BELIZE National Forest Monitoring System 2001-2020

[1]

National Forest Monitoring System

of

Belize

pursuant to Decision 11/CP.19

for the period 2001 -2020.

Version 1.0

2021

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LIST OF ABBREVIATIONS AND ACRONYMS

AFOLU	Agriculture, Forestry, and Other Land Use
BFD	Belize Forest Department
BUR	Biennial Update Report
CfRN	Coalition for Rainforest Nations
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
FAO	Food and Agriculture Organization (of the United Nations)
FOLU	Forest and Other Land Use
FRL	Forest Reference Level
Gg	Gigagrams
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GPG	Good Practice(s) Guidance
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land Use Change, and Forestry
m^3	Cubic meter
MSDCCDRM	Ministry of Sustainable Development, Climate Change and Disaster Risk Management
MRV	Measuring, Reporting, and Verification
N_2O	Nitrous oxide
NCCO	National Climate Change Office
NIR	National Inventory Report
NFMS	National Forest Monitoring System
REDD+	Reducing Emissions from Deforestation and Forest Degradation
UNFCCC	United Nations Framework Convention on Climate Change

National Forest Monitoring System of Belize Ver. 1.0
2001-2020

Given the diversity of vegetation types, tenureship and land-use dynamics, the Belizean Government has employed a multi-tiered monitoring system to monitor land-use changes over the years. These monitoring systems each have their own purpose and characteristics; and contribute individually to a robust arrangement for monitoring and reporting in the LULUCF sector.

The design chosen for the National Forest Monitoring System (NFMS) Version 1.0 of Belize utilizes multiple platforms and datasets. The Belize NFMS is a set of methods, activities and institutional arrangements that aim to produce high-quality, reliable data on human activities and ecosystem processes in forests, including estimates of forest carbon stocks and emissions changes as a result of land-based activities; it is a key tool to assess whether the implementation of Belize's forest management and protection activities, policies and strategies are resulting in measurable benefits. The Belize NFMS uses a combination of remote sensing and ground-based inventory approaches. It provides internationally acceptable estimates that are transparent, consistent and accurate, with acceptable levels of uncertainty, and that are rooted in national circumstances. To ensure effective use of limited resources, Belize's NFMS provides data and information for forest management, REDD+ Measurement, Reporting and Verification, national greenhouse gas inventories, and reporting progress, among others.

1.1 Summary of National Forest Monitoring System and Measurement, Reporting and Verification efforts to date

In the late 1990s, Belize began initial work on the first component of a National Forest Monitoring System of its forest resources, i.e. a permanent ground inventory, specifically to measure forest age, structure, composition and rates of different processes occurring in the forest under natural conditions as well as under anthropogenic stressors. This commenced with the installation of thirty permanent forest plots, each measuring one hectare (ha) in size distributed across the country. The purpose of this new long-term inventory programme was to address the deficiency in information needed for forest management and conservation. Since 2013, the permanent forest inventory has expanded from the original thirty plots, concentrated mainly in the moist upland forests, to now 64 plots spanning different types of forests across the entire length and breadth of the country distributed across the three climatic zones (dry, moist, wet). The expanded network also encompasses 19 permanent plots distributed in mangrove forests and non-forest vegetation including natural grasslands, ferns, shrubland and fallow land.

The second component of the NFMS commenced in 2018, with the specific aim to measure changes in the area and distribution of different land use types across Belize through time as a result of anthropogenic activities and natural disturbances. This component involves a visual classification of various remote sensing data to determine land-use change from 2001 to 2018 by applying systematic virtual plots embedded in the Collect Earth Desktop platform. Changes from forest to other land-use categories, and from non-forest to forest are detected and quantified annually using 21,991 virtual plots. The plots are on a systematic grid of one kilometer so that each plot represents 100.53 hectares as the expansion factor. Each plot represents 0.5 of a hectare and within each virtual plot, there are 49 points, each representing two percent, which is used to detect changes in land use cover within the 0.5 ha plot.

Components one and two jointly comprise the National Forest Monitoring System of Belize Version 1.0, formalized under the auspices of the Reducing Emissions from Deforestation and Forest Degradation (REDD+) mechanism. Belize's NFMS v1.0, therefore, utilizes a two-phased monitoring system, with tree-level forest inventory data continuously producing estimates of stocks and stock change due to natural and anthropogenic activities that are then extrapolated to the national level using remotely-sensed landscape-level data on land-use and land-use change distribution resulting from natural and anthropogenic activities.

Belize also began work in 2018 on a National Forest Information System which is built around a virtual platform to collate, analyze and present forest-related information to government agencies, international organizations and the general public in the spirit of full transparency. Though development continues on this platform, the reporting of forest related information derived from the two components of the NFMS v1.0 is centralized in the Forest Department and National Climate Change Office and occurs through the development of the Greenhouse Gas Inventory, Forest Reference Level, the Biennial Update Report and Technical Annex. Figure 1 presents the main systems that make up this arrangement, while Figure 2 provides a depiction of the how the data from the two sources are combined to inform changes to Belize's forests.

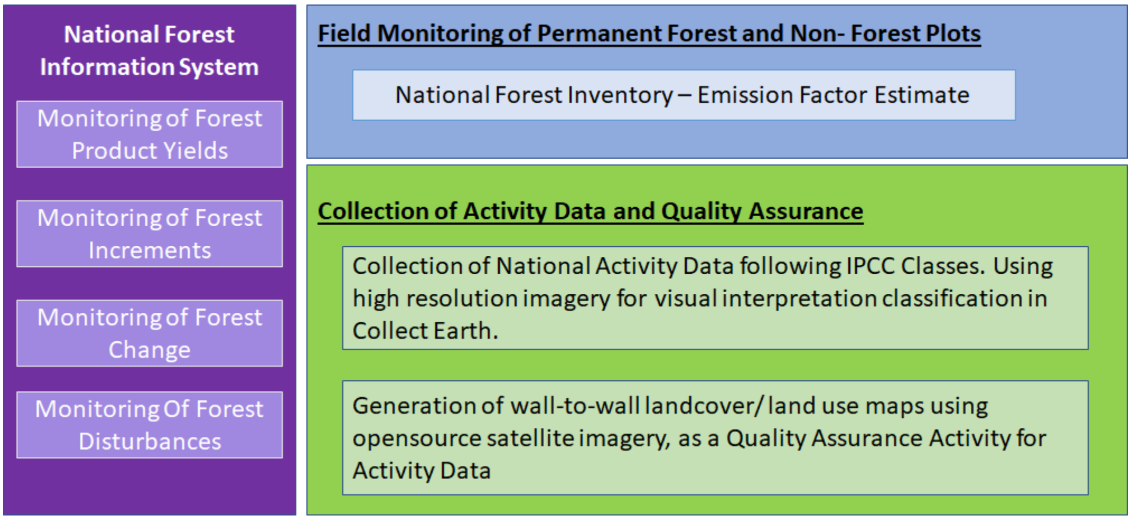

Figure 1. Implementation arrangement for the National Forest Monitoring System of Belize

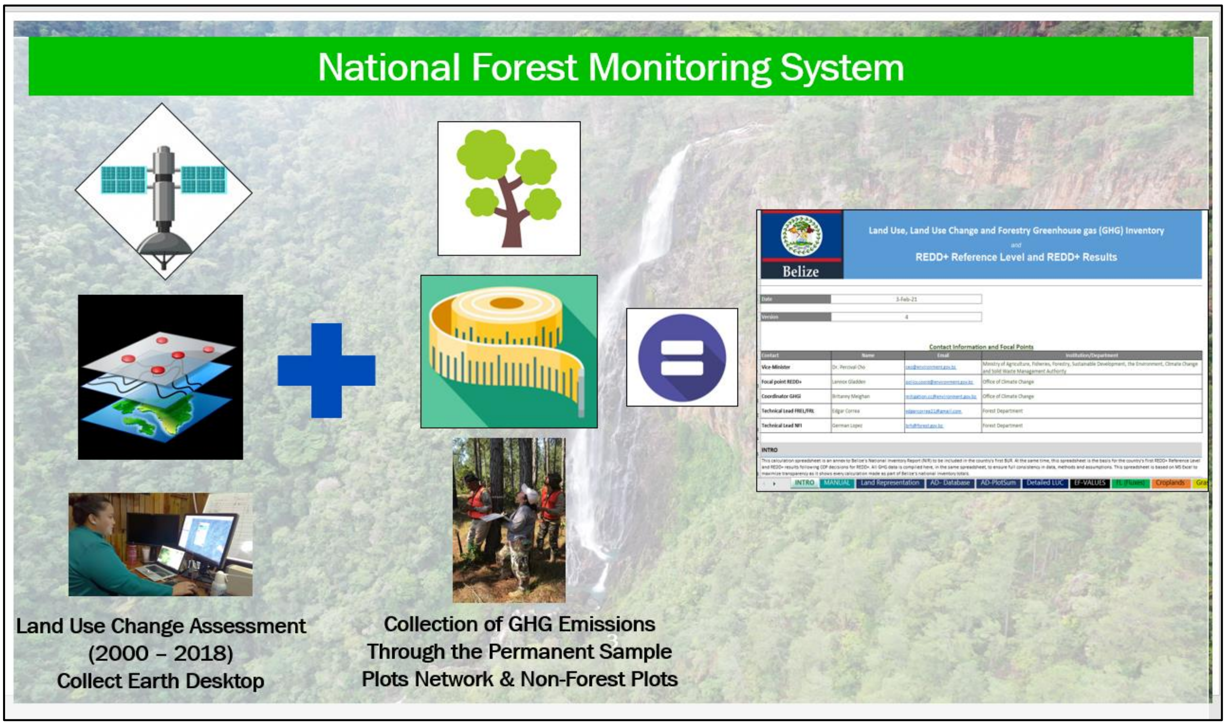

Figure 2. Combining satellite-based land monitoring with ground-based plot data to inform the National Forest Monitoring System of Belize

The plot-based characteristics of the satellite land monitoring system and the ground-based permanent forest inventory are shown in Table 1.

