample in level 2

Like level 1, level 2 also sought to classify satellite imagery; it just used a larger set of training points and was done in two parts instead of one. First, in level 2a, a large sample was collected from the entire area of the Southern Highlands; then, in level 2b, a denser sample was collected from three small pilot areas within that area (Figure 1)

The tentative plantation map and forest mask created in level 1 were used to stratify the sample to create a larger set of points for level 2 data collection. The same strata (plantation, forest, other) and previously used Open Foris Accuracy Assessment app were used to create a sample size of 7,500 sample points with 2,500 points in each stratum (Figure 4). Each pilot area had a total of 750 sample points, 250 points in each stratum.

2.3 Data collection

2.3.1 Data collection in level 1

To collect land-use information, the set of stratified sample points was used with FAO-developed Open Foris Collect Earth Software (FAO, 2016), (Figure 5). The survey for Collect Earth was created using Open Foris Collect Survey Designer, an interface for setting up a user-defined survey (FAO, 2016).

Collect Earth enables users to collect data using high-resolution satellite imagery in Google Earth and Bing Maps as well as contributory data in Google Earth Engine (GEE). GEE (Google Earth Engine Team, 2015) allows for the study of variables like NDVI and EVI vegetation indices and lower resolution satellite images such as Landsat and Sentinel-2. However, since loading each individual plot takes a while, to speed up the process, Landsat-8 mosaics for two seasons (rainy and dry) were downloaded from Google Earth Engine using the GEE Code Editor (Google Earth Engine Team, 2015) for use in QGIS. The Landsat-8 dry season image mosaic was especially helpful in the visual interpretation of plantations and other land-use classes as well as, in many cases, the actual species planted on a particular plantation (Figure 10). These seasonal Landsat-8 images were used in the image classification stage as well.

Figure 3 **The level 1 sample with the manually added points included (1,667 points in total)**

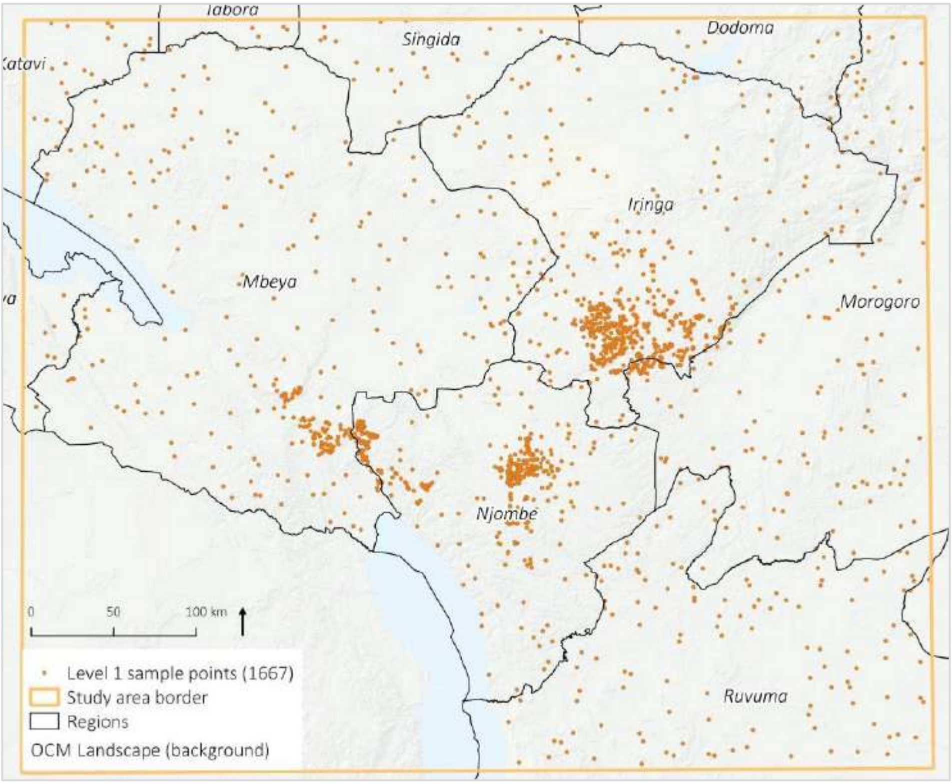


Figure 4 **The level 2 sample (7,500 points in total)**

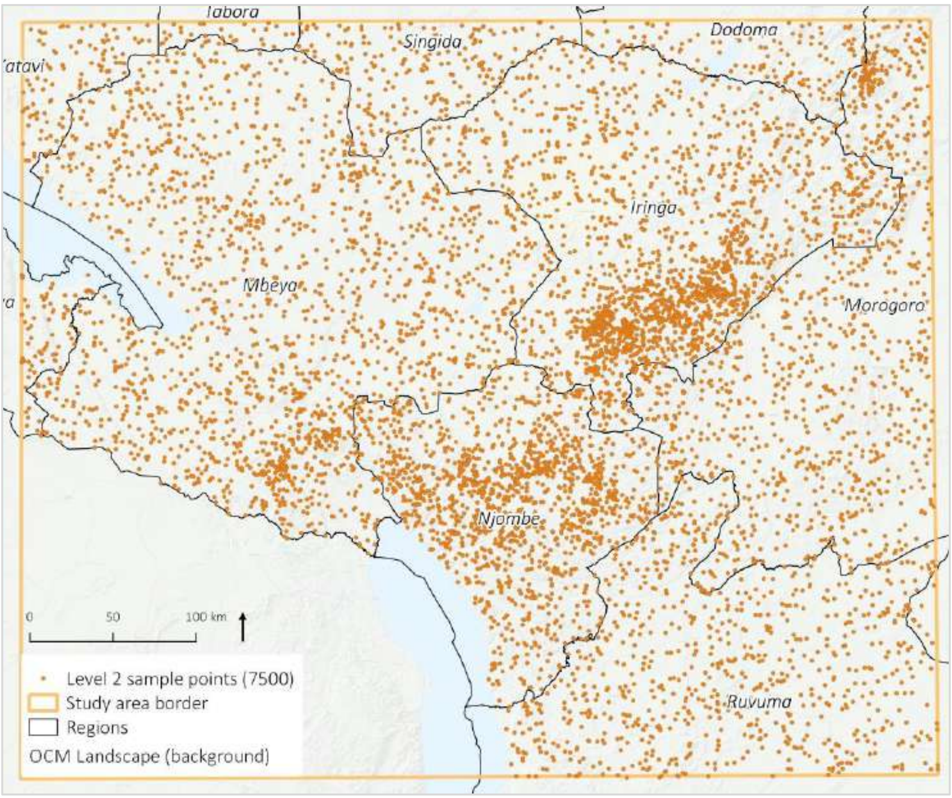
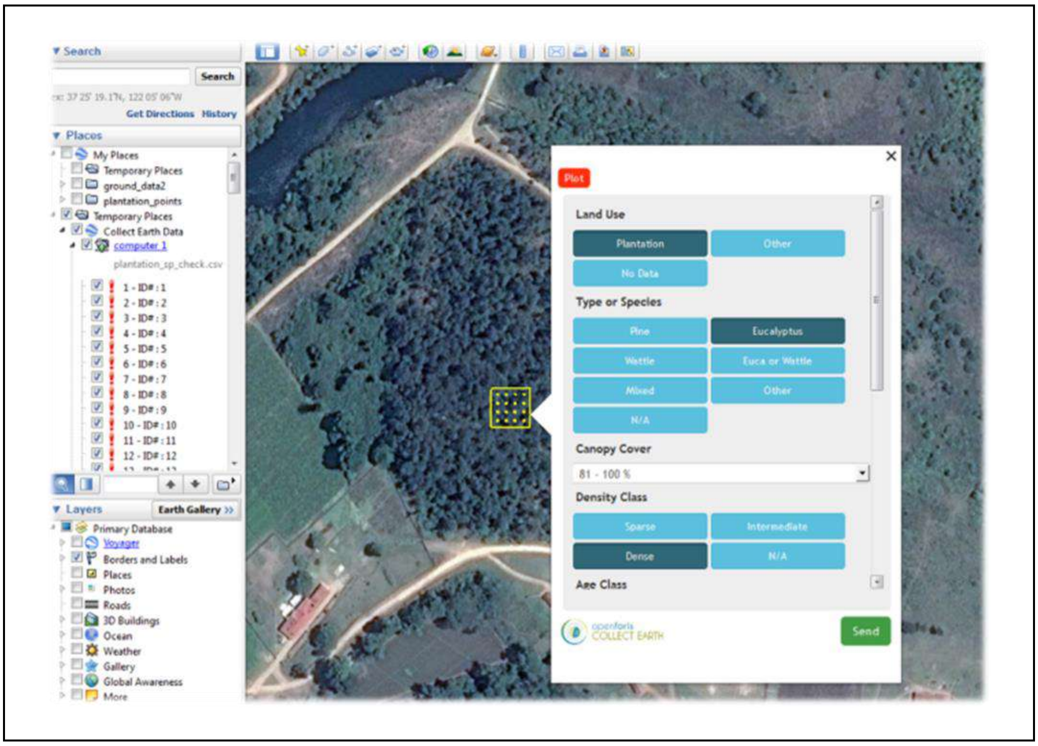


Figure 5 Open Foris Collect Earth Software



In level 1, since only information about plantation vs. other land use was relevant, the survey structure was simple (plantation/non-plantation). The level 1 sample points were used as the sampling grid input in Open Foris Collect to create the survey and data was collected by the UTU expert team. After classifying the collected sample of 963 points, 704 hand-drawn points were added in forest and plantation locations where the initial classification had been incorrect, making a total of 1,667 points. See section 2.4.1 for details about the image classification process in level 1.

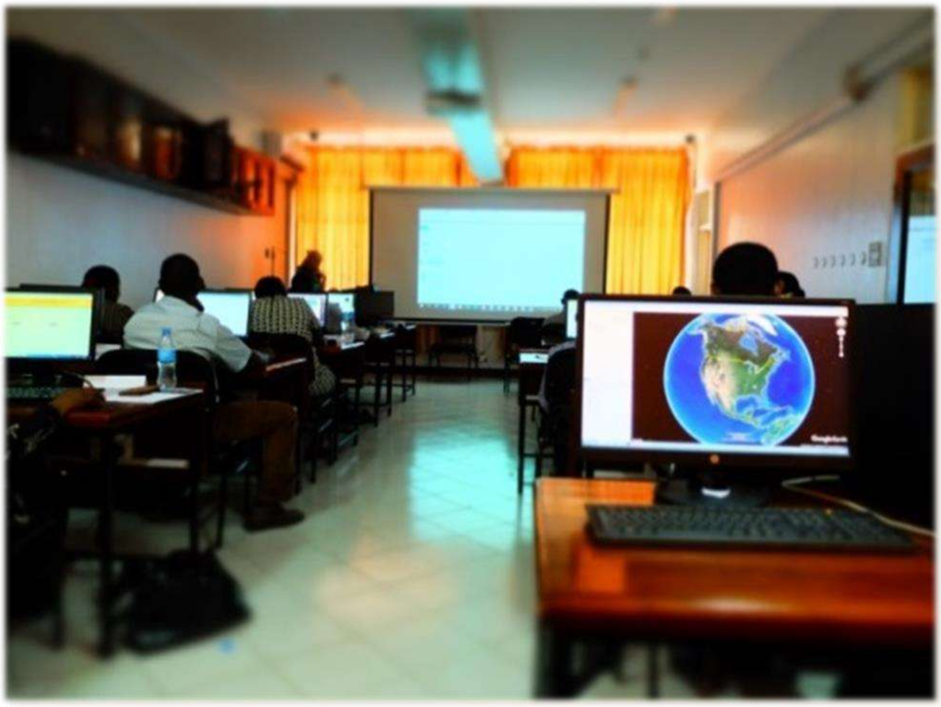
2.3.2 Participatory data collection in level 2

To efficiently collect a larger sample for the more accurate level 2 mapping (7,500 sample points for the whole study area and 750 points for each pilot area) and to gain from local knowledge, a data collection event, Mapathon, was organised in Tanzania (Figure 6) at the UDSM Department of Geography HEI-GIS lab in October 2016. UDSM staff collaborated in the organisation of the event and gathered a group of 14 MSc and BSc students specialising in GIS and remote-sensing at the USDM or the University of Bagamoyo to take part. They were joined by eight forestry, GIS, remote sensing and mapping experts from the PFP, the UDSM, Ardhi University, and the TFS.

During the first week of Mapathon, participants were introduced to and did hands-on training using Open Foris Collect Earth. They also learned from trainers and local experts about the Southern Highlands area and its plantations and other land-use classes. Having the Tanzanian forestry experts share their knowledge was very valuable as there is not a lot of information in the literature or online about plantations or planted species in the Tanzanian context. After the participants gave feedback on the survey, it was adjusted to add, in addition to the dominant planted species (pine, eucalyptus and wattle), classes for ‘eucalyptus or wattle’ and ‘other or mixed’ due to the occasional difficulty in distinguishing between planted species.

Collect Earth software and visual interpretation of high-resolution imagery was used as the main method to collect data but Landsat-8 seasonal mosaics and elevation and climate layers were also used to aid interpretation. The target was to classify imagery at a resolution of 30 m for the whole study area and at a resolution of 10 m for the pilot areas, so the plot sizes in the survey were adjusted correspondingly. The survey attributes were based on the NAFORMA land-cover classes (MNRT, 2015) but adjusted so that they could be identified using high-resolution imagery and the specific plantation attributes were chosen according to the needs of the PFP (Figure 7).

Figure 6 Mapathon at the University of Dar es Salaam



Data was collected during the second week of the Mapathon. Collect Earth survey project files were shared among the participants so that each had the same number of plots to fill. Participants collected information about plantations and also other land uses and land covers. Whenever possible, plantation species, canopy cover, age class and density class as well as information on the year of establishment and latest clearing were recorded. The other land-cover types were also identified in more detail that in the level 1 mapping so it could be used for land-cover analysis. For example, forests were classified as montane or lowland and woodland as open or closed. The survey also included a ‘no data’ option for plots that were not interpretable and a question about interpretation confidence, allowing the participant to express uncertainties about their interpretations.

The species identification was supported by photos and satellite imagery from known places. Because Landsat-8 imagery of different planted species has slightly different tones (Figure 10), it can support the interpretation of high-resolution imagery in Google Earth and Bing Maps. To support the age class estimate, historical imagery in Google Earth was used when it existed, as were the time series cards available for each plot (Figure 8). The time series cards were produced using Landsat and Sentinel-2 imagery from GEE; they showed each plot and its surroundings each year from 2002 to 2016. The density class estimate was based entirely on sample images designed to guide the visual estimate of high-resolution imagery (Figure 9). The data thus collected is referred to as “training data.”

Figure 7 The land-use and land-cover classification systems used in data collection

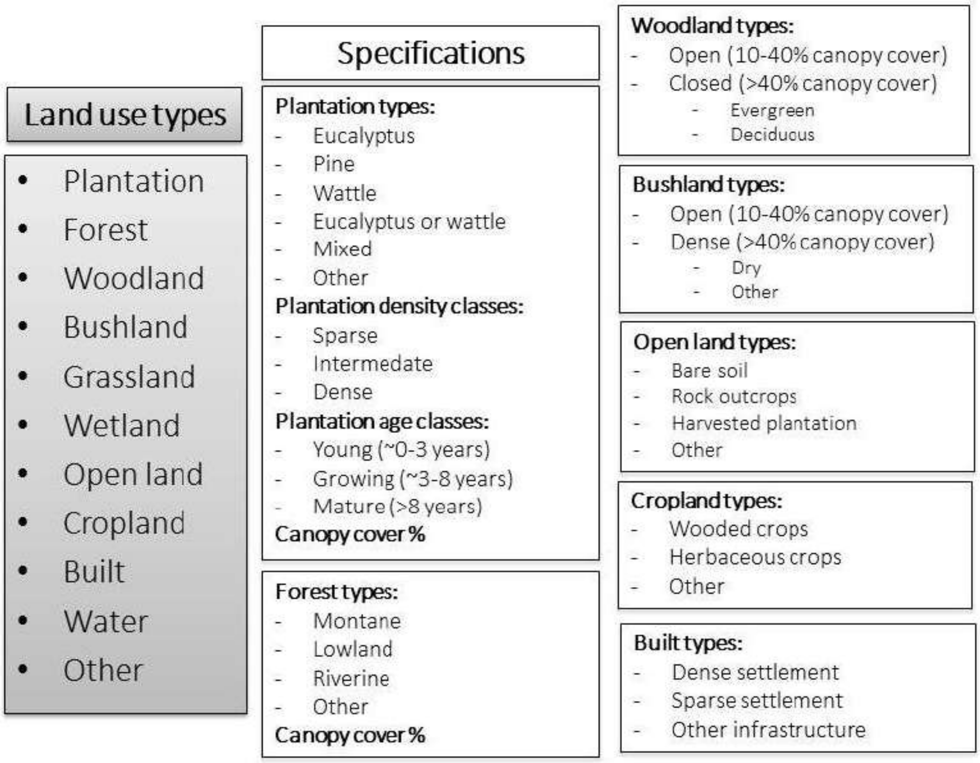


Figure 8 A time series card for a plantation plot in Iringa (in yellow)

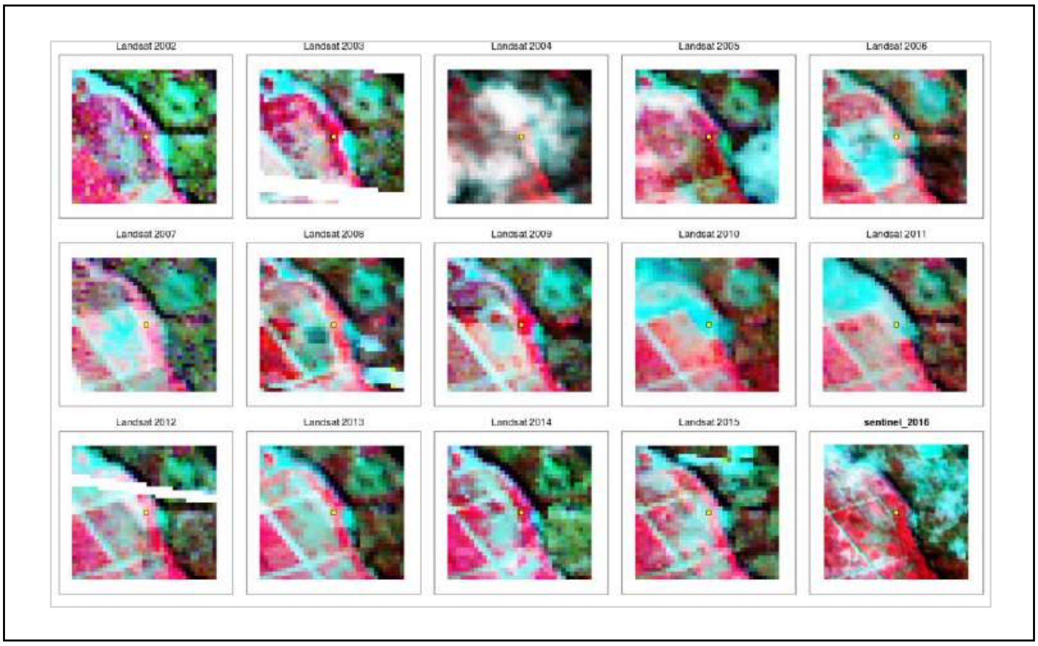


Figure 9 Example imagery was used for plantation age class and density class assessment

2.3.3 Cleaning and completion of training data

The FAO-UTU team had to clean some of the data collected at the as well as to fill in those sample points that had been left incomplete due to time constraints. The team also checked and, if necessary, emended observations marked as having been made with low interpretation confidence. After this process, only image classifications with high confidence and valid land-use class remained. The team had intended to remove observations made from out-of-date imagery (that older than 2010) but this proved difficult because of some errors in observation year so the data was not filtered by year. Most of the imagery of the Southern Highlands in Google Earth is, in any case, from 2010 onwards.

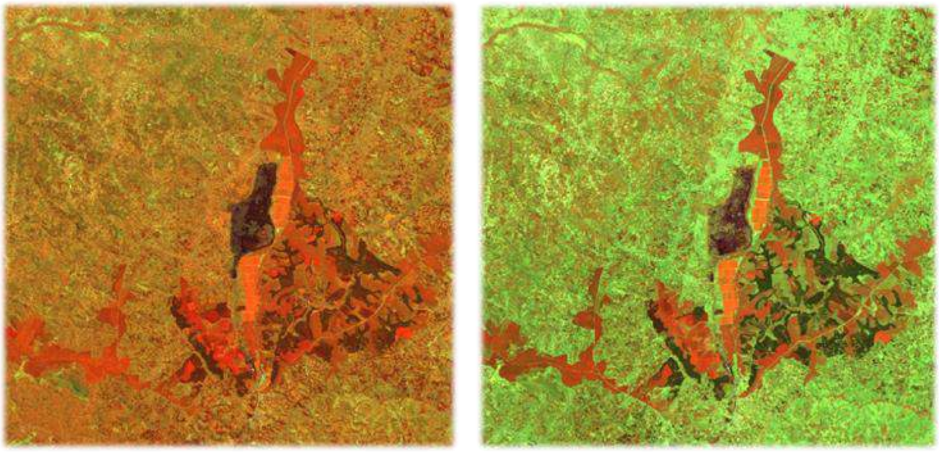
After the cleaning of the data, 6,866 of the original 7,500 sample points were left. For classification purposes, columns were added to the data table with numbers corresponding to the land use classes (1–10), plantation/non-plantation (1–0), forest cover/other (1–0; forest including plantations, natural forests and woodlands), plantation species (1–5), age classes (1–3), and density classes (1–3). The plantation attributes (species, age class, and density class) were also separated so that each had its own table. These tables were converted to Google Fusion tables.

2.4 Satellite image classification

2.4.1 Image classification in level 1

In level 1, the data collected by the expert team at UTU was used to classify a stack of input data sets in GEE with the Cart (decision-tree) classifier. For the classification, greenest-pixel Landsat-8 mosaics from years 2013–2015 were built into GEE for two seasons (Figure 10), wet (January to mid-July) and dry (mid-July to the beginning of November) with bands 3–7, along with ratios of the bands, the NDVIs of the wet and dry seasons, and the seasonal NDVI difference band. Adding radar data to the stack of input layers increased the accuracy of the tentative plantation map. Thus, Sentinel-1 VH and VV channels (2015), ALOS PALSAR (2010), and STRM DEM and slope were included among the input data sets in level 1.

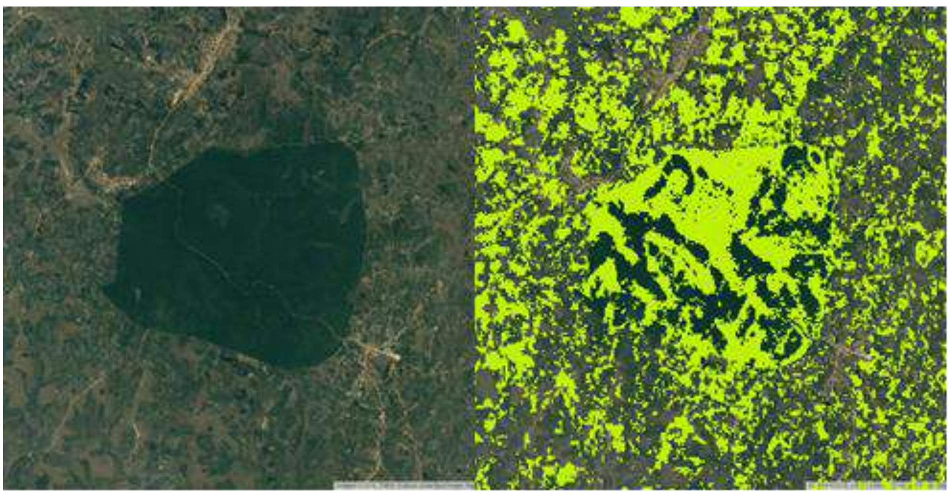
Figure 10 **Wet (julian days 1–200) and dry (julian days 200–305) season Landsat-8 mosaics were used for both visual interpretation and image classification**



Creating the Landsat composite was originally tested with only one year of imagery, as the optimal situation would be to have all the data sets for the same year. However, the cloudiness of the study area made this impossible as, while it proved to be important to include both seasons in the classification, the rainy season is cloudy. Creating a best-pixel mosaic for the years 2013–2015 was the best way to remove the clouds. If a smaller area had been mapped, however, it may have been possible to use a single cloud-free scene.

The team's classification experiments revealed a significant problem: some evergreen natural forests, especially those located on shadowy slopes, and plantations have a very similar pixel signature. Adding elevation and slope data was found to help, but some level 1 mapping had visible errors with natural forests classified as plantations in the automated classification (Figure 11).

Figure 11 **Example of a natural forest misclassified as a plantation in the level 1 map**



2.4.2 Image classification in level 2

With the larger training data set collected in the Mapathon, the team engaged in its level 2 classification round to produce more accurate plantation maps. Since more Sentinel-2 data had also become available, it was included in the layers of classification along with Landsat-8, Sentinel-1 and SRTM elevation data (Table 1). ALOS PALSAR data from 2010 was initially used but then left out since many changes had already happened in intervening years in the rapidly evolving plantation area. Unfortunately, the 2015 mosaic of ALOS Palsar was not usable for the study area.

In level 2a, different classifiers were tested. Of those available in GEE, in addition to the previously used Cart, Random forest and SVM classifiers proved most useful. Random forest was tested with 75, 100, 125, 150 and 200 trees and Random forest with 150 trees was selected to balance the accuracy of the map product and the computing time and to achieve a slightly better accuracy than SVM. Once the plantation area had been classified, maps were also produced for plantation species and age and density classes using the same Random forest classifier (150 trees).

In level 2b, the classification of the three pilot areas was tested with the Random forest classifier (150 trees) and imagery at a resolution of 10 m. Sentinel-2, SRTM DEM and slope data were used as the input data sets. The classification was first tried using only Sentinel-2 since it was the only data set originally in 10 m resolution but resampled elevation and slope data sets were added in the image stack to improve accuracy.

2.5 Accuracy assessment of the maps

After selecting the plantation map created with Random forest classifier as the end result, the accuracy of the plantation maps was tested. A stratified sample was created for this purpose by using the Open Foris Accuracy Assessment app (Open Foris, 2016) and the same classes (plantation, forest, other) as used earlier were used in the stratification. Since the Random forest classifier was more accurate than the Cart classifier, a new forest mask layer was created using the Random forest classifier with 150 trees and the 6,866 sampling points available from the Mapathon data. The plantation and forest masks were stacked as one raster image, and the area outside these layers was considered the ‘other land cover’ category.

To assess the study area as a whole, 1,800 accuracy assessment points were created in the open Foris Accuracy Assessment app, allocating 600 points to each of the three strata (plantation, forest, other) (Figure 12). For the pilot areas, only two strata, plantation and other land cover; the total number of sample points was about 250 for each, but varied according to size: Kilolo had 247 points, Njombe 250 and Makete 240. For each pilot area, one hundred of those accuracy points were located in the plantation strata and the rest in the other strata.

The expert FAO-UTU team collected reference data using high-resolution imagery through Collect Earth and Landsat-8 (2013–2015) and Sentinel-2 (2015–2016) mosaics in QGIS. The team focused on the years 2013–2015, always using the most recent information source available during that period. If the plantation had been harvested after 2015 this was not taken into account as the plantation had existed during the mapping. After data was collected, the ‘no data’ observations were filtered, leaving 1,775 sample points to assess for accuracy.

