BELIZE ZERO-FOREST REFERENCE LEVEL (FRL) 2000 – 2020

MINISTRY OF SUSTIANBLE DEVELOPMENT, CLIMATE CHANGE AND DIASTER RISK MANAGEMENT (MSDCCDRM)

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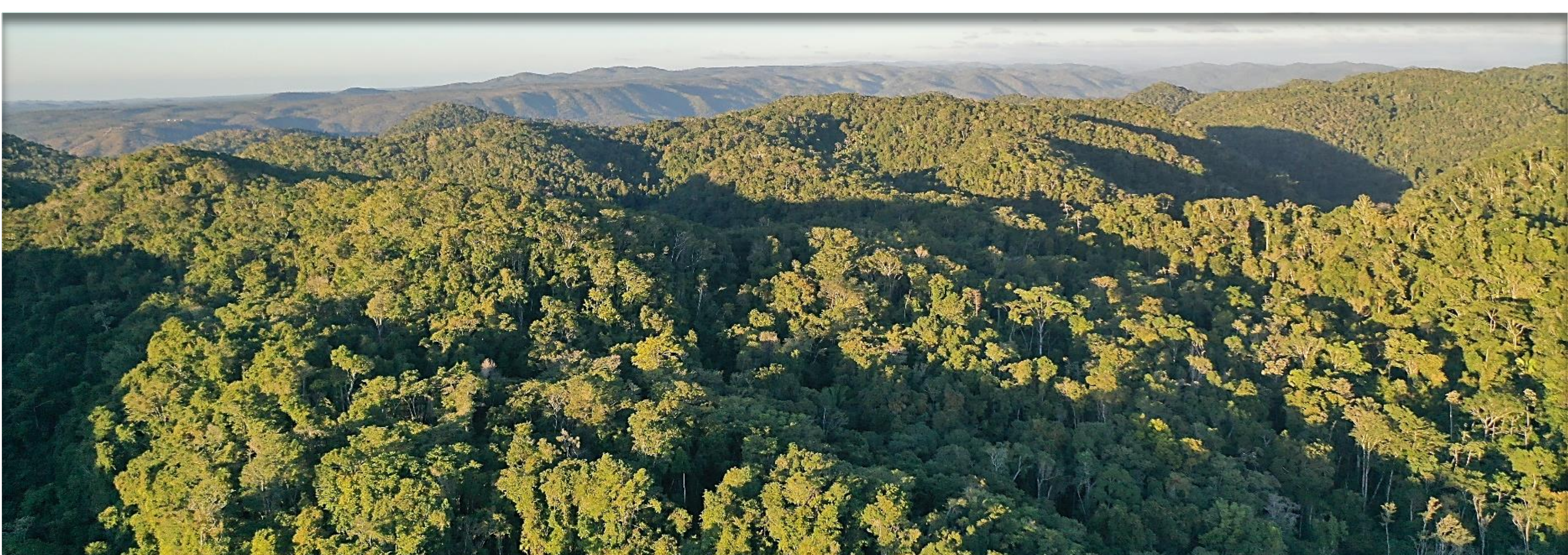


LIST OF ABBREVIATIONS AND ACRONYMS

AFOLU	Agriculture, Forestry, and Other Land Use
AGC	Above Ground Carbon
BGB	Below Ground Biomass
BUR	Biennial Update Report
BTR	Biennial Transparency Report
CRFR	Columbia River Forest Reserve
CfRN	Coalition for Rainforest Nations
CH_4	Methane
CO_2	Carbon dioxide
CWD	Coarse Woody Debris
COP	Conference of the Parties
DBH	Diameter at Breast Height
ETF	Enhanced Transparency Framework
ERI	Environmental Research Institute
FAO	Food and Agriculture Organization (of the United Nations)
FRL/Zero-FRL	Forest Reference Level
FOLU	Forest and Other Land Use
FWD	Fine Woody Debris
Gg	Gigagrams
GHG	Greenhouse Gas
GHGI	Greenhouse Gas Inventory
GPG	Good Practice(s) Guidance

GWP	Global Warming Potential
Ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
INDC	Intended National Determined Contributions
LULUCF	Land Use, Land Use Change and Forestry
LDC	Least Developed Countries
LM	Lowland Moist Broadleaf
LUA	Land Use Assessment
m^3	Cubic meter
MBRS	Mesoamerican Barrier Reef System Projects
MPG	Modalities Procedures and Gridlines
MRV	Monitoring, reporting, and Verification
MSDCCDRM	Ministry of Sustainable Development, Climate Change, and Disaster Risk Management
N_2O	Nitrous oxide
NFI	National Forest Inventory
NIR	National Inventory Report
NAP	National Adaptation Plan
NDC	National Determined Contributions
NDVI	Normalized Difference Vegetation Index
PA	Paris Agreement
POM	Point of diameter Measurement
PP	Parasites Present
REDD+	Reducing emissions from deforestation, reducing emissions from forest degradation, conservation of forest carbon stocks, sustainable management of forests and enhancement of forest carbon stocks

RRR+ Reporting for Results-based REDD+

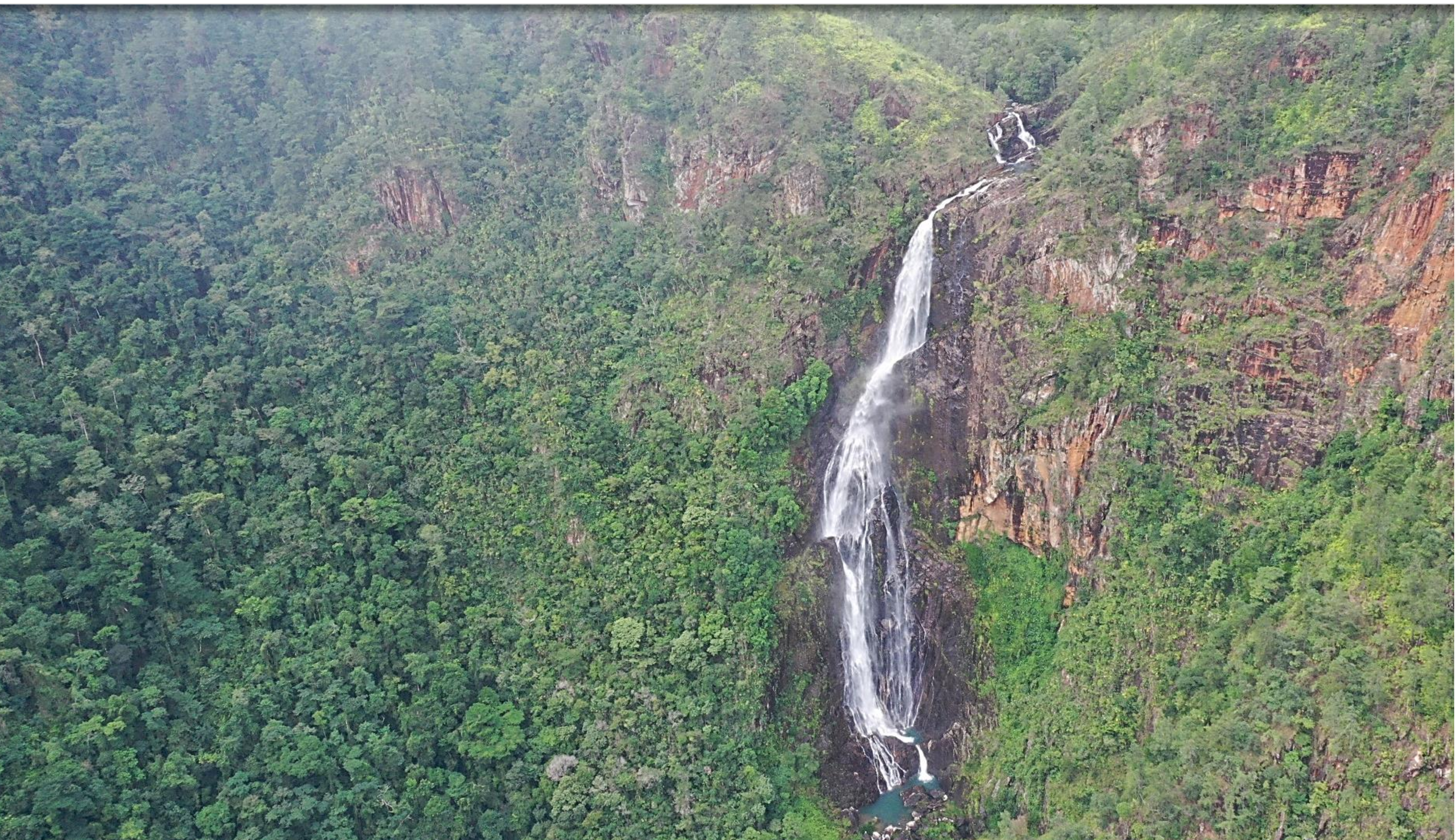
SBSTA Subsidiary Body for Scientific and Technological Advice

SIDS Small Island Developing States

TNC Third National Communication

TOA Top of Atmosphere

UNFCCC United Nations Framework Convention on Climate Change



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1. INTRODUCTION

The Conference of the Parties has encouraged developing country Parties to contribute to mitigation actions in the forest sector by undertaking the following activities: reducing emissions from deforestation; reducing emissions from forest degradation; conservation of forest carbon stocks; sustainable management of forests; and enhancement of forest carbon stocks (decision 1/CP.16, paragraph 70,).

These activities are known as REDD-plus activities and should contribute to the achievement of the objective set out in Article 2 of the Convention, which aims to strengthen the global response to climate change, in the context of sustainable development, which should also contribute to the fulfilment of the commitments set out in Article 4, paragraph 3, of the Convention in relation to the National Determined Contributions (NDC) proposed by the Party.

Belize, as a member of the group of the Small Island Developing States (SIDS), is granted full flexibility in the fulfilment of the Paris Agreement and consequently also in the fulfilment of all its rules including transparency. However, Belize, in its interest in fulfilling these commitments, has been focusing efforts aiming at achieving consistency with the objective of environmental integrity, taking into account the multiple functions of the forests and other ecosystems, and promoting sustainable management in accordance with national development priorities, objectives and sustainable development needs and goals.

With the adoption of the Paris Agreement by the twenty-first Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) the new international climate change regime for the post-2020 period is set.

Article 5 locks REDD+ guidance developed since COP13 into the new climate regime and already provides guidance on how transparency is ensured in the implementation of REDD+ activities. It is important to recall that REDD+ COP guidance emphasizes the importance of accurate and robust national GHG inventories and puts in place a verification process unique compared to all other sectors responsible for GHG emissions.