Table 1. Characteristics of the sampling design of the National Forest Monitoring System (showing 2021 distribution)

Platform	Total area (1000 hectares)	Number of plots						Total number of plots
		Forest	Grassland	Cropland	Other land	Settlement	Wetland	
Satellite	2 211	13 580	4 470	2 064	6	362	1 509	21 991
Ground	1 365	64	17	2	0	0	0	83
Total	3 576	13 644	4 487	2 066	6	362	1 509	22 074

1.2 Remote sensing-based activity data collection

Land Use and Land Use Change Data

According to the 2006 IPCC Guidelines, Belize implemented Approach 3, as it is characterized by a systematic grid of observations of land-use categories and land-use conversions, tracking patterns at specific point locations represented by a 0.5 ha plot within a 1km square grid. Further improvements will scale up the methodological intensity of Approach 3, where individual land areas or parcels of land categories will be assessed and tracked through time.

To achieve this, Belize decided to use the image visualization tool called Collect Earth / Open Foris developed since 2013 as a tool for the collection of Land Use and Land Use Change data using mid- and high-resolution imagery. Collect Earth (as well as all the tools developed within Open Foris) can be downloaded for free from the OpenForis.org page (http://www.openforis.org/). This software is developed in Java, uses Google Earth as its main data collection interface and integrates several web services that provide very high-resolution satellite images, as well as temporal analysis using free images from NASA and ESA since 1984 which facilitates the process of visual interpretation.

This tool combines the ease of use of such a simple and well-known software such as Google Earth, which is used for the data collection interface, with the power to handle Open Foris Collect surveys; as well as, the file and analysis capacity of Google Earth Engine and the very high-resolution images of Bing Maps. Collect Earth uses a sample design predetermined by the survey administrator, as well as a form design (generated through Open Foris Collect) that will be shown when clicking on a plot that is displayed in Google Earth (Figure 3).

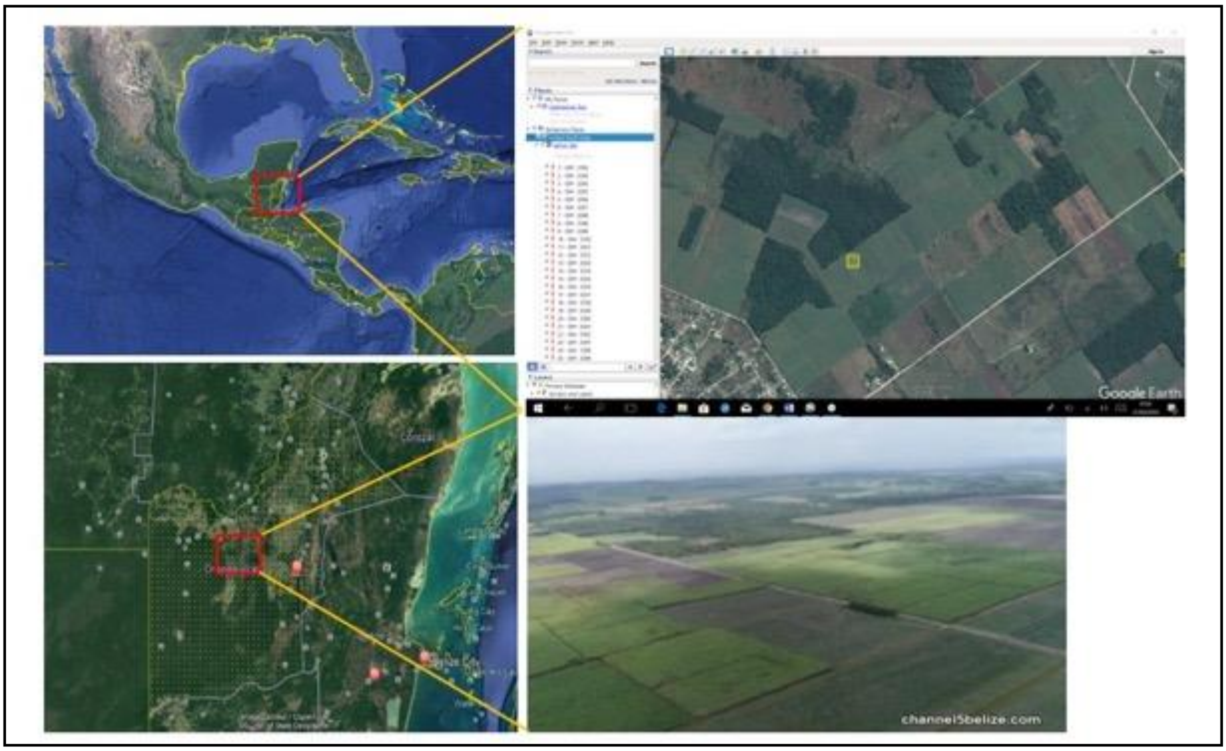

Figure 3. Example of Collect Earth visual interface on google earth.

Collect Earth is integrated with Bing Maps and Google Earth Engine, which means that when the form is displayed (clicking on the plot) a process is initiated that opens several windows showing that same plot in Bing Maps, which will sometimes have better very high-resolution images that Google Earth, as well as in Google Earth Engine Code Editor and Google Earth Engine Explorer. Through Google Earth Engine, access to all the historical archive of NASA (Landsat 5, 7 and 8 and MODIS) from 1984 to the present was made possible, as well as the ESA (Sentinel-2), which offers very high-quality image resolution (10 meters per pixel as opposed to 30 meters per pixel from Landsat) from 2014 every 16 days. Google Earth Engine not only enables imagery capabilities, but also analytical tools producing, for example, vegetation graphs or image composites to eliminate cloud cover (Figure 4).

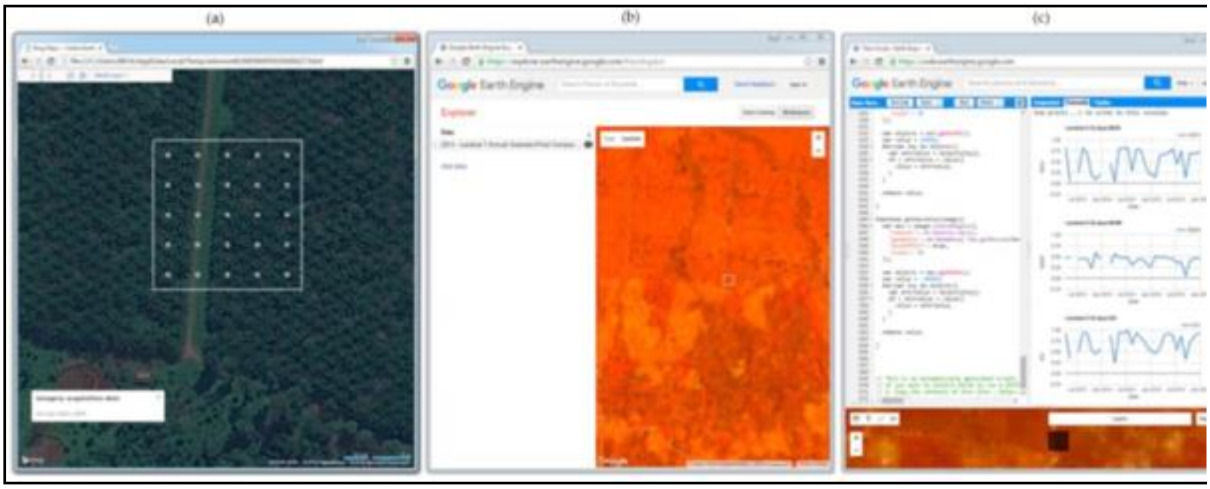

Figure 4. Example of Collect Earth integrated with Bing Maps & Google Earth Engine.