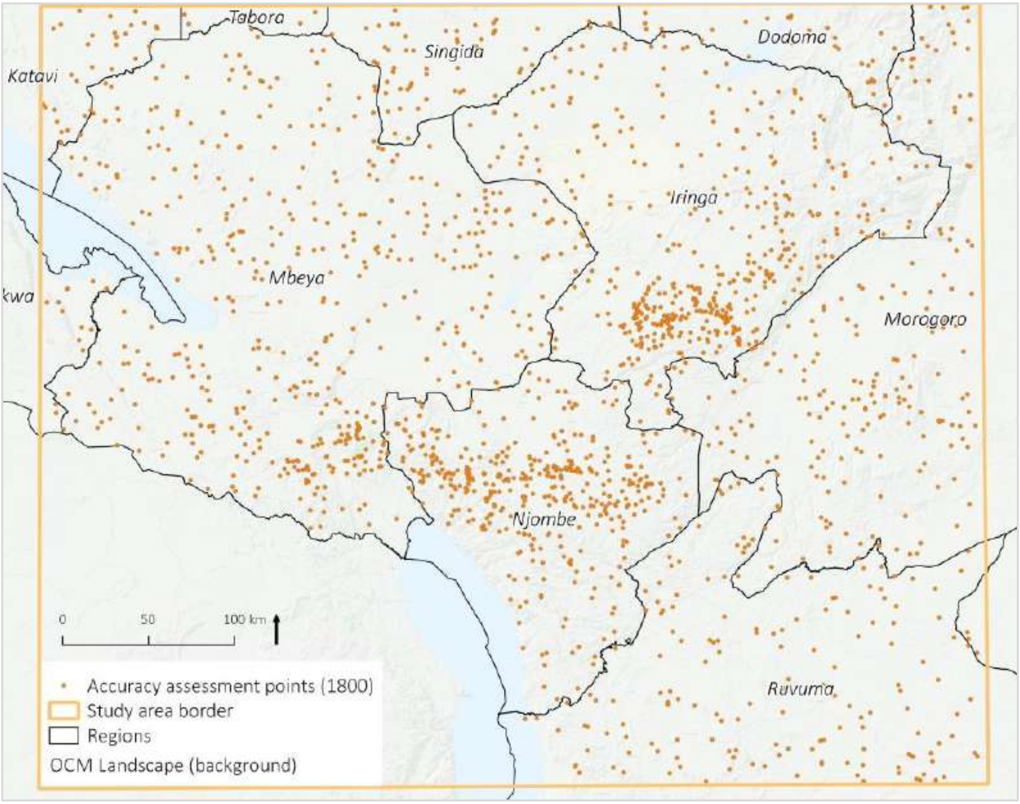
Only the plantation vs. other land cover information could be validated accurately using this assessment method because plantation species, age and density need to be evaluated in the field to truly assess accuracy. As for the plantation variables, species were validated using a small field data set collected during a field visit to Iringa region in November 2016. During this field visit, 218 observations with emphasis on plantations were collected from randomly selected locations near the roads in Mufindi, Mafinga Township Authority and Iringa (Figure 13).

Once the reference data sets had been collected, the agreement of reference and classification was calculated using an error matrix (confusion matrix) for each assessed attribute and area. The calculations were done using R software.

2.6 Map refining, layout and statistics production

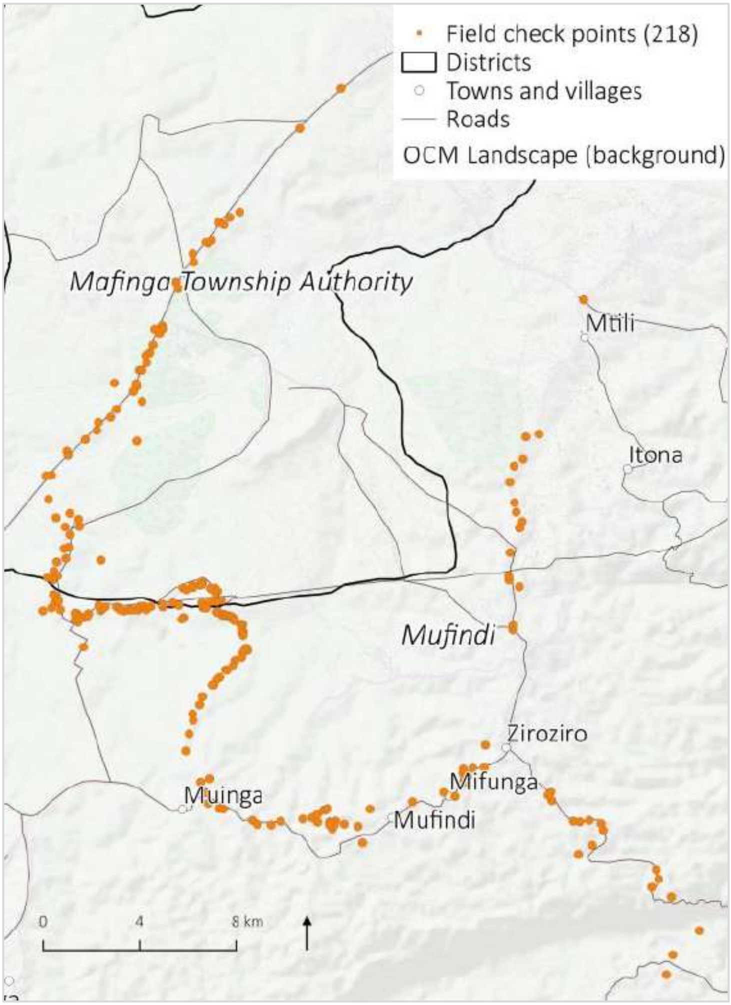
To remove some of the noise from the raster images, the plantation attribute maps (species, age class and density class) were slightly generalised using the threshold 2 and 8-connectedness options of the GDAL Sieve tool (GDAL, 2016) available in QGIS. This tool replaces single raster pixels in a cluster having no same-class neighbours around it with the pixel value of the largest neighbouring cluster of pixels. The tool does not change the class of or remove single pixels without any neighbours. This type of filtering reduces misclassified single pixels, and also improves the visual appearance of the categorical maps.

Figure 12 Sample points for the accuracy assessment (1,800 in total)



The plantation maps were visualised in QGIS for layouts for each district and region using the Atlas mapping tool in the QGIS Print Composer. Area statistics were calculated using the Saga GIS Zonal raster statistics tool in QGIS. The study area district and region polygon layers available from the Tanzania National Bureau of Statistics (NBS, 2012) were rasterised to be used as the zones for which the tool calculates the area of each selected attribute. The company and government plantation polygons provided by the PFP were also rasterised for use in calculations comparing privately owned and commercial plantations.

Figure 13 Field check locations (218 in total)



3. RESULTS

3.1 Forest plantations in the Southern Highlands

3.1.1 Plantation area and ownership

According to the mapping, the plantation area of the Southern Highlands as a whole was 207,000 ha (Table 2). Since the level 2 map, with its greater accuracy, classifies fewer natural forests as plantations, the level 1 tentative plantation area of 418,300 ha declined drastically. However, even the level 2 map probably overlooked some of the small and recently planted plantations because the automated classifier finds it hard to identify them. Thus, the total forest plantation area in the Southern Highlands is likely to be somewhat higher than the mapped coverage.

The fact that more than 70% of the plantation area was located outside the largest government and company-owned plantations suggests that there is significant potential for smaller woodlots (Figure 14, Figure 15). Of the remaining plantations, 10% are company-owned plantations and 17% government-owned. The majority of the forest plantations within the study area are located in the regions of Njombe (89,843 ha) and Iringa (85,918 ha) (Table 2, Figure 16). At the district-level, Mufindi has the most plantation coverage (52,558 ha), followed by Makete (27,696 ha) and Njombe Urban (25,882 ha) (Figure 17).

Table 2 Forest plantation coverage per region (ha)

Region name	Region total area (ha)	Plantations (ha)
Njombe	2,343,413	89,843
Iringa	3,652,373	85,919
Mbeya	6,101,284	24,094
Morogoro	3,200,743	4,205
Dodoma	573,507	1,411
Ruvuma	3,216,429	1,374
Katavi	429,668	52
Singida	755,434	12
Rukwa	266,072	6
Lindi	57,687	0
Tabora	121,572	0
Grand Total	20,718,182	206,916

Figure 14 Plantation ownership and area (ha) by region

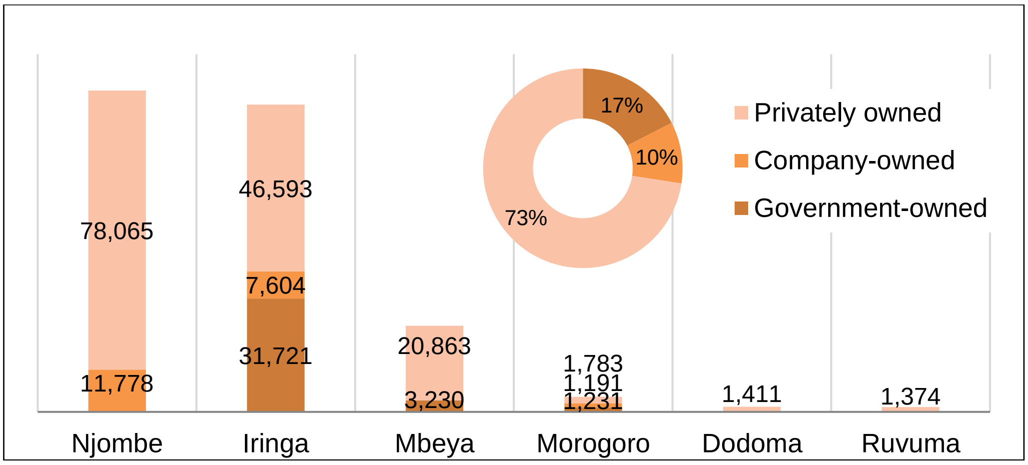


Figure 15 Plantation coverage and ownership in the study area

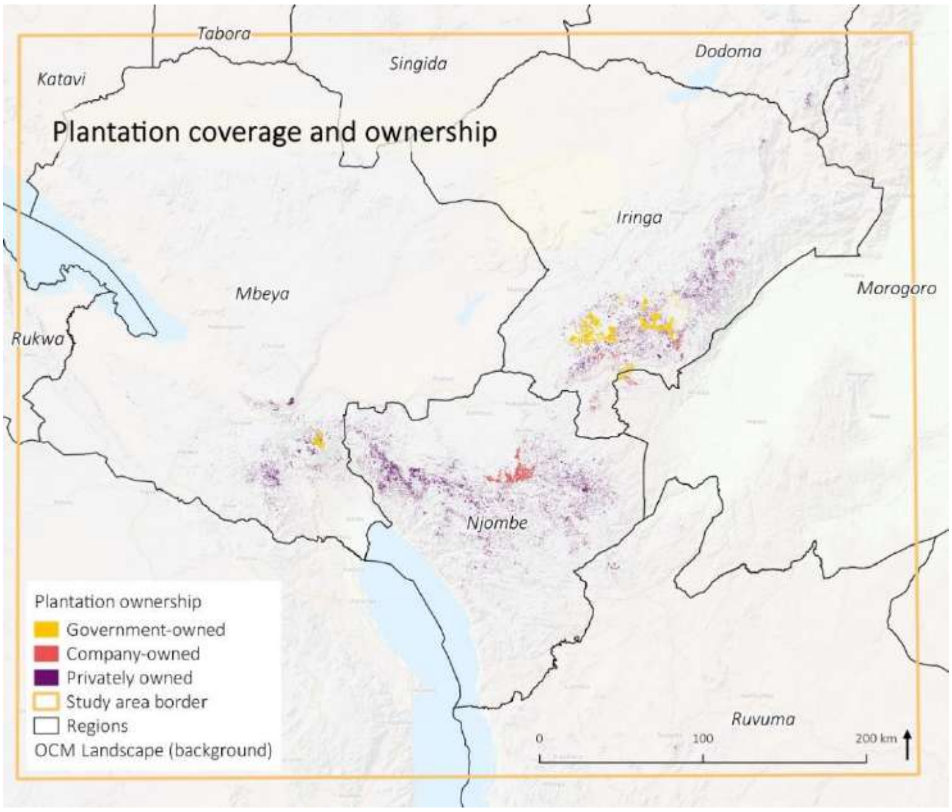


Figure 16 Plantation intensity (ha/km^2) in the study area

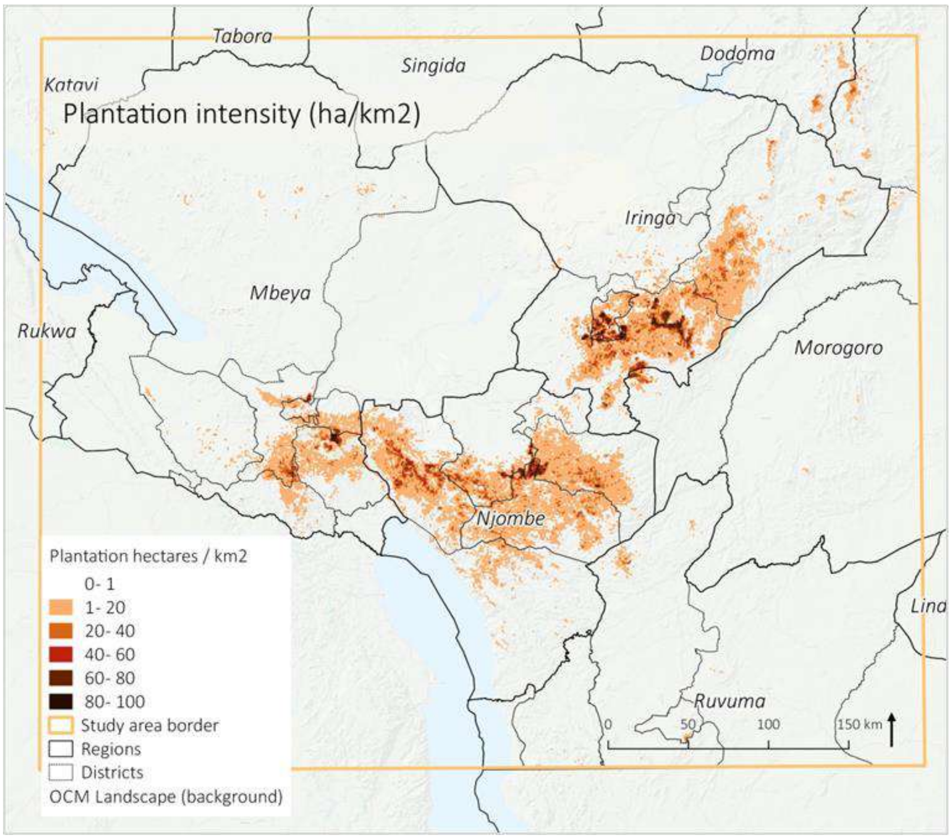
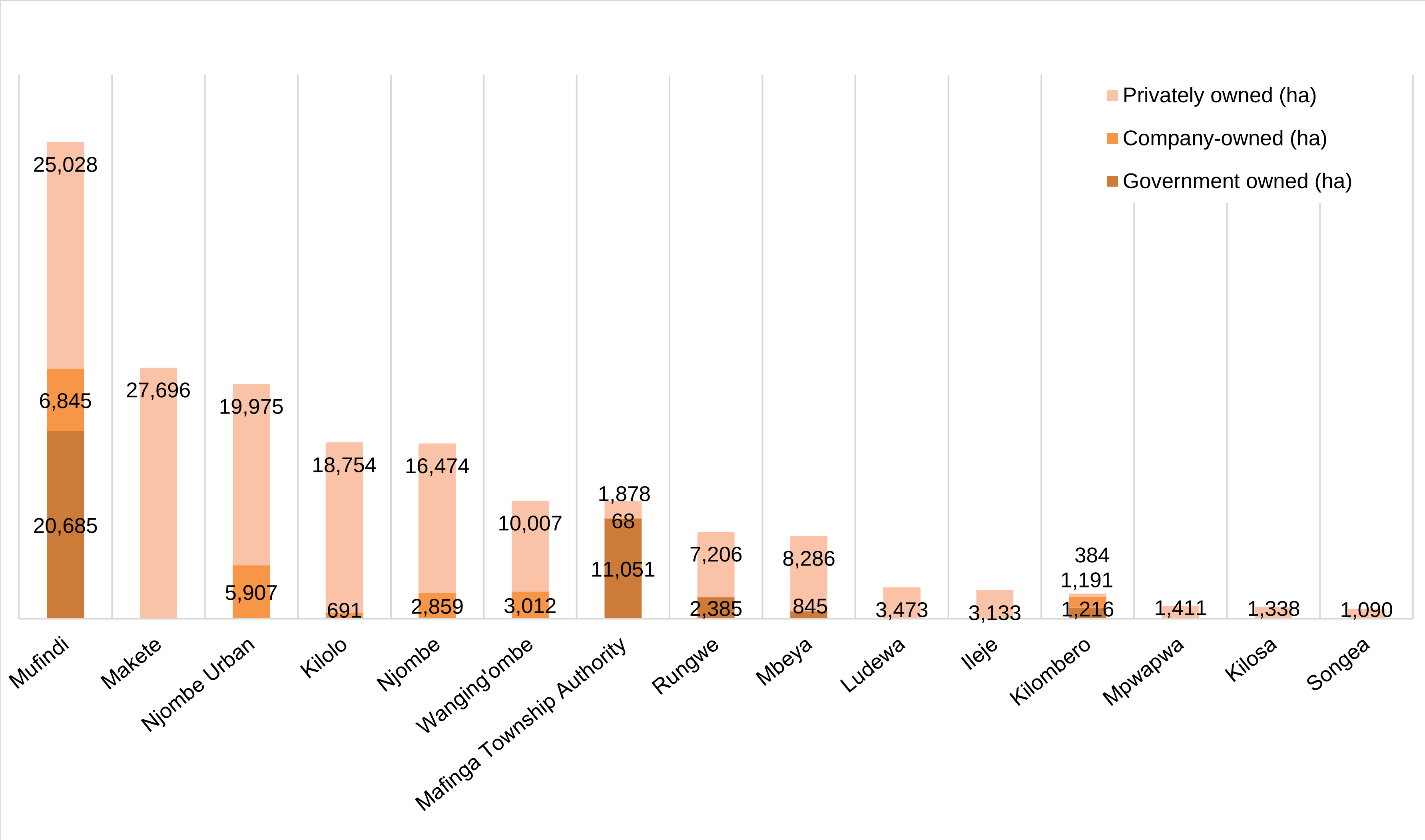


Figure 17 **Plantation coverage and ownership by district (districts with >1,000 ha of plantations)**



3.1.2 Planted species distribution

Pine is the most commonly planted tree species (66%), followed by eucalyptus (19%) and wattle (15%) (Figure 18). Since it is difficult to distinguish between eucalyptus and wattle, the proportions of these two species may not be accurate.

Pine is the dominant tree species in privately owned and government-owned plantations (Table 3), but company-owned plantations have more equal proportions of the different tree species. As for species distribution in the two regions with the greatest plantation areas, Njombe has a bigger share of pine (70%) and wattle (18%) than Iringa (67% and 10% respectively) but only about half the area of eucalyptus (12% and 23% respectively) (Figure 19, Figure 20).

Figure 18 Areas (ha) and proportions (%) of tree species in the study area

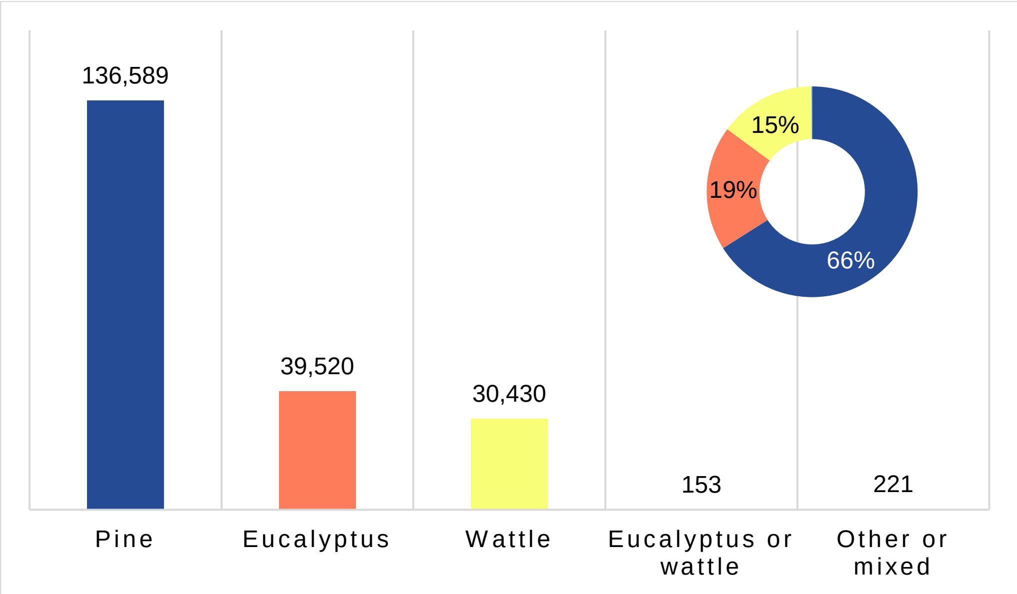


Table 3 Areas (ha) and proportions (%) of tree species by ownership

Ownership	Coverage total (ha)	Pine	Euca	Wattle	Euca or wattle	Other or mixed
Privately owned	150,159	99,218 (66.1%)	28,423 (18.9%)	22,154 (14.8%)	151 (0.1%)	214 (0.1%)
Company-owned	20,573	6,722 (32.7%)	6,423 (31.2%)	7,425 (36.1%)	1 (0.0%)	2 (0.0%)
Government-owned	36,182	30,649 (84.7%)	4,675 (12.9%)	851 (2.4%)	2 (0.0%)	5 (0.0%)
Total	206,914	136,589 (66.0%)	39,520 (19.0%)	30,430 (14.7%)	153 (0.0%)	221 (0.1%)

Figure 19 Tree species planted in Njombe region

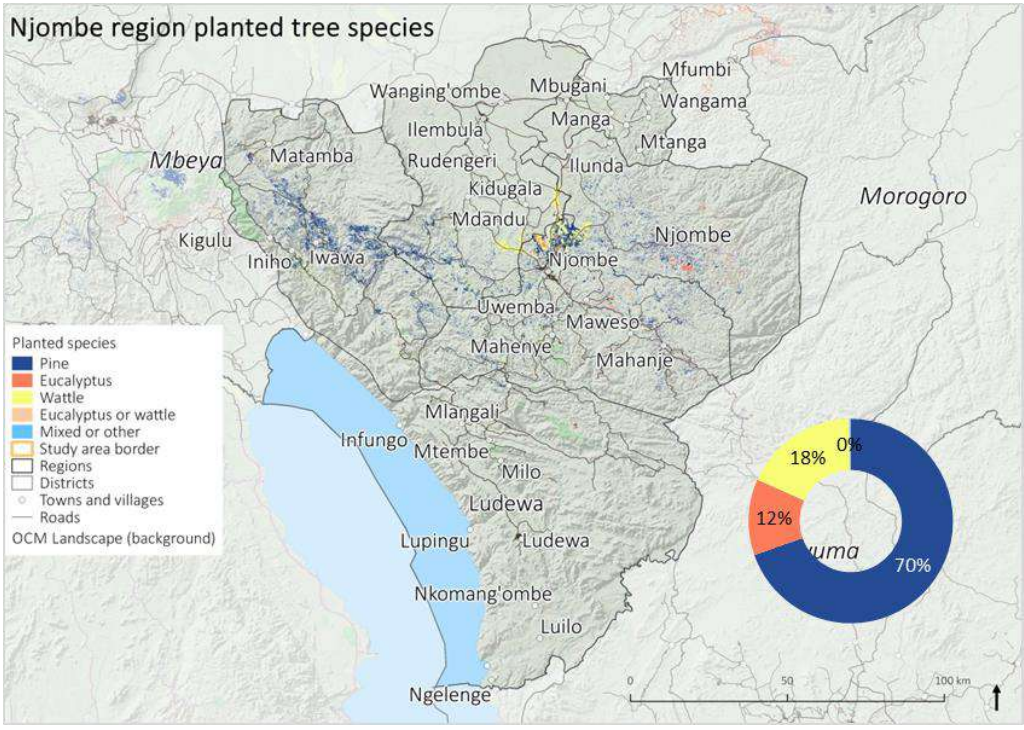
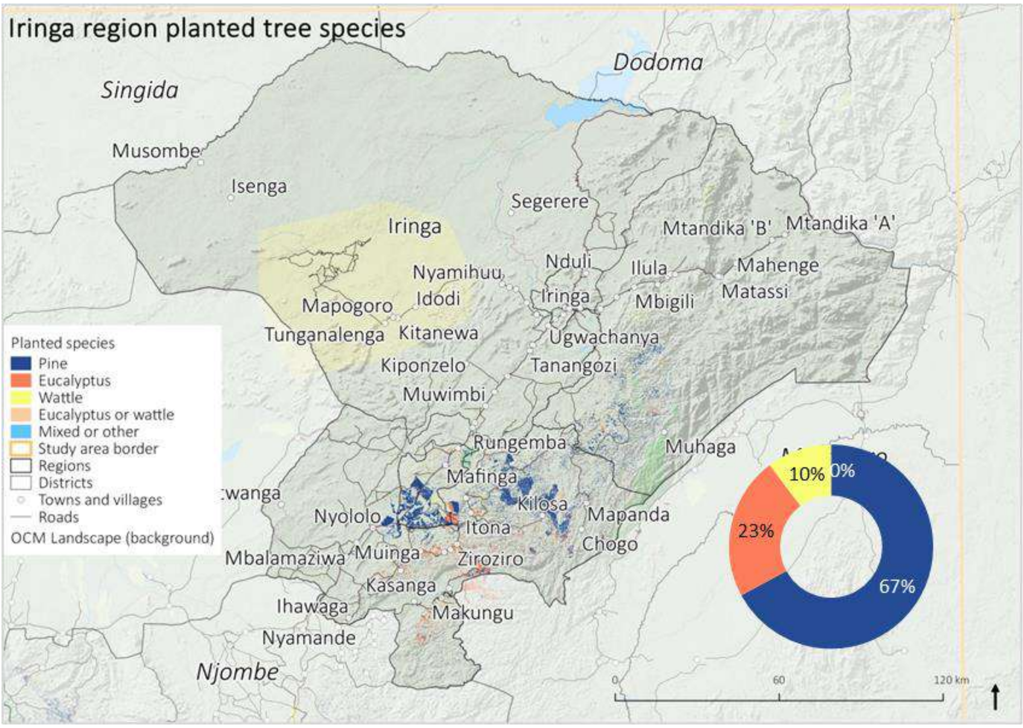


Figure 20 Tree species planted in Iringa region



3.1.3 Plantation age

Three age classes were used in the classification: 'young' (about 0-3 years), 'growing' (about 3–8 years), and 'mature' (more than 8 years old). The age class was determined using visual assessment of the tree size and, in some cases, historical imagery. Most of the study area plantations (59%) fall in the '3–8 years' class (Figure 21). However, this class, as well as the 'more than 8 years' class, may be overrepresented because the automatic classifier misses young woodlots more easily than mature ones.

The proportion of plantations classified as 'more than 8 years' is significantly higher in company- and government-owned plantations (46% and 54% respectively) than in privately owned plantations (28%) (Table 4). In all ownership categories, the proportion of the total area in the youngest (0–3 years) class is very low, not because there are no young plantations but because this class is difficult to classify accurately. For this reason, the coverage given is merely indicative. The proportion of 'more than 8 years' class plantations is slightly greater in Iringa than Njombe region also in part because Iringa has a greater proportion of company and government owned plantations than Njombe does (Figure 22, Figure 23).