Belize presented its first Forest Reference Level in January 2020, and its modified version in August 2020. In August 2020, Belize submitted the Technical Annex with REDD-plus results voluntarily, in the context of results-based payments, through its first biennial update report in accordance with decision 14/CP.19.

Informed by the comments and areas of improvement identified as part of the Technical Assessment of its first Forest Reference Level, the country has decided to update its FRL to address the most relevant comments that may affect emissions and removals.

In this manner, Belize implemented a new land-use data collection campaign using a new tool known as CfRN Land Use Assessment app (LUA app) (ranging from the year 2000 to 2020) with improved methods and knowledge to increase the accuracy of the activity data underlying this updated FRL, its upcoming Biennial Transparency Report (BTR) and to track the progress of its NDC. The improvements introduced in this second FRL submission are key for the continuous improvement of Belize's actions and reporting under the UNFCCC.

Furthermore, Belize intends to prepare a new Technical Annex including any REDD-plus results achieved from 2021 onwards in its first BTR under the Paris Agreement. Belize also intends to participate in cooperative approaches under Article 6 of the Paris Agreement, in line with the objectives and timeframe of the country's Nationally Determined Contribution (NDC).

2. KEY ELEMENTS

2.1 Context and approach of the proposed FRL

The current national FRL proposed by Belize is based on the net balance of greenhouse gas (GHG) emissions and removals including all forest-related sources, sinks, carbon pools and GHGs[1]. **The selected FRL has a value of zero, referred to as Belize's "Zero FRL"** (Figure 1). Defining the FRL as zero means that Belize would only seek results-based payments for net removals after considering all forest-related emissions and removals in the country. This also means that in the case of net emissions, Belize would not claim REDD+ results.

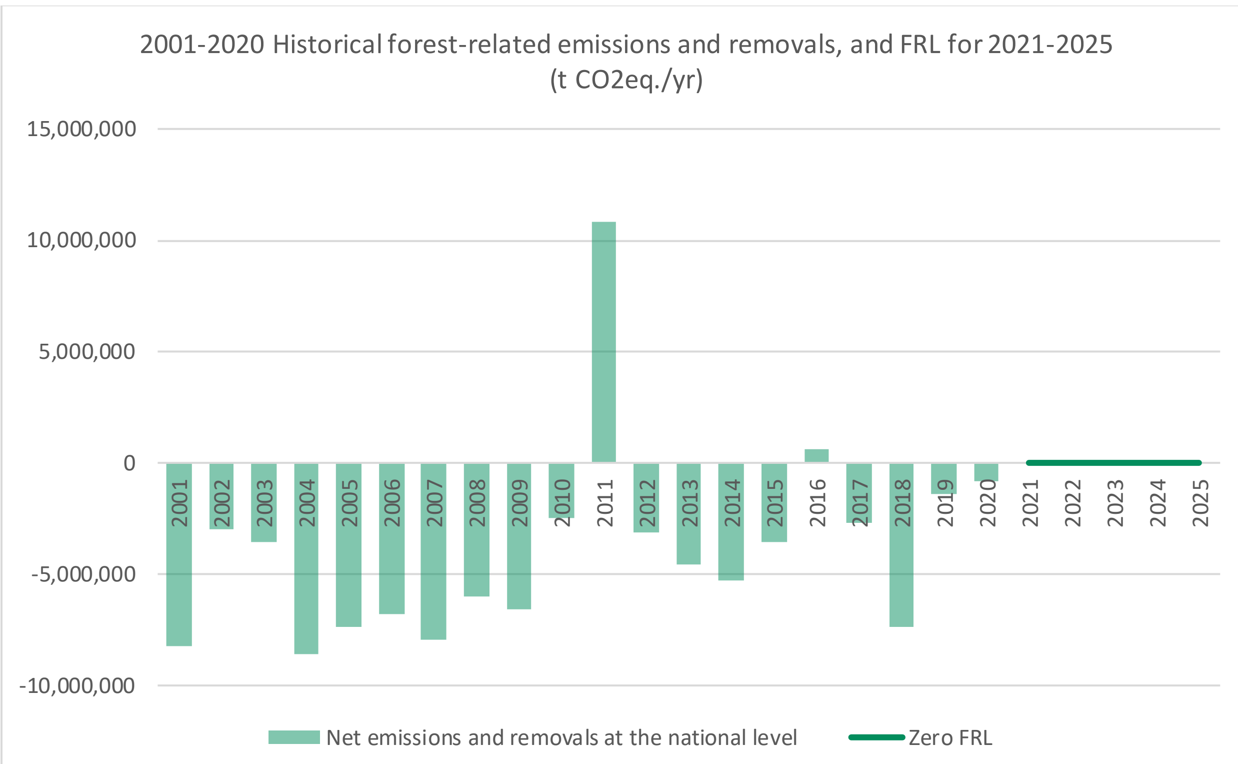

Figure 1: Annual Net Historical Emissions and Removals and FRL (2021-2025).

[1] Belize included above-ground biomass, below-ground biomass, deadwood, litter, soil organic carbon, as well as carbon dioxide, methane and nitrous oxide.

Table 1: 2001-2020, Annual Net Historical Emissions and Removals and FRL (2021-2025), in tabular format.

Year	Net emissions and removals (t CO_2eq./yr)	FRL
2001	-8,263,903	-
2002	-2,968,910	-
2003	-3,561,632	-
2004	-8,608,726	-
2005	-7,357,890	-
2006	-6,826,009	-
2007	-7,909,526	-
2008	-6,033,615	-
2009	-6,548,988	-
2010	-2,500,846	-
2011	10,794,306	-
2012	-3,095,871	-
2013	-4,584,345	-
2014	-5,257,860	-
2015	-3,566,630	-
2016	614,111	-
2017	-2,698,656	-
2018	-7,368,429	-
2019	-1,372,633	-
2020	-1,414,136	-
2021		0
2022		0
2023		0
2024		0
2025		0

Belize's Zero-FRL: Acknowledging the Country's Distinct Role as a Net Carbon Remover

According to Belize’s fourth National Communication (including the latest national GHG inventory submitted to the UNFCCC), the country has a net balance of -7,613.34 Gg CO2eq for the year 2018 (latest reporting year that includes AFOLU), where the agriculture sector resulted in 340.14 Gg CO2eq, the energy sector in 674.63 Gg CO2eq., the industrial processes and product use (IPPU) in 195.85 Gg CO2eq., and the waste sector in 28.40 Gg CO2eq. Together, these sectors comprised 1,239.02 Gg CO2eq. The negative balance is an effect of the -8,852.36 Gg CO2eq. of removals in the LULUCF sector.

When considering all sectors, this means that Belize has already achieved the balance in emissions and removals that the Paris Agreement requests of countries by the second half of the century (Article 4, paragraph 1 of the Paris Agreement)[2]. Further, due to the magnitude of emissions from the non-LULUCF sectors, it is expected that Belize will continue to have a negative balance (net removals) even when considering all sectors of the economy. This grants unparallel environmental integrity to the REDD+ results that would be offered by Belize as a result of the zero FRL approach.

Key principles of Belize’s Zero-FRL on how environmental integrity is ensured:

1. Belize, as a net carbon remover country, provides an invaluable contribution by removing CO_2 from the atmosphere directly impacting global CO_2 concentrations. Thus, REDD-plus results generated by Belize represent real reductions of CO_2 in the atmosphere.
2. Belize seeks to maintain the current balance between emissions and removals by seeking result-based payments for net removals against a Zero-FRL, effectively recognizing the country’s full extent of CO_2 removals from forests.
3. Belize’s Zero-FRL includes all activities, meaning that any emissions from deforestation or forest degradation would impact the country’s REDD+ performance. The Zero-FRL has environmental integrity because it considers all possible sources of emissions.
4. By defining the FRL as zero, Belize seeks recognition and results-based payments for net removals, meaning increased forest carbon stocks, following IPCC guidelines: “increases in total C stocks over time are equated with a net removal of CO2 from the atmosphere”[3]

[2] “In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty.”

[3] IPCC 2006, volume 4, chapter 1, page 1.6.

2.2. Historical reference period and timeframe of the FRL

Belize analysed the historical period 2001-2020 as the basis for the application of the Zero-FRL for 2021-2025. For this Zero-FRL each year is represented by a calendar year going from January 1st to December 31st.

2.3 Non-Permeance

Belize is subject to recurring hurricanes which are usually followed by forest fires. As shown in Figure 1, hurricanes and fires led to net emissions in the years 2011 and 2016. This is a normal part of the forest dynamics in Belize, given its geographical location in the Caribbean hurricane belt. Thus, hurricanes and fires with varying intensity affect Belize regularly. In the context of the Zero-FRL proposed by Belize, whenever net emissions occur, no REDD+ results can be claimed. In these cases, Belize will not claim results and will also reflect these net emissions in the national REDD+ accounting for the corresponding NDC period, by subtracting any reversals from the total REDD+ results. The accounting is reset for each subsequent NDC period.

2.4 Application of the zero-forest reference level approach according to the modalities for FRL under UNFCCC per decision 12/CP.17.

The following table provides the justification for the application of the Zero FRL approach in Belize, for each of the paragraphs in decision 12/CP.17, outlining the modalities for FREL/FRL under the UNFCCC.

Table 2: Justification for Zero-FRL approach in Belize.

Modalities for submission of Zero-FRL (12/CP.17)	Elements for justification
7. Agrees that in accordance with decision 1/CP.16, paragraph 71(b), forest reference emission levels and/or forest reference levels expressed in tonnes of carbon dioxide equivalent per year are benchmarks for assessing each country's performance in implementing the activities referred to in decision 1/CP.16, paragraph 70;	• Belize's Zero-FRL is expressed in tons of CO2 equivalent per year. • It is a special benchmark designed for assessing Belize's efforts in maintaining yearly net removals (when considering all forest-related emissions by sources and removals by sinks). • By setting the FRL at zero, Belize expresses its intention to get recognition for all net removals across the entire national territory.