Collect Earth plot size & distance

To define a grid for plots for Belize, it was necessary to establish the total land area of Belize. This was calculated with Arc Map using the country district shapefiles obtained from the Lands Information Center of Belize. The result of the geometric calculation was an area of 22,110 square kilometers. After a systematic selection done in Google Earth Engine, using the grid design parameters, a total of 21,991 plots were created. For Belize, a plot size of 0.5 hectares with 1 kilometer between plots was defined for the 2018 Mapathon. Half-a-hectare (0.5ha) plot was defined along the country definition of a forest for Belize. Figure 5 illustrates how a plot was visualized in each of the platforms integrated with Collect Earth/Open Foris.

A one-kilometer (km) grid of virtual plots is distributed systematically across the total land area of the country (22 110 km^2) using the Collect Earth platform. A virtual 0.5 ha square plot, corresponding to the minimum area for national definitions for different land use categories, is situated at each grid point as per Figure 5. Each plot consists of 49 points, each representing 2 percent of the plot, which are used as subplots for the virtual sampling of forest cover.

The design of the sample, that is, the grid of virtual plots where the land use, land use change and forestry (LULUCF) data are collected individually and used in Collect Earth, is based on a pre-estimation of the number of virtual plots required to reach a low sampling error, and practical matters such as the available time and workforce to carry out the assessment.

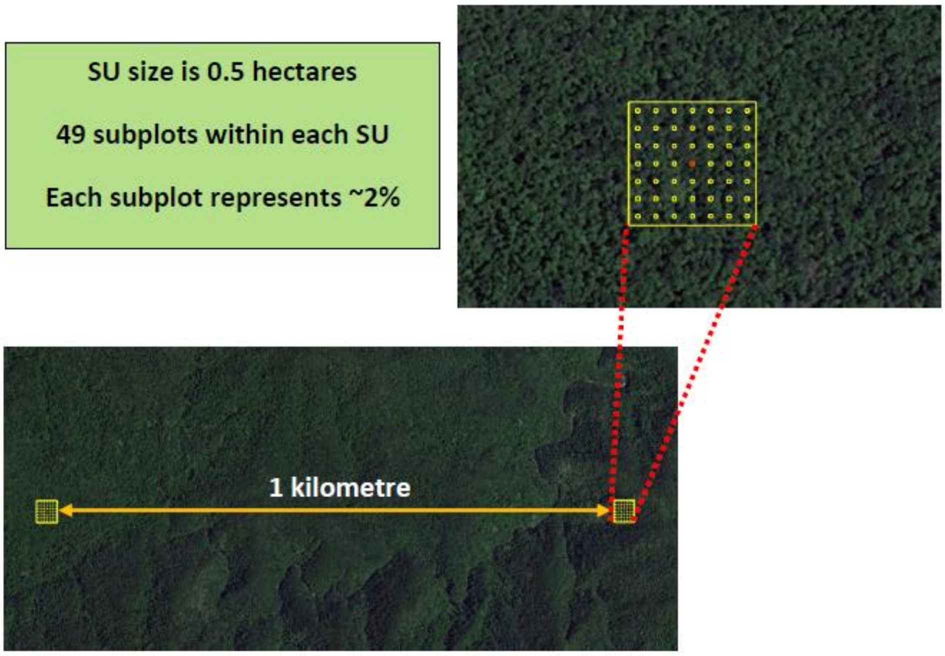

Figure 1. Design of the satellite land monitoring system plots

Land Representation

Belize followed 2006 IPCC Guidelines structure for the AFOLU sector, including the six main land-use categories: Forestland, Cropland, Grassland, Wetlands, Settlements and Other Land (Level 1). Additional subdivisions were defined following national circumstances, including climate, soil and disturbance history in line with IPCC guidance (Levels 2 and 3). Forest land was divided into Broad-leaf Mature Forest, Broad-leaf Secondary Forest, Pine Forest, Mangroves, Plantations. Croplands were divided into annual crops, perennial crops and fallow lands. Grasslands, were divided into Pastures/Shrublands /Savannas/Ferns/Thickets, Regenerating Shrubs & Bushes and Regenerating Shrubs & Bushes (Mountain Pine Ridge). Wetlands, Settlements and Other Lands do not have any further subdivisions.

Hierarchy Level

The distinctions of canopy cover through visual interpretation is intrinsically related to the understanding of a national forest definition. Starting from the premise that plots of 0.5 ha undergo visual and through a visualization system (Google Earth) focusing on the changes in land use. This is part of a hierarchy level presented below in Figure 6, based on the interpretation of the plots for its category definition observed on satellite images.

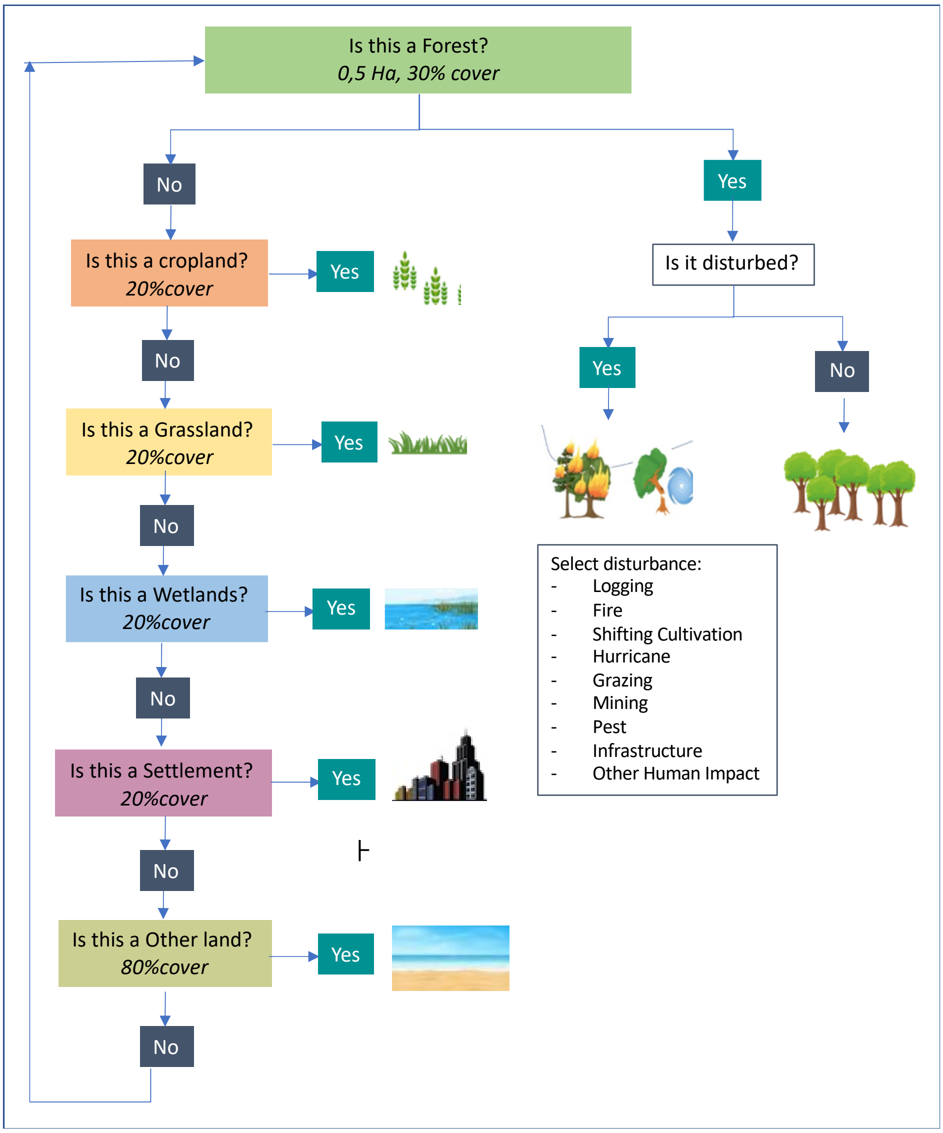

Figure 6. Hierarchy Level

The starting point of this hierarchy is given by the definition of forest acquired by the country visualization of images within CE described below.

According to the classification of the matrix, if a plot seen under CE has 30% of its coverage under any of the forest classifications and its relationship to canopies classes, its land use is classified as "Forest". Similarly, a visual analysis of the parcel environment is made according to expert judgment and if what predominates is Other Land Uses that reflect or represent more than 70% of the image, it is assigned that specific Land Use that predominates.

Classification of land use in Collect Earth

For example, in the image of March 19, 2001, the land use is a mature forest but by September 8, 2001, it has been deforested, converting it to a new land-use category. On the image, it predominates under bare land; however, on June 18, 2003, it has some cultivation. When seen again on February 6, 2011, it is clearly identified as agricultural land. In this sense, it is classified as croplands (Figure 7).

