Brief 02

ALLREDDI

Accountability and Local Level Initiative to Reduce Emission from Deforestation and Degradation in Indonesia

Forest carbon-stock estimates based on National Forest Inventory data

Indonesia's forests were inventoried from 1989 to 1996 (phase 1) and from 1995 to 2000 (phase 2) by the Forest Planning Agency ('the Agency') at the Ministry of Forestry as part of a collaboration between the Government of Indonesia and the United Nations Food and Agriculture Organization. The objective of this National Forest Inventory (NFI) was to assess forest-stand conditions, stocks, growth rates and tree diversity across the landscapes of Indonesia. An improved version of the NFI became known as the Forest Assessment and Monitoring System. This data set had not so far been used to estimate aboveground tree biomass and carbon stock in Indonesia, as quality control of the data had not been completed. We provide an overview of the data and derive carbon-stock densities for different forest types and locations that can be used for estimating historical, aboveground CO_2 emissions from deforestation and forest degradation.

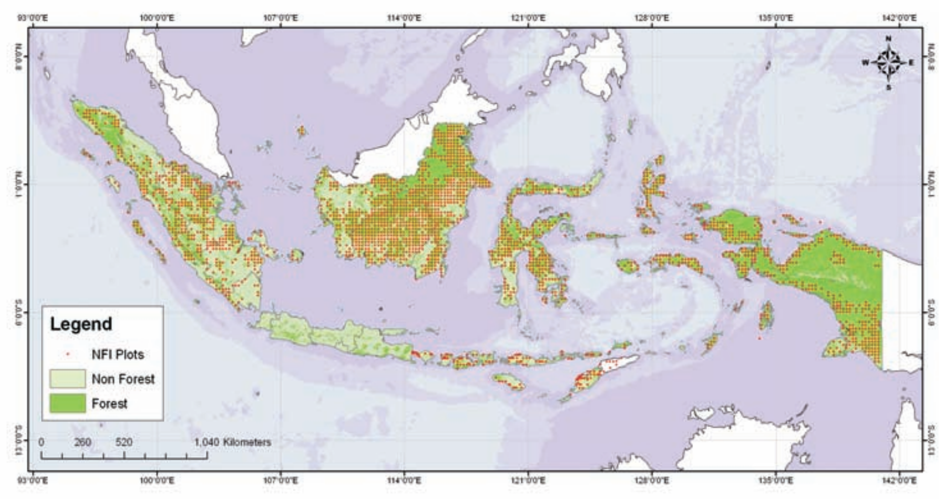

Figure 1. NFI plot location systematically sampled in a 20 x 20 km grid across Indonesia

Photo: Degi Harja

ISSUES	OPPORTUNITIES
The NFI was not initially designed for carbon-stock assessment. The data have not been in the public domain and available for scrutiny. Several experts are sceptical about the quality of the data, especially regarding botanical identification	The inventory was comprehensive and well-designed, using proper techniques of data collection. Tree data (diameter, height) allow use of allometric equations to estimate aboveground tree biomass, a dominant component of total carbon stock. Botanical identity only influences carbon-stock estimates via wood density attributes
The systematic sample design, in contrast to a stratified random design, meant that less frequent forest types are poorly represented	The data allow assessment of the shape of statistical distributions of carbon-stock density in the main (lowland) forest types of Indonesia
Data validation for quality assurance was itself of variable quality, but involved consultants from a number of universities and research institutions during and shortly after the inventories	Internal data consistency tests and comparison with other data sources can indicate weaker parts of the data set

The data set

Sample plots were identified systematically across Indonesia in a 20 x 20 km grid, but mountainous areas (for example, Papua) and regions with low forest-cover (Java, parts of Sumatra and Kalimantan) were not included. Each cluster location was designed as 3 x 3 plots. Each plot size is 1 hectare, and one plot in the centre was designed as a permanent sample plot (PSP) surrounded by eight temporary sample plots (TSP). The inventory of TSPs was made using a basal area factor technique (DirJenInven 1992), while in the PSP plots a census was made of all individual trees with a diameter at breast height (DBH) greater than 20 cm within the 100 x 100 m plot and stratified sampling for trees with less than 20 cm DBH. In the PSP plots, tree height was measured for trees of above 20 cm DBH. The species of individual trees was recorded using local names with a tentative conversion to botanical identities. The data collected by regional offices of the Agency were compiled by the central office with consistent file structures; each track and sub-plot was recorded as a separate file.