Table 4 Approximate plantation age classes by ownership (ha)

Ownership	Coverage total (ha)	0–3 years (ha)	3–8 years (ha)	> 8 years (ha)
Privately owned	150,159	11,493 (7.7%)	96,360 (64.2%)	42,306 (28.2%)
Company-owned	20,573	770 (3.7%)	10,297 (50.1%)	9,506 (46.2%)
Government-owned	36,182	2,035 (5.6%)	14,547 (40.2%)	19,600 (54.2%)
Total	206,914	14,298 (6.9%)	121,204 (58.6%)	71,412 (34.5%)

Figure 21 Plantation age classes in the study area (ha)

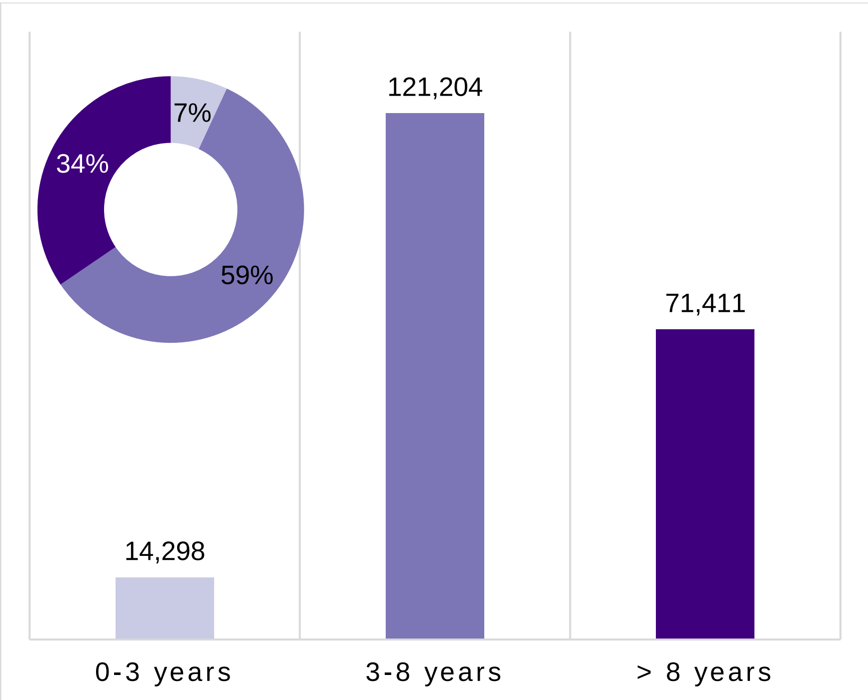


Figure 22 Plantation age classes in Njombe region

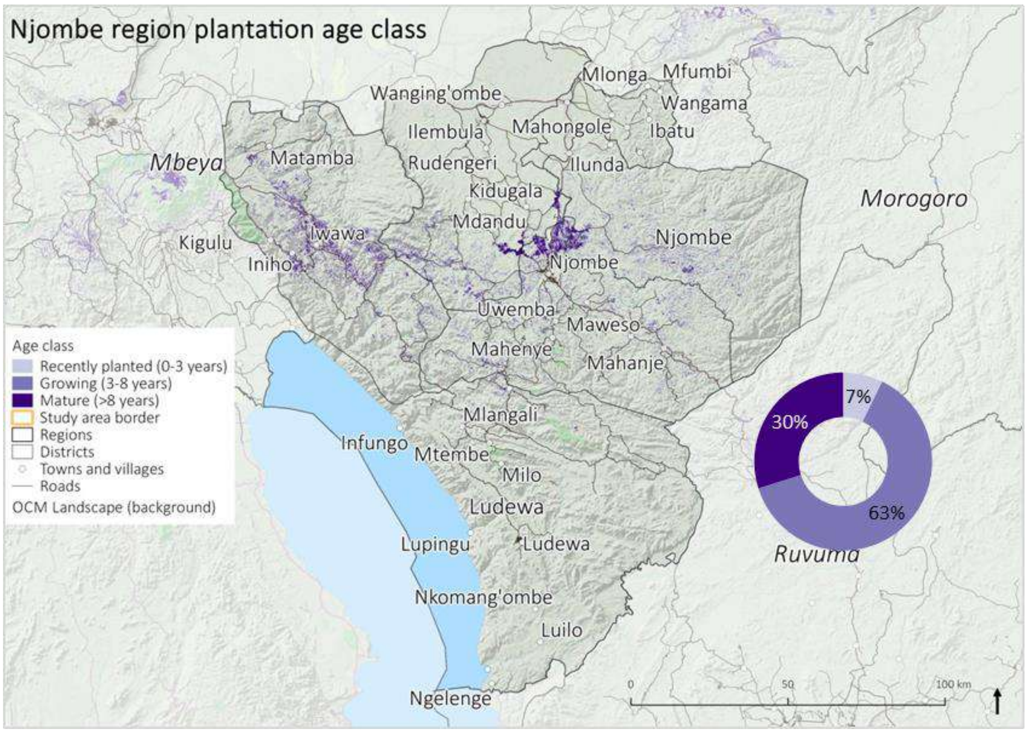
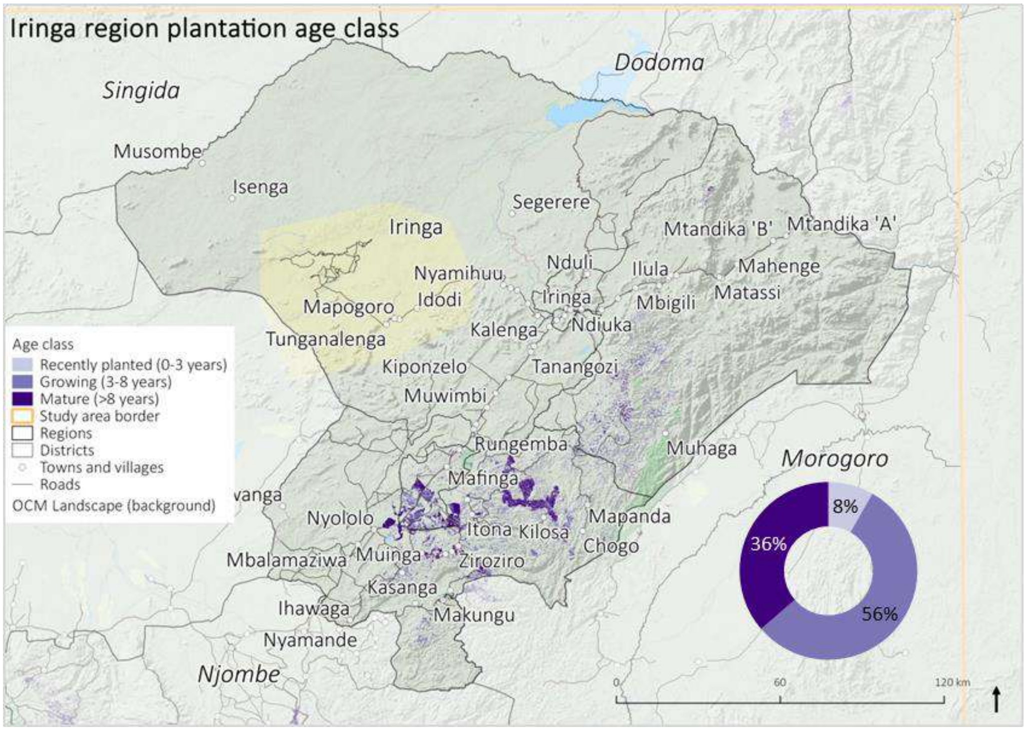


Figure 23 Plantation age classes in Iringa region



3.1.4 Plantation density distribution

The three density classes, 'sparse', 'intermediate', and 'dense,' are approximate as classification was based on visual interpretation of satellite imagery and involved no calculation of trees or use of field data. The classification of density is skewed toward 'dense' because sparse plantations are harder for the classifier to identify than dense ones (Figure 24).

The proportion of dense plantations is greater among company- and government-owned plantations (91% and 85% respectively) than privately owned one (76%) (Table 5). The difference between the two regions with the greatest plantation coverage, Njombe and Iringa (Figure 25, Figure 26) is slight: Iringa has 79% dense plantations and Njombe, 74%.

Table 5 Approximate plantation density classes by ownership (ha)

Ownership	Coverage total (ha)	Sparse (ha)	Intermediate (ha)	Dense (ha)
Privately owned	150,159	2,257 (1.5%)	34,289 (22.8%)	113,614 (75.7%)
Company-owned	20,573	104 (0.5%)	1,796 (8.7%)	18,672 (90.8%)
Government-owned	36,182	354 (1.0%)	5,229 (14.5%)	30,599 (84.6%)
Total	206,914	2,715 (1.3%)	41,314 (20.0%)	162,885 (78.7%)

Figure 24 Proportions of plantation density in the study area (ha)

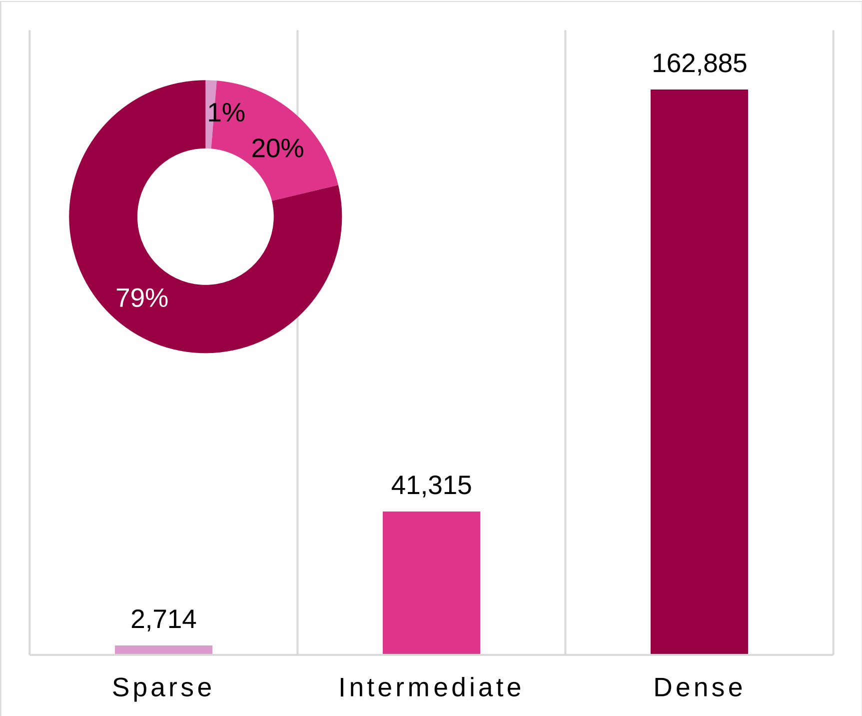


Figure 25 Plantation density classes in Njombe region

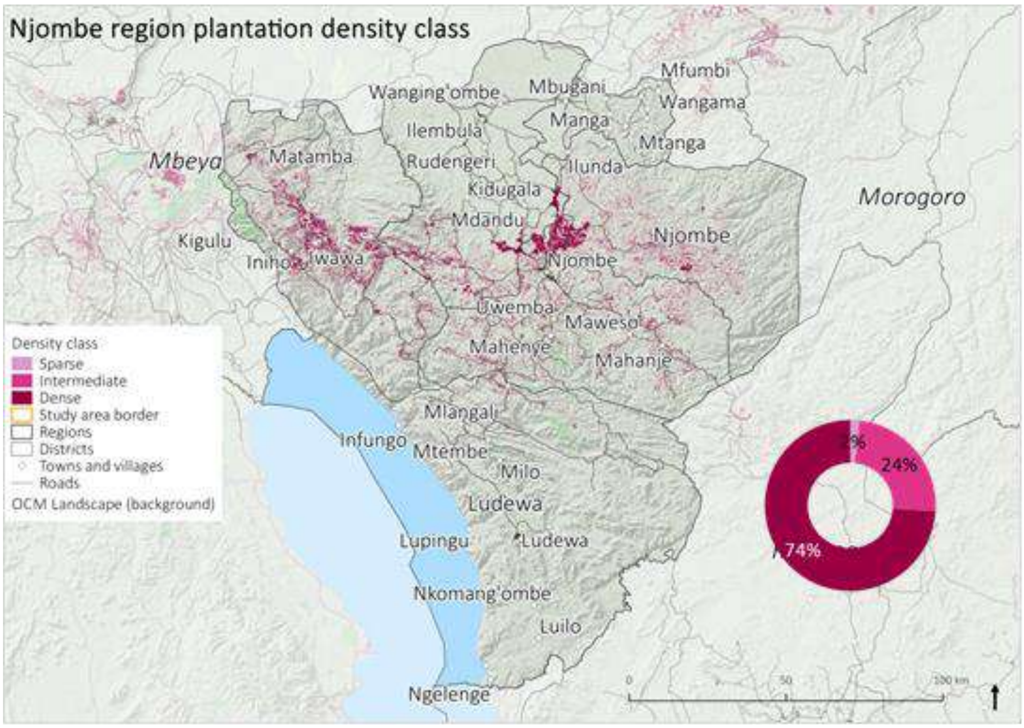
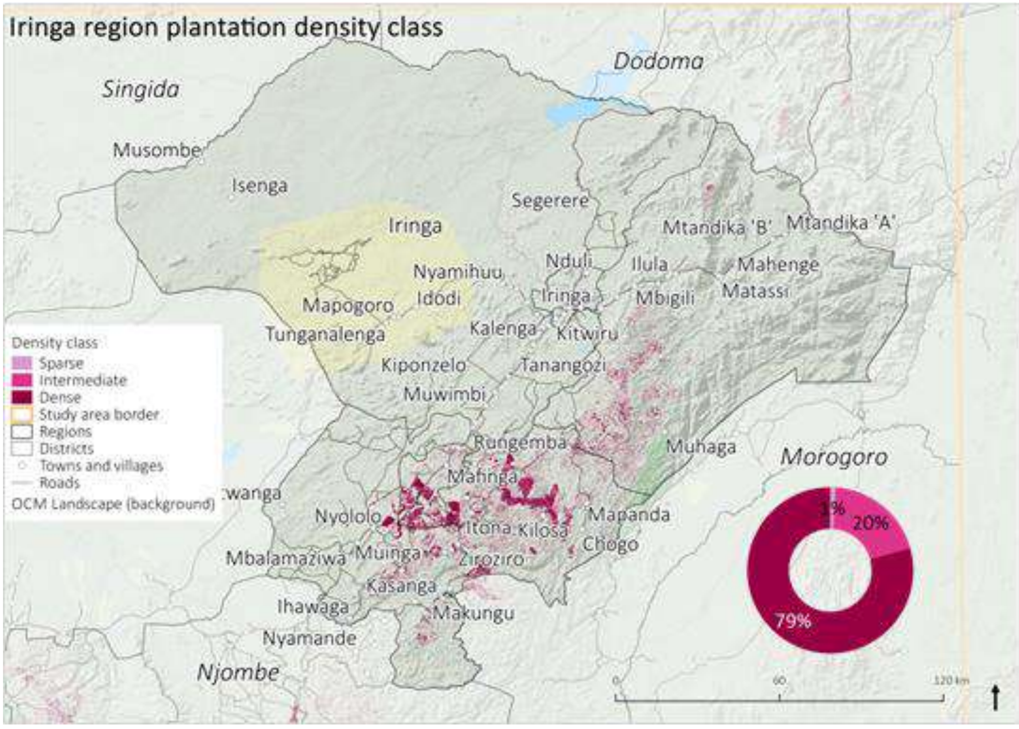


Figure 26 Plantation density classes in Iringa region



3.2 Forest plantations in the pilot areas

The three pilot areas in Kilolo, Njombe and Makete were mapped separately, each using 750 sample points per area, a denser distribution than for the study area as a whole, and 10 m resolution Sentinel-2 data as well as SRTM elevation and slope data (resampled from 30 m to 10 m) (Figure 28, Figure 29, Figure 30). The mapped coverage area differs from that made with 30 m resolution for the whole study area, especially in Makete (Table 6). The accuracies of the estimated plantation areas in Kilolo and Njombe pilot areas improved but that for the Makete pilot area decreased (see section 3.3.2).

Since the pilot areas have only small-scale plantations, mapping them at a higher resolution does give visually better results (Figure 27, Figure 29), but not having other input layers causes some errors. It seems important to include both optical and radar imagery as well as seasonal imagery among the input layers to get reliable results.

Table 6 Forest plantation coverage in the pilot areas

	Total area (ha)	Plantation area in the 10 m map (ha)	Plantation area in the 30 m map (ha)
Pilot area 1: Kilolo	94,879	7,190	9,301
Pilot area 2: Njombe	96,965	6,843	6,899
Pilot area 3: Makete	94,344	5,984	11,203

Figure 27 Difference in visual appearance of the 10 m resolution map (left) and 30m resolution map (right)

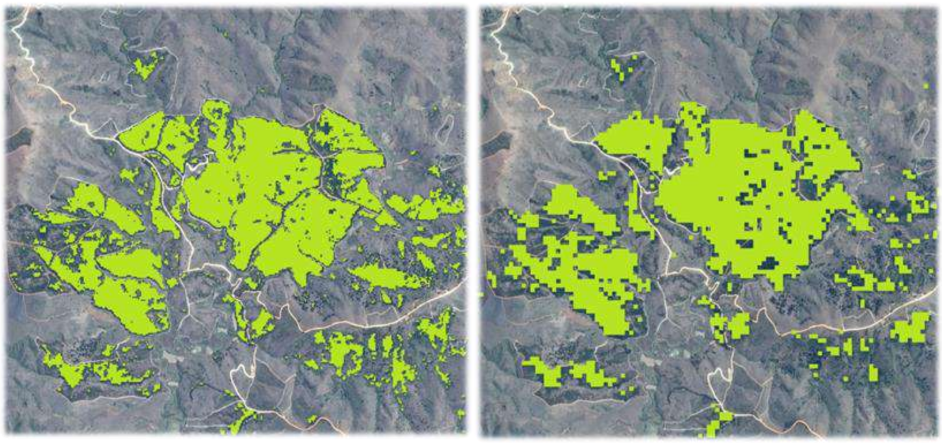


Figure 28 Plantation coverage at 10 m resolution in pilot area 1 in Kilolo

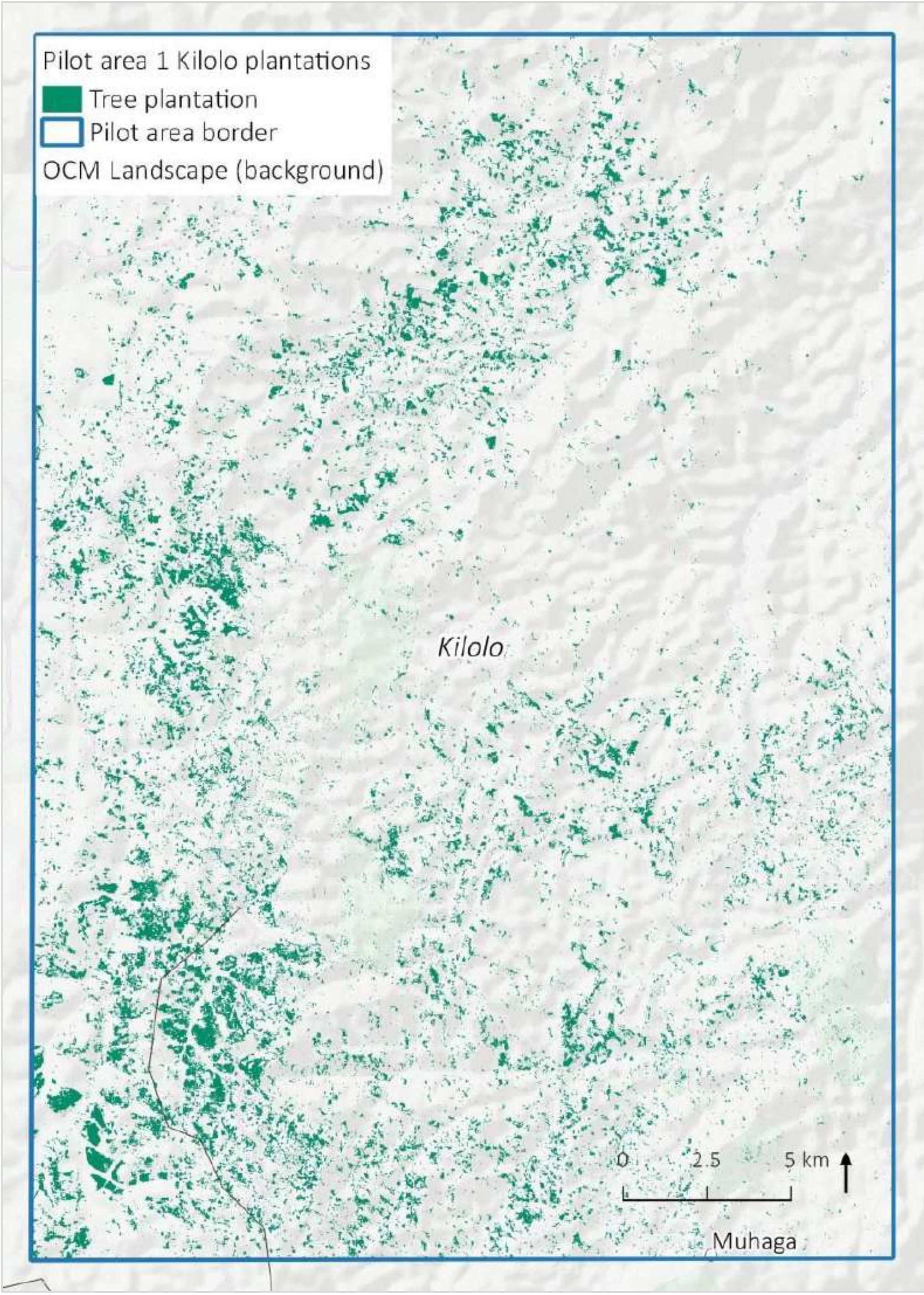


Figure 29 Plantation coverage at 10 m resolution in pilot area 2 in Njombe

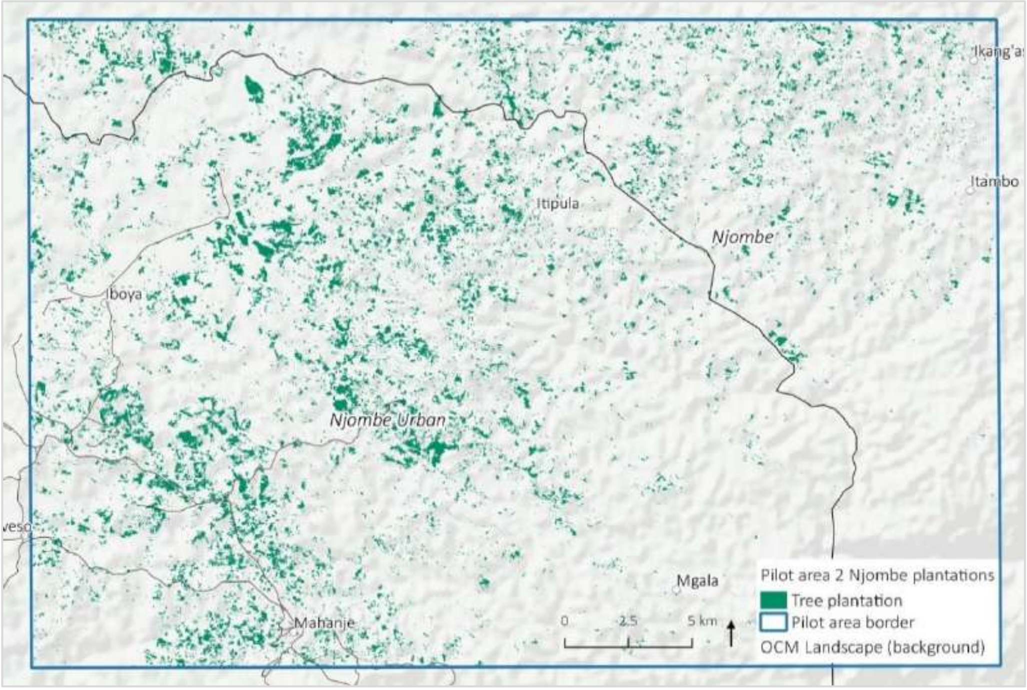
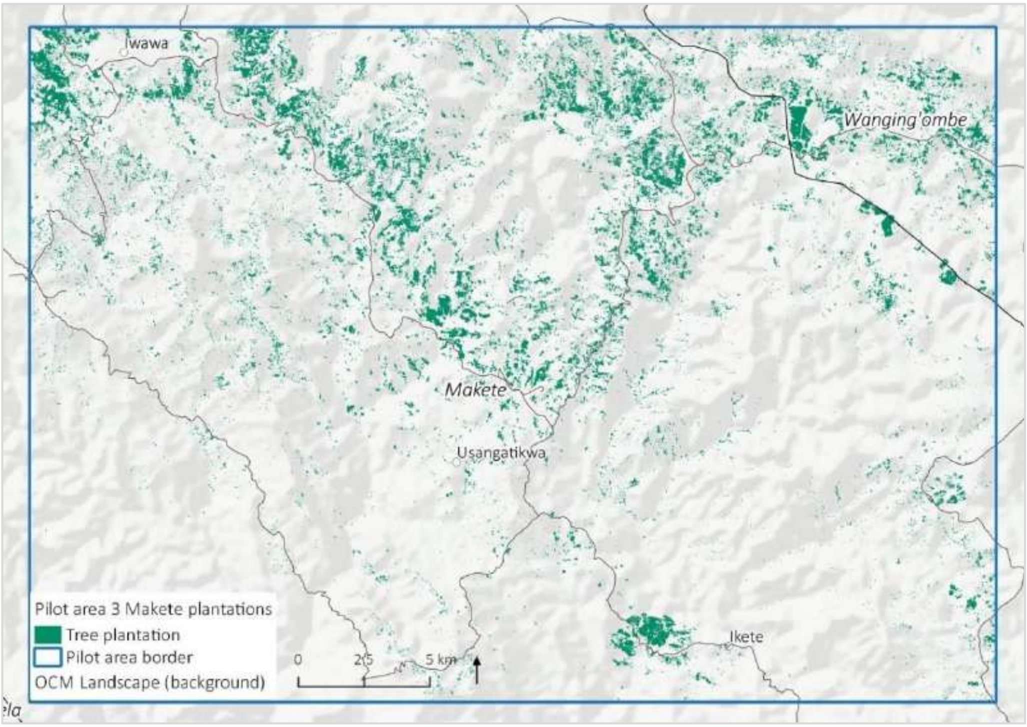


Figure 30 Plantation coverage at 10 m resolution in pilot area 3 in Makete



3.3 Accuracy of the plantation maps

3.3.1 Whole study area map accuracies

The accuracies of the plantation maps were calculated using a set of 1,775 reference points collected by the FAO-UTU expert team from high-resolution imagery. The accuracy parameters derived were overall accuracy (the proportion of all reference sites that were mapped correctly), user's accuracy (the proportion of mapped sites in class 'i' that have reference class 'i') and producer's accuracy (the proportion of sites that have reference class 'j' and also class 'j' on the map) (FAO, 2016).

The estimated overall accuracy of the level 2 plantation area map is 91.5%, slightly greater than that of the level 1 tentative map, 89.6%. Both user's and producer's accuracies were improved in the level 2 map product (Table 7).

Table 7 Accuracy of the whole study area plantation coverage map

Reference	Classification (level 2, Random forest)		Overall estimated accuracy 91.5%	
	Other	Plantation	User's accuracy	Producer's accuracy
Other	1,259	35	97.3%	97.3%
Plantation	116	364	91.2%	75.8%

Reference	Classification (level 1, Cart)		Overall estimated accuracy 89.6%	
	Other	Plantation	User's accuracy	Producer's accuracy
Other	1,246	48	90.2%	96.3%
Plantation	136	344	87.8%	71.7%

The species accuracy was tested with just 218 observations made in the field from alongside the roads in Iringa, Mufindi and Mafinga Township Authority in November 2016 and therefore is only an indicative figure. The team found that the overall accuracy of the species map was just 61% but that the user's accuracies (the probability that a site on the map is also of that class on the ground) for pine and eucalyptus were much higher (91.1% and 88,5% respectively) (Table 8). For wattle and other land-use classes the accuracies are low due to the lack of sample points in these categories. There was no field data for other plantation attributes (age class and density class) available for accuracy assessment at this point.

Table 8 Species map accuracy

Reference	Classification					Overall estimated accuracy 61.2 %	
	Other land use	Pine	Eucalyptus	Wattle	Other for. plantation*	User's accuracy	Producer's accuracy
Other land use	18	1	1	1	0	21.2%	85.7%
Pine	35	69	0	0	0	88.5%	66.3%
Eucalyptus	22	6	41	5	0	91.1%	55.4%
Wattle	10	0	2	3	0	33.3%	20.0%
Other for. plantation*	0	2	1	0	0	0.0%	0.0%

** Includes groups "Eucalyptus or wattle" and "Other or mixed"*

3.3.2 Accuracies of pilot area maps

The accuracy of the pilot areas mapped at a higher resolution (10 m), which was based on a validation made with Collect Earth, ranges between 78.9% and 84.0% (Table 9, Table 10, Table 11). In comparison with the map made of the whole study area at 30 m resolution, the overall accuracy is somewhat higher in the Kilolo and Njombe pilot areas but lower in the Makete pilot area.