Figure 7. Example of how the CE image is analyzed to determine its land-use classification.

This combination of several tools, as well as the power for the temporal analysis of Google Earth Engine, which among other things allows for the visualization of graphs of vegetation indexes on the plots (Figure 8). This facilitates the temporal analysis of land use change and determines definitions accordingly to the type of final land use that will be assigned to that plot.

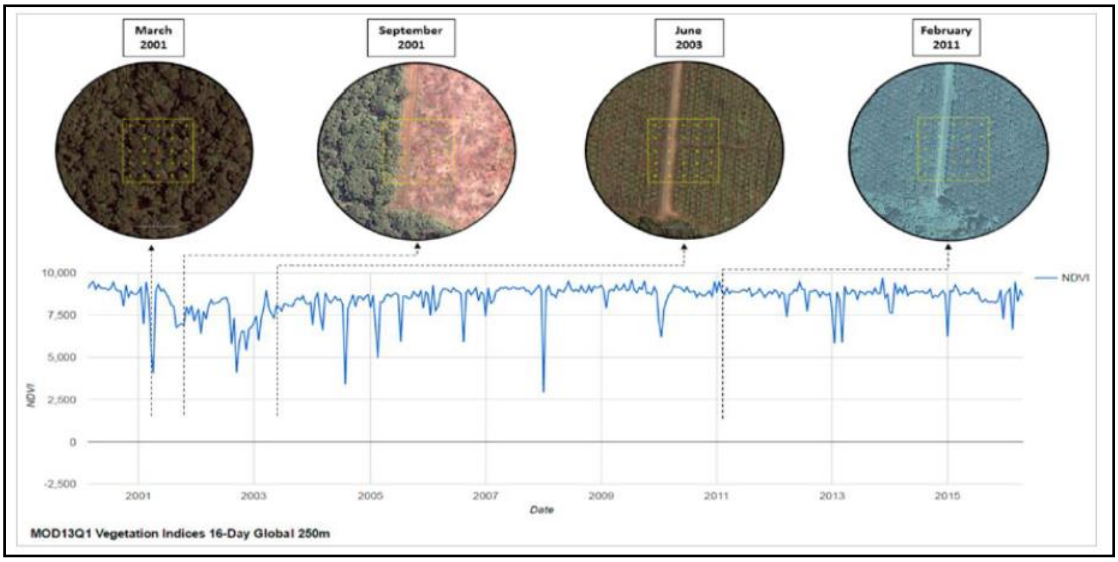

Figure 8. Example of temporal analysis tools to visualize land use change

With this method it was possible to obtain annual data for time series of 2001-2018, and spatially explicit, since the position of each of the plots is known and therefore, auxiliary data - maps- can be used to stratify the information by districts, climatic zones, conservation areas, forest concessions, etc. For each plot, we know the land use for each year, the subdivision, the conversion class and year of conversion, topography, human impact type (disturbance levels 1, 2 and 3), elevation, slope, aspect, climate, soil class, district, community, protection organization, level and year, and ecosystem. This information allowed a very detailed annual analysis of the dynamics of land use.

More details about the methodological processes of the Collect Earth Assessment can be found in the document "Belize Collect Earth/Open Foris Land Use and Land Use Change Assessment Protocol."[3]

Disturbances

Disturbances were identified while doing the classification of the plot. The CE platform provided MODIS data graph to see the occurrence of fire within and around the plot, over the years. Hurricane paths were available as a km layer in Google Earth and damages of plots could be seen in the high-resolution image over the time frame. Logging disturbance was noted in the area due to the best expert knowledge of logging roads and barquedier. Pest disturbance was noted from the area within the Mountain Pine Ridge and the best expert knowledge. Furthermore, changes in the canopy were noted within high-resolution imagery. Infrastructure and Mining disturbances could be seen within the high-resolution imagery over the time frame. Other human Impacts were noted from constant disturbances within an area of best expert knowledge. These areas we along the roadside, buffer zones of Protected Areas, Electrical Boundary Lines, constant maintenance of the property and around urban and rural areas.

1.3 Ground-based emission factor estimation

Forest Inventories

Broad-leaf Mature Forest: The information comes from the study "An investigation of tropical forest response to hurricane disturbance with evidence from long-term plots and earth observation in Central America" by Dr. Percival Cho (Ministry of Agriculture, Fisheries, Forestry and the Environment of Belize and Lancaster University) published in September 2013[4]. The methodology used for the Permanent Sample plots are from "Sustaining the Yield: improved timber harvesting practices in Belize" by Neil Bird and published in 1998[5] and also, from the paper "Diversity, dynamics and carbon budget of tropical forests subject to hurricane and anthropogenic disturbance" (Field Research Methods by Dr. Percival Cho, finalized in 2013[6] .

[3] Forest Department (2019). Belize Collect Earth/Open Foris Land Use and Land Use Change Assessment Protocol.
[4] Percival Cho (2013). An investigation of tropical forest response to hurricane disturbance with evidence from long-term plots and earth observation in Central America.
[5] Neil Bird (1998). Sustaining the Yield: improved timber harvesting practices in Belize 1992-1998.
[6] Percival Cho (2013). Diversity, dynamics and carbon budget of tropical forests subject to hurricane and anthropogenic disturbance: Field Research Methods.

During the period 1992 to 1998, 32 one-hectare permanent forest plots (Figure 9) were established in mature, hurricane-disturbed and/or selectively-logged broadleaf forests of Belize and censused multiple times using the same standardized pan-tropical methodology used in other networks (Bird, 1998); (Brewer and Webb, 2002).[7] Measurements were quality-controlled and well documented (e.g. Bird, 1998), thus providing a robust basis for evaluating growth rates (Clark and Clark, 2000)[8].

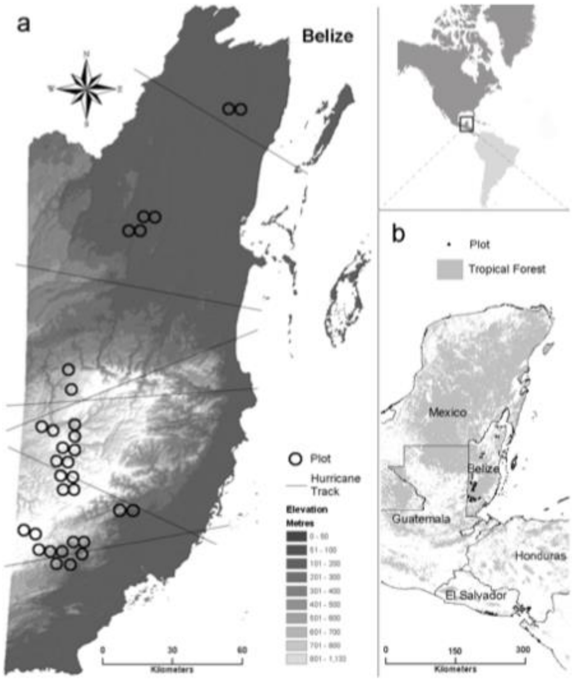

Figure 9. Location of the original 32 FORMNET-B plots.

Plots were divided into 25 quadrats or subplots each 20 x 20 m within which all stems ≥100 mm in diameter at 1300 mm above the ground (diameter at breast height or DBH) were identified, measured, tagged and mapped. The point of diameter measurement (POM) was painted and crown form and position in the canopy were assessed for each tree along with any relevant features including the presence of climbers, pests, rot, stem deformity or damage. Measurements of dead standing trees along with proximate causes were also taken. Stems 10 to 99 mm in diameter were measured in the central quadrat. Plot location methodology followed Beetson *et al.* (1992)[9] and was described in Bird (1998). In total, plots were placed within ten forest types ranging in altitude from 20 to 770 m.a.s.l and within areas receiving mean annual rainfall ranging from 1500 to 3000 mm. yr^{-1}, covering Lowland Moist Broadleaf (LM), Lowland Wet Broadleaf (LW) and Sub-montane Wet Broadleaf (SW), representing a wide range of growing conditions in Belize.

[7] Steven Brewer and Molly Webb (2002). A seasonal evergreen forest in Belize: unusually high tree species richness for northern Central America. Botanical Journal of the Linnean Society.
[8] David Clark and Deborah Clark (2000). Landscape-scale variation in forest structure and biomass in a tropical rain forest. Forest Ecology and Management.
[9]Trevor Beetson, Marks Nester and Jerry Vanclay (1992). Enhancing a Permanent Sample Plot System in Natural Forests. The Statistician.

Most plots are in different stages of recovery following natural or anthropogenic disturbance or degradation. Past disturbances were gleaned from forestry records dating back to the 1920s (Bird, 1998) and from satellite images. Landsat images from the 1970s showed that several plots were established in forests recovering from past fires following hurricane disturbance in 1961 and 16 plots were affected by hurricanes within the past 15 years.