Data pre-processing

The ALLREDDI project started by converting all individual files into a common database for ease of comparison and calculations (Figure 2).

Efforts were made to convert local species' names recorded within each PSP into common/scientific species names, such that the species names could be used as the key ID to link with the wood-density database. The database of local and scientific species names plus associated wood density was compiled from many sources including the Directorate of Forest Planning, Plant Resources of Southeast Asia and the World Agroforestry Centre.

Validation of tree and plot data

The total number of individual trees recorded in the processed NFI database was 620 500. During the data-cleaning processes we removed severely damaged trees (5%), trees that violated 'normal' rules of diameter/height relations (1.5%) and outliers (less than 0.01%). The damaged trees (as defined by the damage codes in the original NFI database) were removed from the next processing step by considering them as necromass (dead standing trees rather than living biomass). Rules used to test normality of trees were 'tree below 20 cm DBH should be in radius of 5 m of each subplot (25 x 25 m) and there should be no height information for the related tree' (otherwise there was a possibility of typographical errors). Outliers were selected based on common tree profiles, that is, diameter–height relationships ln(height)/ln(DBH) were first tested whether it was inside the common range of 0.1–2 and later the data was manually checked.

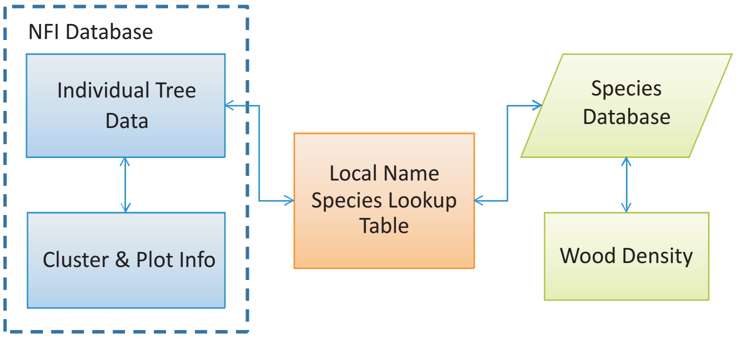

Figure 2. General structure of NFI Database as analysed by ALLREDDI combined with the species database

Other than records of trees, each subplot within a PSP (25 x 25 m) had information of land cover and description of uses. From 2205 cluster locations (from phase 1), 1595 PSP were selected through a data-consistency checking process within subplots and were used in the subsequent analysis. Within a subplot, land-cover and land-use descriptions might vary, while in scaling up each sampling location should have only one land-use or land-cover class attributed to it.

Diameter distribution and diameter–height relationships of trees across Indonesian forests

The overall tree diameter distribution of PSP is shown at Figure 3. The distribution follows the common size distribution of a mixed-strata stand. Forest and non-forest stands show a similar profile within the overall plots.

Whilst there are clear overall tendencies of positive correlation between tree diameter and height, the relationships are highly climate-specific (Figure 4). Trees of a particular diameter tend to be taller in wet climate conditions compared to those in a dry climate with the same diameter. One plausible explanation is the fiercer competition for light in wet climates since the water availability enables trees to grow faster. Further research is necessary before this can be confirmed.

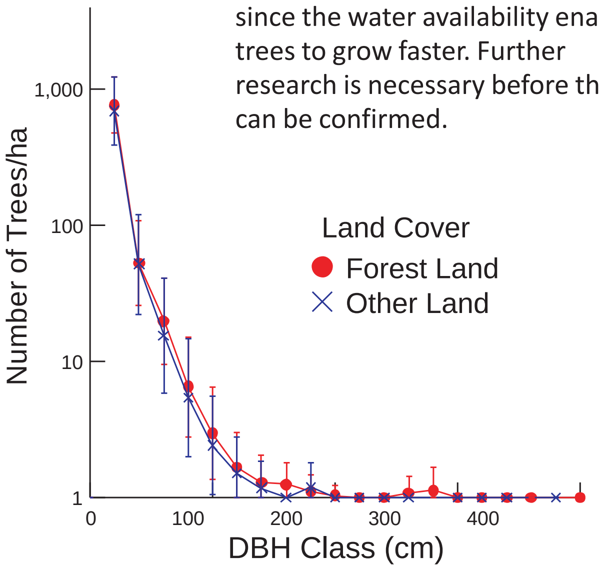

Figure 3. The typical stand profile from 1595 PSPs in landscapes in Indonesia. Y axis is the number of trees for each DBH class per plot, in log scale.