Table 9 Accuracy of pilot area 1 (Kilolo) plantation coverage maps

Reference	Classification (pilot area map, 10 m)		Overall estimated accuracy 84.0%	
	Other	Plantation	User’s accuracy	Producer’s accuracy
Other	145	15	87.3%	90.6%
Plantation	21	44	74.6%	67.7%

Reference	Classification (whole study area map, 30 m)		Overall estimated accuracy 80.9%	
	Other	Plantation	User’s accuracy	Producer’s accuracy
Other	148	12	82.7%	92.5%
Plantation	31	34	73.9%	52.3%

Table 10 Accuracy of pilot area 2 (Njombe) plantation coverage maps

Reference	Classification (pilot area map, 10 m)		Overall estimated accuracy 78.9%	
	Other	Plantation	User’s accuracy	Producer’s accuracy
Other	155	9	78.3%	94.5%
Plantation	43	39	81.3%	47.6%

Reference	Classification (whole study area map, 30 m)		Overall estimated accuracy 76.8%	
	Other	Plantation	User’s accuracy	Producer’s accuracy
Other	157	7	75.8%	95.7%
Plantation	50	32	82.1%	39.0%

Table 11 Accuracy of pilot area 3 (Makete) plantation coverage maps

Reference	Classification (pilot area map, 10 m)		Overall estimated accuracy 80.8%	
	Other	Plantation	User's accuracy	Producer's accuracy
Other	136	15	81.4%	90.1%
Plantation	31	58	79.5%	65.2%

Reference	Classification (whole study area map, 30 m)		Overall estimated accuracy 81.0%	
	Other	Plantation	User's accuracy	Producer's accuracy
Other	127	25	85.8%	83.6%
Plantation	21	69	73.4%	76.7%

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Cover and distribution of plantation forests in the Southern Highlands

- The total estimated plantation area in the Southern Highlands is 207,000 ha and the overall estimated accuracy of the plantation area map 91%.
- The mapped plantation area (207,000 ha) is likely to be less than the actual area as the automated classification process finds it hard to classify recently established and very small forest plantations.
- The majority of the forest plantations in the Southern Highlands are located in Njombe and Iringa regions. Mufindi, Makete, and Njombe Urban are the districts with the greatest forest plantation coverage.
- The fact that more than 70% of forest plantations are privately owned suggests that, at least in terms of area, smallholder plantations have great potential.
- Approximately 66% of the plantations are pine, 19% eucalyptus and 15% wattle.
- Indicative plantation density and age classes are lower in privately owned forest plantations than in company- and government-owned ones.

4.2 Mapping and monitoring plantation forests using remote sensing

- Mapping forest plantations using remote sensing techniques is more time- and cost-efficient than intensive field studies, which are often not feasible for extensive areas. The fact that automated classification methods based on free geospatial data sets and tools are readily available means that the mapping exercises can be repeated frequently without great effort for monitoring purposes
- Carrying out the mapping exercises every two or three years would allow the Tanzanian government or other interested stakeholders to monitor forest plantation cover. By looking at changes over time, it is easier to estimate plantation age and growth more reliably than looking at a static picture.
- Using a combination of optical and radar imagery and adding seasonal imagery proved to be useful for plantation classification.
- Although collecting data from satellite imagery through participation was fast, it is necessary to use field data to improve the accuracy of local-level mapping. Access to more extensive field data would have improved the results of this mapping exercise.
- Having a group of Tanzanian experts take part in data collection was very valuable for the project because they shared much local knowledge. Identifying plantations and tree species from high-resolution imagery is challenging, and it was very useful for the participants as well as the trainers of the event to learn from the forestry experts about the tree species planted and local planting practices, among other things. The coming plantation mapping events might likely be even more efficient if the groups consist only of forestry experts.
- Mapping accuracy would increase if classification could be done using input data from one year only. Producing such a map may become possible if more cloud-free satellite imagery becomes available.
- For high resolution maps, the Sentinel-2 data available since mid-2015 at 10 m resolution is promising. Combining it with other data layers resampled into the 10 m resolution could be tried in the future.

- Large monoculture plantations were mapped easily but it was challenging to map the heterogeneous study area landscape. In particular, small patchy plantations and very young woodlots are easy to miss. Planted trees can also be mixed up with natural forests.
- Using remote-sensing data alone, it is difficult to distinguish between plantation age and density classes. The methods presented in this report are best suited for mapping plantation cover, distribution and species.
- Because of spatial variations in the natural conditions, such as topography, rainfall, and temperature, it is recommended that future plantation mappings are stratified based on variables like ecoregions, as well as the plantation map data produced in this study.

4.3 Applicability of mapping results to forest plantation planning and management

- As geospatial data on forest plantations in the Southern Highlands has so far been scarce, this estimation of plantation coverage in a map form will help to target forest plantation management and land-use planning activities to specific areas. However, the spatial scale and mapping accuracy does not allow very detailed planning and management allocation. In addition, in areas where plantations are small and scattered across the landscape, the mapping results are prone to spatial errors.
- The plantation mapping data and the maps in particular can be used to identify where plantations are currently concentrated. Such information is of strategic value to large-scale forestry-sector operations since it allows for the identification of potential locations of interest, which then could be refined in the field using, for example, drones and site observations.
- Forest plantation maps and GIS data can help in making various location-allocation decisions: forest industry operations and businesses, designing extension services and fire management, the design of services for the forest industry (roads, electricity, social facilities), and, combined with land availability and ownership information, it could be used to identify new plantation areas.
- Plantation maps, together with road and industry data, may also help the PFP to identify intermediate-level operations between TGAs and the TGA Apex Body.
- In addition to the 30 m x 30 m resolution species maps made, maps showing the spatial variation of plantation intensity at the scale of 1 km x 1 km are useful for comparing different areas and estimating how intensively the land is used for forest plantations in different parts of the Southern Highlands.

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REFERENCES

Akida, A., & Blomley, R. (2007). *Trends in forest ownership, forest resources tenure and institutional arrangements: Are they contributing to better forest management and poverty reduction? Case study from the United Republic of Tanzania.*

FAO. (2015). *Global Forest Resource Assessment 2015 - Desk Reference.* Rome: Food and Agriculture Organization of the United Nations (FAO).

FAO. (2016). *Map Accuracy Assessment and Area Estimation. A Practical Guide.* Rome: Food and Agriculture Organization of the United Nations (FAO).

FAO. (2016). *Open Foris. Free open-source solutions for environmental monitoring*. Retrieved from http://www.openforis.org/

FDT. (2016). *Forestry Development Trust*. Retrieved from http://forestry-trust.org/

GDAL. (2016). *gdal_sieve.py*. Retrieved from http://www.gdal.org/gdal_sieve.html

Google Earth Engine Team. (2015). *Google Earth Engine: A planetary-scale geospatial analysis platform.* Retrieved from https://earthengine.google.com and https://code.earthengine.google.com

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., et al. (2013). High-Resolution Global Maps of 21st-Century Global Forest Change. *Science* (342), 850-853. Data available on-line from: http://earthenginepartners.appspot.com/science-2013-global-forest.

Jarvis, A., Reuter, H., Nelson, A., & Guevara, E. (2008). *Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database*. Retrieved from http://srtm.csi.cgiar.org

Mankinen, U., Koskinen, J., Käyhkö, N., & Pekkarinen, A. (2016). *Remote sensing and participatory based forest plantation mapping of the Southern Highlands, Tanzania.* FAO/UTU.

MNRT. (2015). *NAFORMA. National Forest Reasources Monitoring and Assessment of Tanzania Mainland. Main results.* Ministry of Natural Resources and Tourism.

NBS. (2012). *2012 Population and Housing Census 2012. Shapefiles - level one and two.* Retrieved from http://www.nbs.go.tz/

Ngaga, Y. (2011). *Forest plantations and woodlots in Tanzania.* 1(16): 1-76.

Open Foris. (2016). *Oft-kmeans*. Retrieved from http://www.openforis.org/OFwiki/index.php/Oft-kmeans

Open Foris. (2016). *Accuracy assessment design and analysis tool*. Retrieved from https://github.com/openforis/accuracy-assessment

Ortmann, A. (2015). *Script for creation of cloud-free mosaic and supervised classification of land cover based on Landsat 8 in Google Earth Engine.* Retrieved from https://code.earthengine.google.com/2595a1b8ba53f52714b3f3aba58df29f

Penttilä, J. (2016). *Influence of smallholder woodlot management to tree growth and tree quality. Case study of pine plantations in Iringa and Njombe regions, Tanzania. Master's thesis.* Department of Forest Sciences, University of Helsinki.

PFP. (2015). *Private Forestry Programme – Panda Miti Kibiashara. Programme Document.* Dar es Salaam: Ministry of Natural Resources and Tourism of United Republic of Tanzania and Embassy of Finland.

UTU. (2016). *UTU Tanzania Team*. Retrieved from www.utu.fi/tanzania

Annex 1 Practical guidelines for the plantation mapping

Repeating the plantation mapping

The mapping can be repeated to monitor the changes in plantations. This annex presents step-by-step instructions for classifying satellite imagery to produce plantation maps. More information on the steps of work can also be found in the report section 2 (Materials and methods).

The mapping can be repeated using the data collected in this exercise (2016) in Google Earth Engine. If there is a need to collect a new sample, follow the instructions from chapter 1 (Collecting training data from high-resolution imagery). If however the previous data sets and training data will be used, you can go straight to topic 2 (Producing the plantation maps with satellite image classification).

Note that the tools used in these instructions are examples and also other options are available. The tools used here are all open-source and free of charge.

List of software and tools used in the process:

R (www.r-project.org)

Rstudio (www.rstudio.org)

Open Foris Accuracy Assessment app (https://github.com/openforis/accuracy-assessment)

Open Foris Collect (http://www.openforis.org/tools/collect.html)

Open Foris Collect Earth (http://www.openforis.org/tools/collect-earth.html)

QGIS (http://www.qgis.org)

Google Earth Engine (https://earthengine.google.com, https://code.earthengine.google.com, https://developers.google.com/earth-engine/)

Accounts you need in the process:

You need a **Google account** for Google drive and Google Fusion tables app and **Google Earth Engine Trusted tester access** to be able to use Google Earth Engine Code Editor. Google account can be acquired from https://accounts.google.com. Get the trusted tester access from the **Sign Up** section in the Earth Engine website (https://signup.earthengine.google.com/) and allow some days to a week for the access to be granted. You will then receive an email with instructions for activating your trusted tester account.

The Collect Earth survey creating process requires a **Bing Maps key** if you wish to use Bing Maps alongside Google Earth for data collection. You need a **Microsoft account** for signing in to create they key. The account may be created when signing in to Bing Maps the first time. See the instructions part 1.2 Creating a Collect Earth survey for more information.

1. Collecting training data from high-resolution imagery

1.1 Stratification of a sample

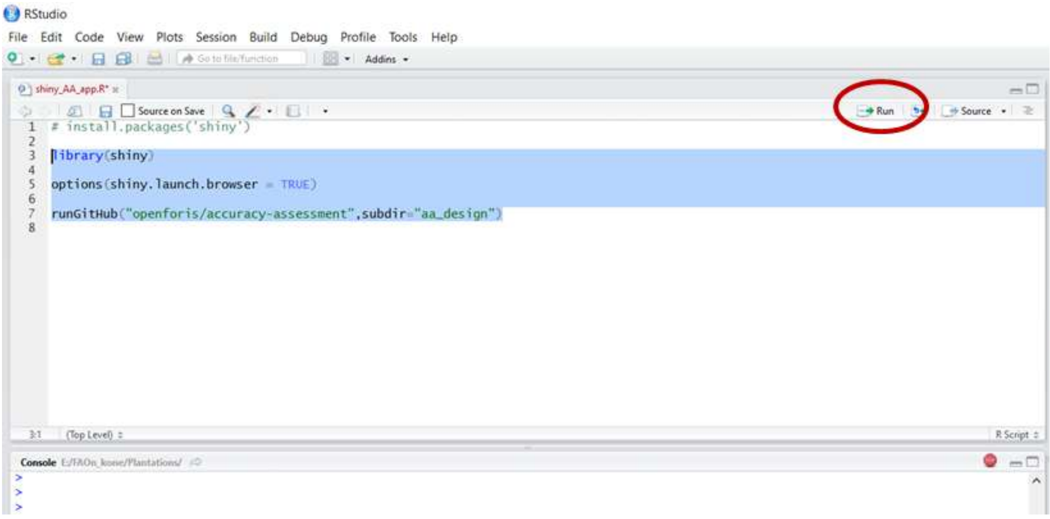
For basic information about sampling, see e.g. FAO report Map Accuracy Assessment and Area Estimation: A Practical Guide (FAO, 2016). The tool used here is originally for map accuracy assessments, but provides an easy way to create a stratified sample for any spatial data collection purpose.

For the stratification of a sample to collect data, you need a **raster image** with numbered classes representing the land cover classes, i.e. strata (e.g. 1=plantation, 2=forest, 3=other). The image should be in **WGS84** (EPSG:4326) coordinate system to work with the tool presented here.

The tool for creating the stratified sample, **Open Foris Accuracy Assessment app** is available from Open Foris Github page (https://github.com/openforis/accuracy-assessment). The app is run in R software. Follow the instructions in the Github page to download **R and R Studio** if needed, **configure** the app and install the **shiny package** for R. After this, start the **Accuracy assessment design app** in R Studio by typing and running the following commands (**select all** and hit **Run** from the top of the script window) (Figure 1):

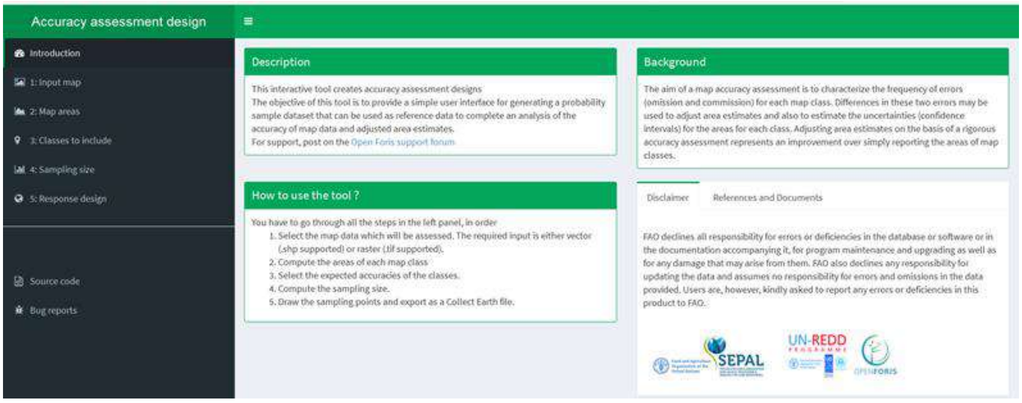
```
library(shiny)
options(shiny.launch.browser = TRUE)
runGitHub("openforis/accuracy-assessment",subdir="aa_design")
```

Figure 1. Studio interface. Type your commands each in their own line in the Script view, then click Run at the top right corner.



The app launches in a web browser window (Figure 2):

Figure 2. The Accuracy Assessment App



Follow the instructions given by the app to select the **Input map** (the raster image with classes that you want to use for the stratification), then calculate the **Map areas** and choose the **Classes to include**. Even though you are not doing an accuracy assessment with your sample, follow the instructions given to select the **expected user's accuracies** of each class (this influences the sample size per strata). Common classes are expected to have higher user accuracies and should be assigned a higher confidence. Plantations are a more rare class, so they can be placed in the lower confidence section. More classes with lower confidence will increase the overall sample size.

In the **Sampling size** section you can adjust the sampling scheme. Depending on the area of interest, tree plantations may cover a fairly small portion of the total area, so you can still manually adjust the sample to be bigger in this class. Use the **Minimum sample size per strata** menu to do this.

Proceed to **Response Design** for downloading the points file for your sample. The app can create the sample as a .csv, .shp or a .cep (Collect Earth) file. Download the data as a csv table to be able to edit it for your own Collect Earth survey.

The edits can be done in any software able to read csv files (e.g. R Studio, Libre Office Calc, Microsoft Excel). For a Collect Earth survey, your csv file column headers should be the following:

id	YCoordinate	XCoordinate	elevation	slope	aspect

Make sure you have these columns in exactly this order (you can delete the extra columns created for accuracy assessment). All the **IDs** need to be **unique** and the coordinates in **WGS84 coordinate system** (automatically will be if you used the Accuracy assessment app). You can also split the csv file into smaller batches if you wish to share it between several participants who collect the data. Also in this case keep the unique IDs. Each file needs the same headers. Save the file(s) in csv (comma-separated) format.

1.2 Creating a Collect Earth survey with Collect

To create a Collect Earth survey for data collection from high-resolution imagery, you need two Open Foris tools: Open Foris **Collect** and Open Foris **Collect Earth**. You can download them and user manuals for each tool at www.openforis.org.

To create the survey template, the tool used is **Collect**. Use **Startup Open Foris Collect** icon to launch the software. Collect will open in the default internet browser which needs to be **Firefox or Chrome** (make sure you have one of the two). Sometimes it takes a while for the software to launch, in which case you get an error such as 'Unable to connect'. In this case reload the page a few times and wait a while. A **Tomcat server** window will also open (black window with the Java logo). Leave this window open while working in Collect.

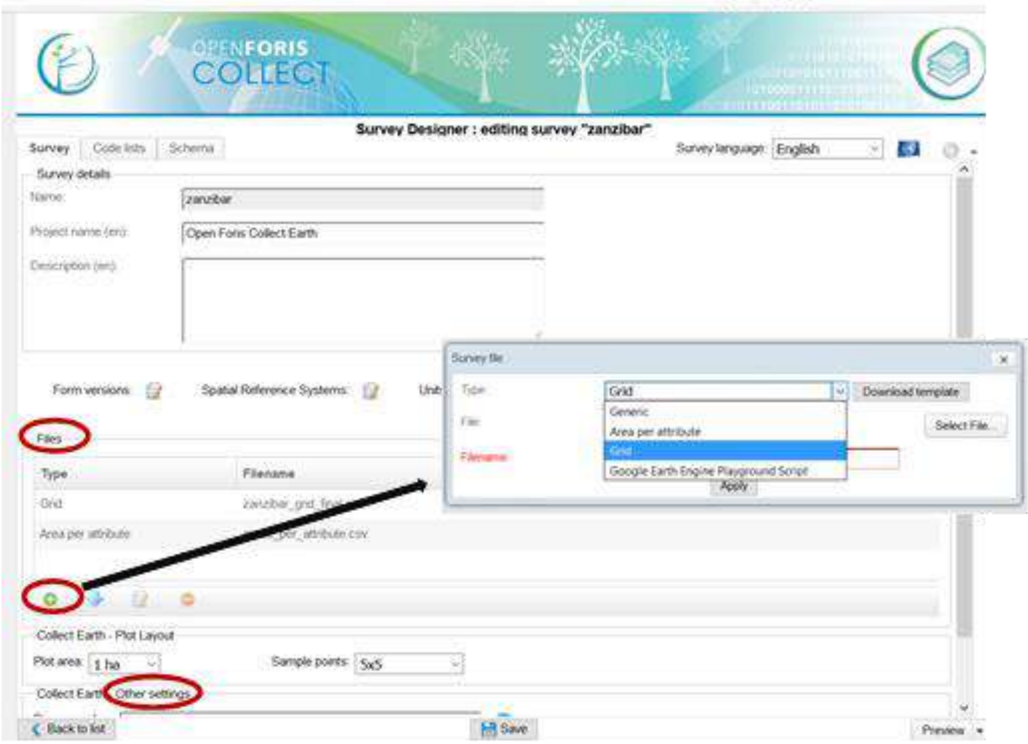
Figure 3. Open Foris Collect Survey Designer

Login with the default **User name** *admin* and **Password** *admin*. Open the **Survey designer** from menu on the right (Figure 3). If you want to create a survey from scratch, this could be done from **New** at the bottom of the screen, naming the survey and selecting **Collect Earth** as the **Template type**. You can however use the ready template used for the previous plantation survey to save time: click **Import** from the bottom of the screen and select the file **plantation_survey_2016.collect** from data package provided. Once uploaded, double-click the imported survey and you will proceed to the tabs where the contents of the survey are defined (Figure 4).

Figure 4. The Collect Survey Designer tabs

On the **Survey tab**, in the **Files** section, click the green plus icon to upload the sampling grid csv file you created in the previous step (Figure 5). File type should be **Grid**. Also other files could be added here (see the Collect user manual for more information). On the same Survey tab, adjust the **plot size** (can be also done later in Collect Earth) and add a **Bing Maps key** in **Other Settings** section, if you wish to use Bing Maps imagery alongside Google Earth. Go to https://www.bingmapsportal.com and login with a **Microsoft account** to do this (you will be directed to create an account if you don't have one). Once logged in, the key can be created under **My Keys** section. Follow the instructions provided in the web site to create the key, copy the **key ID** and paste it onto Collect. You can de-select other pop-up windows (Google Earth Engine) if you are running the software with weak internet connection. These adjustments can however also be changed once working with the survey in Collect Earth.

Figure 5. The Survey tab



On the Code Lists tab you can edit the lists of attributes that the survey uses. If you add or remove some code lists, make sure you update the changes also in the Schema tab, where you define all the objects in your survey. See more information about code lists and the schema in the Collect User manual.

Once the survey is ready, go back to the **Survey Designer** main page and click once to select the survey you want to export. **Export** becomes available at the bottom of the page (Figure 6). **Target** should be **Collect Earth**. The exported file with **.cep** extension (Collect Earth project) will be downloaded into your Downloads folder. You can edit the automatically created .cep file name to something else if you wish.

Figure 6. Exporting the survey

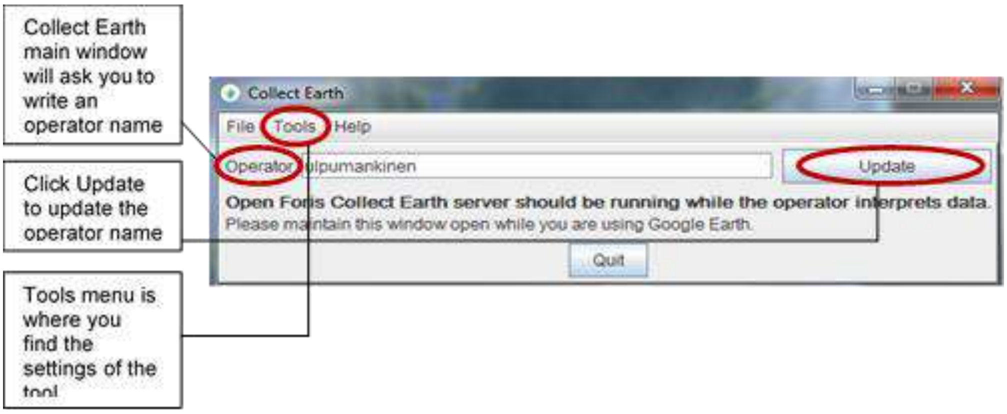
Close Collect browser and Tomcat server windows and use **Shutdown Open Foris Collect** to shut down the program.

Note: if you have different grids for many participants, you may load several separate grids into one project or **clone** your survey by clicking it once in the **Survey Designer** page and going to **Advanced Functions** at the bottom of the page. By selecting **Clone** a copy of the survey will be created and you can replace the grid file with another one. Repeat as many times as needed. This way each participant can have their own cep file, which prevents accidental duplicated data collection.

1.3 Collecting the training data with Collect Earth

The **.cep** file opens in Collect Earth by double-clicking it. When Collect Earth program opens for the first time, it will give you a warning about **Empty operator name:** click OK and proceed to the **Collect Earth main window** to type in an **operator name** (6-50 characters) and click **Update** to save it (Figure 7). The field color changes to white and you can continue. Collect Earth will also automatically launch **Google Earth**.

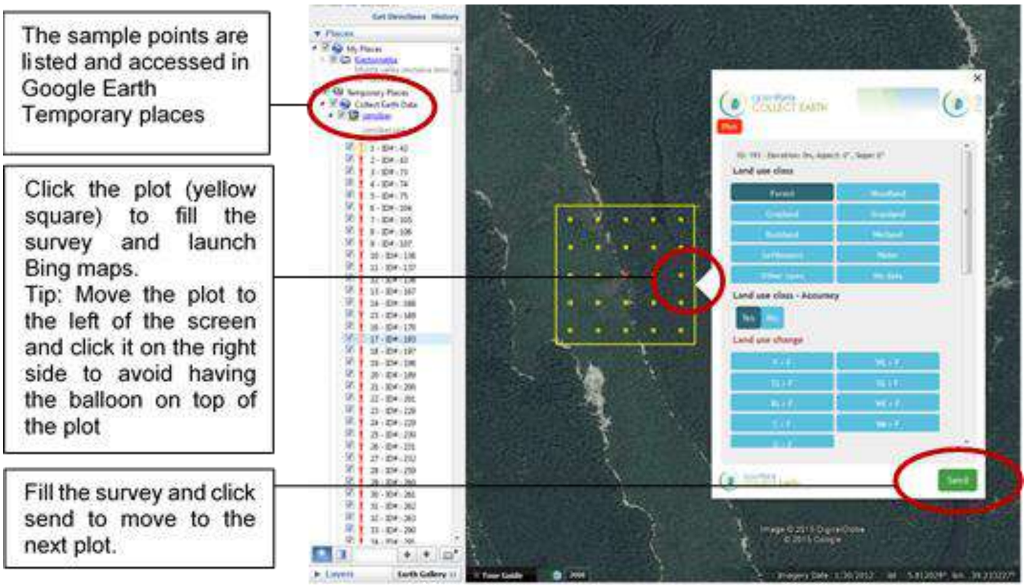
Figure 7. Collect Earth main window



Tips: if you have problems launching your cep file, another way to open your project is to launch Collect Earth, go to **Tools - Properties – Projects – Load a new project file** and select the path to the .cep file. In the **Properties** tabs you can also make other adjustments to the project, e.g. in the **Plot layout** tab change the plot size and number of points inside it. If the pop-up windows (Bing Maps, Google Earth Engine) don't open or you wish to de-select them from opening, go to **Tools - Properties - Advanced** to change the settings. Check which the default browser is and define the path to it if needed.

Google Earth is where the data is collected (Figure 8). However, don't close the small **Collect Earth server** window (Figure 7) while collecting the data. The sample locations from your grid can be found from Google Earth **Temporary places** panel (Figure 8). Expand the **Collect Earth data** under Temporary places to view the list of plots and double-click a plot ID to zoom into it.

Figure 8. Google Earth functions as the data collection platform for Collect Earth



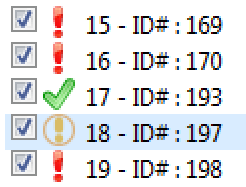
Tips: Minimize the **Tour Guide** at the bottom of the Google Earth screen. In **Layers** menu on the bottom left of the Google Earth window de-select everything but **Borders and Labels** and minimize the menu so you have more space for the Collect Earth data. Also mouse wheel functions as the zoom. Use **CTRL + mouse wheel** to rotate and **SHIFT + mouse wheel** to tilt the view. Adjustments, such as changing Google Earth **fly-to-speed** and **mouse wheel speed** to faster, can be made in **Options** in the top panel. Tick 'Do not automatically tilt while zooming' to see the plot straight from the above when zooming in. Up in the Icon menu you can find the clock icon to view historical imagery which is often useful (Figure 9).

Figure 9. The historical imagery icon in Google Earth

Click inside the yellow plot border to open the survey and launch Bing maps (or also Google Earth Engine, depending what you have defined your survey to use). Fill the survey by clicking through the options in the form. Click **Send** when ready. You will automatically be taken to the next plot (sample point) location (Figure 10).

Figure 10. The sample plots in Google Earth

Red explanation mark next to the plot ID turns to a green tick when a plot has been assessed and data has been saved. When the assessment has been started but not actively saved, the icon is a yellow explanation mark.



Once all data has been collected you can export it from **the Collect Earth window - Tools - Data Import/Export**. Choose **Export data to csv** for exporting into a table format if you wish to do any edits.