- ***Broad-leaf Mature Forest - Logging:*** Selective logging began in the CRFR around 1920 and continued at intervals in the 1940s, 70s, and 90s (Bird, 1998). In 1996 the forest was zoned into compartments and placed under sustained-yield timber production with harvesting limited to one 500-hectare compartment per annum. To support the implementation of sustained-yield harvesting, ten 1-hectare permanent sample plots were established in the reserve between 1993 and 1997 (Bird, 1998). Twelve (12) of the plots were included in a controlled experiment to study the long-term impacts of selective logging (Bird, 1998). The plots were placed in six replicates of adjacent logged and unlogged pairs, and each plot was surrounded by a buffer of eight hectares of similar treatment. Logged plots and buffers were subjected to a uniformed felling intensity of six stems ha^{-1} and wood volume removals were meticulously recorded (Bird, 1998). Other plots in the network were logged under conventional selective logging methods as part of a study of logging damage. Unfortunately, after 1998 the plots were abandoned due to financial and institutional constraints. At the time of establishment, the forest within the plots resembled undisturbed old-growth and exhibited characteristics of all-aged, old-growth tropical forest, with a high stocking of trees greater than 60 cm in diameter (Bird, 1998).

- ***Broad-leaf Mature Forest - Hurricane:*** On 8 October 2001 Hurricane Iris struck the CRFR and affected eight (8) of the ten (10) permanent plots. Maximum sustained winds were estimated at around 225 km hr^{-1}. Hurricane tracks in the North Atlantic Hurricane Database (Landsea *et al.*, 2004)[10] indicate the last major hurricane (category 3 or higher on the Saffir-Simpson scale) to have affected the location of the plots occurred at least one hundred years prior to Hurricane Iris (Bird, 1998). Seven (7) of the disturbed plots (Figure 10) were used to study the effect of hurricane damage on tree mortality and recruitment (one plot could not be relocated during this study as the demarcation records were unavailable at the time). As controls, an equivalent number of undisturbed plots established in nearby areas around the same time were used. One control plot was located within the CRFR and six were in the nearby Chiquibul Forest Reserve. The seven (7) control plots were situated in mature tropical forests that have not been disturbed by hurricanes since 1961 (Bird, 1998). Censuses took place before and after the hurricane. BZ-2, BZ-3 and BZ-4 were censused in March 1993 and four years later in February 1997. BZ-27, BZ-28, BZ-29, and BZ-30 were censused in 1997 only. All the plots were censused again approximately ten years after Hurricane Iris: BZ-2 in June 2010, BZ-3 and BZ-4 in May 2011, and BZ-27, BZ-28, BZ-29 and BZ-30 between March and May 2011.

[10] Christopher W. Landsea, Steve Feuer, Andrew Hagen, David A. Glenn, Nicholas T. Anderson, Jamese Sims, Ramon Perez, and Michael Chenoweth (2004). The Atlantic hurricane database reanalysis project documentation for 1851-1910 alterations and additions to the HURDAT database. Hurricanes and Typhoons Past, Present and Future.

As part of Cho *et al* (2013) studies of forest recovery after hurricane degradation, data from all 85 censuses in the 1990s was compiled, sourced directly from the authors. During the period 2010 to 2013 seventeen (17) of the plots were restored and new censuses of live trees and dead logs were carried out. Botanical vouchers were collected from previously unknown abundant and rare species and taxonomical records were standardized against 'The Plant List' (www.theplantlist.org) (Kalwij, 2012)[11]. The data were digitized and validated following methods outlined in Peacock *et al.* (2007)[12] and Fox *et al.* (2010)[13].

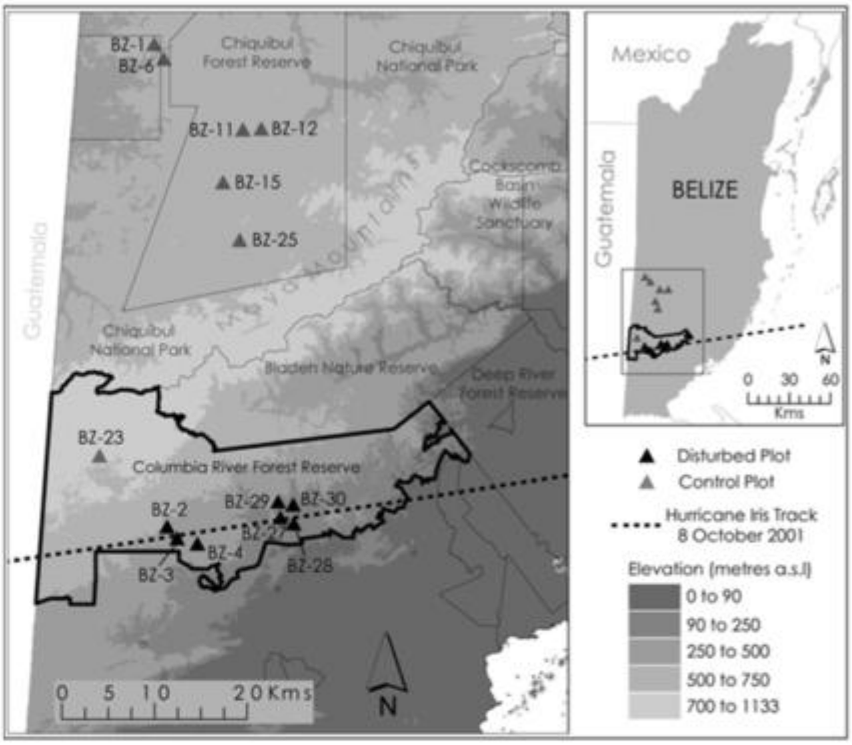

Figure 10. Map of the study area showing the location of the study plots.

Plot numbers follow the officially designated numbering system for FORMNET-B plots, where 'BZ' stands for Belize and is followed by the number representing the sequence in which the plots were established. Symbols of adjacent plots are offset by approximately 1.5 kilometers to prevent overlap.

A relational database was constructed in MS Access to house and link individuals to their respective repeat measurements. The aim of the database is to store and make available long-term forest monitoring data from the forest ecosystems of Belize and to facilitate linkages to other databases of permanent forest plot measurements such as 'Forestplots.net' (Lopez-

[11] Jesse Kalwij (2012). Review of 'The Plant List, a working list of all plant species'. Journal of Vegetation Science.
[12] Julie Peacock, Tim Baker, Simon Lewis, Gabriela Lopez-Gonzalez and Oliver Phillips (2007). The RAINFOR database: Monitoring forest biomass and dynamics. Journal of Vegetation Science.
[13] Julian Fox, Cossey Yosi, Patrick Niamago, Forova Oavika, Joe Pokana, Kunsey Lavong and Rodney J. Keenan (2010). Assessment of Aboveground Carbon in Primary and Selectively Harvested Tropical Forest in Papua New Guinea. Biotropica.

Gonzalez *et al.,* 2011)[14]. FORMNET-B (GIVD ID# NA-BZ-001), as the database is known, contains 33 722 stems (32 066 individuals) of which 79 % are palms, lianas and woody trees ≥ 100 mm DBH, 17 % are saplings 10 to 99 mm DBH), 2 % are seedlings < 10 mm DBH and 2 % are immature palms (with an indefinite stem). Repeat-census data incorporate 62 436 total individual records of tree measurements. On average, plots in FORMNET-B have been monitored for ten years (±7.35 st dev) with an average of 2.7 censuses (±1.07 st dev) per plot. This database was published, and more details can be found in "*The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests*"[15].

Mangroves: The methodology for the estimation of Mangrove biomass originates from the protocol "Mesoamerican Barrier Reef Systems Project (MBRS) Manual of Methods for the MBRS Synoptic Monitoring Program/Selected Methods for Monitoring Physical and Biological Parameters for use in The Mesoamerican Region"[16]. The Environmental Research Institute (ERI) of the University of Belize has a long-term monitoring presence in five study sites on Turneffe Atoll. Turneffe Atoll is located 32 kilometers east of Belize City. It is a part of the Mesoamerican Barrier Reef System and is within a marine reserve co-managed by the Turneffe Atoll Sustainability Association with the Belize Fisheries Department. The five sites are Calabash, North East Turneffe, Zone V, West Turneffe and North West Turneffe. Calabash, North East Turneffe and Zone V are sites that are located on the eastern coast whereas West Turneffe and North West Turneffe are on the western coast.