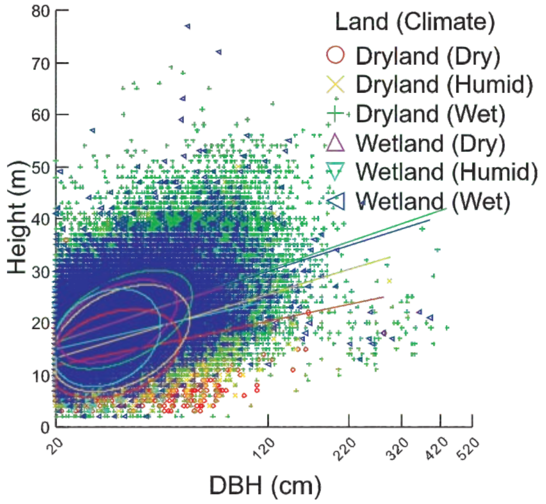

Figure 4. DBH–Height plot of all individual trees above 20 cm DBH and grouped into climatic area. The line is a linear smoother and the ellipse is sample confidence area. The drier zones are shown to have shorter trees for the same diameter

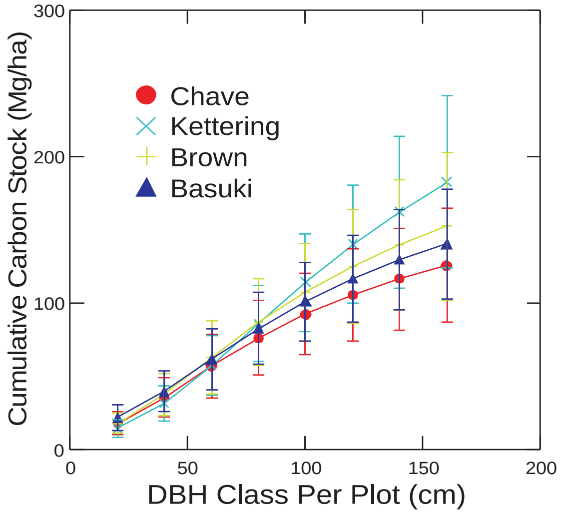

Figure 5. Cumulative carbon-stock over DBH class within a typical forest plot. The plots were sampled by similar largest DBH of 160 cm. The number of plots is 21, selected based on the complete distribution of the defined class size. The error bar is standard deviation. Kettering's allometry has higher estimates when the plot contains trees with > 100 cm DBH

Forest or tree-based vegetation?

*The National Forest Inventory was set up to sample 'woody vegetation'. Overall about 70% of Indonesia is considered to be 'permanent forest estate (*kawasan hutan*)—a land-use class regulated by forestry laws—whether the land currently has tree cover or not. About 20% of the plots were located outside of the* kawasan hutan *and their tree cover and frequency distribution of tree diameters proved to be remarkably similar to the* kawasan hutan. *Monocultural tree plantations, whether tree crops such as rubber, coconut, coffee or oil palm, or industrial timber estates with slow-growing, high-quality timber such as teak or mahogany or fast-growing species such as Acacia mangium or Gmelina were not included in the dataset. The data do, however, include part of the 'agroforests' where farmer-planted trees share the space with trees spontaneously established and maintained by farmers if they are considered to be of use or at least they don't stand in the way of more valuable trees.*

Selecting allometric functions: elements and interpolation domain

Many allometric functions developed for estimating the biomass of trees can be found in the literature. Some were developed based on wide geographical and climate conditions, such as Chave's (Chave et al. 2005) and Brown's (Brown et al. 1989), and some were more geographically focused, such as Kettering's for Sumatra (Kettering et al. 2001) and Basuki's for Kalimantan (Basuki et al. 2009). The significance of applying different allometric functions to the same NFI dataset is presented in Figure 5.

Figure 5 shows that all four functions result in similar estimates of biomass (and therefore carbon stock , in our case using 0.46 factor) for plots with trees less than 100 cm DBH. Comparing the estimation results from the four equations, we observed that until 60 cm DBH the four functions agree in terms of biomass estimation. Chave's estimates diverge from the rest after 60 cm DBH and become the lowest of all four estimates. Then after 80 cm DBH the three other estimates diverge from each other: Kettering's is by far the highest followed by Brown's and Basuki's.