Good to know about Collect Earth:

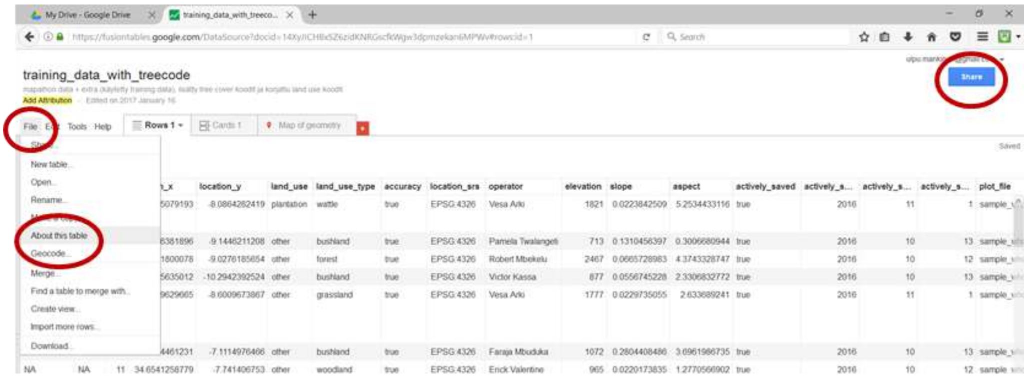
- Once the program is downloaded, the Collect Earth folder is created in C:\OpenForis\CollectEarth
- Whenever you close Google Earth, you don't need to actively save any data; you can select **Discard**.
- All the data generated is automatically saved into a database which can be found from under your own user folder in C:\Users\your_username\AppData\Roaming\CollectEarth
- You can empty this folder to refresh everything in your database and Collect Earth; however make sure you have exported all the data you want to keep before doing this.
- NOTE: If you cannot see the AppData folder, it's hidden and you need to make it visible. Go to Windows Start Menu → Control Panel →search for Folder options →check Show hidden files and folders.

1.4 Load the data file into Google drive

For classification in Google Earth Engine, the data table should have an **integer column** with numbers according to classes used in the classification. Add the column(s) and make any other edits using software of your choice (e.g. R Studio, LibreOffice Calc, Microsoft Excel). You can also remove the 'No data' observations and unsure observations if you have used an interpretation confidence yes/no question in your survey. When all edits are ready, change the file format to **Fusion table** e.g. in QGIS (open the csv file in QGIS – choose **Save as** - **Fusion table**).

Load the **Fusion table** into your **Google Drive** (drive.google.com) using the **Fusion tables app** available from **Google drive** – **New** – **More** – **Connect more apps**. Once you have the app, use **New – More – Google Fusion Tables** to upload the table onto your Drive. Change the sharing settings from the top right corner **Share** button to **On-Anyone with the link can view** (Figure 11). Copy the Fusion table ID from **File – About this table** for use in Google Earth Engine. The ID code is also in the web address of the Fusion table (a sequence of numbers and letters after **docid=** such as docid=**16XyJICHBxSZ6zidKNRGscfkWgw3dpmzekan6MPWg**).

Figure 11. Google Fusion table. Change the sharing settings and find the table ID



2. Producing the plantation maps with satellite image classification

2.1 The classification process in Google Earth Engine

The classification of satellite imagery is done in **Google Earth Engine Code editor** (Figure 12). For using it you need the Earth Engine **trusted tester access**, so sign up (https://signup.earthengine.google.com/) and wait for the email of acceptance which might take some days.

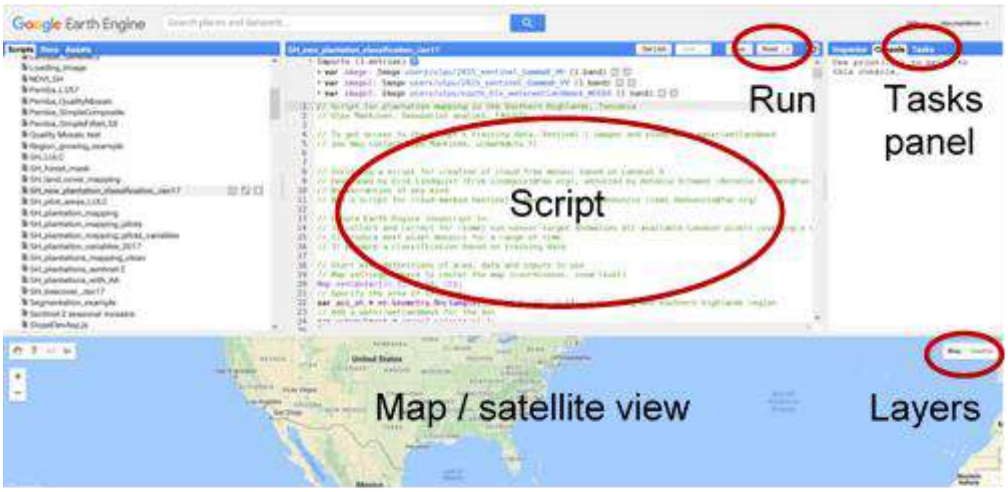
There is a ready script for the classification of satellite imagery available at:

https://code.earthengine.google.com/5194f24510b61abce7767783a22d568b

If you wish to have access the Sentinel-1 mosaics and study area mask that the script uses, **ask for the access at uimank@utu.fi.** These data sets are uploaded into Google Earth Engine as assets so they can't be used without the owner sharing them to you and you get an error when running the script.

For general information and tutorials about the Earth Engine code editor, go to https://developers.google.com/earth-engine.

Figure 12. The Google Earth Engine Code Editor



The script defines the input data and training data for supervised classification using Random forest classifier. For information about supervised classification in Google Earth Engine, visit https://developers.google.com/earth-engine/classification.

In Google Earth Engine script, any line starting with // is a comment line, and not part of the script. See the comments for help and where each part of the script (1-14) described below is located.

Stage 1

The first stage of the script classifies the plantation area and second one the specified plantation attribute.

Part 1. Defines the area of interest. The variable (var) 'aoi_sh' is a rectangle with corner coordinates which can be adjusted if the mapped area should be changed.

Part 2. Adds the Sentinel-1 images and the study area water/wetland mask which are uploaded as assets into Google Drive (the script does not create these on the fly like other input layers). Note: you need to ask for permissions to use the files from uimank@utu.fi, otherwise the script won't run.

Part 3. Adds the SRTM elevation model and calculates slope based on it.

Part 4. Creates the Landsat-8 mosaic. This part of the script is fairly long, since corrections are done to the input imagery and the mosaics are created for two seasons (wet and dry). The script creates a best-pixel mosaic based on the target day of year, pixel temperature and wetness. The parameters that can be changed in this part of the script if wanted are:

- The range of dates to filter imagery to use. Note that several years of data usually need to be used in the Southern Highlands area for cloud-free mosaics.
- The time frames for which the seasonal mosaics are built. The days are given as julian days of the year.
- The target julian day of the year to create the mosaic (choice can be made based on e.g. least clouds and most vegetation)
- The cloud cover accepted for the input imagery can be adjusted.

```
// Create a range of date to filter imagery to use
var t1start = '2013-01-01';
var t1end = '2015-12-31';

// Which days of the year to use? season 1 = beginning of the year, rain season
var julianDayStart_seas1 = 0;
var julianDayEnd_seas1 = 200;

// Which days of the year to use? season 2 = end of the year, dry season
var julianDayStart_seas2 = 200;
var julianDayEnd_seas2 = 305;

// Target day for each mosaic; least cloudy / with most vegetation during the time
period
var targetday1 = 180; // season 1
var targetday2 = 260; // season 2

// Which cloud cover is accepted? 90 will look at any imagery up to 90% cloud
cover
// A higher threshold will include more imagery
var cloudcovthres = 80;
```

The function ADD QUALITY BAND FOR LANDSAT-8 should not be changed. This function corrects for the latitudinal component of sun-sensor-target geometry per pixel (landsat.usgs.gov/Landsat8_Using_Product.php) and creates the weight band for a best-pixel mosaic. At the end of the Landsat-8 part of the script, ratios of the bands are also calculated.

Part 5. Adds the Sentinel-2 mosaic. The function adds a cloud mask to create a cloud-free mosaic using Sentinel-2 imagery for specified time range. You can change the time range of the input imagery in the DateFilter line. With Sentinel-2, a shorter time range compared to Landsat should be enough for creating a cloud-free mosaic due to high revisit time of the satellite.

```
// Create a range of date to filter imagery to use (Sentinel-2 was launched June 2015)
var DateFilter = ee.Filter.date('2015-06-01', '2016-12-31');
```

Part 6. All the layers are stacked.

Part 7. The training data set is defined. The training data needs to be a Google Fusion table format. The ID of the fusion table acts as the identifier (in this example 14XyJICHBxSZ6zidKNRGscfkWgw3dpmzekan6MPWv):

```
 var training_data =
ee.FeatureCollection("ft:14XyJICHBxSZ6zidKNRGscfkWgw3dpmzekan6MPWv")
.filterBounds(aoi_sh);
```

Part 8. The classification. First, all the inputs (training data, training column, and input image stack) are defined. Then the classifier is trained using the specified inputs, and Random forest classifier is used for the classification. The image is masked with the water/wetland mask after this, to have 0 values in water areas.

Part 9. Creates a table to export for creating an error matrix for accuracy assessment of the plantation area map created. You can run the script with different parameters and just export the accuracy table first to find the best settings, input layers and classifier before exporting the actual image mosaic. The validation data needs to be a Google Fusion table. The best option would be to use field data as validation data.

Stage 2

The second stage of the script classifies the plantation attributes (species, age class, density class). The same imagery is being used for classification, so only the training data differs from the first round of classification.

Part 10. Defines the plantation attribute training data (Fusion tables). There are separate files for each attribute. The training data should have numerical classes for the attribute classes, and the data should be filtered so it has no observations without the attribute information in question (only plantation observations with valid values for species/age/density, no ‘no data’).

Part 11. The plantation attributes classification. Training data, training column, and input image stack are defined for each attribute. The image stack used in stage 1 is being masked with the plantation area. This way the classification will only happen for the plantation areas.

Part 12. If you have a validation data set for the plantation attributes (species, age class, density class), you can un-comment and modify this section for creating a validation table.

Part 13. Each line with command Map.addLayer adds map layers in the Map view. Note that if the end of the line states 'false', the layer is not automatically appearing into the view (this would make running the script slow). You should go to Layers panel in the map view to see all layers available and tick those visible you wish to view. The layers include the input layers created in GEE (Landsat-8 and Sentinel-2 mosaics) and classification outputs. Note: for large areas the classification output is often too heavy for display and will fail. The exporting is however possible.

Part 14. Exporting: it is advisable to export just one layer at a time because each layer will have 30 tiles, and having all of them exporting at the same time is not possible in terms of computing-power. At the beginning, define the image you wish to export by un-commenting its line and leaving other options commented. This example has the plantation area image selected (other layers are commented out):

```
// Selecting the image to export; uncomment the line you want to use
// Plantation area
var export_image = classimg_all;
// Species
// var export_image = species_classimg_all;
// Age class
// var export_image = age_classimg_all;
// Density
// var export_image = density_classimg_all;
```

Next, define the name for the tiles to export, the CRS (in EPSG format) and resolution (pixel size in meters) to use:

```
// The beginning of the name to give the tiles to export (will have the tile number
//added)
var image_name = 'plantations_RF150_36S_';
// The CRS to use (EPSG code)
var crs = 'EPSG:32736';
// scale to export in meters
var scale = 30;
```

Click the 'Run' icon at the top of the script window to start running the script. Once the script is run, all the files to export will appear in the Tasks panel in the right. Click Run icons next to the tiles to start exporting the files to your Google Drive. Unless you specify a Drive folder to export to, the exports will be downloaded to your root folder in Google Drive. Note that despite the high computing power of Google Earth Engine, the exporting takes a long time and sometimes will fail if you have too many processes running at the same time. Try downloading some 10 tiles at a time to avoid this.

2.1 Merging the map tiles and refining the data sets for layout production

Once the tiles have been downloaded, merge them into a mosaic using e.g. the 'Build virtual mosaic' tool (gdalbuildvrt) in QGIS under Raster Menu / Miscellaneous. Then clip to extent you want to use with Clipper tool in QGIS Raster menu. Don't use the 'Crop the extent of the target dataset to the extent of the cutline' (crop_to_cutline) option of the tool so you don't accidentally resample the raster when cropping.

Visualize the results in QGIS or other GIS software to see how the end result looks. If you wish, the results can be generalized to remove some noise from the pixel mosaic using e.g. Sieve tool available in QGIS under Raster – Analysis. The Atlas Map creation tool in QGIS Print Composer is useful for automating the creation of maps for each feature of e.g. a district shapefile.

Annex 2 Region level plantation statistics

Table 2.1 Plantation area and ownership in study area regions (ha)

Region name	Region total area (ha)	Rank (in plantation area)	Plantations (ha)	Privately owned (ha)	Company-owned (ha)	Government-owned (ha)	NBS ID
Njombe	2,343,413	1	89,843	78,065	11,778	0	22
Iringa	3,652,373	2	85,919	46,593	7,604	31,721	11
Mbeya	6,101,284	3	24,094	20,863	0	3,230	12
Morogoro	3,200,743	4	4,205	1,783	1,191	1,231	5
Dodoma	573,507	5	1,411	1,411	0	0	1
Ruvuma	3,216,429	6	1,374	1,374	0	0	10
Katavi	429,668	7	52	52	0	0	23
Singida	755,434	8	12	12	0	0	13
Rukwa	266,072	9	6	6	0	0	15
Lindi	57,687	10	0	0	0	0	8
Tabora	121,572	11	0	0	0	0	14
TOTAL	20,718,183	n/a	206,914	150,159	20,573	36,182	n/a

Table 2.2 Plantation species share in study area regions (ha)

Region name	Plantations total (ha)	Pine (ha)	Eucalyptus (ha)	Wattle (ha)	Eucalyptus or wattle (ha)	Other or mixed (ha)
Njombe	89,843	62,540	10,824	16,228	78	172
Iringa	85,919	57,647	19,453	8,766	35	19
Mbeya	24,094	14,676	5,642	3,724	39	12
Morogoro	4,205	578	2,801	818	0	7
Dodoma	1,411	470	39	891	1	10
Ruvuma	1,374	622	748	3	0	0
Katavi	52	44	8	0	0	0
Singida	12	9	2	0	0	0
Rukwa	6	3	2	1	0	0
Lindi	0	0	0	0	0	0
Tabora	0	0	0	0	0	0
TOTAL	206,914	136,589	39,520	30,430	153	221

Table 2.3 Plantation approximate age class share in study area regions (ha)

Region name	Plantations total (ha)	0–3 years (ha)	3–8 years (ha)	> 8 years (ha)
Njombe	89,843	6,495	56,504	26,845
Iringa	85,919	7,073	47,639	31,207
Mbeya	24,094	461	13,351	10,282
Morogoro	4,205	163	2,369	1,672
Dodoma	1,411	9	459	943
Ruvuma	1,374	95	825	454
Katavi	52	1	46	5
Singida	12	2	7	3
Rukwa	6	0	4	2
Lindi	0	0	0	0
Tabora	0	0	0	0
TOTAL	206,914	14,298	121,204	71,411

Table 2.4 Plantation approximate density class share in study area regions (ha)

Region name	Plantations total (ha)	Sparse (ha)	Intermediate (ha)	Dense (ha)
Njombe	89,843	1,607	21,824	66,412
Iringa	85,919	906	16,804	68,208
Mbeya	24,094	162	2,159	21,772
Morogoro	4,205	29	235	3,941
Dodoma	1,411	1	92	1,317
Ruvuma	1,374	9	197	1,167
Katavi	52	0	0	52
Singida	12	0	1	11
Rukwa	6	0	1	5
Lindi	0	0	0	0
Tabora	0	0	0	0
TOTAL	206,914	2,714	41,315	162,885

Annex 3 District level plantation statistics

Table 3.1 Plantation area and ownership in study area districts (ha)

District name	District total area (ha)	Rank (in plantation area)	Plantations (ha)	Privately owned (ha)	Company-owned (ha)	Government-owned (ha)	NBS ID
Mufindi	752,031	1	52,558	25,028	6,845	20,685	36
Makete	399,480	2	27,696	27,696	0	0	51
Njombe Urban	354,348	3	25,882	19,975	5,907	0	16
Kilolo	926,546	4	19,445	18,754	691	0	73
Njombe	345,010	5	19,333	16,474	2,859	0	79
Wanging'ombe	343,700	6	13,018	10,007	3,012	0	44
Mafinga Township Authority	57,290	7	12,997	1,878	68	11,051	95
Rungwe	215,365	8	9,591	7,206	0	2,385	80
Mbeya	281,088	9	9,131	8,286	0	845	33
Ludewa	812,682	10	3,473	3,473	0	0	94
Ileje	187,897	11	3,133	3,133	0	0	93
Kilombero	857,029	12	2,792	384	1,191	1,216	147
Mpwapwa	352,722	13	1,411	1,411	0	0	35
Kilosa	442,111	14	1,338	1,338	0	0	148
Songea	1,029,814	15	1,090	1,090	0	0	42
Iringa	1,879,806	16	931	931	0	0	6
Mbeya Urban	25,236	17	885	885	0	0	140
Mbozi	385,462	18	603	603	0	0	117
Chunya	2,997,529	19	566	566	0	0	3
Makambako Township Authority	88,375	20	440	440	0	0	116
Songea Urban	59,689	21	166	166	0	0	82
Mbarali	1,443,451	22	153	153	0	0	133
Mbinga	312,587	23	91	91	0	0	54
Ulanga	1,902,058	24	59	59	0	0	86
Mlele	429,835	25	52	52	0	0	151
Kyela	75,543	26	25	25	0	0	50
Namtumbo	1,357,613	27	22	22	0	0	100
Manyoni	755,680	28	12	12	0	0	52
Momba	481,426	29	7	7	0	0	142
Nyasa	116,061	30	6	6	0	0	122
Sumbawanga	231,000	31	4	4	0	0	43
Iringa Urban	36,963	32	3	3	0	0	46
Kalambo	35,134	33	2	2	0	0	7
Tunduru	339,510	34	0	0	0	0	21
Chamwino	221,010	35	0	0	0	0	70
Liwale	57,719	36	0	0	0	0	75
Sikonge	121,679	37	0	0	0	0	106
Tunduma	8,739	38	0	0	0	0	144
TOTAL (ha)	20,719,221		206,914	150,159	20,573	36,182	

Table 3.2 Plantation species share in study area districts (ha)

District name	Plantations total (ha)	Pine (ha)	Eucalyptus (ha)	Wattle (ha)	Eucalyptus or wattle (ha)	Other or mixed (ha)
Mufindi	52,558	33,999	14,750	3,787	17	5
Makete	27,696	22,211	1,011	4,333	47	94
Njombe Urban	25,882	16,755	4,126	4,961	17	23
Kilolo	19,445	12,537	2,775	4,111	8	14
Njombe	19,333	13,356	4,078	1,897	2	1
Wanging'ombe	13,018	8,188	325	4,444	9	52
Mafinga Township Authority	12,997	10,650	1,562	777	7	0
Rungwe	9,591	5,292	3,480	810	3	6
Mbeya	9,131	6,143	996	1,960	28	4
Ludewa	3,473	1,936	942	589	3	3
Ileje	3,133	2,127	302	699	2	2
Kilombero	2,792	325	2,463	2	0	2
Mpwapwa	1,411	470	39	891	1	10
Kilosa	1,338	232	285	816	0	5
Songea	1,090	581	507	1	0	0
Iringa	931	465	374	90	2	0
Mbeya Urban	885	347	418	115	4	0
Mbozi	603	344	187	70	2	0
Chunya	566	306	198	61	0	0
Makambako Township Authority	440	94	343	4	0	0
Songea Urban	166	8	158	0	0	0
Mbarali	153	90	56	7	0	0
Mbinga	91	17	72	2	0	0
Ulanga	59	16	43	0	0	0
Mlele	52	44	8	0	0	0
Kyela	25	23	2	0	0	0
Namtumbo	22	12	10	0	0	0
Manyoni	12	9	2	0	0	0
Momba	7	5	2	0	0	0
Nyasa	6	4	1	0	0	0
Sumbawanga	4	2	1	1	0	0
Iringa Urban	3	1	3	0	0	0
Kalambo	2	1	1	0	0	0
Tunduru	0	0	0	0	0	0
Chamwino	0	0	0	0	0	0
Liwale	0	0	0	0	0	0
Sikonge	0	0	0	0	0	0
Tunduma	0	0	0	0	0	0
TOTAL	206,914	136,589	39,520	30,430	153	221

Table 3.3 Plantation approximate age class share in study area districts (ha)

District name	Plantations total (ha)	0–3 years (ha)	3–8 years (ha)	> 8 years (ha)
Mufindi	52,558	4,568	28,017	19,974
Makete	27,696	444	16,722	10,530
Njombe Urban	25,882	2,365	16,096	7,420
Kilolo	19,445	1,280	11,477	6,688
Njombe	19,333	3,186	12,723	3,424
Wanging'ombe	13,018	227	8,422	4,370
Mafinga Township Authority	12,997	1,076	7,540	4,381
Rungwe	9,591	121	4,970	4,500
Mbeya	9,131	191	5,081	3,860
Ludewa	3,473	185	2,207	1,081
Ileje	3,133	72	1,805	1,256
Kilombero	2,792	143	1,920	729
Mpwapwa	1,411	9	459	943
Kilosa	1,338	11	404	923
Songea	1,090	84	667	339
Iringa	931	151	613	167
Mbeya Urban	885	12	505	368
Mbozi	603	23	420	161
Chunya	566	32	427	107
Makambako Township Authority	440	87	334	19
Songea Urban	166	1	69	96
Mbarali	153	9	125	19
Mbinga	91	6	71	13
Ulanga	59	8	35	17
Mlele	52	1	46	5
Kyela	25	0	15	9
Namtumbo	22	3	13	5
Manyoni	12	2	7	3
Momba	7	0	5	2
Nyasa	6	1	4	1
Sumbawanga	4	0	3	1
Iringa Urban	3	0	2	1
Kalambo	2	0	1	1
Tunduru	0	0	0	0
Chamwino	0	0	0	0
Liwale	0	0	0	0
Sikonge	0	0	0	0
Tunduma	0	0	0	0
TOTAL	206,914	14,298	121,204	71,411

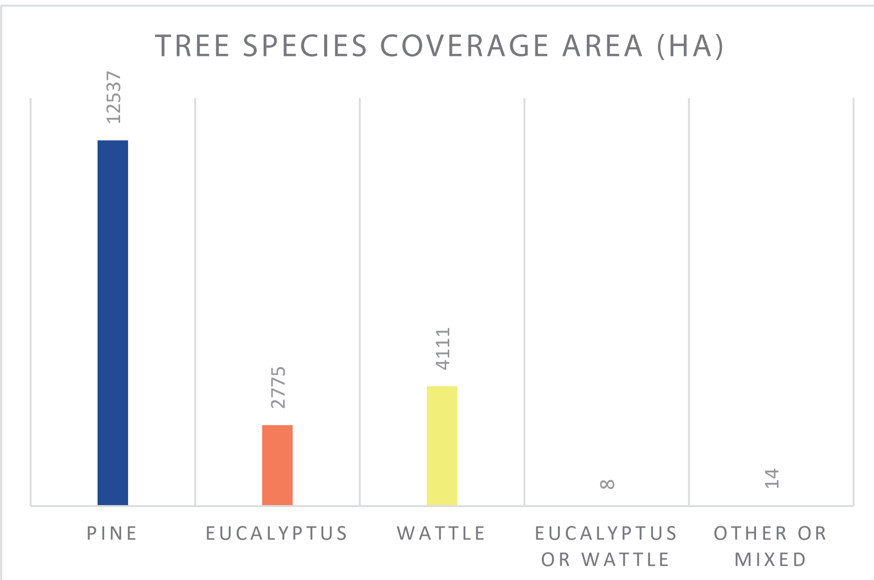
Table 3.4 Plantation approximate density class share in study area districts (ha)

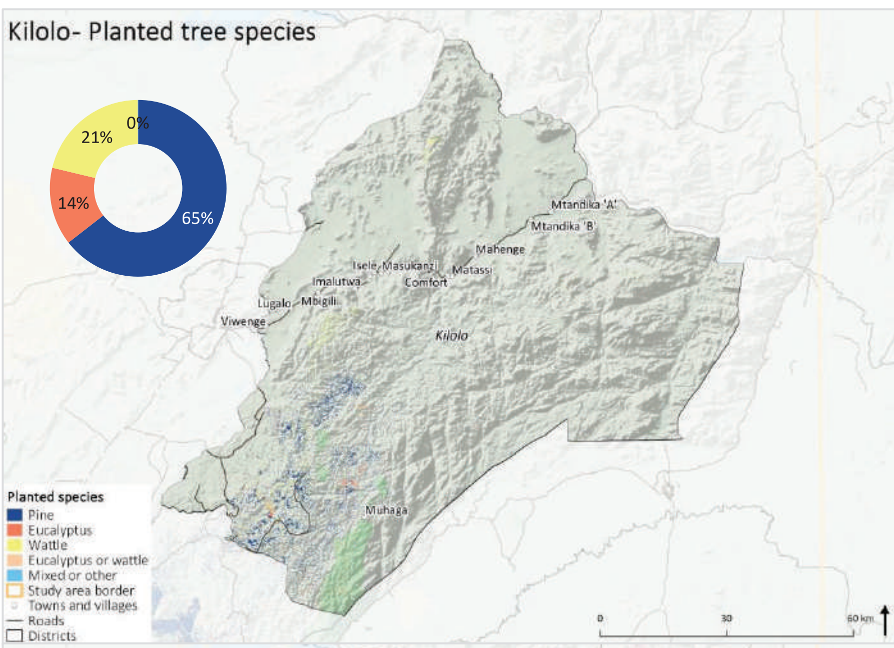
District name	Plantations total (ha)	Sparse (ha)	Intermediate (ha)	Dense (ha)
Mufindi	52,558	525	9,582	42,451
Makete	27,696	688	4,364	22,644
Njombe Urban	25,882	392	7,075	18,416
Kilolo	19,445	135	3,680	15,629
Njombe	19,333	341	7,294	11,699
Wanging'ombe	13,018	134	2,302	10,582
Mafinga Township Authority	12,997	211	3,255	9,532
Rungwe	9,591	19	445	9,127
Mbeya	9,131	95	1,077	7,959
Ludewa	3,473	41	682	2,751
Ileje	3,133	36	336	2,761
Kilombero	2,792	25	181	2,586
Mpwapwa	1,411	1	92	1,318
Kilosa	1,338	3	45	1,290
Songea	1,090	7	180	903
Iringa	931	36	289	605
Mbeya Urban	885	2	47	836
Mbozi	603	3	85	515
Chunya	566	6	122	439
Makambako Township Authority	440	11	108	322
Songea Urban	166	0	1	164
Mbarali	153	1	48	104
Mbinga	91	2	10	79
Ulanga	59	1	6	53
Mlele	52	0	0	52
Kyela	25	0	1	24
Namtumbo	22	0	5	17
Manyoni	12	0	1	11
Momba	7	0	1	6
Nyasa	6	0	1	4
Sumbawanga	4	0	0	3
Iringa Urban	3	0	0	3
Kalambo	2	0	1	1
Tunduru	0	0	0	0
Chamwino	0	0	0	0
Liwale	0	0	0	0
Sikonge	0	0	0	0
Tunduma	0	0	0	0
TOTAL	206,914	2,714	41,315	162,885

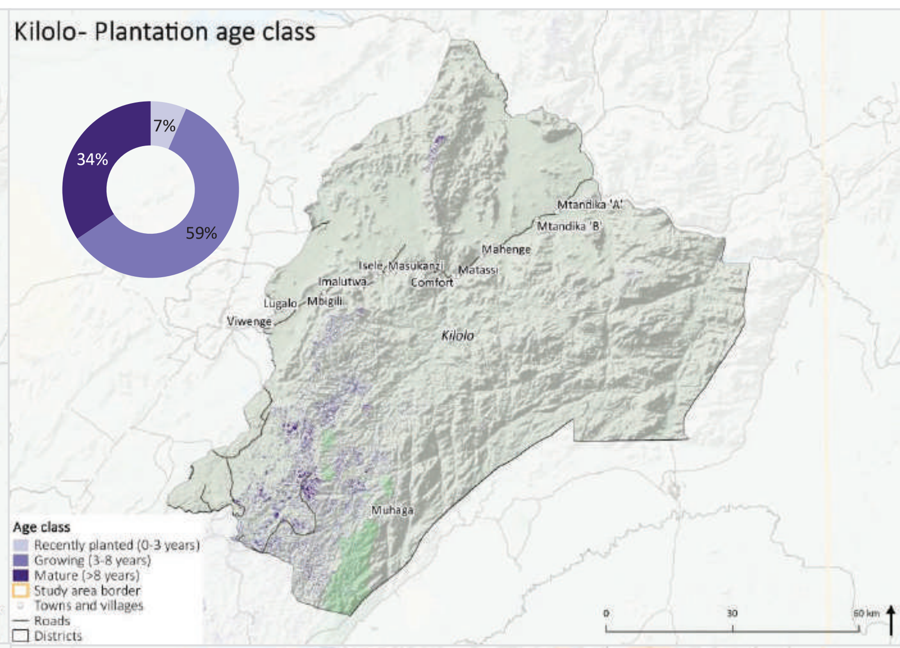
Annex 4 District-level maps for PFP operating area