Each study site has three mangrove plots which measure 10 meters by 10 meters in area. ERI annually collects monitoring data from these study sites (methodology from CARICOMP Methods Manual)[17]. General methods for measurement of mangrove ecosystem structure and function are as described by Lugo and Snedaker (1975)[18], Pool *et al.* (1977)[19], and Snedaker and Snedaker (1984)[20]. The standardized procedure for mangrove communities requested specific parameters to be recorded. Forest characterization, recognizing stress, the establishment of plots, trunk diameter at breast height (dbh), height range for trees within the plot, the salinity of sub-surface (interstitial) water, biomass within the plot, standing crop, community description (within the plot), tidal range, abundance and percentage cover. In terms of seedlings and saplings, subplots are established, and seedlings are tagged, identified, mapped, root seedlings (<2.5 cm dbh) are measured, growth (new leaf biomass) is also measured.

Pine Forest: The data obtained for Pine Forest in Belize is based on data collected by the Forest Department from two plots located in the Mountain Pine Ridge Forest Reserve (BZ-45 and BZ-

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[14] Gabriela Lopez-Gonzalez, Simon Lewis, Mark Burkitt and Oliver Phillips (2011). ForestPlots.net: A web application and research tool to manage and analyse tropical forest plot data. Journal of Vegetation Science.

[15] Cho, P., Blackburn, G. A., Bird, N. M., Brewer, S. W., and Barlow, JPercival Cho, George Blackburn, Neil Bird, Steven Brewer and Jos Barlow (2013).: The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests. Journal of Vegetation Science., doi: 10.1111/jvs.12103, 2013.

[16] Patricia Almada-Villela (2003). Manual of Methods for the MBRS Synoptic Monitoring Program.

[17] CARICOMP (2001). Caribbean Coastal and Marine Productivity (CARICOMP). A Comparative Research and Monitoring Network of Marine Laboratories, Parks and Reserves. CARICOMP Methods Manual Levels 1 and 2. CARICOMP Data Management Center and Florida Institute of Oceanography.

[18] Ariel Lugo, Samuel Snedaker (1975). Properties of a mangrove forest in southern Florida. Proceedings of the International Symposium on the Biology and Management of Mangroves.

[19] Douglas Pool, Samuel Snedaker and Ariel Lugo (1977). Structure of mangrove forests in Florida, Puerto Rico, Mexico and Costa Rica. Biotropica.

[20] Samuel Snedaker and Jane Snedaker (1984). The Mangrove Ecosystem: Research Methods. UNESCO Monographs on Oceanographic Methodology.

54). Two censuses, 2017 and 2018, from Plot BZ-45 were used for calculation purposes for the growth rate as this is the only plot with more than one census. The above-ground biomass was calculated from one plot (BZ-54), unlike the disturbed Plot BZ-45, BZ-54 is a mature undisturbed Upland Pine Forest. The methodology to establish and census permanent sample plots in Pine Forests follows closely the same methodology for broad-leaf forests except for certain variations as documented.

Initially, the location of the 32 permanent plots were based on representation of different forest classes determined by the national vegetation classification in use at the time, and a stratification was developed to represent different levels of altitude, climatic conditions and disturbance, whilst ensuring accessibility. A total of 32 permanent forest plots were thus established in major forest classes according to levels of environmental variation. In 2013, plans were drawn up to add 30 new permanent forest plots to the network to provide forest dynamics data from forest types that were currently unrepresented. In a geographic information system, spatial data on soils, rainfall, dry season length, altitude, aspect, forest type, land tenure, road access, ecosystems, and plot representation were combined in a deterministic model to calculate an importance index for areas of forest that are currently unrepresented. The resolution on this model was 1 km^2, and it was used to determine the location of the 30 new permanent forest plots. In 2013, plot expansion commenced and the network of plots has since been expanded to a total of 64 in forests and 19 in non-forest strata to serve the purpose of monitoring carbon stock and stock changes as a result of anthropogenic activities and natural disturbances for the purposes of REDD+ reporting (Figure 11). This improvement is consistent with the recommendations in the TAR of Belize's FRL.

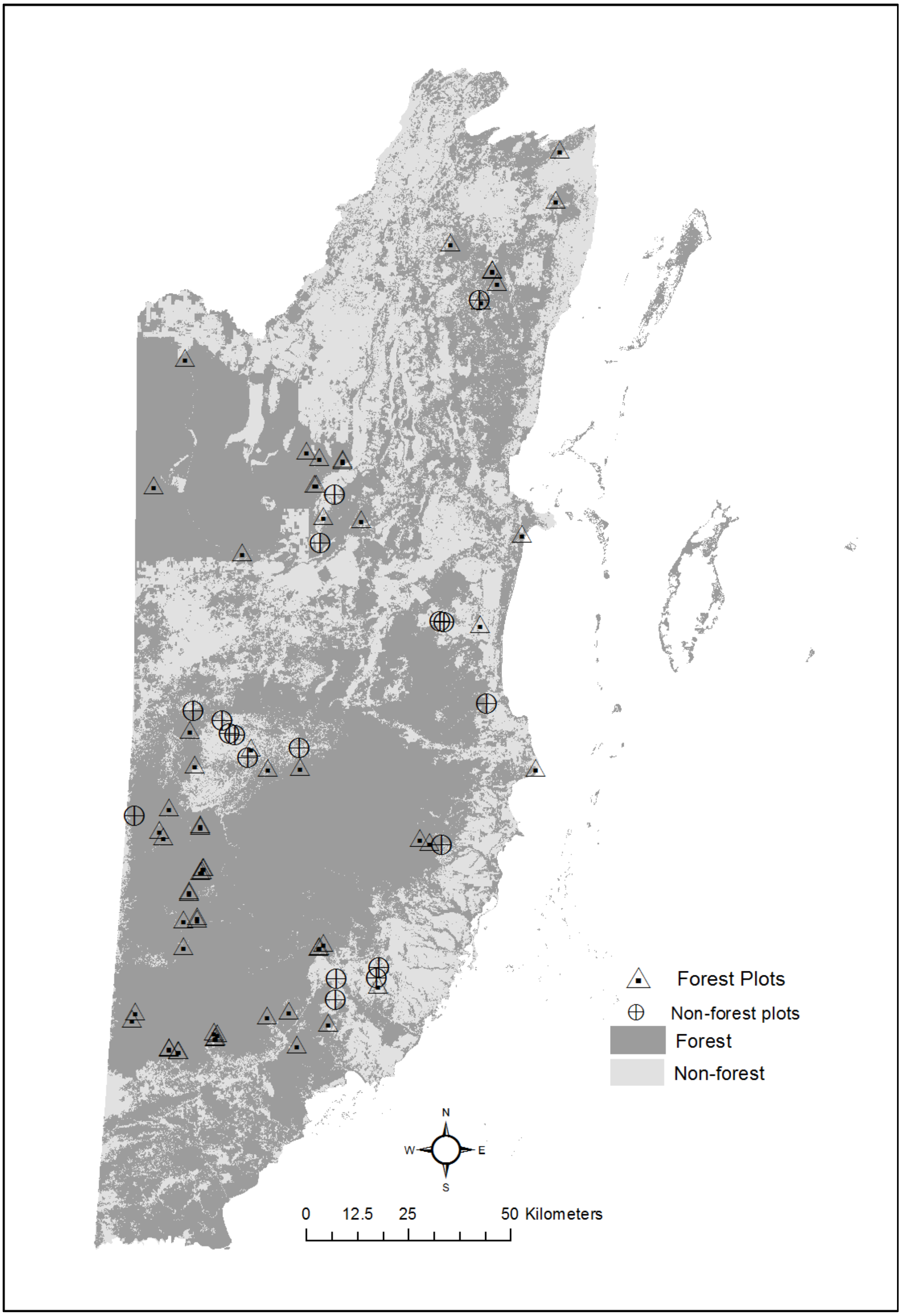

Figure 11. Distribution of 64 forest and 19 non-forest permanent plots

1.4 Calculation of emissions and removals

Biomass estimation

Broadleaf Mature Forest: For the study "Rapid carbon sequestration following hurricane disturbance in mature tropical forest: new insights and methods from Central America" by Cho *et al.* (2013), 304 trees of 48 species ranging in diameter from 10 to 223 cm were harvested in forests across Belize. An allometric model was designed to estimate stem AGB separately from crown AGB, thereby allowing for more sensitivity to stem and crown damage. It is a volume to biomass model, which is useful for both timber and biomass purposes, where the volume of the stem is converted to biomass by multiplying by wood density (Brown, 1997[21]; Chave *et al*., 2005[22]).

The approach was to first develop a stem volume equation to estimate the volume of the entire stem from the ground to the first major branch. Second, convert stem volume to biomass by multiplying by oven-dried wood density. Oven-dried wood density values were obtained from a local database of oven-dried wood densities for 42 tree species in Belize (Belize Forest Department, 1942[23]). For species not represented in this local database, mean values were obtained from the Global Wood Density Database (Chave *et al*., 2009a[24]; Chave *et al*., 2009b[25]), first by averaging at the species level within Central America, and second at the genus level. For genera not represented and for unidentified trees, the plot mean wood density based on a stem was calculated for the census in which the tree first appeared (Baker *et al*., 2004[26]). For these trees, the plot mean wood density was kept constant across censuses to avoid spurious changes in a tree's biomass. Third, develop an expansion factor to estimate crown biomass from stem biomass, for different crown forms according to the Dawkins crown classification system (Dawkins, 1958[27]).