Modalities for submission of Zero-FRL (12/CP.17)	Elements for justification
8. Decides that forest reference emission levels and/or forest reference levels, in accordance with decision 1/CP.16, paragraph 71(b), shall be established taking into account decision 4/CP.15, paragraph 7, and maintaining consistency with anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks as contained in each country's greenhouse gas inventories;	• Belize's Zero-FRL is based on the estimation of emissions and removals during the historical reference period 2001-2020. • During this 20-year period, Belize maintained net removals across its territory (Figure 1), despite recurring hurricane and fire impacts. • Belize's Zero-FRL is underlined by a 20-yr time-series that will be the basis for the upcoming National GHG Inventory to be submitted in the first Biennial Transparency Report (BTR). • When reporting any REDD-plus results in the BTR, Belize will ensure a consistent estimation of emissions and removals between the FRL, the estimated results and the updated National GHG Inventory.
9. Invites Parties to submit information and rationale on the development of their forest reference emission levels and/or forest reference levels, including details of national circumstances and if adjusted include details on how the national circumstances were considered, in accordance with the guidelines contained in the annex to this decision and any future decision by the Conference of the Parties;	• By applying a Zero-FRL approach, Belize is considering its very special national circumstance of being a net carbon remover, *i.e.* having net removals rather than net emissions. As explained above, total CO_2 removals in the country far surpass its GHG emissions historically. • This circumstance is the main reason behind the application of the approach, *i.e.* to recognize all removals considering that Belize has been contributing to reducing CO_2 from the global CO_2 concentrations and thus has a direct impact on the stabilization of the climate. • Net removals are additional every year. Consequently, for Belize, the best FRL approach is to set it at zero to get full recognition of the ongoing climate change mitigation.

Modalities for submission of Zero-FRL (12/CP.17)	Elements for justification
	• This approach does not require adjustments, it's based on real, measured net removals, in line with the best science and knowledge and following IPCC's definition of a CO_2 removal.
10. Agrees that a step-wise approach to national forest reference emission level and/or forest reference level development may be useful, enabling Parties to improve the forest reference emission level and/or forest reference level by incorporating better data, improved methodologies and, where appropriate, additional pools, noting the importance of adequate and predictable support as referenced by decision 1/CP.16, paragraph 71;	• Belize may use the step-wise approach to improve the estimation of emissions and removals that underlie the Zero-FRL approach, following IPCC guidance and guidelines, and as methods, data and knowledge improve.
11. Acknowledges that subnational forest reference emission levels and/or forest reference levels may be elaborated as an interim measure while transitioning to a national forest reference emission level and/or forest reference level, and that interim forest reference emission levels and/or forest reference levels of a Party may cover less than its entire national territory of forest area;	• Belize's Zero-FRL approach is applied at a national scale, ensuring that all forests and all lands are accounted for. This eliminates any concerns related to the displacement of emissions and shows the commitment of the national government to take responsibility for every single hectare of land.
12. Agrees that a developing country Party should update a forest reference emission level and/or forest reference level periodically as appropriate, taking into	• See above, in paragraph 10.

Modalities for submission of Zero-FRL (12/CP.17)	Elements for justification
account new knowledge, new trends and any modification of scope and methodologies;	
(a) Information that was used by Parties in constructing a forest reference emission level and/or forest reference level, including historical data, comprehensively and transparently;	• Before applying a Zero-FRL approach, Belize first estimated emissions and removals following the 2006 IPCC guidance and guidelines. • Through this process, Belize confirmed that removals are larger than emissions (net removals), and thus decided to apply the Zero-FRL approach. • The estimation of historical emissions and removals, and the understanding that the country presents yearly net removals, is what enables Belize to apply this approach, and as such, it is based on historical data.
(b) Transparent, complete, consistent and accurate information, including methodological information, used at the time of construction of forest reference emission levels and/or forest reference levels, including, inter alia, as appropriate, a description of data sets, approaches, methods, models, if applicable and assumptions used, descriptions of relevant policies and plans, and descriptions of changes from previously submitted information;	• Belize's Zero-FRL approach is based on transparent, complete, consistent, and accurate information. • All descriptions of methods, data and assumptions have been provided in this report along with the Foundational Platform, an Excel-based tool for the estimation of emissions and removals explained in detail under section 5 of this report. • A description of changes versus previously submitted information was also included in section 2.11

Modalities for submission of Zero-FRL (12/CP.17)	Elements for justification
(c) Pools and gases, and activities listed in decision 1/CP.16, paragraph 70, which have been included in forest reference emission levels and/or forest reference levels and the reasons for omitting a pool and/or activity from the construction of forest reference emission levels and/or forest reference levels, noting that significant pools and/or activities should not be excluded;	• Belize's Zero FRL approach complies with the same rules and COP decisions on the inclusion of carbon pools, gases and activities. • In fact, by applying the Zero-FRL Belize ensures that the IPCC category forest land remaining forest land is included, often a key category excluded from most FREL/FRL under the UNFCCC. Note: more traditional FRL types include only deforestation. Belize's Zero-FRL goes beyond just emissions and focuses on the GHG balance in forests across the national territory. In this way, the Zero-FRL approach ensures that all forest areas in the country are considered, effectively transitioning to a fully national scope.
(d) The definition of forest used in the construction of forest reference emission levels and/or forest reference levels and, if appropriate, in case there is a difference with the definition of forest used in the national greenhouse gas inventory or in reporting to other international organizations, an explanation of why and how the definition used in the construction of forest reference emission levels and/or forest reference levels was chosen.	• The forest definition is consistent with the latest GHG inventory and will be consistent with the definition to be submitted as part of the upcoming national GHG inventory in Belize's first BTR.

2.5 REDD+ activities included.

As indicated in Decision 1/CP.16, paragraph 71, Belize has decided to develop a **national** forest reference level (FRL) in accordance with national circumstances and as a *benchmark* to assess the country's performance in implementing the activities referred to in Decision 1/CP.16, paragraph 70: **reducing emissions from deforestation**, **reducing emissions from forest degradation**, **conservation of forest carbon stocks**, **sustainable management of forests** and **enhancement of forest carbon stocks**.

In its current Zero-FRL Belize includes all forest-related emissions and removals, all forest areas, with the intention to implement all REDD+ activities according to decision 1/CP.16 paragraph 70.

2.6 Consistency with the National GHG Inventory

Belize has prepared and submitted four National Communications and a BUR to the UNFCCC, where methods and data have been improved over time leading to more accurate GHG estimates following IPCC guidelines and guidance. The current Zero-FRL presents new activity data and emission factors, methods and knowledge resulting in an updated estimation approach when compared to the current National GHG Inventory submitted as part of the 4th National Communication (the latest report to the UNFCC). This follows paragraph 10 of decision 12/CP.17 which states that: "*Agrees* that a step-wise approach to national forest reference emission level and/or forest reference level development may be useful, enabling Parties to improve the forest reference emission level and/or forest reference level by incorporating better data, improved methodologies and, where appropriate, additional pools, noting the importance of adequate and predictable support as referenced by decision 1/CP.16, paragraph 71;" In this context, and to achieve consistency with the National GHG Inventory, Belize will use this new estimation approach for the preparation of its first Biennial Transparency Report (BTR).

2.7 Scale

The total land area considered for this FRL is 22,960 square kilometres (km2) (8,867 square miles [mi2]), of which 95% are located on the mainland, and 5% is distributed over more than 1,060 cays or islands. The country is divided into six districts, nine municipalities, and more than 240 villages.

In its first FRL Belize distinguished between managed and unmanaged lands for the purpose of excluding the effect of recurring hurricanes and subsequent forest fires. Considering that hurricanes and subsequent fire disturbances is increasing with climate change, the country decided to define all lands as managed for this FRL. With this change, Belize takes responsibility for all emissions and removals in all lands of the national territory. Belize considers this to be in line with IPCC's definition of managed lands "*Managed* *land is land where human interventions and practices have been applied to perform production, ecological or social functions*".[4]

2.8 Carbon pools

The national GHG inventory and the Zero-FRL include all carbon pools: above-ground biomass, below-ground biomass, dead wood, litter and soil carbon.

2.9 Greenhouse gases

The national GHG inventory and the Zero-FRL include CO2, methane (CH4) and nitrous oxide (N2O) emissions from biomass burning. Emissions in carbon dioxide equivalents (CO2e) are reported using the 100-year global warming potentials (GWPs) contained in IPCC's Fifth Assessment Report (AR 5).

2.10 Application of the step-wise approach

This Zero-FRL has been prepared through methodological processes aimed at strengthening the technical areas of improvement in reference to previous processes, ensuring the methodological implementation of the IPCC guidelines and mainly aimed at creating permanent institutional capacities that allow the country to advance towards continuous improvement. Belize may provide updates to this FRL in the context of COP decision 12/CP:17: "*Agrees that a developing country Party should update a forest reference emission level and/or forest reference level periodically as appropriate, taking into account new knowledge, new trends and any modification of scope and methodologies*".[5]

2.11 Changes from previously submitted information.

The land use and land-use change analysis saw significant enhancements in various aspects. The adoption of the LUA App, equipped with additional external tools (Geodash, LandTrendr UI, GEE Script) for identifying forest degradation, marked a pivotal improvement. This analysis now incorporates multiple disturbances and land-use changes, providing a more comprehensive understanding of the dynamics at play. Emission and removal factors have been refined based on recent field data, contributing to more accurate estimations of greenhouse gas emissions and removals. The calculation tool has undergone improvements, allowing for greater detail and precision in estimations. The inclusion of Dead Organic Matter (DOM) and Soil Organic Carbon (SOC) pools adds depth to the analysis. Moreover, the consideration of transfers among carbon pools, especially after disturbances like hurricanes and pests, contributes to a more understanding of carbon dynamics. The shift from a trend projection to a Zero Forest Reference Level (FRL) approach signifies a methodological change, enhancing completeness of assessments. Additionally, the acknowledgment of all lands as managed enables the inclusion of forests

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[4] IPCC 2006, Volume 4, Chapter 1, Section 1.1, page 1.5.
[5] Decision 12/CP.17, paragraph 12.

under conservation management, ensuring a more comprehensive evaluation of carbon dynamics across various land categories.