Kettering's estimation departs from the other three when trees of > 80 cm DBH are found in the plots. Looking closely at Kettering's data and equation, we see that the range of tree DBH within her destructive sampling is quite narrow (only up to 60 cm DBH of tree samples) and, since it was conducted specifically in one area in Jambi province, the equation does not consider the climatic region. Kettering also does not incorporate tree height in her allometric modelling. Basuki did cover a wider range of diameter classes within his destructive sample sets (up to 200 cm DBH), however, the tree samples also were selected in a particular region in East Kalimantan and therefore variability in climates is not incorporated. Basuki's allometric function also excludes tree height while we see from Figure 4 that tree height is not perfectly correlated with diameter and therefore contains independent additional information to diameter that determines biomass.

Chave's and Brown's equations take into account tree heights and climatic zones. We opted to use Chave's as the default function for the aboveground carbon-stock estimates of NFI data because it has much wider geographical distribution and forest conditions than Brown's and, moreover, it incorporates the wood density of species into the function. Wood density is known as a very important variable in determining biomass (Chave 2005).

Aboveground carbon stock in 'forest' across Indonesia

We grouped plots of the NFI by the largest trees found and showed the distribution of the plot groups. Figure 6a shows that only a few plots within the dataset belong to the group

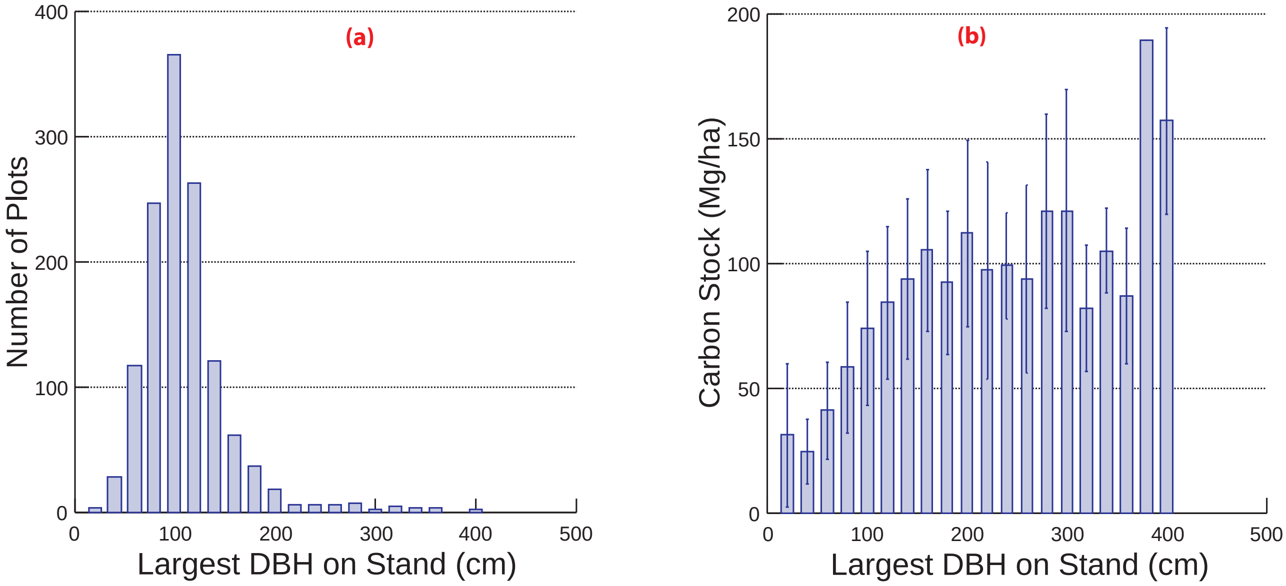

Figure 6. The frequency distribution of each plot group, defined by the largest trees found in the plot (a) and the estimation of plot-level carbon stock in each plot group (b)