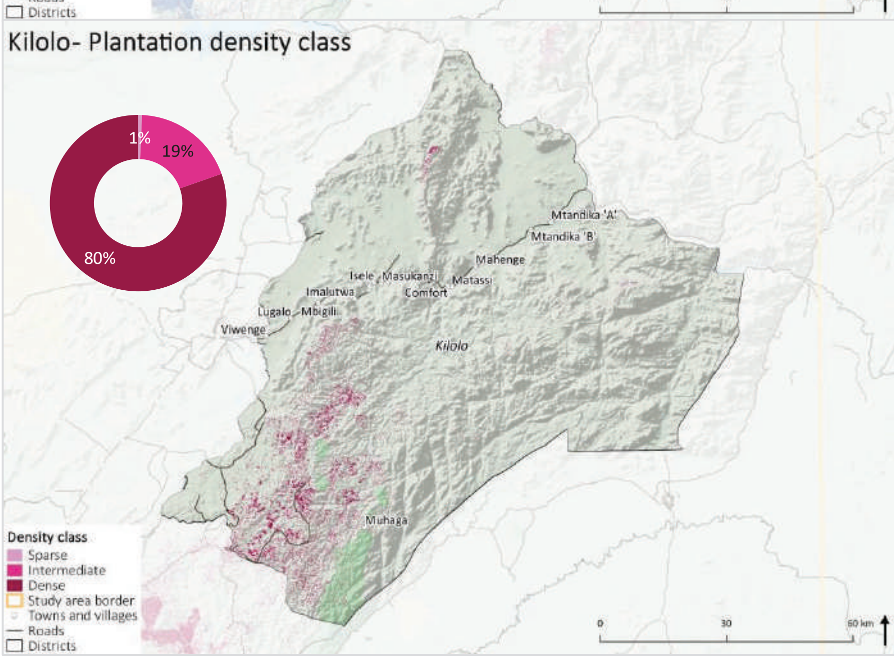
FOREST PLANTATIONS IN KILOLO DISTRICT

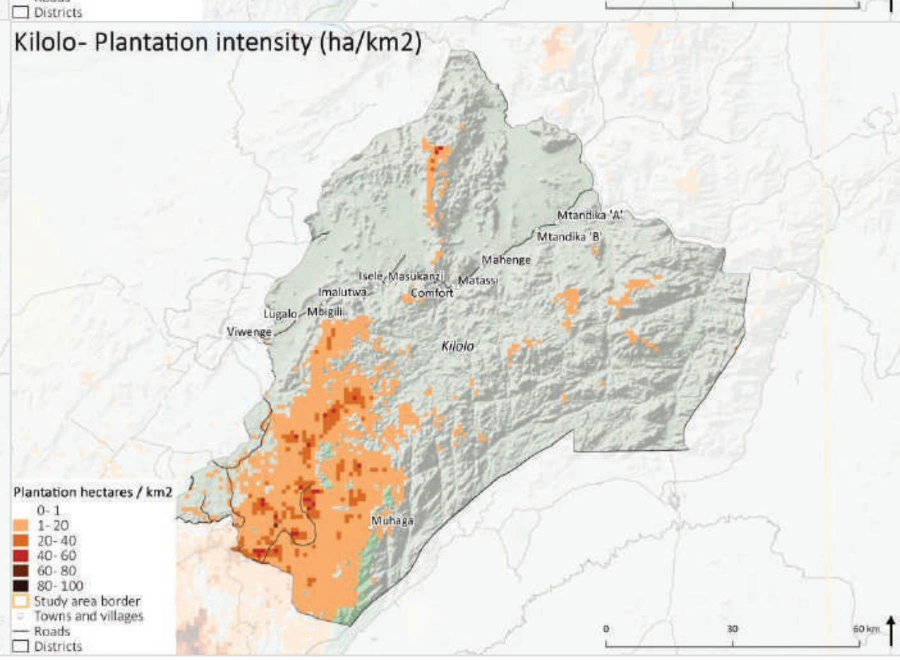
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government owned (ha)	Company-owned (ha)	Privately owned (ha)
Kilolo	926546	19445	4	0	691	18754











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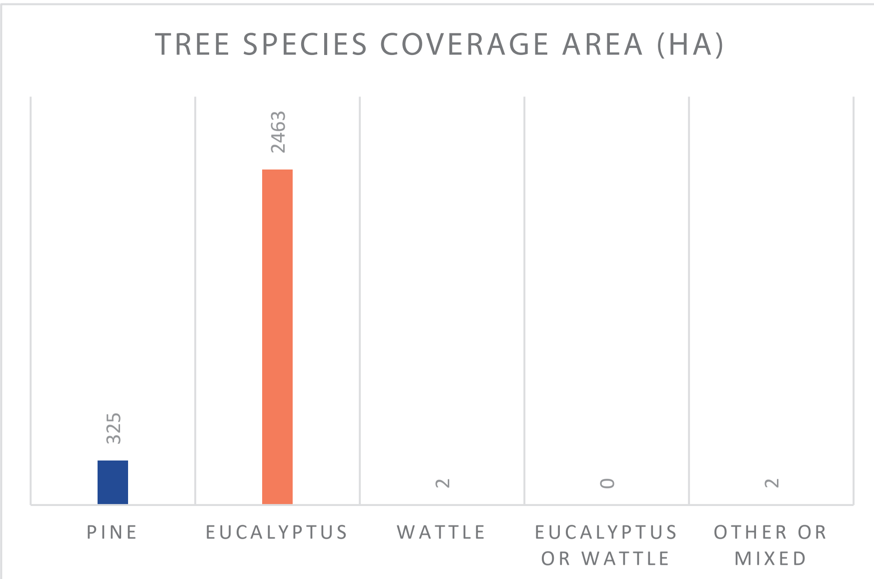
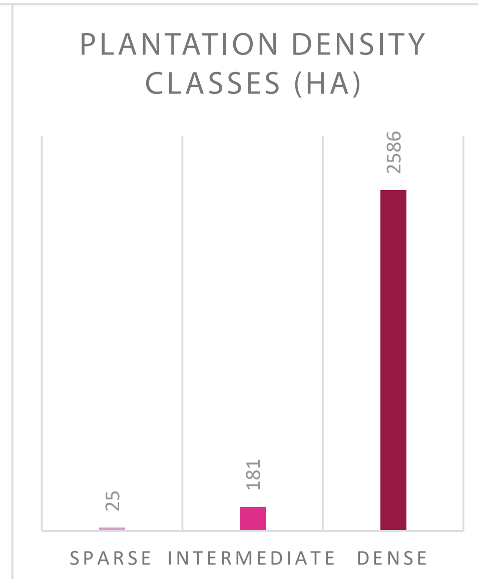
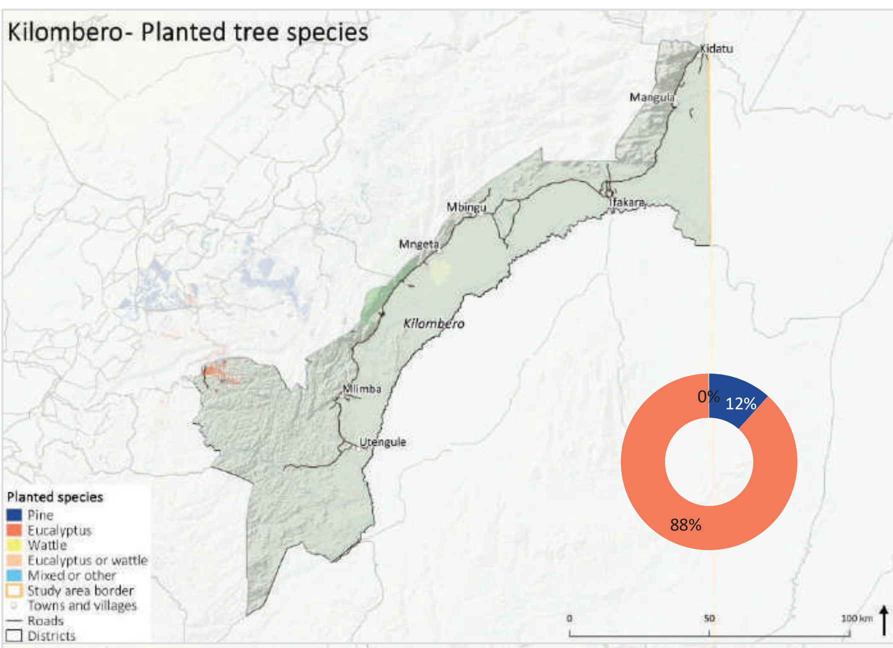
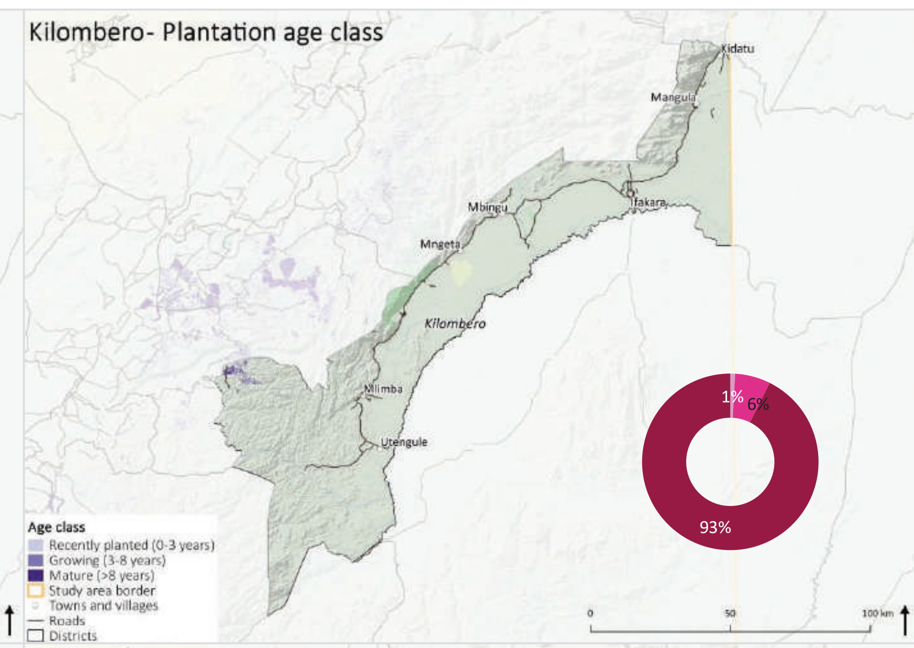
FOREST PLANTATIONS IN KILOMBERO DISTRICT

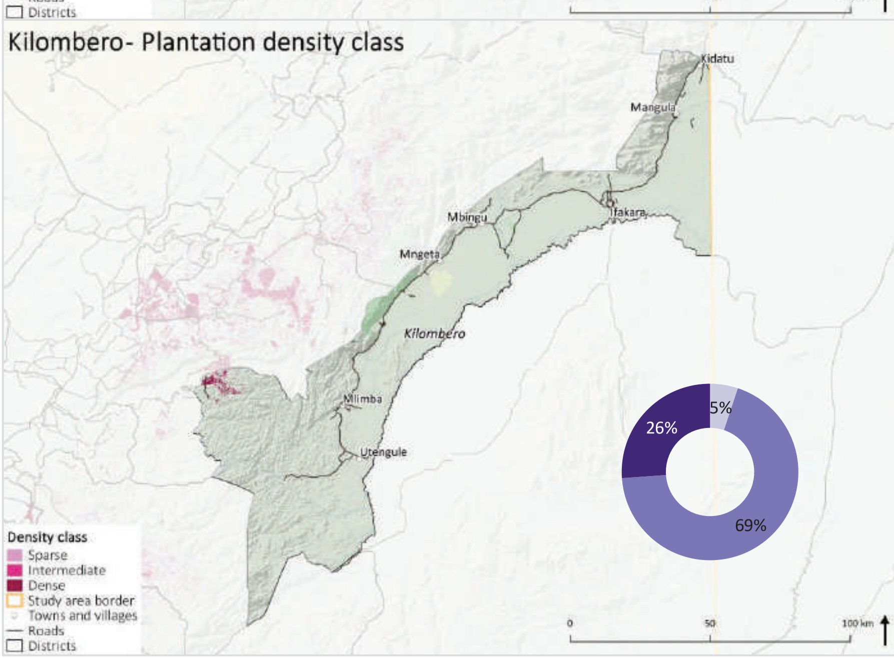
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Goverment-owned (ha)	Company-owned (ha)	Privately owned (ha)
Kilombero	857029	2792	12	1216	1191	384

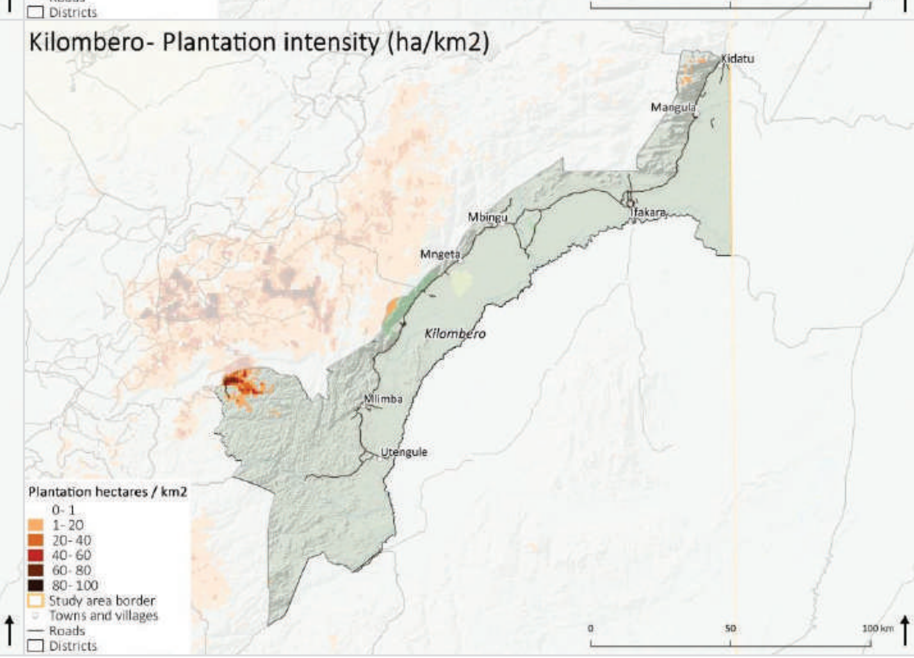












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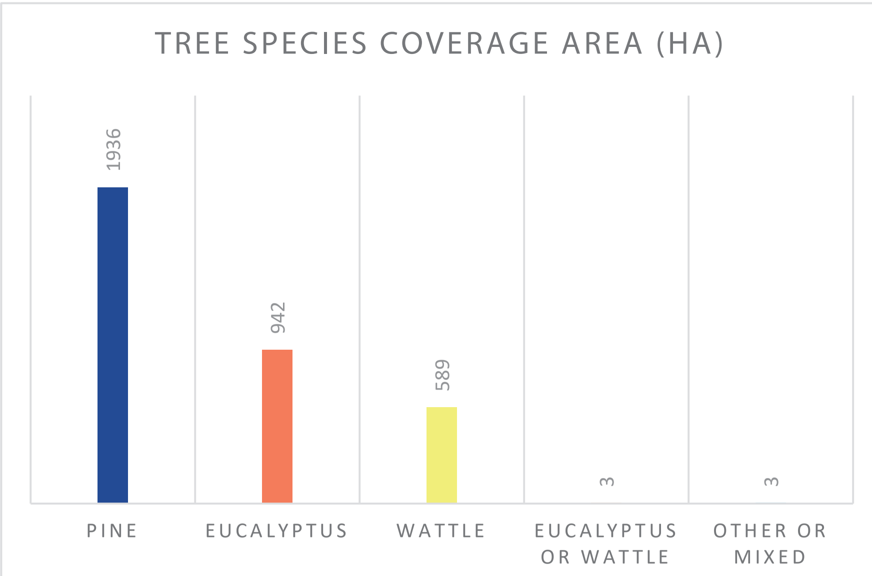
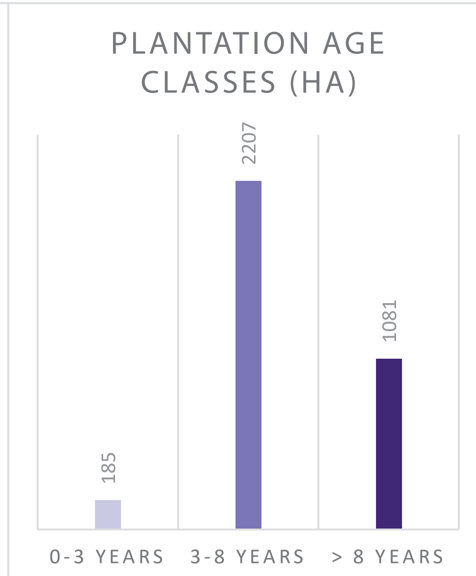
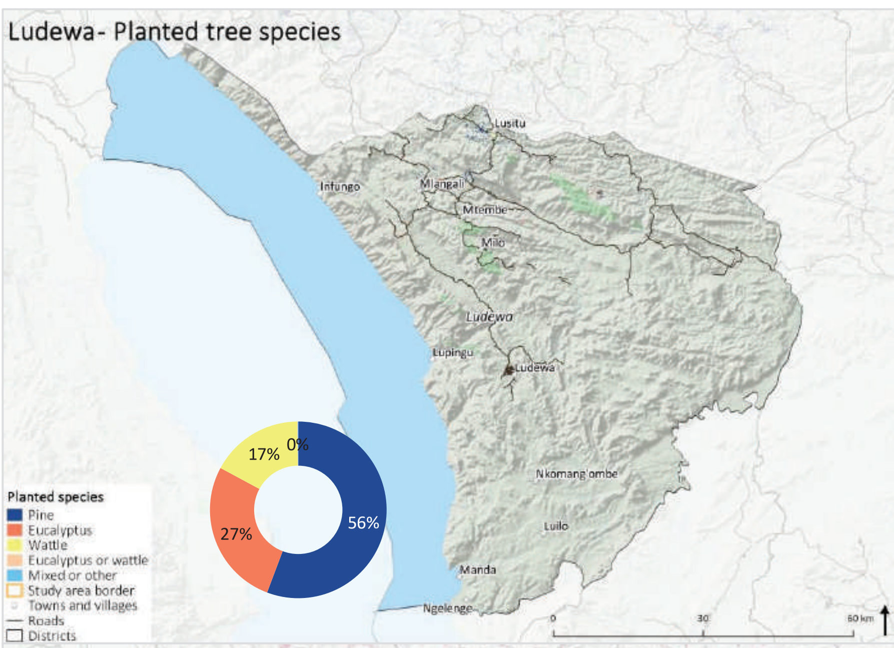
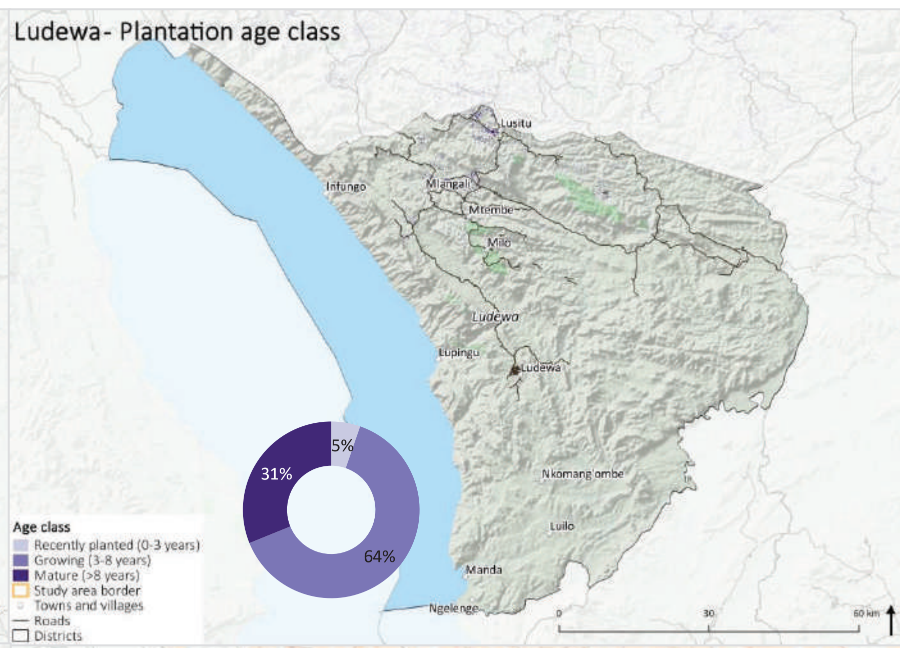
FOREST PLANTATIONS IN LUDEWA DISTRICT

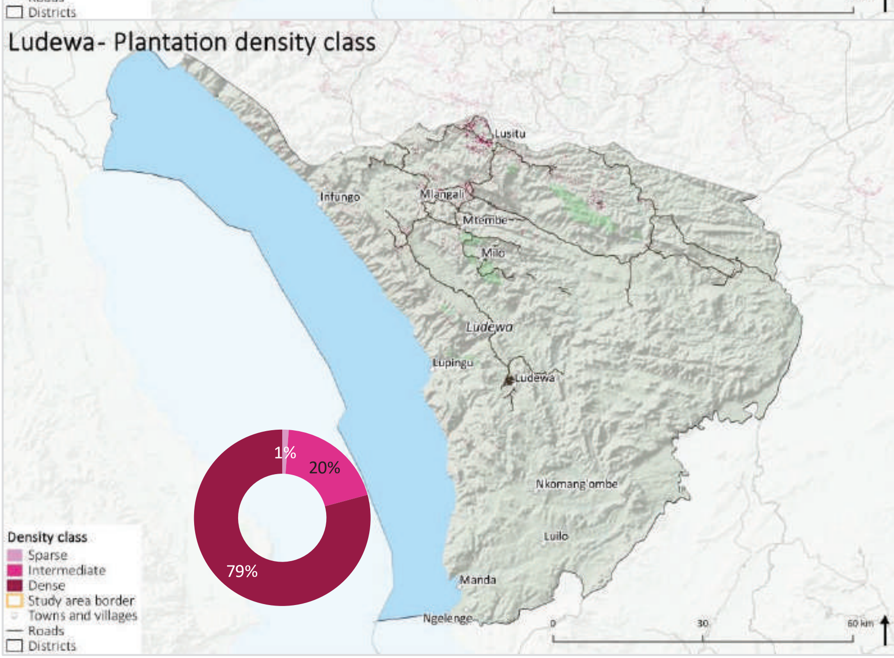
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Ludewa	812682	3473	10	0	0	3473

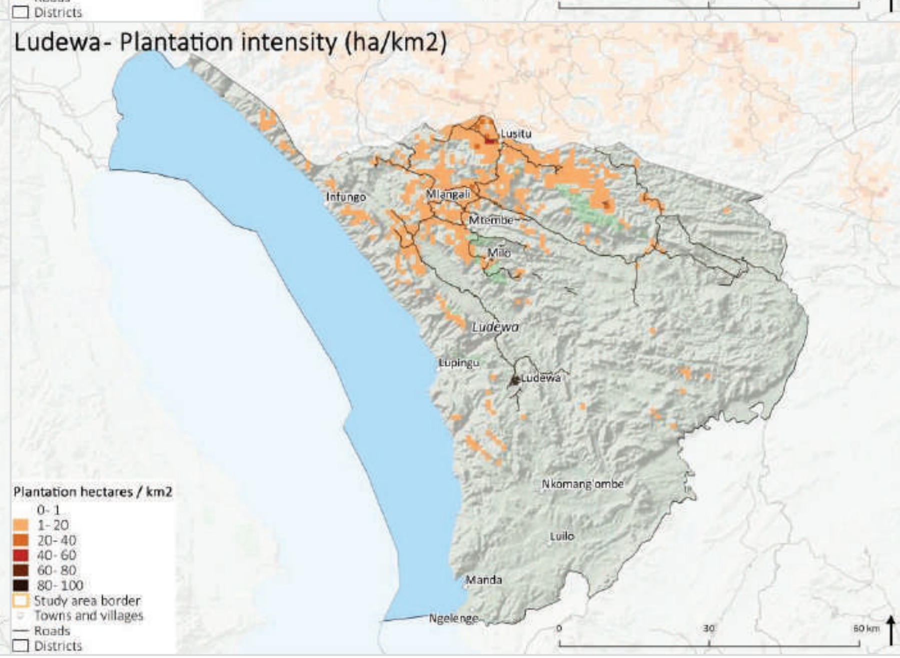












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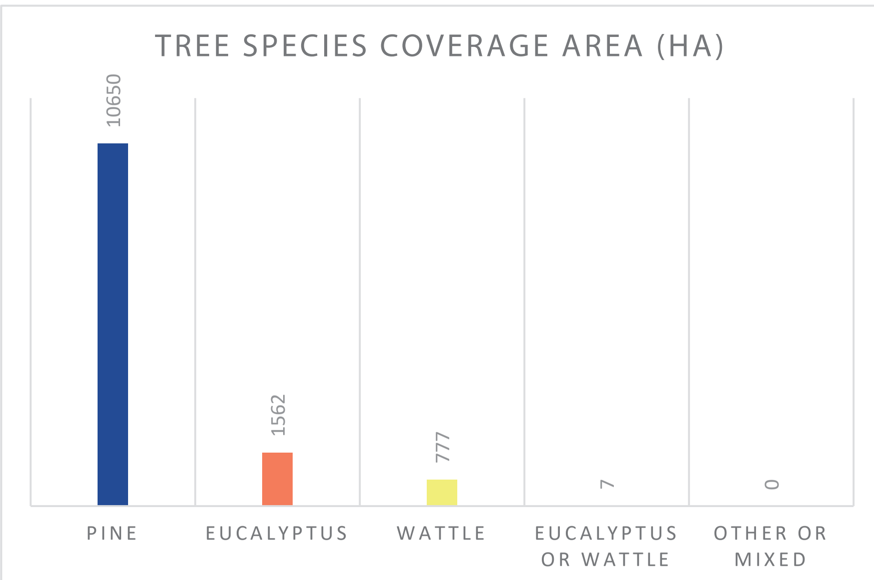
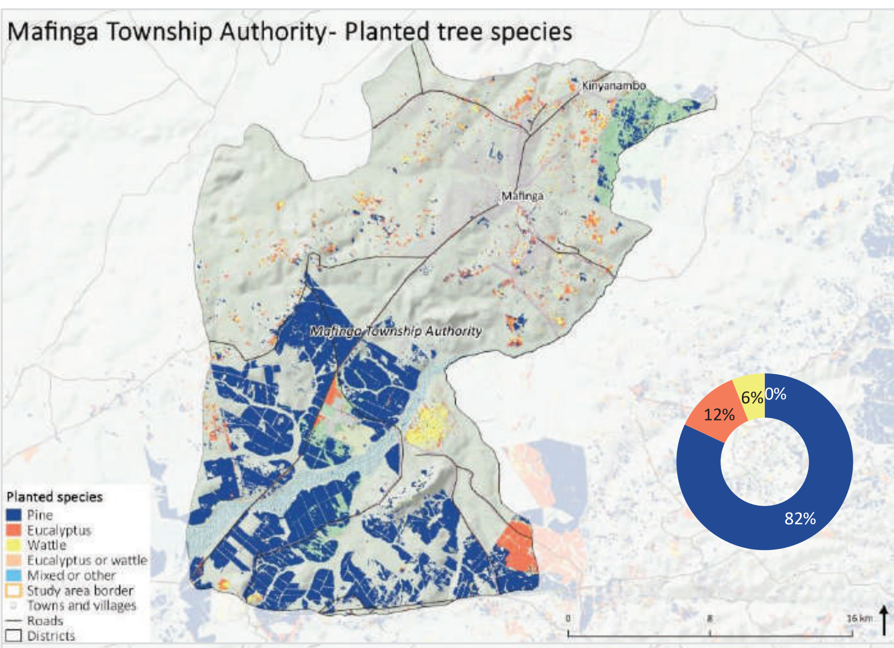
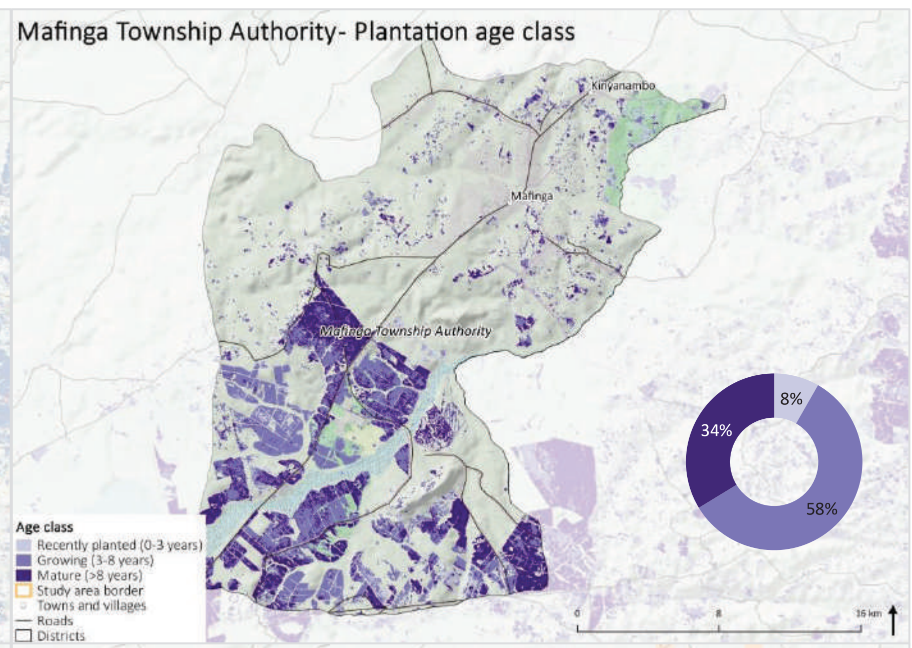
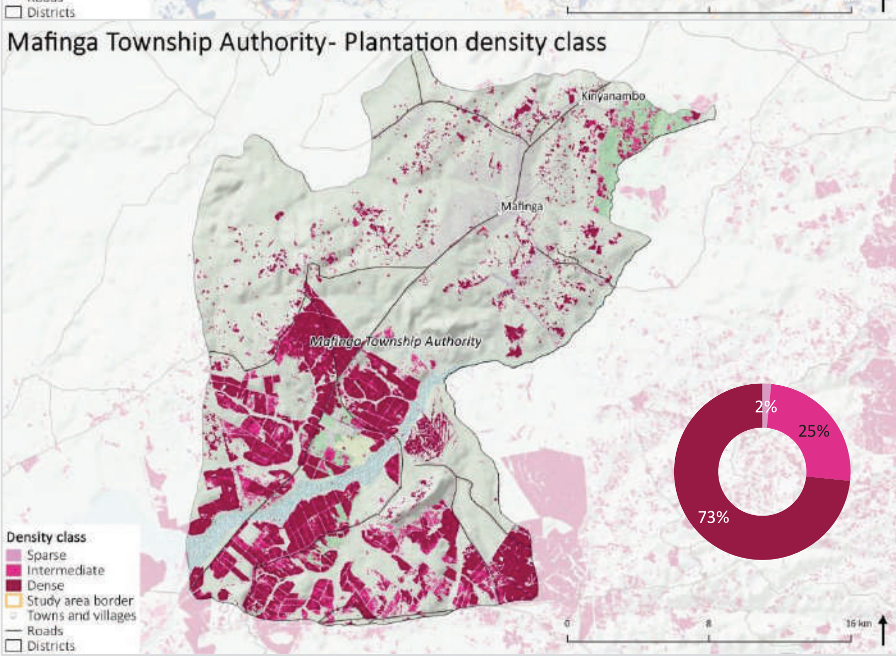
FOREST PLANTATIONS IN MAFINGA TOWNSHIP AUTHORITY DISTRICT