Table 3: Improvement from previous FRL and update FRL

Previous FRL	Update FRL
Concepts Improvement - Change from Historical average to Zero FRL approach - Considering all lands as managed, allowing the inclusion of forests under conservation management.	
Activity Data	
Collection of AD in 2018 1) Use of Open Foris, Collect Earth Desktop from FAO for the collection of AD. 2) Using CE desktop ooperators exported XML files daily and uploaded them to a drive, where the team lead compiled the data. 3) CE Desktop provided only Google Earth, Bing Maps, Here We Go maps and Google Earth Engine platforms to access imagery. 4) Only primary and secondary disturbance could be recorded. 5) Only 2 land use changes could be recorded 6) For QC, 5% of the total plots were randomly assigned to 2 operators to assess the same plots.	**Collection of AD in 2023** 1) Use of Collect Earth Online, CfRN LUA-App 2)With the LUA app, there was no need to export XML files. These were saved automatically. 3) The LUA- app incorporated all the features available in CE Desktop and expanded its capabilities with the inclusion of Planet Base Maps, Geo-Dash, Landtrendr, and imagery featuring multiple band combinations for enhanced visualization. Furthermore, it optimized raw data downloads for essential edits and introduced tools for identifying forest degradation. The integration of these tools granted access to higher-resolution imagery and advanced change detection algorithms, significantly enhancing the accuracy of land use change (LUC) and disturbances capture. 4) Inclusion of multiple disturbances using the LUA app 5) Inclusion of multiple land use changes using the LUA app 6) For QC, 5% of the total plots were randomly assigned to 3 operators to assess the same plots.

Previous FRL	Update FRL
Emission Factor: Improved emission and removal factors, based on recent field data collected on Main Forest Categories: Pine Forests, Secondary Broadleaf Forests and Mangrove Forests.	
Secondary Broadleaf Forest	
- AGB = 120 t.d.m./ha (Based on IPCC default values, lowest value). - No national allometric equation -No Dead Wood - No Litter Stocks -No plots established/No methodology	- AGB = 204.53 t.d.m/ha (Based on 3 plots) -National allometric equation used - Dead Wood = 15.75 t.d.m./ha - Litter Stocks -Comparable methodology for MBL, so at the point of maturity, the plot can be expanded to the standard 1ha MBL PSP
Pine Forests	
-AGB = 210.70 t.d.m. /ha (Based on one plot, in the MPR) -AGB = estimate was calculated using live Pine Trees only (>10 cm) -Equation for AGB = no national allometric equation was used. -DW = no national value -Annual Increment = 0.18 t.d.m./ha	-AGB = 117.8 t.d.m/ha (Based on 4 plots) -AGB= estimate was calculated using Pine Saplings (>1 cm, < 10 cm), Pine Trees (> 10 cm), Hardwood Saplings (>1 cm,<10 cm), Hardwood Trees (>10 cm), Understory (Grasses, Shrubs, Ferns), CWD (Dead Trees and Stumps) -Equation for AGB Pine = allometric equation was obtained reference Brown et al. 2005 and Viergever 2009. Between 2002-2003, it was developed for RBCMA (Brown et al.) -Equation for AGB hardwoods (Craboo, Oak, Calabash, Clethra) = was obtained from Schroeder 1997 -DW= national value = 0.69 t.d.m/ha -Annual increment = 1.94 t.d.m/ha
Mangrove Forests	

Previous FRL	Update FRL
-AGB = 80.55 MgC/ha Based on the UB-ERI study, 4 sites only (2014-2017) and within tall/medium mature mangrove sites. - BGB = 39.47 MgC/ha was calculated using the standard R/S ratio as per IPCC guidelines. - SOC = No data	-AGB = 60.6 MgC/ha (Based on 158 plots, 36 sites, 5 studies) Weighted average across mangrove categories based on 2019 mangrove cover (Cherrington et al.) Includes dwarf, tall and medium mangroves. -BGB= 19 MgC/ha was calculated using a standard Blue Carbon Equation (Based on 138 plots, 32 sites, and 4 studies) Komiyama (2008). - SOC = 319.5 tC/ha Based on Blue Carbon Study (111 plots, 19 sites)
Belize GHGI Foundational Platform TOOL Improved calculation tool, which allows including more detail, increasing accuracy of the estimations of GHG emissions and removals.	
- Manually calculation (equations) - Manually Color coding - A manually concatenate function in Excel is used to join the same code of text together. e.g C/INTAGR/ - Types of category sheets such as Forest, grassland, etc. - No color code by groups of disturbances - Only two disturbances were recorded (Primary and secondary). Only primary disturbances were added to the GHGi tool. - Only recorded the Initial and final land use. - No data on SOC and DOM pools. - No inclusion of transfers among C pools (AGB>DOM).	- Using Macros to perform complex tasks, such as calculating formulas. Macros can save significant amounts of time when applied to repetitive tasks and avoid human error. IPCC guidelines are embedded in the Macro function in the FP tool. - Using Macros to allow to perform complex tasks, such as color coding the land use categories and disturbances. This allows better understanding by visual observation of the land use dynamic throughout the whole time series, and at the national level. - The Land Use Assessment application automatically formulates the land use and disturbance codes after assessing a plot. This code allows understanding of all land use changes and all disturbances, with the corresponding years, that happened in one single plot, from 2000 to 2020. - Moved from estimations by individual land use category sheets to calculation sheet by equations (Gains, Losses, conversions), & DOM, SOC & Non-CO2 (CH4, N2O). This allowed the calculation emission of removals for each plot annually, regardless of the current land use; therefore, multiple land uses were captured in one single transition, and the corresponding equation could be applied for the specific land use in the year of the analysis - Enhancing the accuracy of assessments by differentiation of disturbances:

Previous FRL	Update FRL
	i. Group 1, No expected regeneration: Agriculture, Infrastructure, Grazing, Mining. ii. Group 2, Expected Regeneration: Hurricanes, Logging. iii. Fire, Expected Regeneration, different Gw. iv. Pest, Expected Regeneration, different Gw. - Inclusion of DOM and SOC pools. - Inclusion of transfers among C pools (AGB>DOM), especially after disturbances such as hurricanes and pest - Detailed results sheet by sub-categories of land use and for each disturbance.

2.12 Completeness

Belize created a shared folder including the following:

- Zero-FRL pdf document
- BEL Foundational Platform Tool 2024
- Folder with Supporting Documents from publications used within the development of this Zero-FRL and FP.

Access to this information can be found here.

3. NATIONAL CONTEXT

3.1 Forest Sector

Belize has submitted its Updated Nationally Determined Contribution (NDC), National Communication, and updated Greenhouse Gas inventory reports to the UNFCCC. As part of its reporting commitments, the country reports on greenhouse gas emissions and removals from all sectors, including the Forestry and Other Land Use (FOLU) sector. The Forest Department (FD), as the FOLU sector lead, is responsible for the associated measurement, reporting and verification (MRV) of national emissions and removals from activities within this sector. The Department, as part of the broader Ministry of Sustainable Development, Climate Change and Disaster Risk Management, is the country's regulatory agency that aims to sustainably manage forest resources for long-term benefits6. To guide and ensure sustainable management of Belize's forests, the following functions, goals, and strategic objectives are adhered to:

Core Functions

i. Oversight of use and protection of forest,
ii. Granting of forest licenses and permits,
iii. Collection of royalties for the forest resources,
iv. Monitoring (including ensuring compliance with conditions of licenses),
v. Design and implementation of Management plans,
vi. Maintain revenue records and revenue database, and
vii. Promoting public awareness.

Goals and strategic objectives

i. Goal: Proactive Forest stewardship through "SFM":
   a. SO1: Foster resilient, healthy functioning forest ecosystems,

[6] Government of Belize Forest Department Strategic Action Plan (2019-2023).

b. SO2: Enhance economic, social, and environmental benefits of forest through sustainable utilization of forest resources by stakeholders,
c. SO3: Deliver focused programmatic strategies with measurable and impact results,
d. SO4: Maintain no net loss in forest cover in priority areas, and

ii. GL2: Organizational Excellence,

a. SO5: Enhance collaboration and stakeholder participation for improved efficiency and implementation of Forest Department programs,
b. SO6: Create a supportive, cohesive, and inclusive work environment, and maintain SFM expertise through professional development,
c. SO7: Build the Forest Department as an efficient service delivery organization,
d. SO8: Harmonize and strengthen forest policies and legislation, and
e. SO9: Develop stable, diverse, sustainable sources of finances".

Within the Forest Department (see Figure 2), the Geospatial Monitoring Unit and the Measuring, Reporting, and Verification (MRV) Program play pivotal roles in fulfilling the MRV mandate. They meticulously track land use and changes occurring annually across Belize's national territory through the National Forest Monitoring System (NFMS). This comprehensive system encompasses the Geospatial Monitoring Unit's advanced spatial analysis techniques and the MRV Program's stringent measurement and reporting protocols. Together, these components constitute a robust framework aimed at producing reliable data on human activities and ecosystem processes within forests.

The Belize NFMS, empowered by these specialized units and programs, is dedicated to estimating forest carbon stocks, emissions changes resulting from land-based activities, and other critical metrics. The insights gleaned from these estimations serve not only the Department but also extend to its parent Ministry and the broader Government. By offering a detailed understanding of ongoing trends and potential strategies, the NFMS supports informed decision-making for more effective and efficient management practices.

Utilizing a combination of cutting-edge remote sensing technologies and ground-based inventory approaches, Belize's NFMS consistently delivers internationally recognized estimates. These estimates prioritize transparency, accuracy, and consistency while acknowledging and managing acceptable levels of uncertainty. Additionally, they are tailored to reflect the unique national circumstances of Belize.