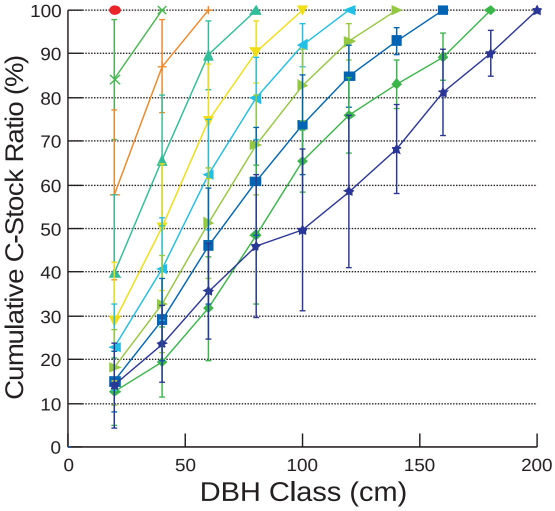

Figure 7. The average cumulative tree-size class contribution to total carbon stock in a 1 hectare area. The lines indicate the plot grouping based on the highest tree-size class found in the plot, for example, the blue line with star symbol represents plots where some trees of diameter 200 cm are found

with maximum tree diameter greater than 140 cm. Figure 6b shows the distribution of plot-level carbon stock, estimated using Chave allometric functions, of each plot group. The highest uncertainty of carbon stock across the dataset mainly comes from the plot groups with trees larger than 140 cm, simply because very few such plots occur in the dataset.

The typical cumulative contribution of size-specific class to total carbon (estimated using Chave allometry) is shown in Figure 7. The contribution of each DBH class to total carbon stock varies among plots and plot groups. Depending on the stand profile, the contribution of trees above 80 cm can be up to 50% of the plot's carbon stock. The dominant contribution is mostly from the medium-sized classes. In plots with the largest trees greater than 75 cm in diameter, more than 10% of total carbon was found in the largest trees. The contribution of the largest class was about 10% in all stand profiles.

The distribution of aboveground carbon-stock in forest and non-forest plots is shown in Figure 8. Both distributions do not seem to follow normal distributions, rather they are right-skewed, that is, a lesser number of plots have high aboveground carbon-stock than would have appeared in a normal distribution (the Log Normal and Gamma distribution can be considered as another alternative and may be used in further analysis). We can find plots with aboveground carbon stock of around 250 Mg/ha, however, the average of overall forest plots is around 80–100 Mg/ha. This range is lower than many other published numbers of aboveground carbon-stock in a small number of forest plots in particular areas in Indonesia, but are comparable to areas in Indonesia where we had access to the raw data (for example, 'Sepuluh Tahun Riset Hutan Hujan Tropika Dataran Rendah Di Labanan, Kalimantan Timur, Plot Penelitian' (Ten Years of Research on Tropical Lowland Rainforest in Labanan, East Kalimantan, Research Plot) or STREK project and Lembaga Ilmu Pengetahuan Indonesia or LIPI, the Indonesian Institute of Sciences (unpublished data) and many tropical areas (Clark and Clark 2000, Hairiah et. al 2010).

With the geographical coverage of the dataset collected under consistent protocols, data verification, data validation and data modelling techniques, we consider these results as best in describing 'typical' forest aboveground carbon-stock across Indonesia. Unless data verification can be repeated and conducted in a systematic manner that accounts for changes between the time of measurement and the present, it will be difficult to further assess the data quality.

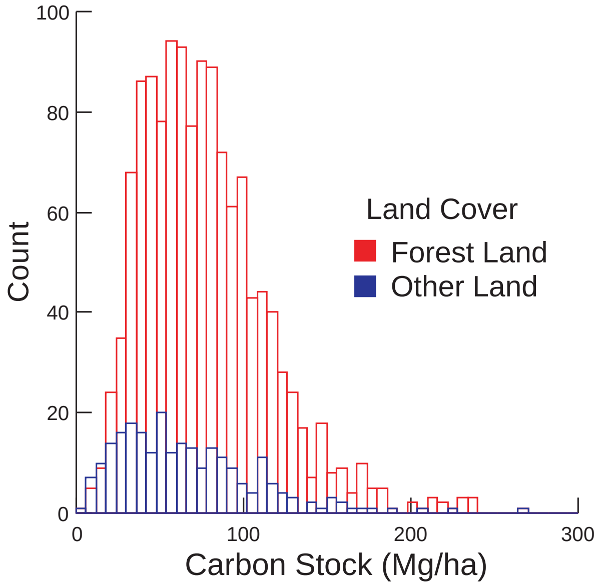

Figure 8. Aboveground carbon stock of all 1322 forest-type plots and 245 non-forest plots

Typical aboveground carbon-stock of forest stratified by eco-regions

In order to determine the emission factor of forest changes into non-forest classes in particular areas of Indonesia, we needed to produce some forest stratification, based on forest category and eco-region. Forest category was determined in accordance with the legend categories of the land-use and land-cover maps that were used in calculating activity data. Eco-regions were taken from WWF (2000) and were selected to stratify the climate variation and other biophysical characteristics across Indonesia. Figure 9 presents the error bar of aboveground carbon-stock in each combination of forest category and eco-region. We further calculated the weighted average of forest condition class defined by the NFI and used this as the typical aboveground carbon-stock of a particular forest category within a particular eco-region. The set of typical aboveground carbon-stock became the reference data for emission factors for land-use-change analysis of landscapes across Indonesia.