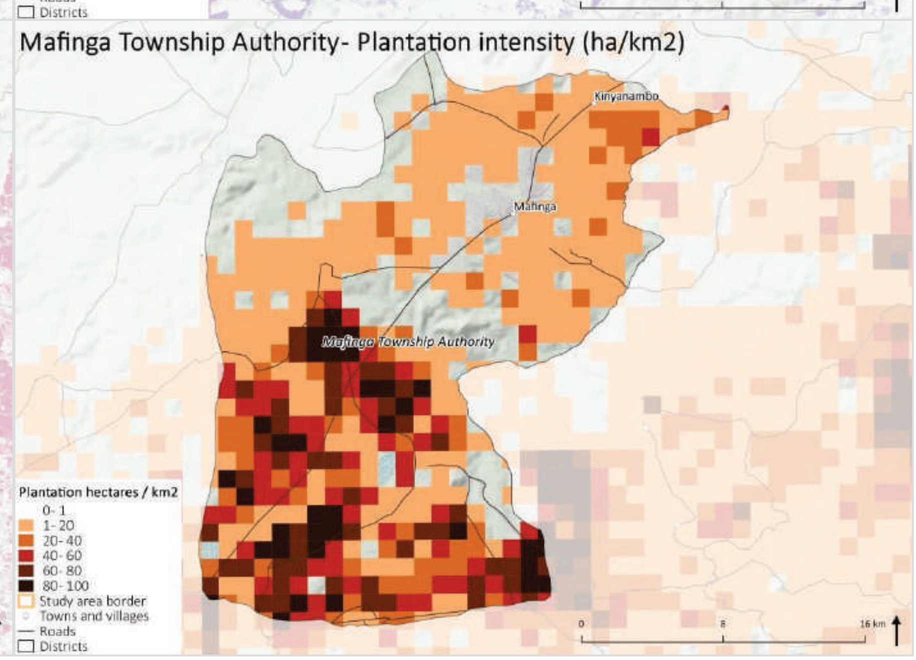
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Mafinga Township Authority	57290	12997	7	11051	68	1878











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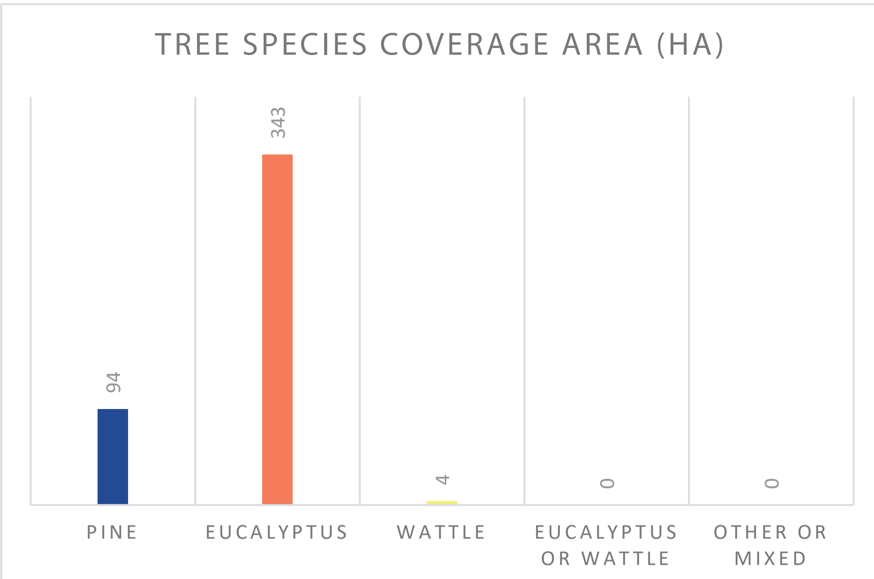
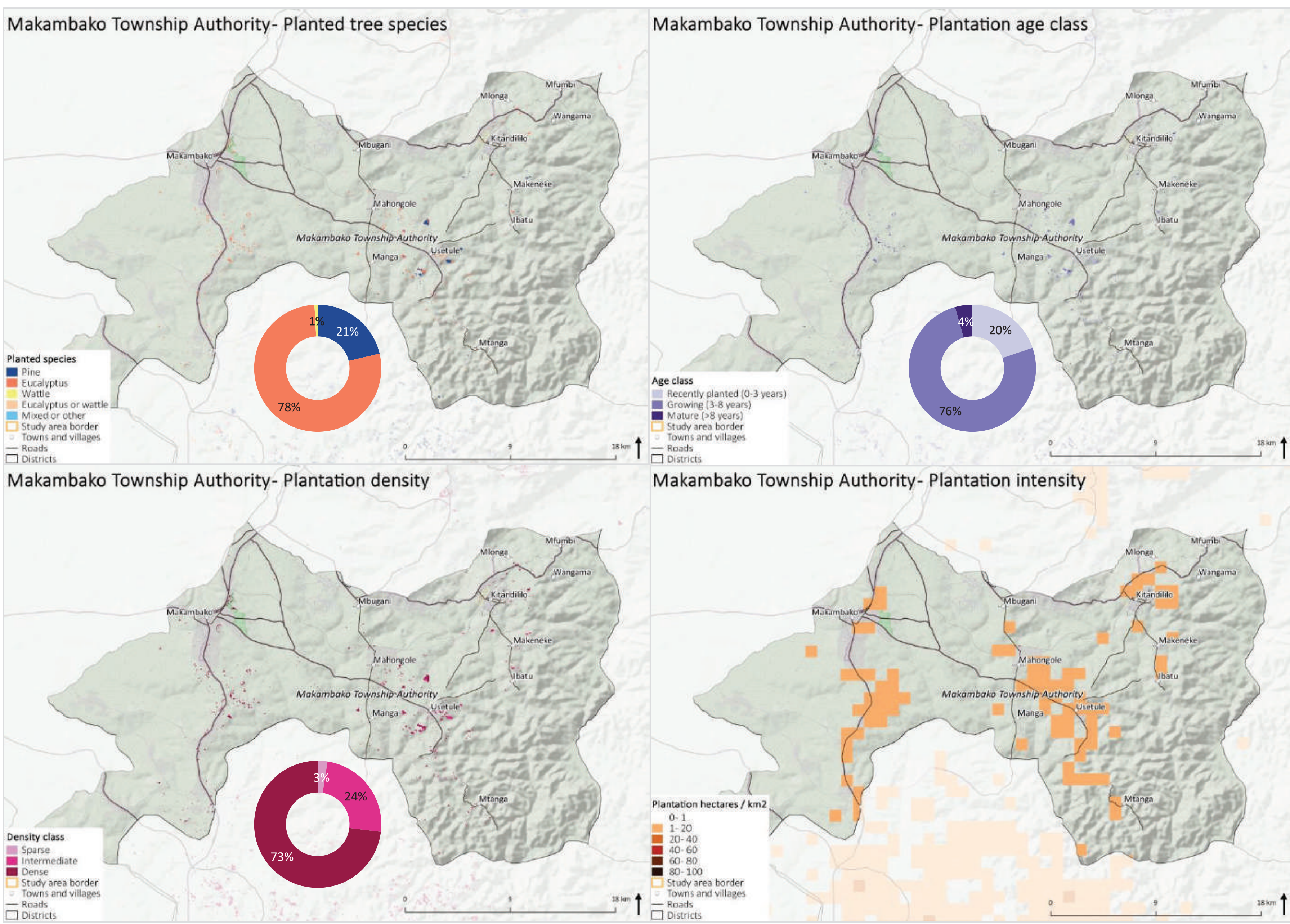
FOREST PLANTATIONS IN MAKAMBAKO TOWNSHIP AUTHORITY DISTRICT

District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Makambako Township Authority	88375	440	20	0	0	440





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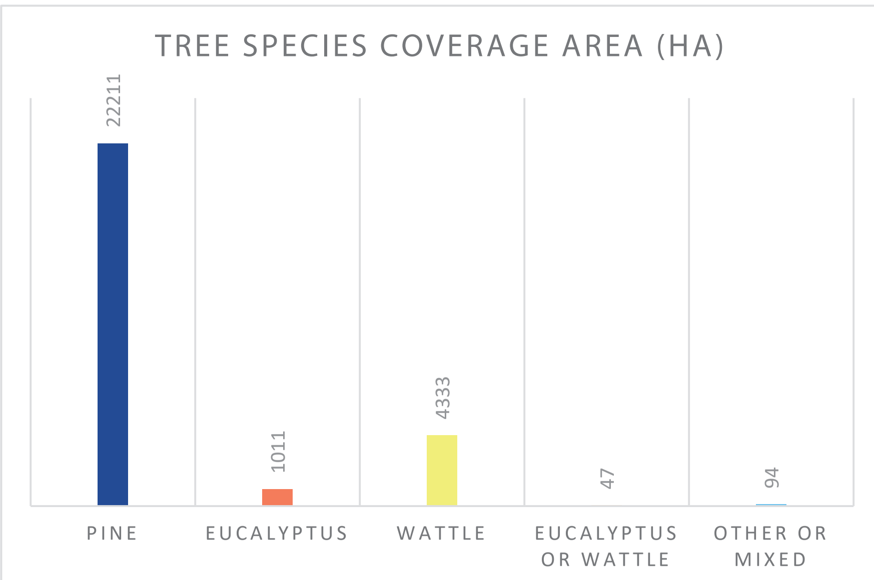
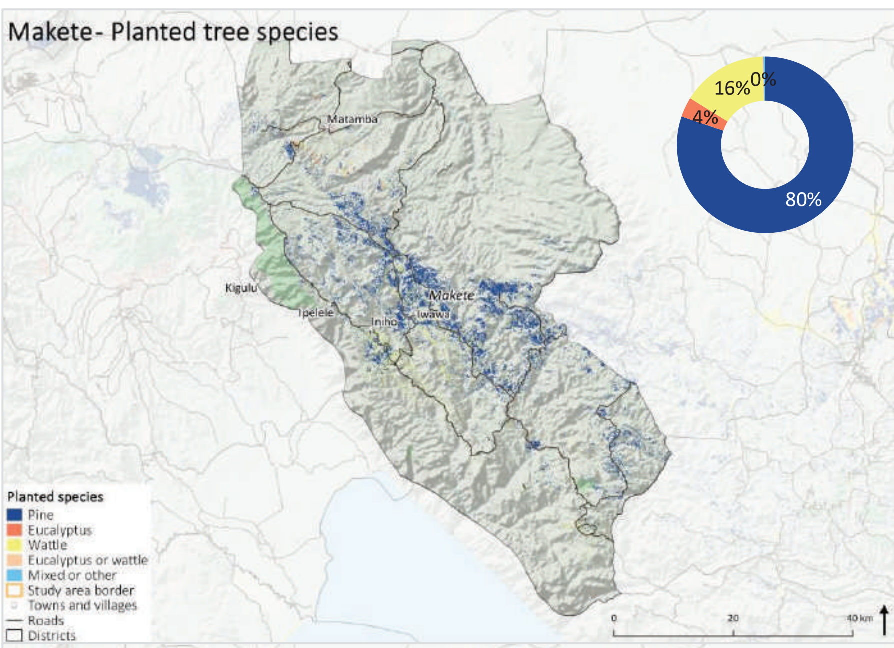
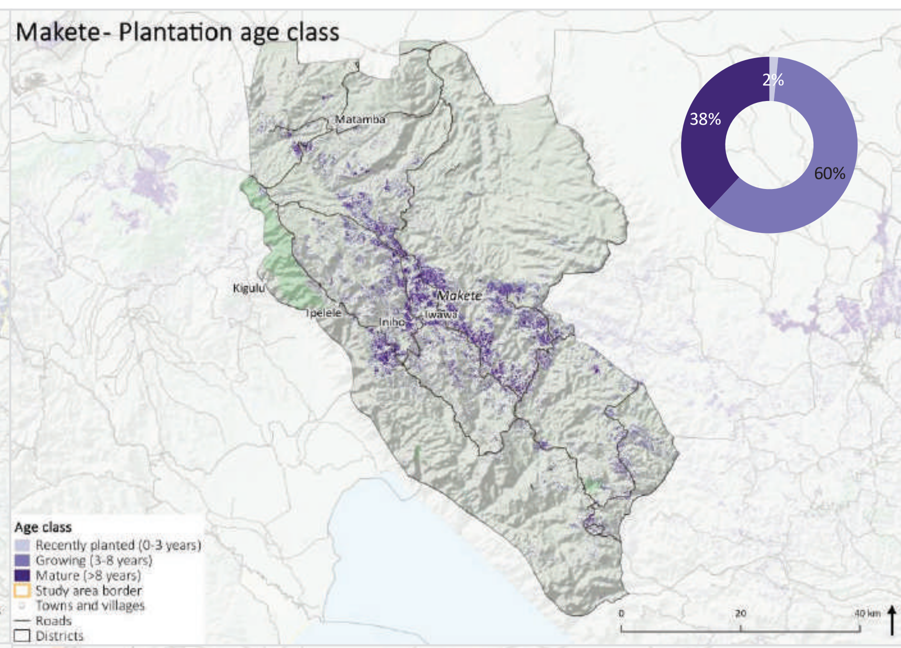
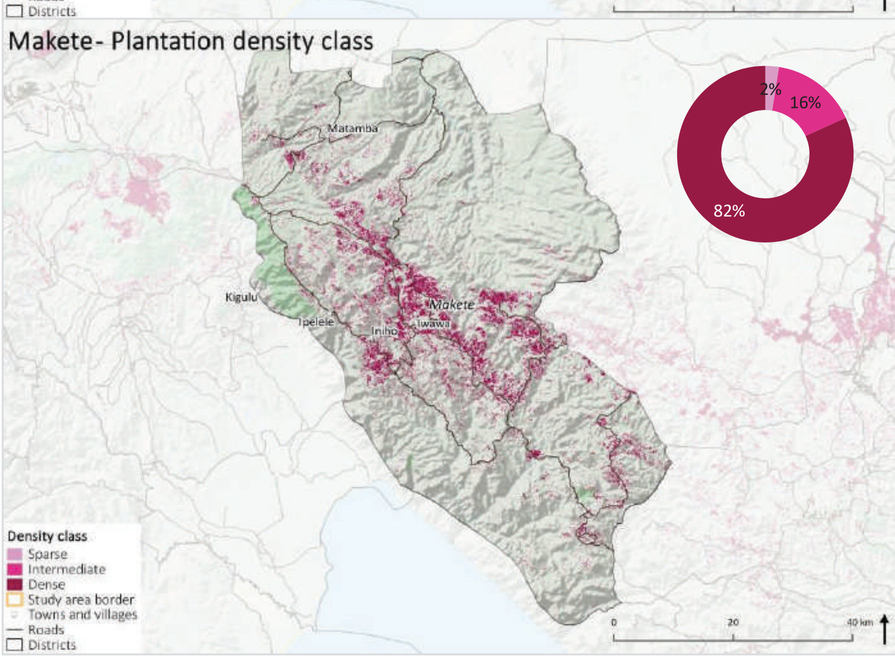
FOREST PLANTATIONS IN MAKETE DISTRICT

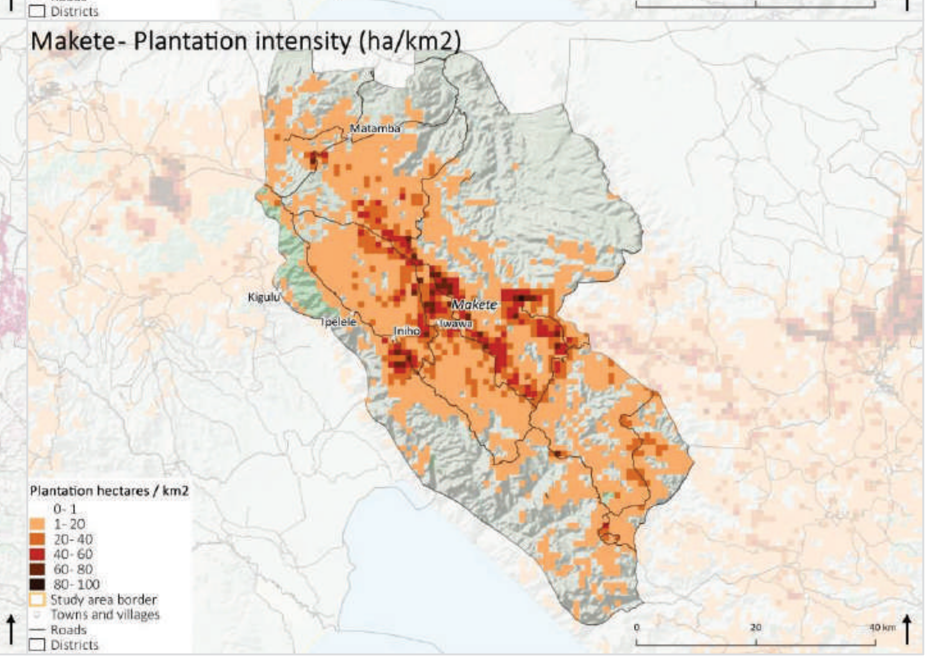
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Makete	399480	27696	2	0	0	27696











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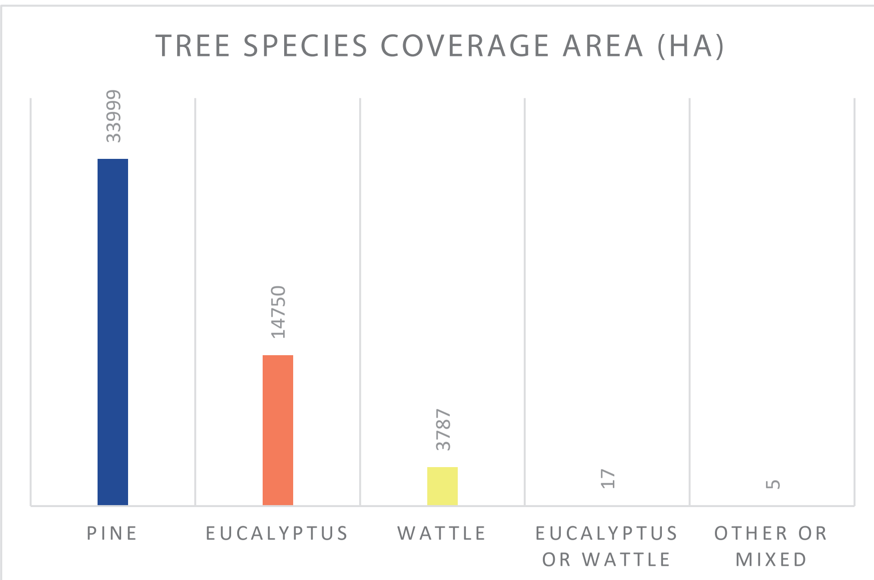
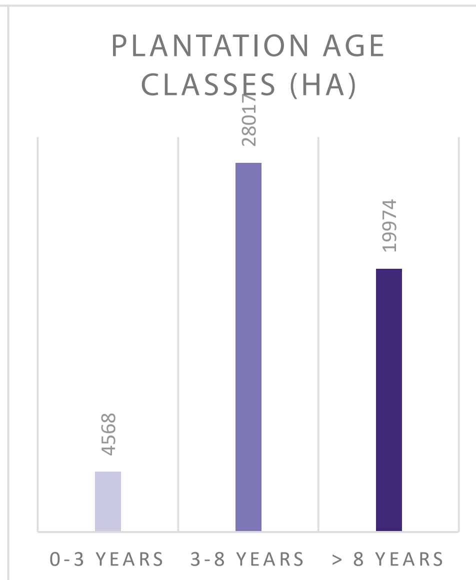
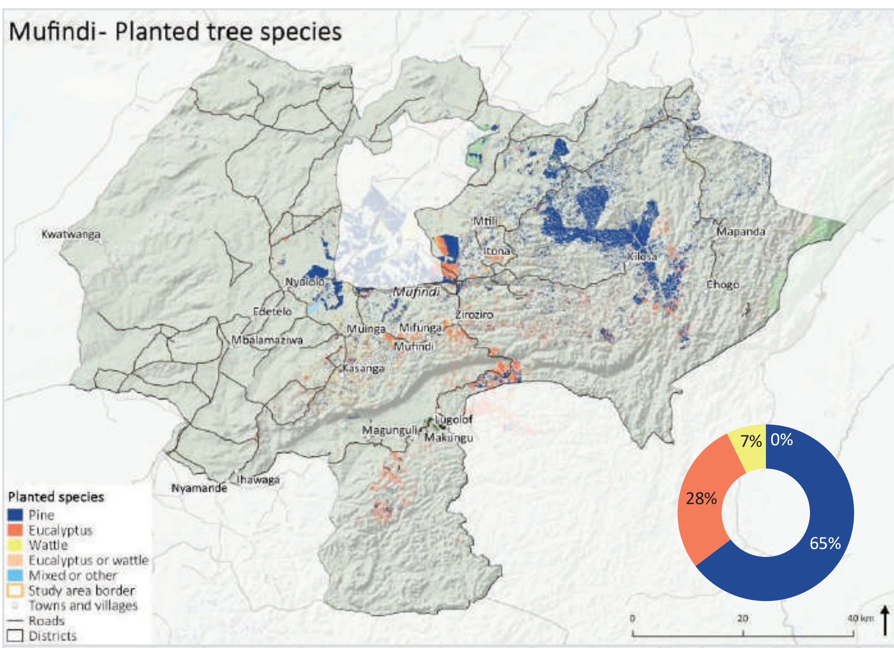
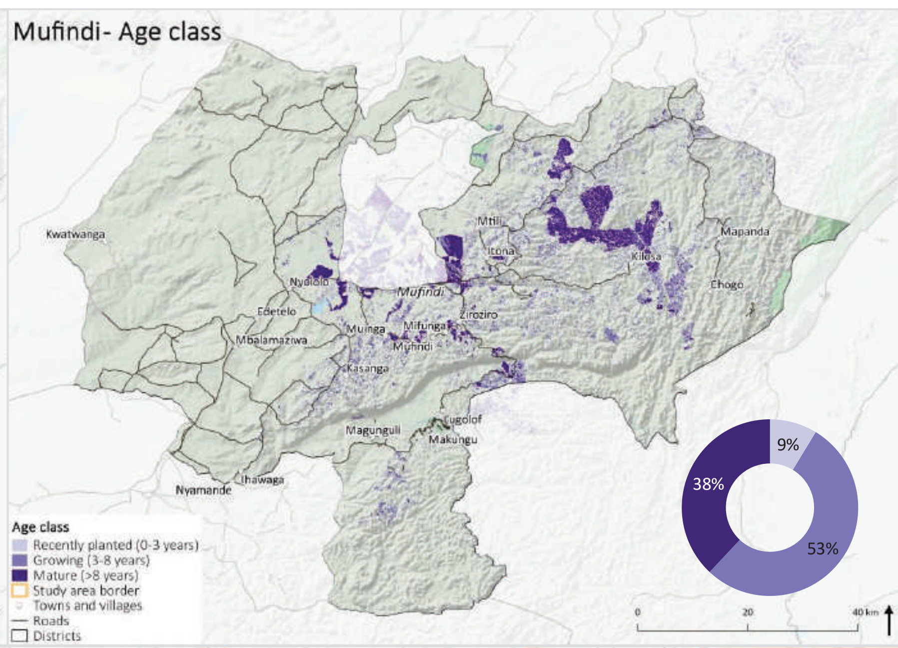
FOREST PLANTATIONS IN MUFINDI DISTRICT

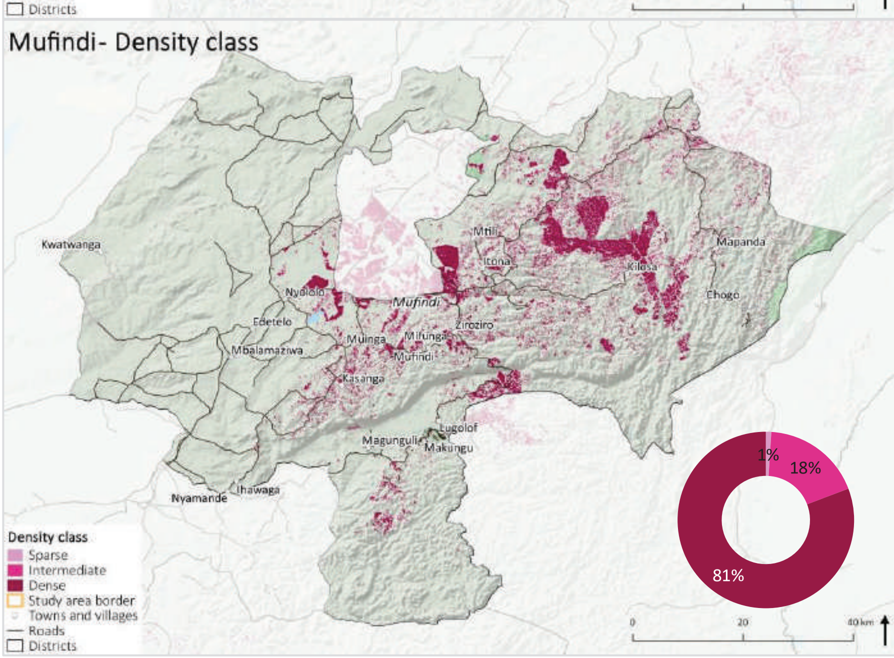
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government owned	Company-owned	Privately owned
Mufindi	752031	52558	1	20685	6845	25028