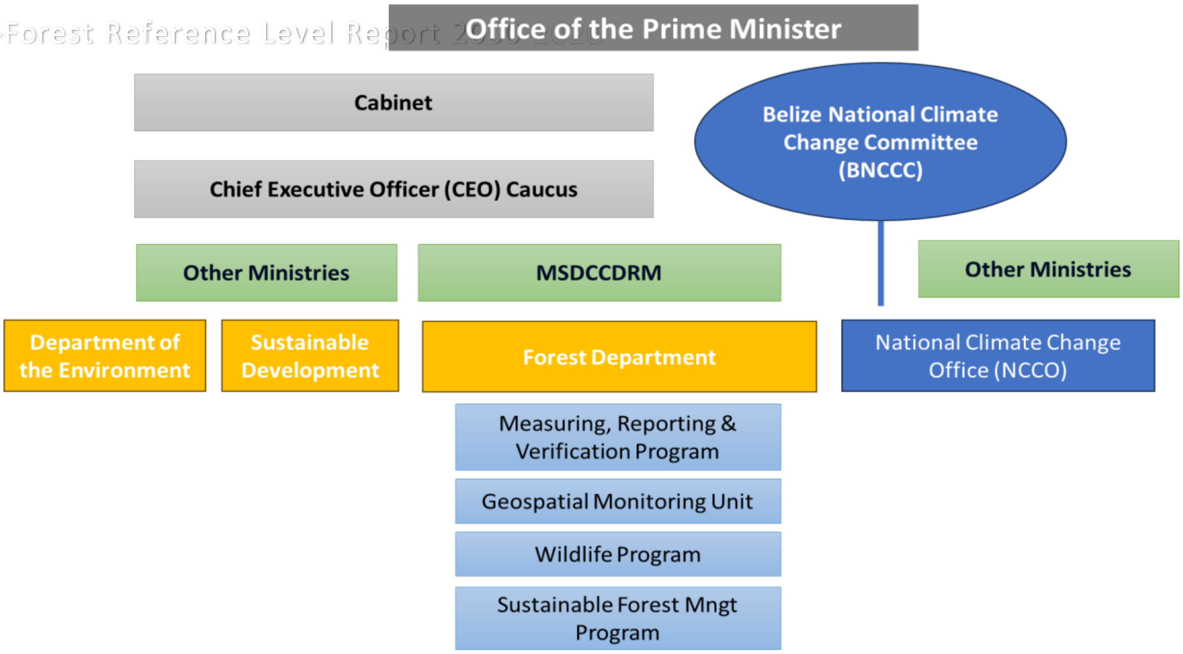


Figure 2: Illustrating the Government of Belize's Organizational Chart: Outlining MSDCCDRM, FD, and Relevant Programs Responsible for FOLU MRV Oversight.

3.2 Wildlife

Vast and unique tropical forests exist in Belize which is a habitat to unique biodiversity of global significance 5. Most of the country and the entire coastal area consist of low-lying plains. Belize is known for its abundant natural resources and a vast array of ecotypes especially concerning water and biodiversity, (Figure 3).

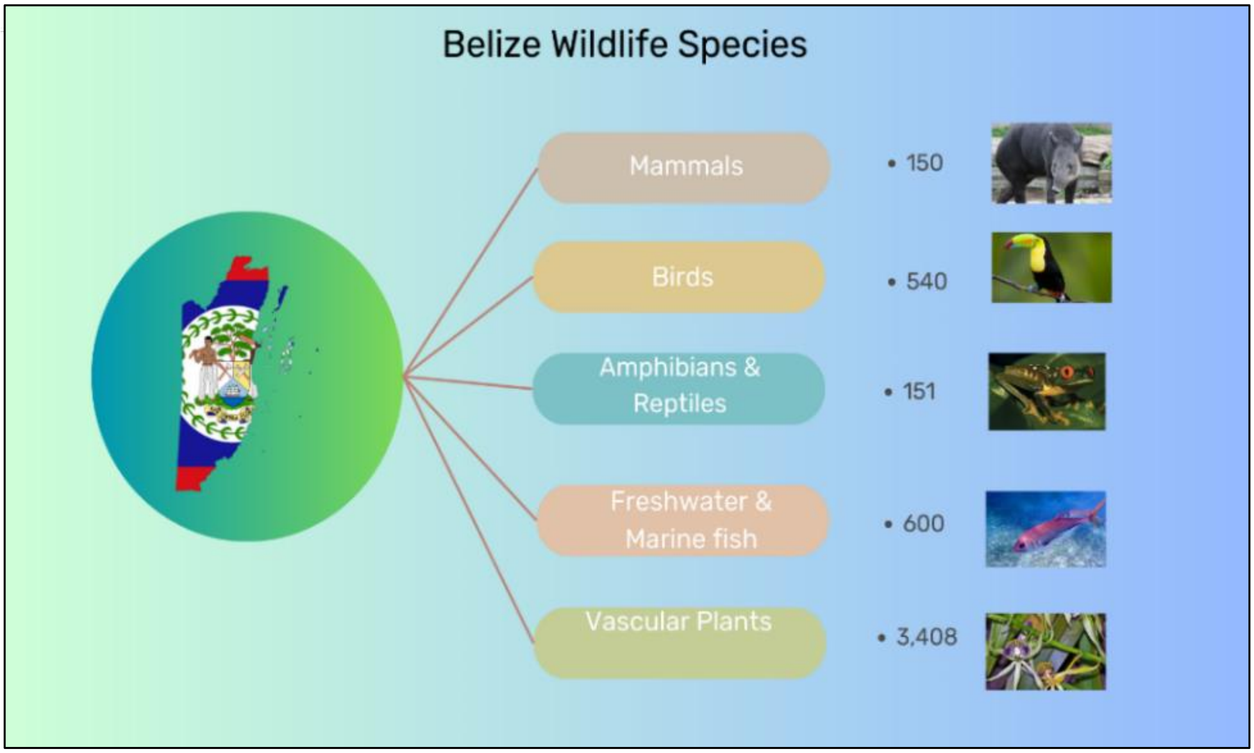


Figure 3: Showing Wildlife Species in Belize Groups.

Belize has the highest forest cover in both Central America and the Caribbean, including the largest intact blocks of forests in Central America, namely the Selva Maya and the Maya Mountain Massif 7.

3.3 Protected Areas

Forest conservation has, historically, been a major priority for Belize. This is evidenced by the country's extensive protected areas system[8]. The Protected Areas of Belize have evolved over the last few decades from being considered primarily as a resource bank, typically for forestry, to become a complex network of large and small "enclaves" having a diversity of purposes and under a variety of management regimes, some more effective than others, reflecting changing conservation attitudes, as has the scope and direction of the various agencies responsible for their administration[9].

The country has 44% (1.22 million hectares) of its land and sea resources protected under a variety of management structures: 769,093 ha of terrestrial reserves, 159,030 ha of marine reserves, and a further

7 FCPF R-PP Belize https://www.forestcarbonpartnership.org/redd-countries-1

8 FCPF R-PP Belize https://www.forestcarbonpartnership.org/redd-countries-1

9 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

128,535 ha protected through 'officially recognized' private conservation initiatives[10]. Belize has 102 protected areas (PAs) representing 22.6% of its national territory (land and marine). These include 19 Forest Reserves, 17 National Parks, 3 Nature Reserves, 7 Wildlife Sanctuaries, 5 Natural Monuments, 9 Archaeological Reserves, 8 Private Reserves, 8 Marines Reserves, 13 Spawning Sites, 6 Public Reserves, and 7 Bird sanctuaries (see figure 4). The terrestrial PAs cover 34.9% of the total land surface, while the marine reserves cover 10.6% of the country's marine area[11].

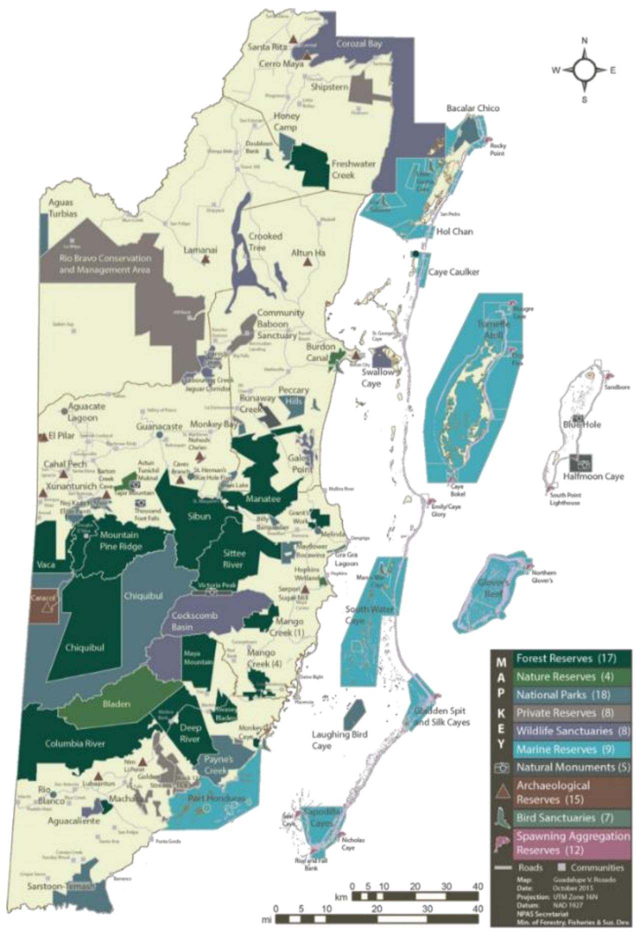


Figure 4: Map showing National Protected Areas System 2015

Protected Areas in Belize include archaeological reserves and “accepted” private reserves. As part of Belize’s protected areas system, there are bird sanctuaries that are some of the oldest protected areas. Archaeological Reserves include several Maya Sites managed by the National Institute of Culture and History (NICH)[12].

10 https://www.thegef.org/sites/default/files/project_documents/PIMS%2504907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

11 https://www.thegef.org/sites/default/files/project_documents/9-19-11%2520Belize%2520PIF_0.pdf

12 https://www.thegef.org/sites/default/files/project_documents/PIMS%2504907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

Extractive Reserves form a grouping of Forest Reserves and Marine Reserves. These management categories were created for the management of extractive resources. This is the largest section of Protected Areas Categories (50% of total protected area extension):

- Forest Reserves = 9.3% of Total National Territory.
- Marine Reserves = 3.7% of Total National Territory; and,
- Combined coverage = 13.0% of the Total National Territory.

The other conservation management categories are a grouping that represents management categories with conservation objectives. These include Nature Reserves, Wildlife Sanctuaries, no-take areas (marine reserves), National Parks, and Natural Monuments. This grouping includes a total of 53 areas falling in 6 different classes including conservation/wilderness/no-take zones of marine reserves. The total national coverage of this category of protected areas is 9.3% of the total national territory[13]. Concerning Private Protected Areas, 8 private protected areas meet the classification of either having a standing agreement with the Government and those have a de facto recognition and a management structure in place (Shipstern Nature Reserve, Community Baboon Sanctuary, Runaway Creek, Aguacate Lagoon, Monkey Bay Wildlife Sanctuary and Golden Stream Corridor Preserve). The total area that these 8 protected areas represent is 31,663 hectares or 3.2% of Belize's National Territory[14].

These forests also provide sustenance for much of the population. Recently, forests have been under increasing pressure from land conversion and degradation activities. Belize's biodiversity is exposed to various direct anthropogenic and natural threats both within and outside of the Protected Areas (PAs). Over the last five decades, the forest cover in Belize has steadily decreased due in general, to the expansion of unsustainable economic activities, such as large-scale and slash-and-burn agriculture, aquaculture, illegal logging, unsustainable logging, encroachment, forest/bush fires and other uncontrolled conversions of forest to intense anthropogenic land and extensive damages from climate climate-related hurricanes, and storms and pests. These include the unregulated development of urban and coastal areas and the rising pollution from cruise ship tourism leading to the degradation of mangroves and coral reefs and deforestation and unsustainable extraction of non-timber forest products in hotspot areas [15,16].