The 304 sample trees were divided into two datasets. The first included 289 large trees from 33 to 223 cm DBH collected in Belize as part of a study of log volume carried out during the 1990s (Bird, 1998). The second included 15 small trees from 10 to 30 cm DBH which were destructively harvested in 2013 to estimate stem volume of smaller trees and to determine crown biomass ratios for different Dawkins crown form classes. The trees were collected within a logging concession along proposed skid trails. Approximately four trees were selected in each

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[21] Brown, S.: Estimating biomass and biomass change of tropical forests: a Primer. FAO Forestry Paper 134, Food and Agricultural Organization of the United Nations, Rome, Italy, 55 pp., 1997.

[22] Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B.W., Ogawa, H., Puig, H., Riera, B. and Yamakura, T.: Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145, 87-99,2005.

[23] Belize Forest Department: 42 secondary hardwoods of British Honduras. Bulletin No. 13, Belize Forest Department, Belize, 56 pp., 1942.

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[26] Baker, T. R., Phillips, O. L., Malhi, Y., Almeida, S., Arroyo, L., Di Fiore, A., Erwin, T., Higuchi, N., Killeen, T. J., Laurance, S. G., Laurance, W. F., Lewis, S. L., Monteagudo, A., Neill, D. A., Vargas, P. N., Pitman, N. C. A., Silva, J. N. M. and Martinez, R. V.: Increasing biomass in Amazonian forest plots. *Phil. Trans.: Biol. Sci*., 359, 353-365, 2004a

[27] Dawkins, H. C.: The management of natural tropical high forest with special reference to Uganda. *Institute Paper No. 34*. Oxford: Imperial Forestry Institute, University of Oxford, UK, 1958

Dawkins crown form class from one to four to provide suitable averages. No trees were found which had crown form scores of five.

Two stem volume equations were developed: one that included a term for stem height and another that did not.

$$AGB_T = \frac{\rho \times \exp(-9.480 + 0.975 \ln DBH^2 H_S)}{1 - (0.723 CFI - 0.091)}$$

where $AGBT$ is total tree aboveground biomass in Mg, ρ is oven-dried wood density in g cm^{-3}, DBH is diameter at breast height in cm, HS is stem height in meters, and CFI is Dawkins crown form index (crown form / 5). The second equation without stem height was:

$$AGB_T = \frac{\rho \times \exp(-8.367 + 2.261 \ln DBH)}{1 - (0.723 CFI - 0.091)}$$

Uncertainty of the estimates was quantified for model and measurement error following the methods outlined in Chave *et al.* (2004)[28].

The AGB of all live trees were summed at the stand level in each census and converted to live aboveground carbon (AGC) assuming 47% carbon (C) content [47.35 ⍰ 2.51] (Martin & Thomas, 2011)[29].

To estimate net hurricane-related C flux, the approach used was to estimate total C removed by Hurricane Iris and subtract this from total C sequestered following the hurricane (Figure 12). Live aboveground carbon stocks (AGC) are represented by rectangles. Horizontal arrows represent changes in AGC between two censuses; dashed arrows represent change due to hurricane disturbance; solid arrows represent background change. Vertical grey arrows are background carbon fluxes that contribute to changes in stand AGC. Vertical black arrows are carbon fluxes caused directly or indirectly by the hurricane, that also contribute to changes in stand AGC.

[28] Chave, J., Condit, R., Aguilar, S., Hernandez, A., Lao, S. and Perez, R.: Error propagation and scaling for tropical forest biomass estimates. *Phil. Trans. R. Soc. Lond. B*, 03TB055D.1, doi: 10.1098/rstb.2003.1425, 2004.

[29] Martin, A. R. and Thomas, S. C.: A reassessment of carbon content in tropical trees. *Plos One*, 6, e23533, doi: 10.1371/journal.pone.0023533, 2011.

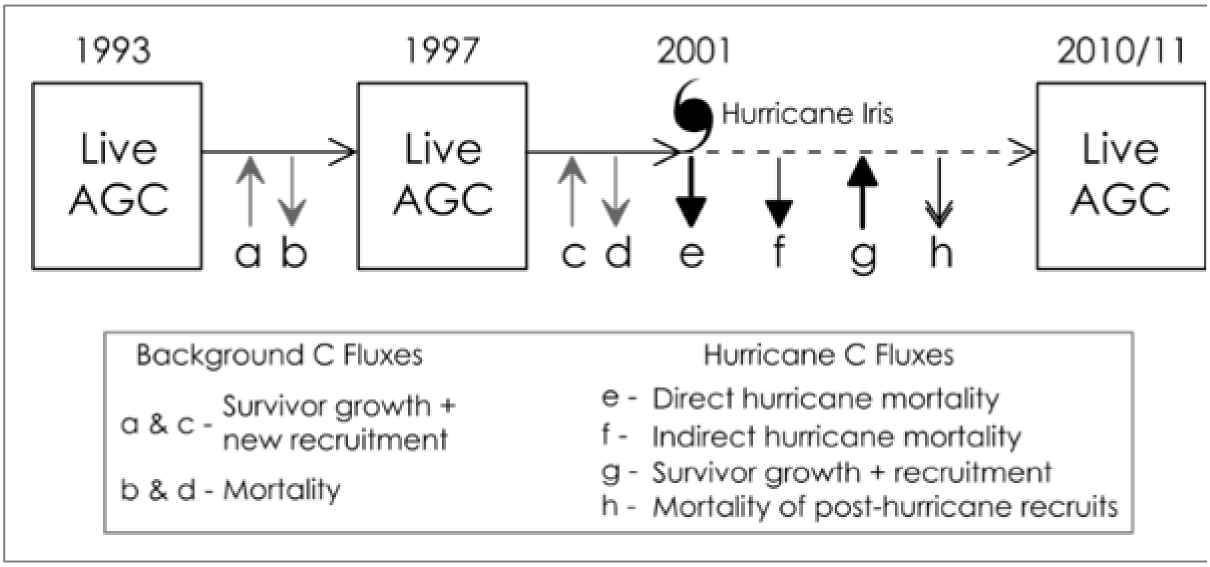

Figure 12. Sketch of forest dynamics over the study period from 1993 to 2010/2011.

Mangrove: Data from the plots and sub-plots by the Environmental Research Institute (ERI) of the University of Belize were used to estimate biomass. Biomass of the mangrove forest trees greater than 2.5 cm dbh was estimated by using trunk diameter and tree density (number of trees per unit area). Individual tree biomass was calculated using the dbh to weight conversion factor of (1) Golley *et al*. (1962):

$$\text{Biomass (g)} = \text{dbh (cm)} \times 3{,}390$$

and (2) Cintron and Shaeffer Novelli (1984):

$$\text{Biomass (g)} = B \times (DBH^2 \times H)^m$$

where b and m are constants of 125.9571 and 0.8557, respectively. The total biomass of trees was calculated for the plots by summing individual tree measurements. Data are expressed as wet weight for the living biomass (kg/m2).

Pine:

Pine in Biomass was estimated using the equation:

$$(\text{Log vol } (m^3) = 2.4 \text{ Loge (dbh cm)} - 8.69) \times 0.0625 \text{ (wd)}$$

Where:
Vol: Volume (m^3)
dbh: Diameter at Breast Height (cm)
wd: Wood Density (kg/m^3)

This equation to calculate the biomass was applied only to Pine trees within the permanent sample plot and excluded broad-leaf species which are a minimal percentage of the total permanent sample plot.

The Belize GHG inventory was conducted from a series of steps and using a range of data from diverse sources. The estimation of the emissions and removals used a combination of (a) country-specific methods and data, (b) IPCC methodologies, and (c) emission factors (EFs). The methods were consistent with the 2006 IPCC Guidelines and are to the extent possible, in line with international practice. IPCC methodology tiers 1, 2 and 3 were applied.

For the estimation of Forest related GHG emissions and removals, Belize has followed the methodologies proposed in the 2006 IPCC Guidelines, Volume 4, Chapter 2 "*Generic Methodologies Applicable to Multiple Land-use Categories*", for biomass carbon stock changes (above-ground biomass and below-ground biomass) and non-CO2 emissions. It includes the analysis for forest land remaining in the same land-use forest land converted to a new land-use category, and other land use to forest lands.

1.5 Institutional roles and responsibilities for Measurement, Reporting and Verification of results

To respond to the set of international reporting requirements inscribed in the UNFCCC and in the Paris Agreement, Belize is fully committed to establishing a coherent, overarching governance structure to coordinate climate change management initiatives at the national level. The institutional framework critical for the implementation of climate change commitments and opportunities, including REDD+ is provided by Figure 13 below.