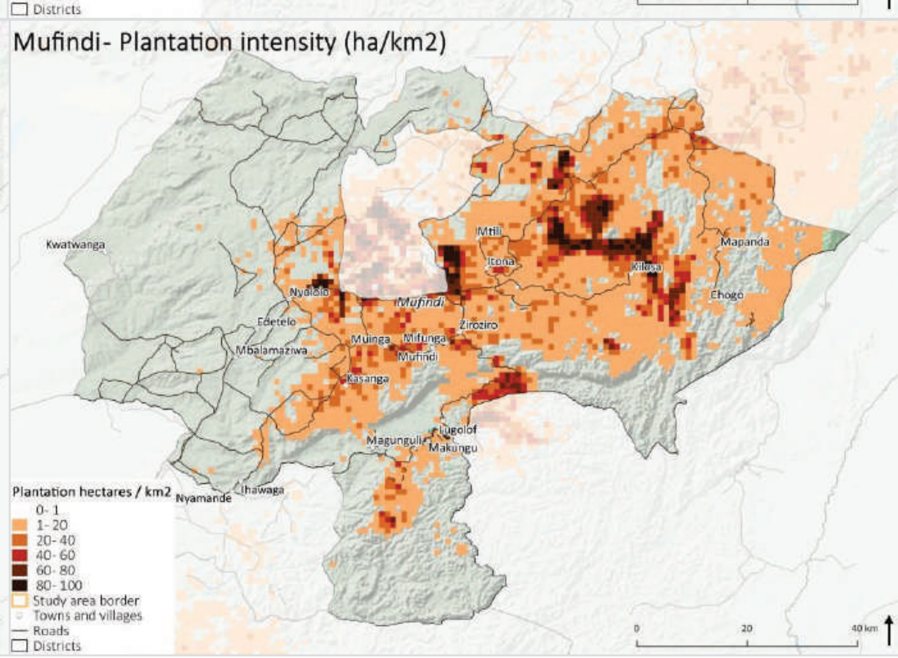












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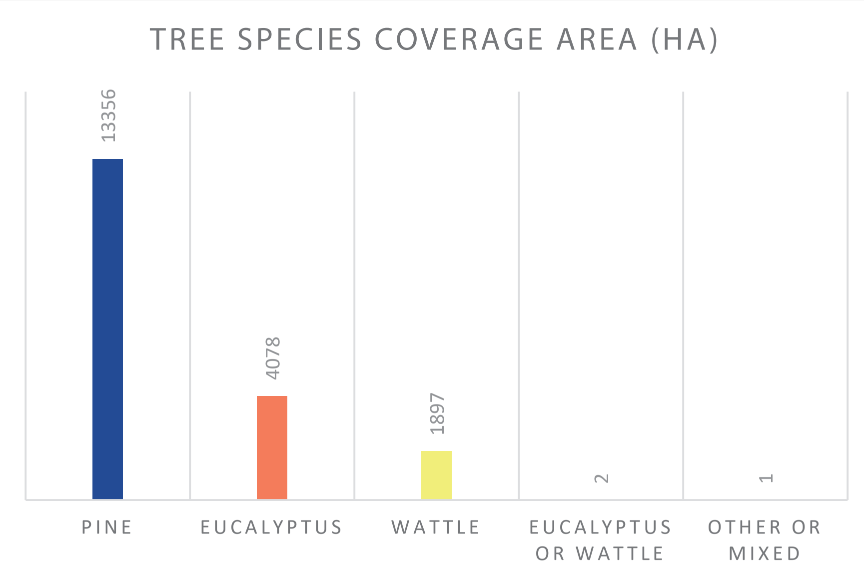
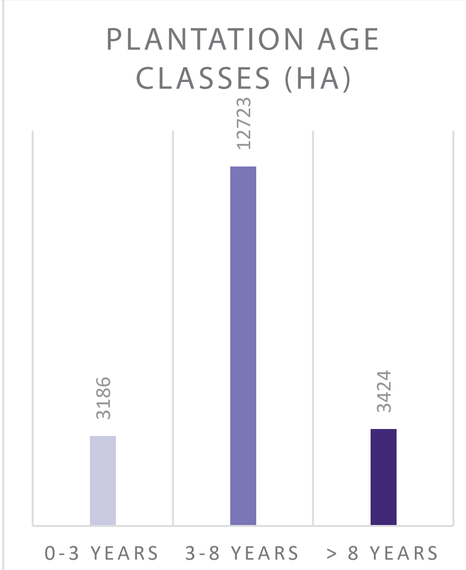
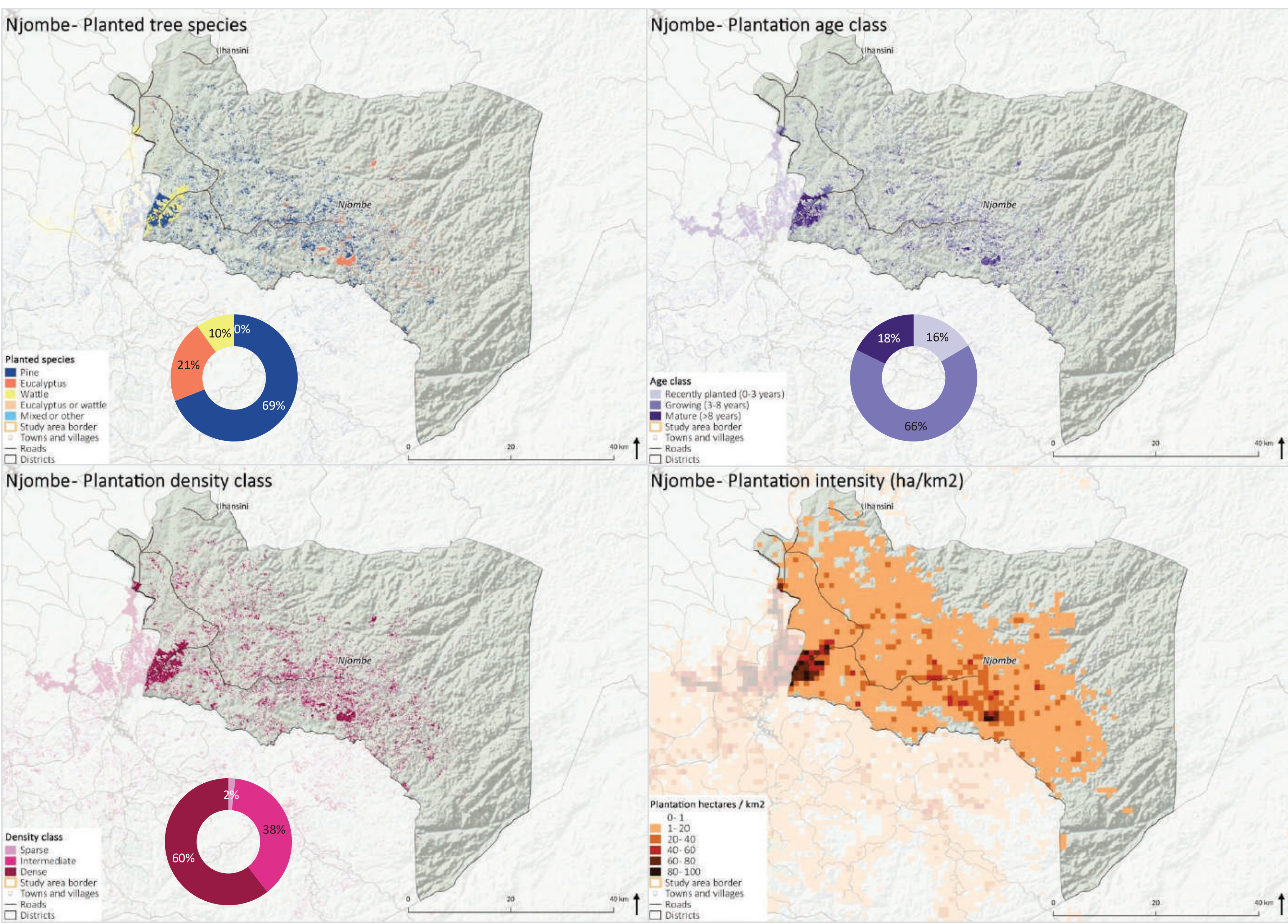
Administrative borders provided by Tanzanian National Bureau of Statistics (2012). Roads, towns and villages Map data copyrighted OpenStreetMap contributors and available from http://www.openstreetmap.org.
Background data: Maps © www.thunderforest.com, Data © www.osm.org/copyright

FOREST PLANTATIONS IN NJOMBE DISTRICT

District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Njombe	345010	19333	5	0	2859	16474







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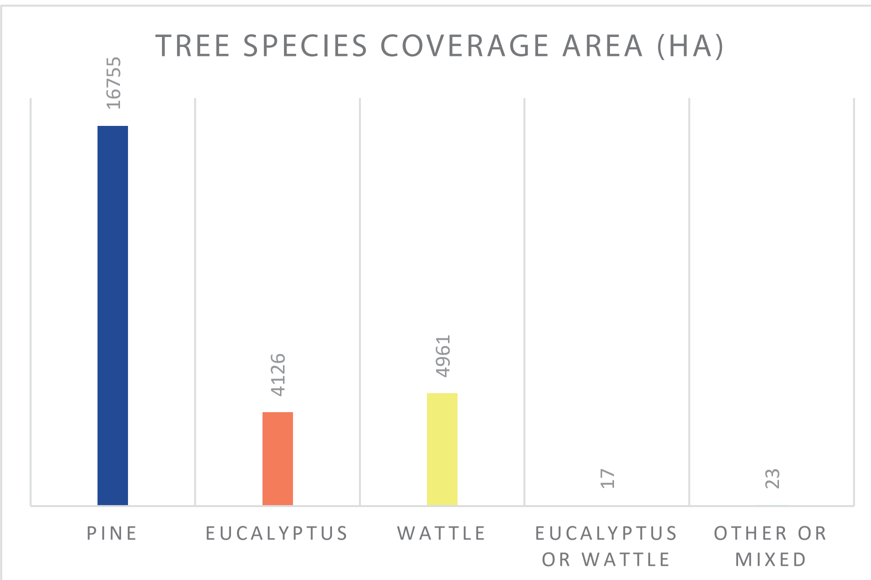
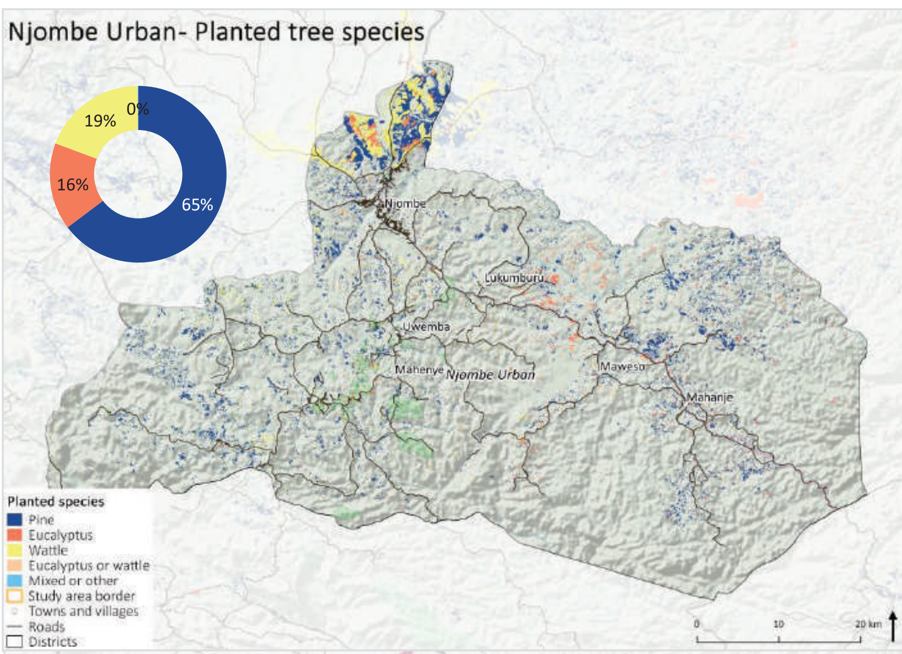
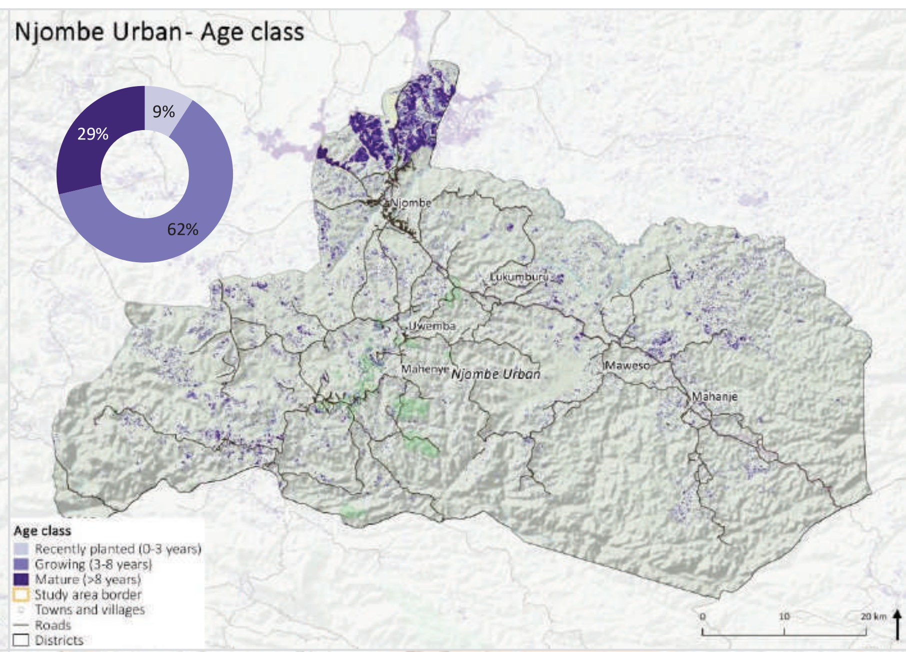
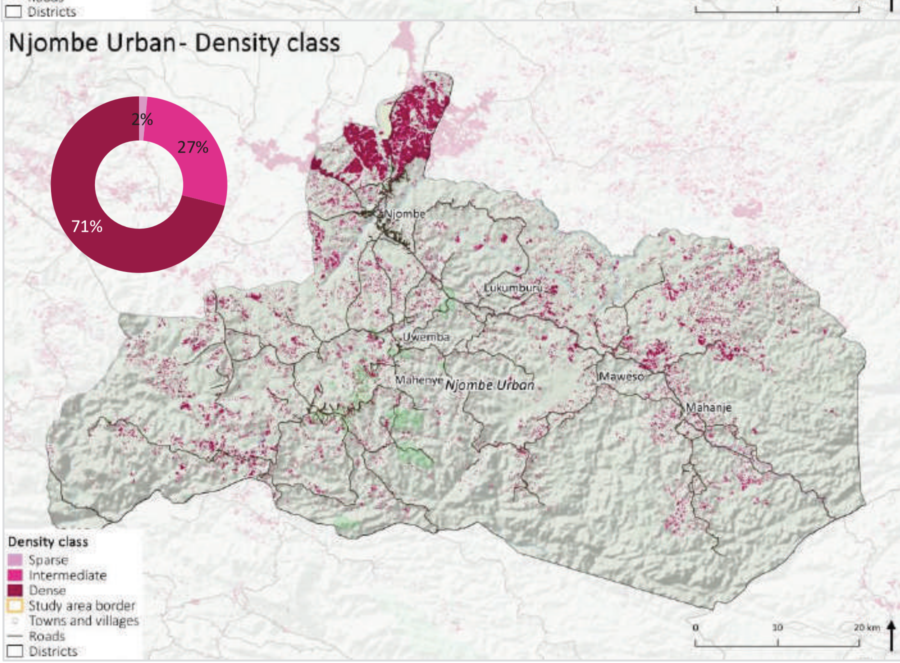
FOREST PLANTATIONS IN NJOMBE URBAN DISTRICT

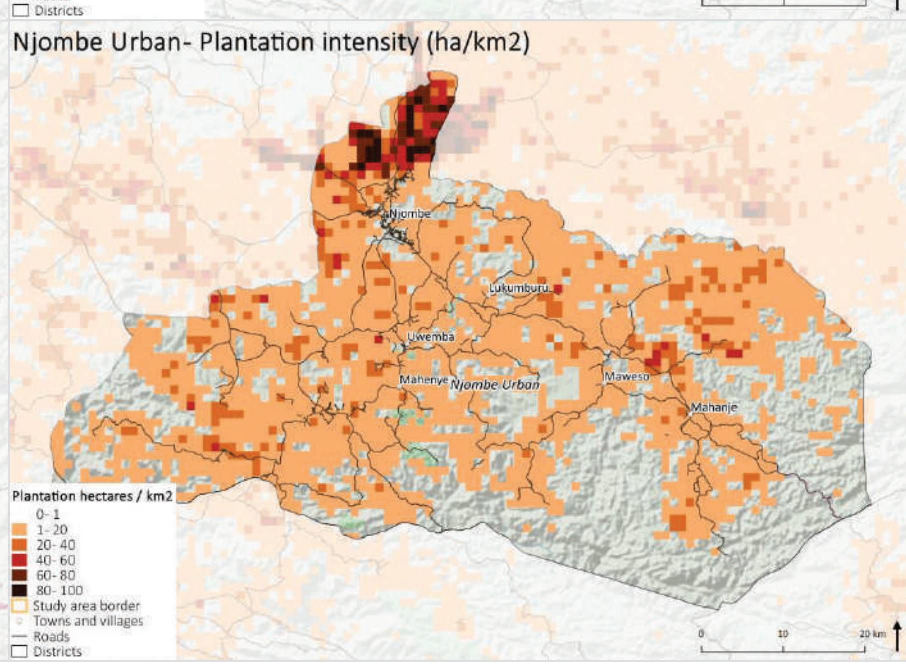
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Njombe Urban	354348	25882	3	0	5907	19975











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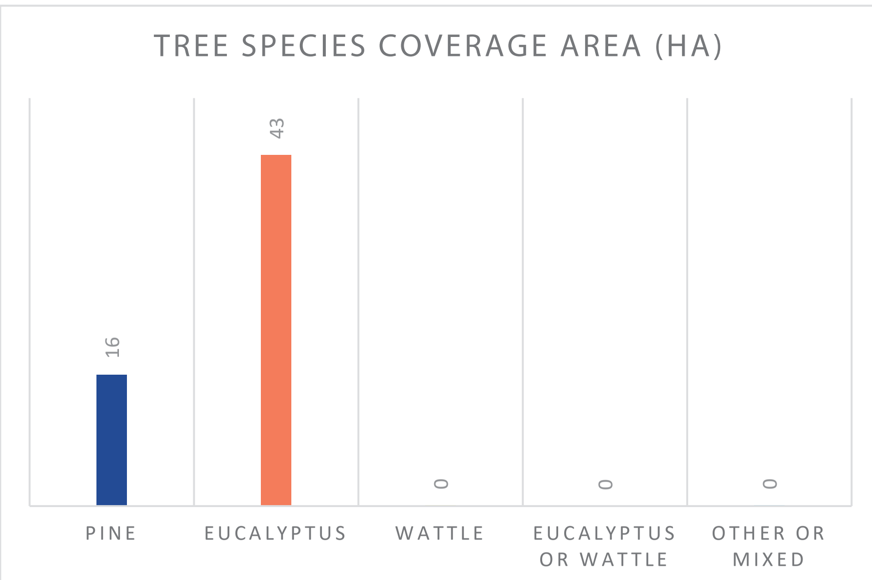
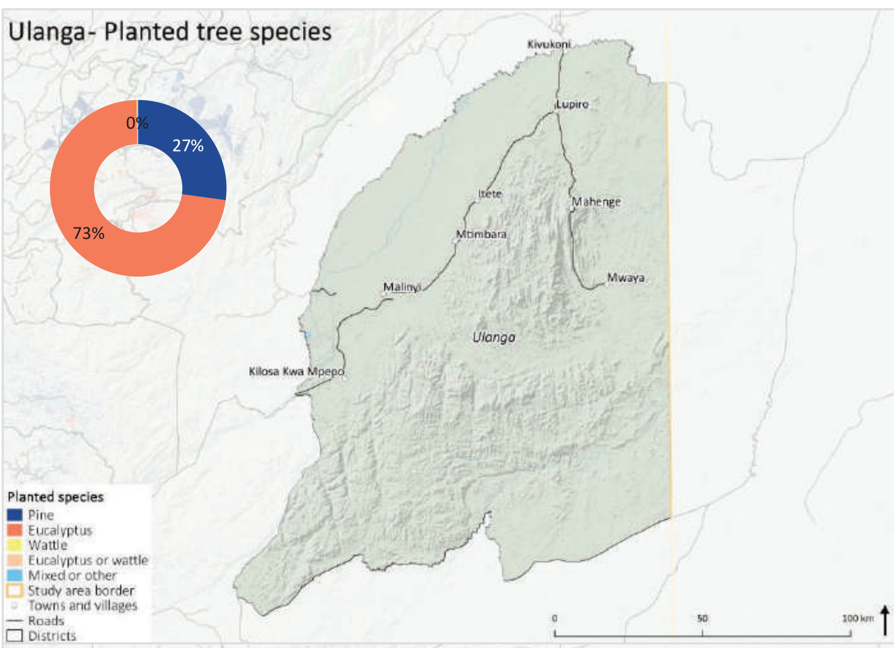
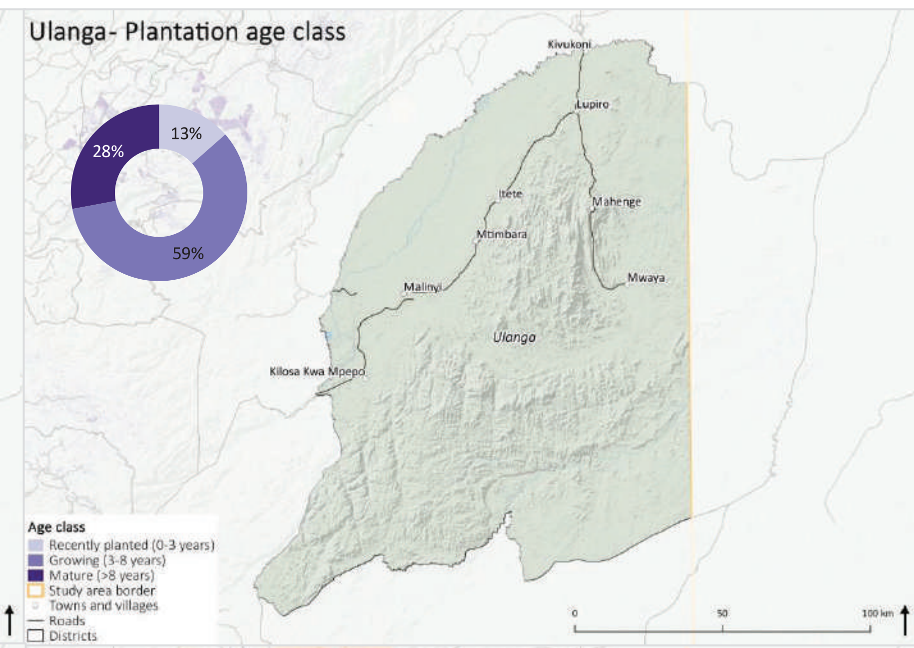
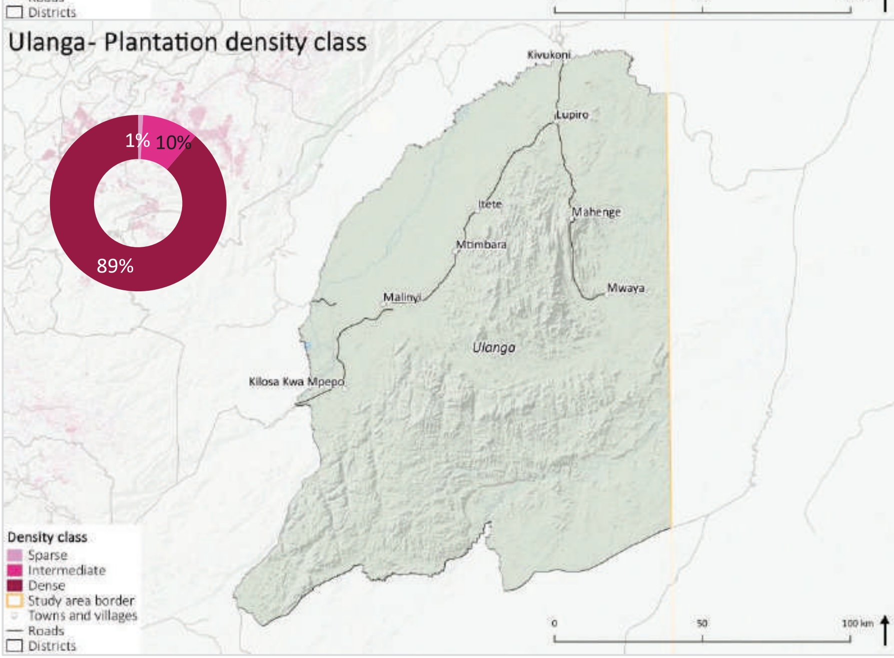
FOREST PLANTATIONS IN ULANGA DISTRICT

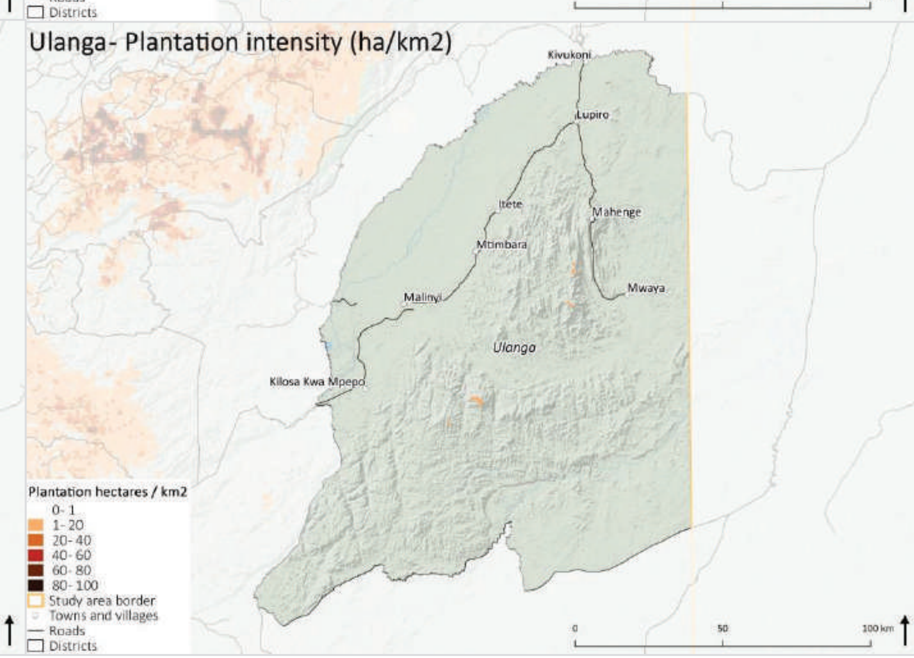
District name	Total area (ha)	Plantations (ha)	Rank (out of 38 districts)	Government-owned (ha)	Company-owned (ha)	Privately owned (ha)
Ulanga	1902058	59	24	0	0	59











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