Deforestation has been more severe along rivers. Increases in illegal transboundary incursions by immigrants into Belize forests and Protected Areas for farming, hunting, and harvesting non-timber forest products present possibilities for increasing deforestation, affecting many of the 3,408 species of vascular

13 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf
14 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf
15 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf
16 https://www.thegef.org/sites/default/files/project_documents/9-19-11%2520Belize%2520PIF_0.pdf

plants occurring in Belize and the animal populations that depend on them for food and shelter[17]. Loss of forests in deforestation hotspots, particularly in key watersheds, leads to loss of ecosystem services: protection of water quality in adjacent watersheds, and reduction of nutrient flows that are damaging to the reefs[18].

Rapid and uncontrolled coastal development has resulted in increased habitat loss in Belize's coastal zone. It is estimated that about 75-80% of all coastal land in Belize has been purchased for the development of tourism and residential areas, posing a serious threat to mangroves, coastal wetlands, and other coastal ecosystems. It estimated that in 1990 about 98% of Belize's original mangroves (approximately 80,016 ha) remained; however, two years later an additional 519 ha had been lost due to increased urban expansion and tourism development, a 0.7% reduction in the national total. Since mangroves play a crucial role in coastal tropical biodiversity by acting as a nursery for many species that live in and around coral reefs and providing multiple niches for great numbers of fish, crustaceans, and other species, their disappearance due to coastal development poses a serious threat to both mangrove and reef diversity in Belize[19].

Coastal ecosystems are also threatened by the expansion of aquaculture, primarily through shrimp and tilapia farming. Aquaculture in Belize has been expanding in volume and value more rapidly than most other agro-production activities. It was estimated that aquaculture experienced a 160% annual increase in production volume from 2000 to 2010, particularly farmed shrimp[20].

Many of the country's poor population are forced to rely on subsistence agriculture where they slash and burn the forests and often squat on and farm public lands and in protected areas. There is increased pressure on natural resources through the harvesting of forest products and the demand for bushmeat and protein from marine resources, which may lead to the over-harvesting of many species like gibnut and turtles[21].

On the other hand, and after analysis of drivers of deforestation and forest degradation in Belize[22] from 2000 -2017, the predominant conversion is from Forest to Cropland. It seems that the main factor driving deforestation in Belize is the existing land tenure legislation, which requires that leased lands that are forested must be "developed" by the owners, or their leases would be revoked. This provides an enormous incentive for landowners to clear the land to meet the requirements of "development". However, it has been observed that many of these lands lie idle after they have been cleared since the landowners lack the capital to engage in alternative land uses. Hence, simple amendments to the existing land tenure law could have a significant impact on biodiversity conservation, the deforestation and forest

17 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

18 https://www.thegef.org/sites/default/files/project_documents/9-19-11%2520Belize%2520PIF_0.pdf

19 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

20 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

21 https://www.thegef.org/sites/default/files/project_documents/PIMS%25204907_GEF5%2520BD%2520EA%2520Belize_20-Jun-2012_0.pdf

22 First Draft of REDD+ Strategy April 2019. Section 4: Drivers of Deforestation and Forest Degradation

degradation rate and the subsequent fragmentation of Key Biodiversity Areas and forests [23] as well as in the implementation of the REDD+ Strategy.

3.4 Socioeconomic & Cultural

Since the pre-independence period, timber has been one of Belize's major export products. Forests are valuable assets and generate a range of important ecosystem services such as biodiversity habitats, non-timber forest products for local and indigenous communities, fuel for rural communities, and largely untapped potential for the use of medicinal plants in the pharmaceutical industry. Forests provide soil stabilization, which prevents excessive sedimentation of estuaries and coral reefs and reduces the runoff of nutrients from agricultural areas to the sensitive reef and mangrove ecosystems. In terms of the loss of ecosystem services such as water quality protection by riparian forests, location is important[24].

Historically the development of Belize's economy was based on logging. The country of Belize was established based on logwood cutting. Throughout history, we have seen the extraction of *Haematoxylum campechianum* (Logwood), *Swietenia macrophylla* (mahogany), *Cedrela odorata* (cedar) and currently the extraction of *Dalbergia stevensonii* (rosewood) which is leading to forest degradation because all sizes are being extracted with and without permits countrywide [25].

3.5 Institutional Arrangements Related to the FOLU Sector

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 MRV is provided at the ministerial level, and 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 for 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).

23 https://www.thegef.org/sites/default/files/project_documents/9-19-11%2520Belize%2520PIF_0.pdf

24 https://www.thegef.org/sites/default/files/project_documents/9-19-11%2520Belize%2520PIF_0.pdf

25 Identification of Deforestation and Forest Degradation drivers in Belize: Program for the Reduction of Emissions from Deforestation and Forest Degradation in Central America and the Dominican Republic (2011)

The National Climate Change Office (NCCO) was established in 2012 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 increasing production and productivity, promoting investment, and encouraging private sector involvement in agribusiness enterprises in a manner that ensures competitiveness, quality production, trade, and sustainability[26].

3.6 Description of National Legislation

Belize is fully committed to the international regime established on the promotion of sustainable development and the fight against climate change. In those areas, Belize has made significant progress in transitioning from the Millennium Development Goals in 2015 and has ratified the Paris Agreement on climate change in 2016. As such, Belize has taken ownership of the SDGs and developed several policy frameworks towards sustainable development and climate change over the last decade. These include, among others: (1) Horizon 2010-2030, (2) National Energy Policy Framework, (3) Sustainable Energy Action Plan 2014-2033, (4) National Climate Resilience Investment Plan 2013, (5) Growth and Sustainable Development Strategy 2016-2019, (6) the National Climate Change Policy, Strategy and Action Plan 2015-2020.

In addition, as a Party to the Paris Agreement, Belize submitted its updated Nationally Determined Contribution (NDC) to the UNFCCC in 2020. It is also important to emphasize that Belize is currently also undertaking a full review of existing policies such as forest and land-use policies to enhance their effectiveness and to better align them with the national climate change commitments.

26 https://www.agriculture.gov.bz/.

In addition, the MSDCCDR did a detailed policy review called 'Legal and Institutional Framework for REDD+ implementation in Belize". All strategic documents mentioned below provide policy guidance on the forest and land used sector, amongst others.

Strategic policy frameworks

- National Development Framework for Belize (2010-2030), "Horizon 2030", 2016

Revised Low Carbon Development Roadmap for Belize, April 2016

- Growth and Sustainable Development Strategy (GSDS), 2016-2019
- National Change Policy, Strategy and Action Plan (NCCPSAP), MAFFESDI, 2014

Framework environmental protection law

- National Environmental Policy and Strategy (2014-2024), 2014
- National Environmental Action Plan (2015– 2020), 2014
- The Environmental Protection (Amendment) Act, 2009

Forest

- National Forest Policy, 2015
- The Forest (Amendment) Act, 2017
- Forests (protection of mangroves) Regulations, 2018
- Forest (Protection of Trees) Regulations, 2010
- Private Forest (Conservation) Act, 2000
- Forest Fire Protection Act, 2000
- Sustainable Forest Management Licenses (SFML)

Agriculture

- The National Food and Agriculture Policy (2002- 2020), 2003
- The National Agriculture and Food Policy of Belize (NAFP) (2015-2030), 2015
- Agriculture Development Management and Operational Strategy (ADMOS), 2005
- National Adaptation Strategy to address Climate Change in the Agriculture Sector in Belize, 2014
- Agricultural Fires Act, 2000

Land tenure

- National Land Use Policy and Integrated Planning Framework for Land Resource Development (Draft), Ministry of Natural Resources, November 2011
- National Lands Act, 2003
- The Land Utilization (Amendment) Act, 2017
- Land Tax Act, 2003
- Land Acquisition Act, 2000

Spatial Planning

- National Protected Areas Policy and System Plan, 2015
- National Protected Areas System Act, 2015
- Protected Areas Conservation Trust (PACT) (Amendment) Act, 2017
- Integrated Coastal Zone Management Plan, 2016
- Coastal Zone Management Act, 2003

Biodiversity

- National Biodiversity Strategy and Action Plan (NBSAP) (2016- 2020), 2018
- Biodiversity Initiative – Biodiversity Policy and Institutional Review

Taxation

- Environmental Tax (Amended) Act, 2017
- The Fiscal Incentive Program, 2016
- The Fiscal Incentives Act, 2011
- Finance and Audit (Reform) Act, 2011
- The Mines and Minerals Act

4. METHODOLOGICAL PROCESS FOR ESTIMATING GHG EMISSIONS AND REMOVALS

4.1 Activity data

The information on Activity Data (AD) used was obtained from a land use and land-use change assessment, which was conducted based on a spatially explicit sample-based methodology (IPCC approach 3) using the Land Use Assessment (LUA) app.

The data for the estimation of wood removals (IPCC equation 2.12) was derived from the same sample-based land use assessment, by equating canopy cover loss with above-ground biomass loss.. We identified various contributing factors to these losses, including hurricanes, fires, logging, grazing, shifting cultivation, pest infestations, infrastructure development, mining activities, and other human impacts.

One significant improvement over the previous FREL/FRL is the ability to monitor multiple land use changes and multiple disturbances occurring on the same plot throughout time. This advancement enables us to account for emissions or removals associated with each specific disturbance or land use change. In contrast, the earlier FRL/FREL only considered the initial and final land use states, along with the primary disturbance event. The new approach implemented in this FRL is higher-tier as it increases the accuracy of the GHG estimations.

4.2 Activity data collection

For data collection, we employed the LUA app, an application developed by the Coalition for Rainforest Nations (CfRN), specifically designed for land use assessment. This application serves as a comprehensive framework for gathering proprietary data to meet the systematic reporting requirements of the United Nations Framework Convention on Climate Change (UNFCCC), aligning with the guidance provided by the Intergovernmental Panel on Climate Change (IPCC).

This application is an adaptation of the Collect Earth Desktop and Collect Earth Online applications, initially developed by SERVIR, a joint program of USAID and NASA, in collaboration with the Food and Agriculture Organization (FAO). The adaptation ensured full consistency with the formatting standards required for Greenhouse Gas (GHG) inventories and REDD+ initiatives under the UNFCCC.