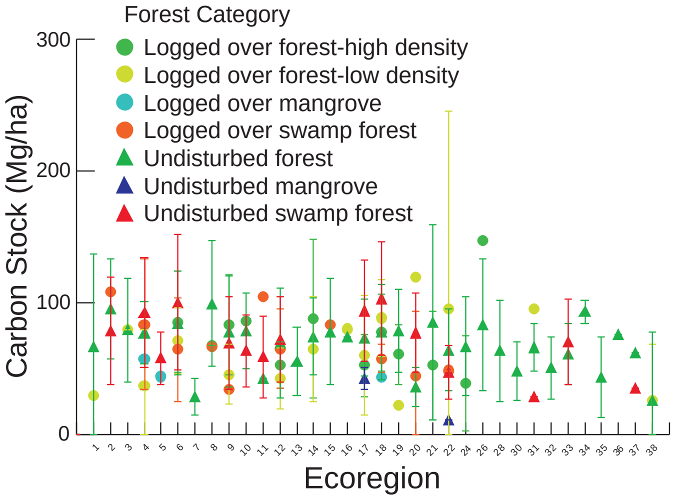

Figure 9. The error bars of aboveground carbon stock over eco-regions and forest categories. The means range varies within eco-region, showing the diversity of stock over the landscape of similar class cover

Conclusion and recommendations

The NFI data is the richest and largest database of forest inventory across Indonesia. It was created using systematic sampling and consistent, well designed, protocols of field measurement. The database has been well maintained by the Forest Planning Agency of the Ministry of Forestry. Through the ALLREDDI project we conducted verification and validation of NFI data to the extent allowed by existing resources. Several sources of error were addressed: errors due to field measurement and data entry; errors from applying allometric equations; and errors in plot samplings.

We conducted consistency checking and data cleaning of the NFI dataset and visited several plots in the field. We filtered out the data that were inconsistent and did not fulfill our data-cleaning criteria and extracted 1595 plots. In general, there is a positive correlation between diameter and height. Observing this correlation against climatic variations across Indonesia, we can see that trees of same diameters tend to be taller in wet areas compared to those in dry areas. Therefore, we concluded that in estimating biomass, diameter as well as height needs to be incorporated; that climatic condition and wood density are two other important variables to be considered. We selected and applied Chave's function that embraces all those four determining factors of biomass.

The NFI plots were designed systematically across Indonesia, every 20 x 20 km, rather than stratified. This causes data gaps in some forest categories and eco-regions, which are small in area and not very well represented in the current NFI dataset. The uncertainties in carbon-stock estimates within those becomes very high.

Typical aboveground carbon-stock of forests in Indonesia ranges from 16.92 to 92.73 Mg/ha, with the highest in the Sumatran peat-swamp forests eco-region and the lowest in the Lesser Sundas' deciduous forests. The non-forest carbon-stock ranges from 3.5 to 99.4 Mg/ha. The uncertainty was higher on fewer numbers of plots sampling such as the Sunda Shelf mangroves eco-region, which associates with 10% error.

Concerning the huge potential of the dataset to be the single biggest dataset for determining carbon stocks in Indonesia's forests—on which will be based the estimates of emissions from land use, land-use change and forestry (LULUCF) , baseline estimation and any additionality of climate-change mitigation actions—more rigorous and more systematic validation and verification of the existing plots and data, including field checks, needs to be carried out. Filling data gaps in some eco-regions should also be considered when redesigning the NFI. In addition, the current NFI was not designed to cover all carbon pools; adding a set of protocols to be inclusive of necromass, litter and soil carbon in NFI data collection for the next round of monitoring would be ideal.

There have been many efforts at compiling plot inventories by other institutions in Indonesia. We have established a prototype of a platform for data sharing through an integrated web-based database, accessible online. This will enrich the dataset at the national level and will enable people to cross-validate the data and contribute significantly to the monitoring, reporting and validating system to be developed for Indonesia. A screenshot of the web-based interface of the database is shown in Figure 10.