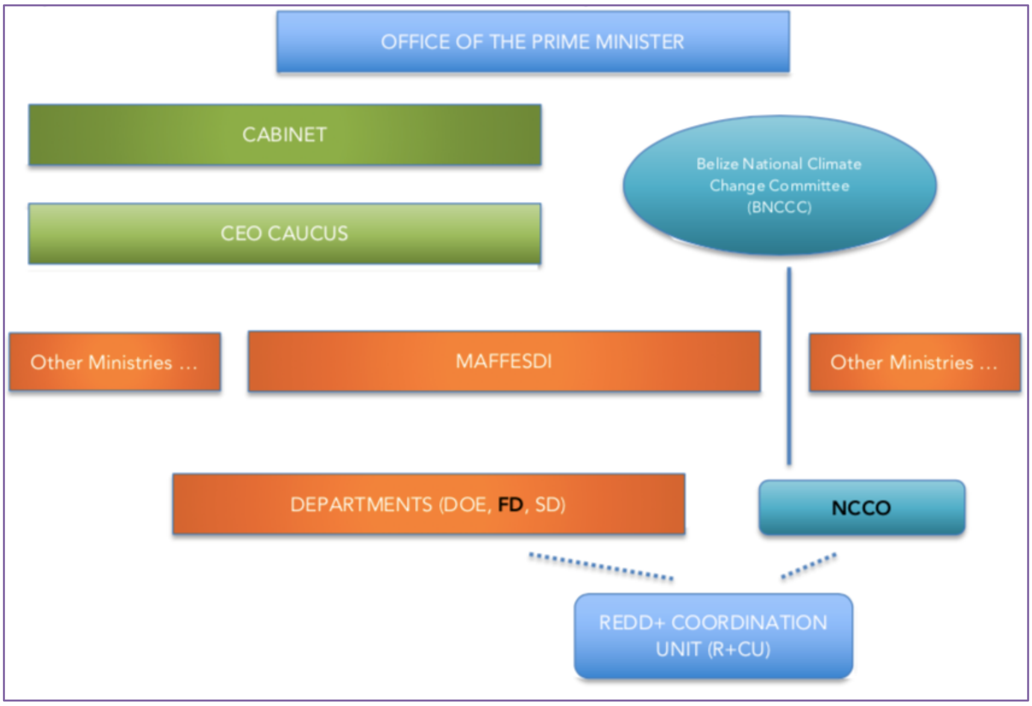

Figure 13. Institutional Arrangements for REDD+ in Belize.

At the ministerial level, the competence to deal with climate change issues is within the Ministry of Sustainable Development, Climate Change and Disaster Risk Management (MSDCCDRM).

MSDCCDRM is responsible for the governance and management of natural resources towards the sustainable development of Belize. This includes, among others, the collaborative efforts to implement, monitor and evaluate the strategic sustainable long and medium-term development of the country. In addition, MSDCCDRM is responsible for guiding the development of Belize in line with all major multilateral environmental agreements including the United Nations Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Convention to Combat Desertification (UNCCD).

The National Climate Change Office (NCCO) was established in 2017 within the Ministry responsible for Environment and Sustainable Development as a national entity responsible for climate change initiatives at the national level. To this end, the Office is strategically positioned to coordinate the implementation of climate change adaptation and mitigation actions and to coordinate climate change programs, projects, and initiatives.

The Belize Forest Department (BFD) is a public entity under the authority of MSDCCDRM. Its main task is to foster Belize's economic and human development by effectively enforcing relevant policies and regulations for the sustainable management of its natural resources through strategic alliances and efficient coordination with relevant stakeholders. The BFD has the mandate to manage Belize's forest resources and develop the Belize National Forest Policy.
The Department of Agriculture's aim is to provide an environment that is conducive to increase production and productivity, promoting investment, and encouraging private sector involvement in agribusiness enterprises in a manner that ensures competitiveness, quality production, trade, and sustainability[30].

The REDD+ Coordination Unit (R+CU) has been established within the premises of MSDCCDRM and under the NCCO. The main tasks of the R+CU are to manage and coordinate the REDD+ readiness phase and ensure all REDD+ requirements under the UNFCCC are respected so that REDD+ implementation can start promptly.

A brief description of procedures and arrangements are undertaken to collect and archive data for the preparation of the FRL and REDD+ results is included (Table 2), as well as efforts to make this a continuous process for the Measurement, Reporting, and Verification (MRV) system, including information on the role of the institutions involved.

The process started with the review of previous emission estimation methods and estimates, identification and formation of the teams, allocation of tasks, technical training, data collection, data analysis, QA/QC procedures, and finalized with a compilation of the FRL and posteriors REDD+ results. The process was completed by an external independent review, the technical assessment by the UNFCCC assessment team and structuring of an improvement plan.

[30] https://www.agriculture.gov.bz/.

Table 2. Schedule of inventory tasks

Phases	Responsible
Identification and formation of the teams	National Climate Change Office (NCCO) & Belize Forest Department (BFD)
Allocation of tasks	National Climate Change Office (NCCO) & Belize Forest Department (BFD)
Technical training	CfRN, GHG Institute, CE Experts.
Data collection	Forest Department, NCCO, R+CU
QC/QA procedures	QC: NCCO, Forest Department, R+CU / QA: CfRN
Data analysis	NCCO, Forest Department, R+CU, CfRN
Compilation of the GHG AFOLU inventory, FRL and REDD+ Results	NCCO, Forest Department, R+CU, CfRN
QC/QA procedures	QC: NCCO, Forest Department, R+CU / QA: CfRN
Independent review	CfRN Independent Panel of review, UNFCCC Assessment team
Improvement plan	NCCO, Belize Forest Department (BFD)

The mapping of roles and responsibilities for the measuring, reporting and verifying (MRV) processes for REDD+ results in Belize is presented in Table 3 below.

Table 3. Roles and institutional responsibilities for REDD+ MRV in Belize

MRV Component	Responsibility	Role	Timeframe
Measuring	Forest Department	Satellite land monitoring to collect activity data using Collect Earth	Annually
		Quality Control and Quality Assurance	Annually
		Updating of Forest Information System	
	Forest Department and REDD+ Coordinating Unit	Ground-based Forest and non-forest inventory	Biennially
		Emission factor estimation	Biennially
		Calculation of Annual Emissions and Removals for five REDD+ Activities in the GHG inventory.	Annually
		Uncertainty Analysis	Periodically
	Contracted Expertise	Development of wall-to-wall land cover maps	Periodically
Reporting	REDD+ Coordinating Unit and Forest Department	Development of Forest Reference Level	Periodically
	National Climate Change Office & FD (FOLU)	Development of Greenhouse Gas Inventory	Periodically
	National Climate Change Office	Development of the Biennial Update Report	Periodically
	REDD+ Coordinating Unit and Forest Department	Development of Technical Annex	Periodically
	National Climate Change Office	Submission of FRL, BUR and TA to UNFCCC	Periodically
Verification	UNFCCC	Verifying the FRL and TA	Periodically
	REDD+ Coordinating Unit, Forest Department, and National Climate Change	Provide clarification information requested by experts conducting technical assessment of FRL and TA.	Periodically

	Office		

Means of data acquisition and management

The Belize Forest Department identified all the national experts and/or institutions where the data would be sourced. All data are documented and stored as per archiving and documentation procedures, with the main custodian being the Forest Department in its database for archiving and retrieval.

The archives database contains; (a) all inputs datasets and datasheets; (b) country-specific excel calculation tool, including Forest related-GHG emission and removals estimates from 2000-2017, (c) manuals and protocols, (f) literature reviewed, (g) completed QA/QC templates and protocols, and (h) all reports and documentation.

1.6 Conclusion and Future Improvements

The National Forest Monitoring System of Belize was developed retroactively and proactively in this first iteration. Retroactively, the permanent plot network (known as the Forest Monitoring Network of Belize or FORMNET-B) was established in the 1990s and further developed between 2009 and 2016. Proactively, the virtual land use inventory was designed and developed in 2018 using Collect Earth, which was thought of as the most suitable technology at the time given national circumstances. This configuration of the National Forest Monitoring System of Belize is termed version 1.0.

Future improvements will see further ground plots established to measure changes in carbon stock over time due to different activities and intensity of activities. Wall to wall mapping of land use will also be added to increase the spatial explicitness of the activity database from 1 km resolution to 30 meter resolution, so that land use changes can be tracked for individual parcels of land or class of land management (eg. managed vs unmanaged). Near real time change detection will also constitute a critical part of the next iteration of the National Forest Monitoring System (version 2.0). Finally, new carbon pools such as dead organic matter will be included in the measurement protocol.

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