The data collected through the LUA app was entered into the CfRN's Foundational Platform, a Microsoft Excel-based spreadsheet designed to align with Belize's specific national circumstances. This platform allows for the implementation of IPCC's equations for national GHG inventories, following IPCC guidance and guidelines.

Similar to Collect Earth Desktop and Collect Earth Online, the LUA app leverages free access to Google Earth Pro and Google Earth Engine imagery. Access to high-resolution images enhances our ability to comprehend the dynamic nature of land use changes over time and enables us to interpret various aspects, including degradation and disturbances such as fires, logging, hurricanes, bark beetle, grazing, shifting cultivation, mining, infrastructure and others.

4.3 Sampling design

To define a grid for sample plots for Belize, it was necessary to establish the total land area of Belize. This was calculated with ArcGIS Pro, 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 kilometres. After a systematic selection done in Google Earth Engine using the grid design parameters, a total of 21,993 sample plots were created. Each plot measures 0.5 ha and they were separated by 1km x 1km systematically. Figure 5 below illustrates this. From a statistical perspective a sample of 21,993 is deemed to be extremely robust for the estimation of land use and land use changes.

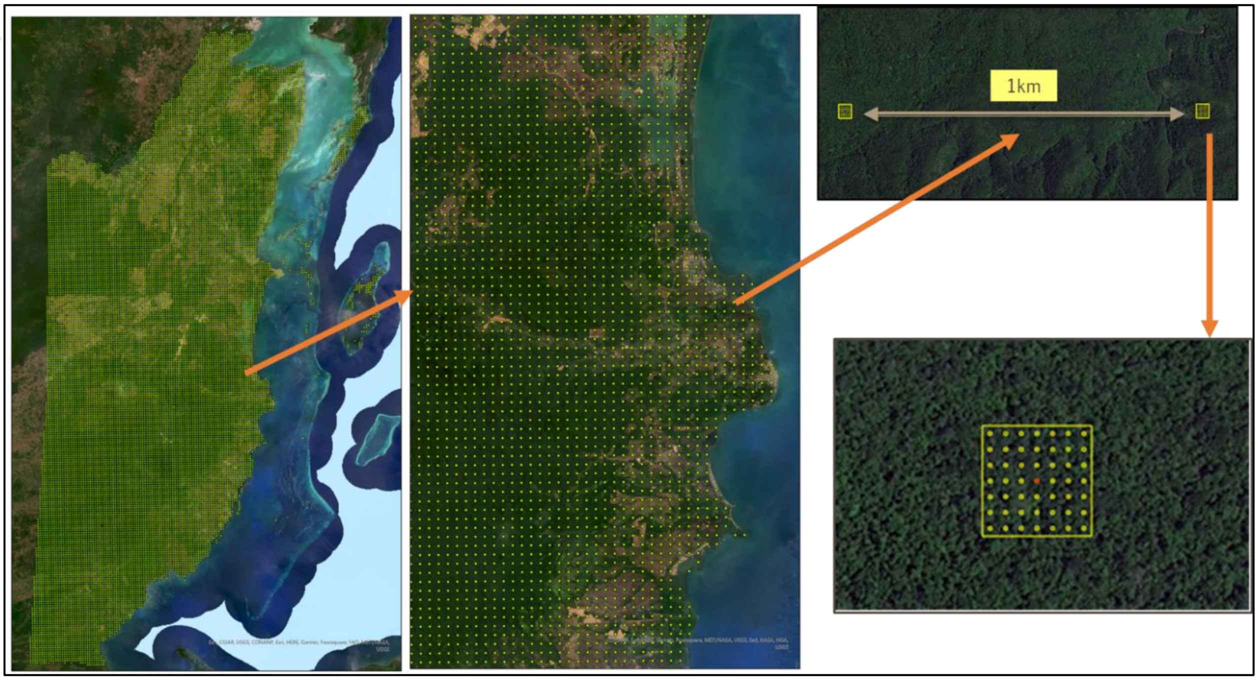


Figure 5: Showing 1x1 km systematic grid design used within the Belize LUA app for collection of AD.

4.4 Land Representation and Definitions

The Intergovernmental Panel on Climate Change has the following six (6) categories for the Agriculture, Forestry, and Other Land Use (AFOLU) sectors. These are forest, cropland, grassland, wetland, settlement, and other lands. Each IPPC category has further subcategories and specific classes. Table 4 below illustrates the classification and codes developed for Belize. The following section provides a definition of the IPCC category, subcategory, and specific class for the AFOLU sector of Belize.

Table 4: Showing the Land classification in Belize following the six IPCC land uses.

LEVEL 1	LEVEL 2	LEVEL 3
Forest Land	**Broad-leaf Mature Forest**	Riparian Forest
		Swamp Forest
		Other Forest
	Broad-leaf Secondary Forest	Riparian Forest
		Swamp Forest

		Other Forest
	Pine Forest	Mature Pine Forest
		Secondary Pine Forest
	Mangroves	Tall mangroves
		Dwarf mangroves
		Medium Mangroves
	Plantations	Teak
		Other Plantations (Tectona sp.)
Cropland	**Swidden Farming**	
	Intensive Agriculture	Rice, Beans, Corn, Sugar Cane Banana, Coffee, Citrus
	Fallow lands	
Grassland	**Pastures/Shrublands /Savannas/Ferns/Thickets**	Riparian shrubland vegetation, Shrubland (thicket), Ferns, Savannah with scattered pine trees, Savannah with scattered shrubs, Bare-savannah, Agriculture-pasture
	Fallow lands	
	Simultaneous Grasslands	
Wetlands		Wetland, Coastal lagoon, Inland water bodies, Aquaculture

Settlements		Residential areas, rooftops, market, sport facilities areas and parking lots.
Other lands		Roads, highways, quarries, eroded areas, beach sand, dried up soil in savannah areas, bare rock, and exposed riverbeds

LEVEL 1: Forest

Definition of forest:

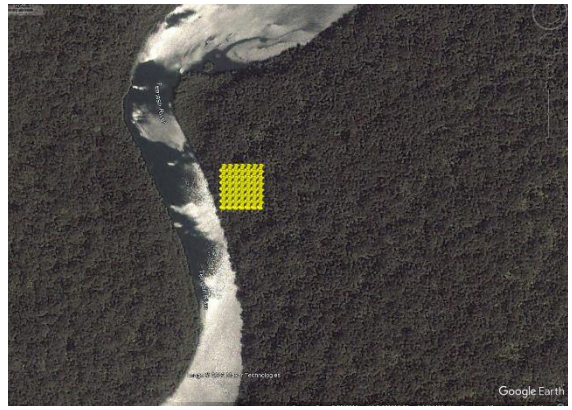
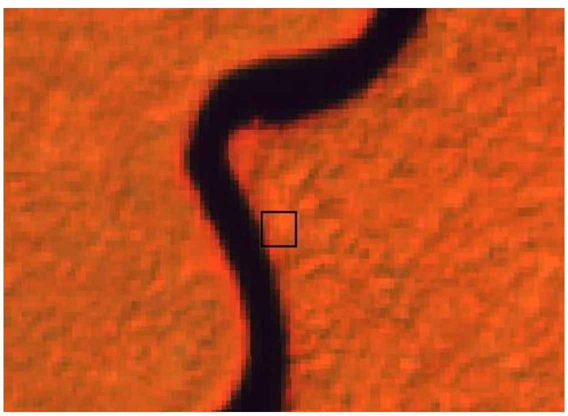
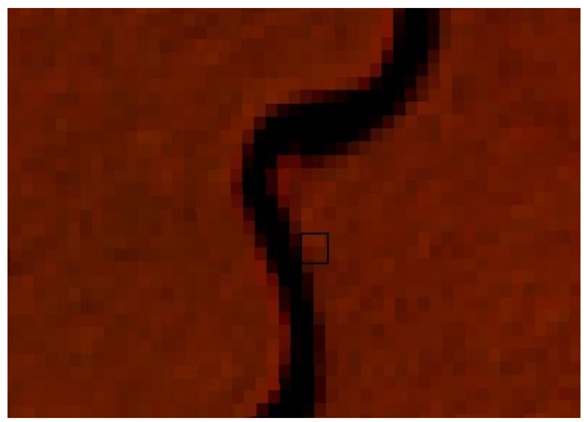
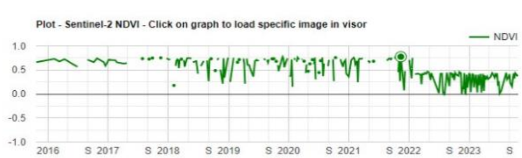
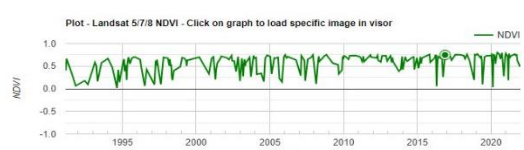
A forest is a plot of land with an area of 0.5 hectares or more, with trees of heights of 5 meters or higher, and a canopy cover of 30% or higher. This definition also includes forest plantation. In addition, it includes an ecosystem that due to biotic conditions (terrain, soil type, rainfall, et cetera) the trees cannot grow higher than 5 meters.

Level 2: *Mature Broadleaf Forest (MBL)*

Definition: Broadleaf dominated semi-deciduous/semi-evergreen mature forest that includes all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations.

Level 3. Mature Riparian Forest (FMBLRIP)

Definition: Broadleaf dominated semi-deciduous/semi-evergreen mature forest generally located on alluvial plains along watercourses or in gullies in mountainous areas. The defining characteristic is that a mature riparian forest is found within 66 feet (20 m) of a water source.