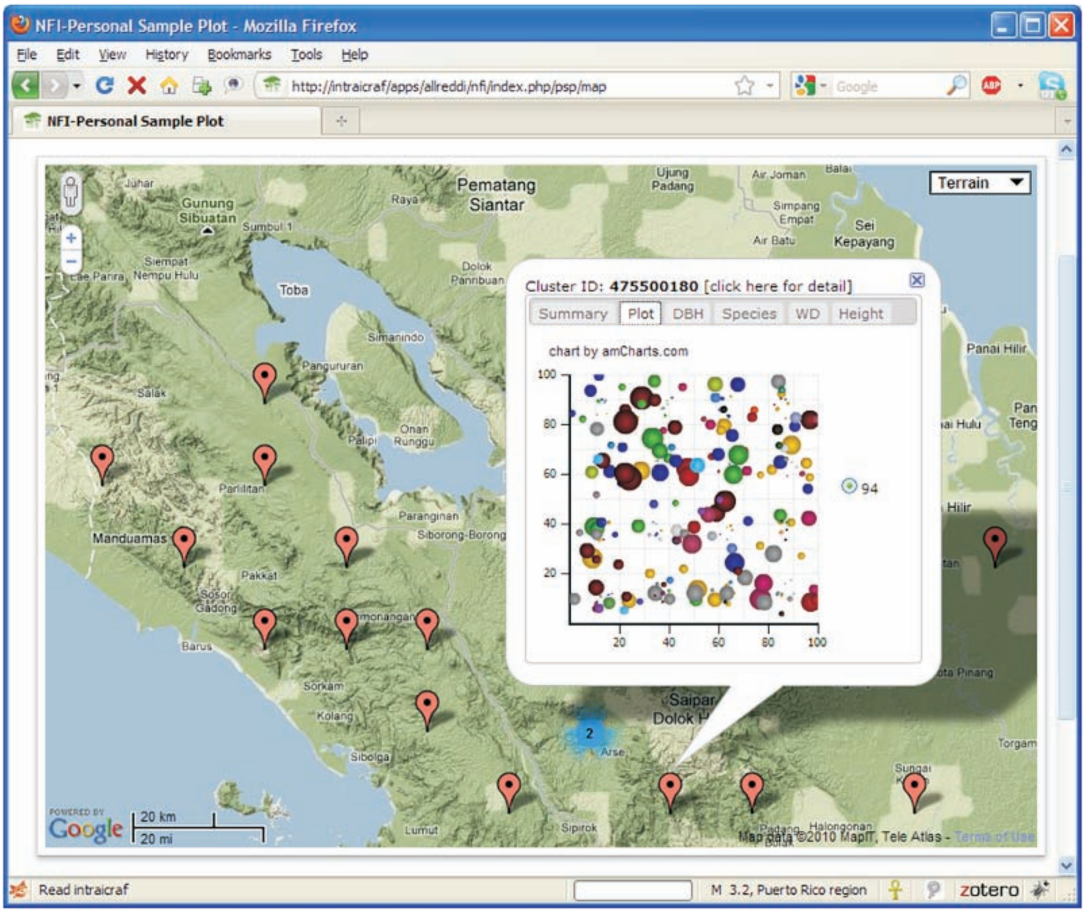

Figure 10. Web-based graphical user interfaces of NFI database overlaid on Google Maps. The platform was used as the analysis tool and stores the user data

ALLREDDI

Accountability and Local Level Initiative to Reduce Emission from Deforestation and Degradation (ALLREDDI) is a project implemented jointly by the World Agroforestry Centre and the Indonesian Government's Forest Planning Agency and involves partnership with Brawijaya University and the Indonesia Centre for Agricultural Land Resources Research and Development. The overall aim of the project is to assist Indonesia to account for land-use-based greenhouse gas emissions and to be ready to use international economic 'REDD' incentives for emission reduction in its decision making at the local and national levels.

There are specific objectives to be accomplished in its three-year implementation (2009–2011).

- Develop national carbon-accounting systems that comply with Tier 3 of the Intergovernmental Panel on Climate Change guidelines for agriculture, forestry and other land uses, complementing and maximising existing efforts
- Strengthen national and sub-national capacity in carbon accounting and monitoring
- Design operational mechanisms in five settings for REDD

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