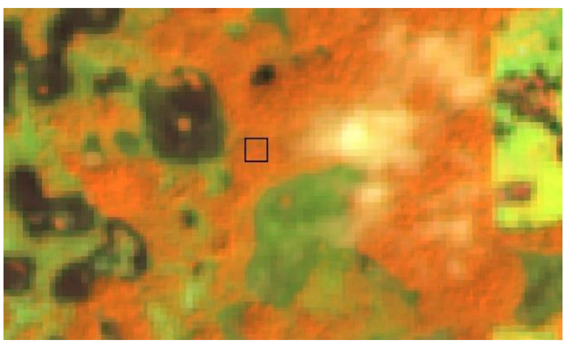
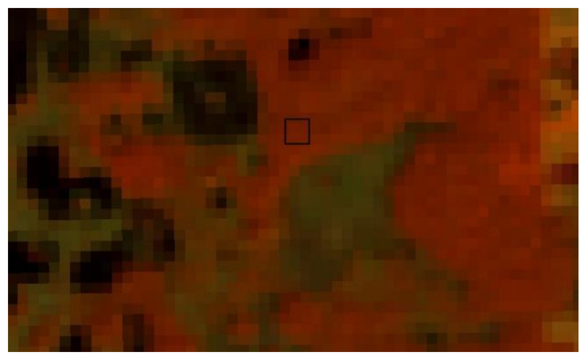
Visualization/Interpretation	
Vegetation picture	**Google Earth Pro image**
	
Sentinel 2 image	**Landsat 8 image**
	
NDVI image Sentinel 2	**NDVI Landsat 5,7,8**
	

Level 3. Mature Swamp Forest (FMBLSWAMP)

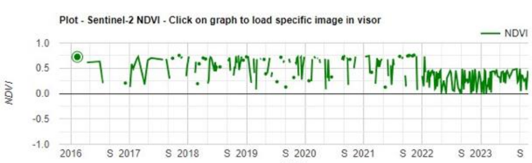
Definition: Broadleaf dominated semi-deciduous/semi-evergreen mature forest characterized by being inundated seasonally or permanently.

Visualization/Interpretation

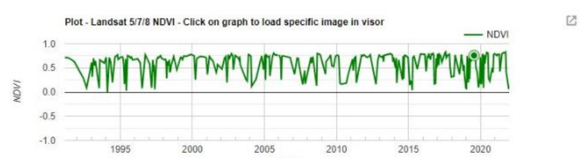
Vegetation picture	Google Earth Pro image
	

Sentinel 2 image	Landsat 8 image
	

NDVI image Sentinel 2



NDVI Landsat 5,7,8



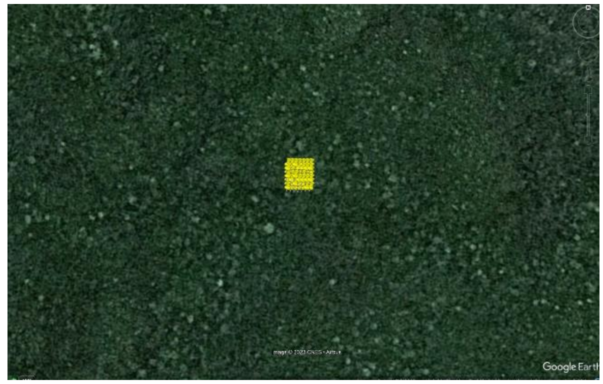
Level 3. Other Mature Broadleaf Forest (FMBLO)

Definition: Other Broadleaf-dominated semi-deciduous/semi-evergreen mature forest that include all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations. If the specific class was not Riparian or Swamp MBL, then MBLO was used.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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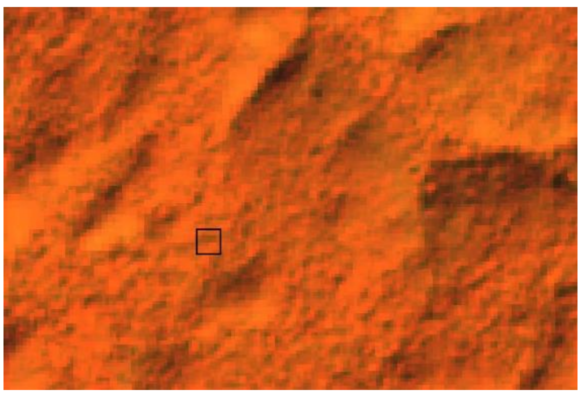
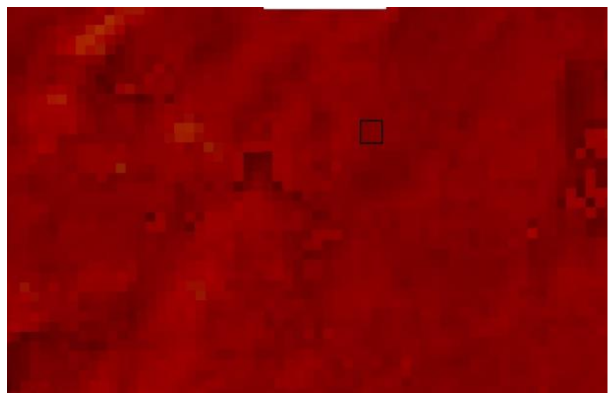


Landsat 8 image



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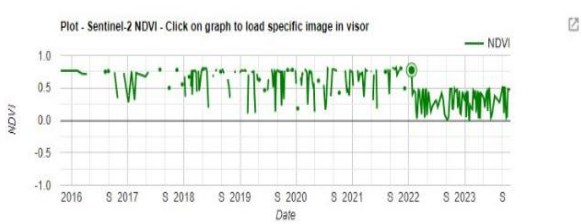
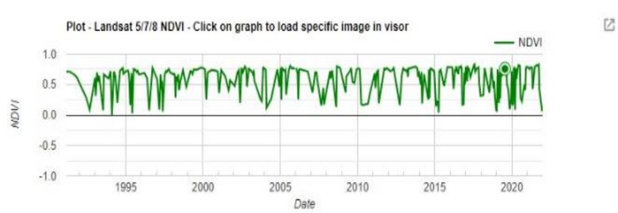


NDVI Landsat 5,7,8



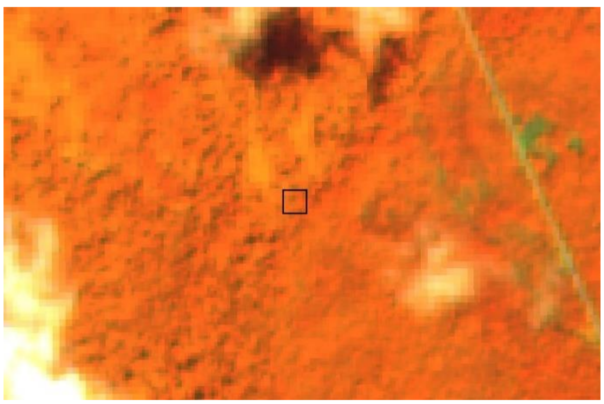
Level 2: Secondary Broadleaf Forest (SBL)

Definition: Broadleaf dominated semi-deciduous/semi-evergreen forest that include all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations.

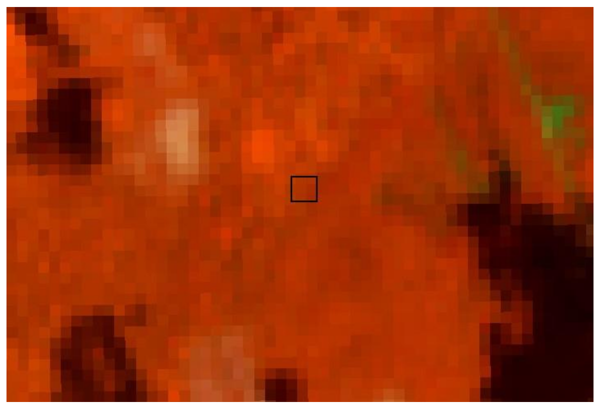
These are forests regenerating largely through natural processes after significant human and/or natural disturbance land-use change (with more than 70% mortality) of the original forest vegetation at a single point in time or over an extended period. These forests also display a major difference in forest structure and/or canopy species composition with respect to nearby mature forest on similar sites.

Visualization/Interpretation	
Vegetation picture	**Google Earth Pro image**

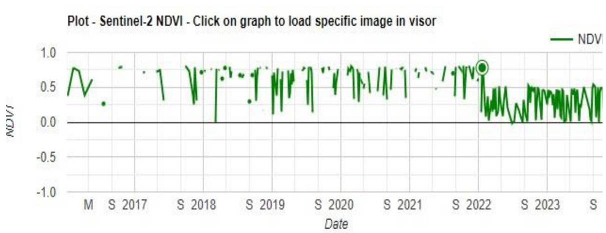
Sentinel 2 image



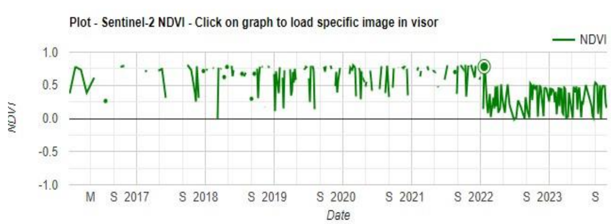
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 3. Secondary Riparian Forest (FSBLRIP)

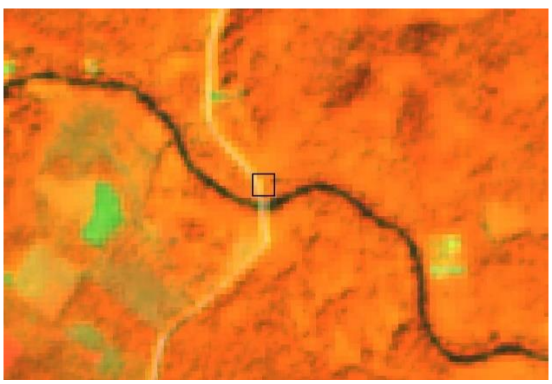
Definition: Broadleaf dominated semi-deciduous/semi-evergreen forest that include all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations.

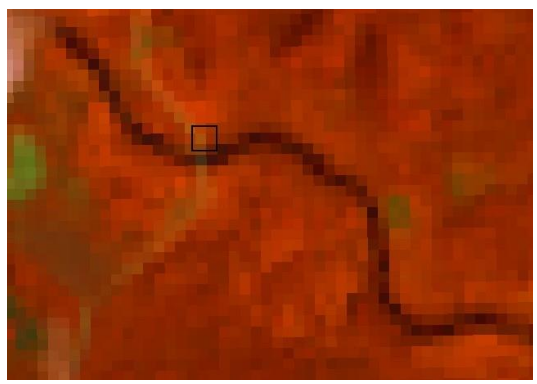
The defining characteristic is that secondary riparian forest is found within 66 feet (20 m) from a water source. These are forests regenerating largely through natural processes after significant human and/or natural disturbance land use change (with more than 70% mortality) of the original forest vegetation at a single point in time or over an extended period. These forests also display a major difference in forest structure and/or canopy species composition with respect to nearby mature forest on similar sites.

Visualization/Interpretation

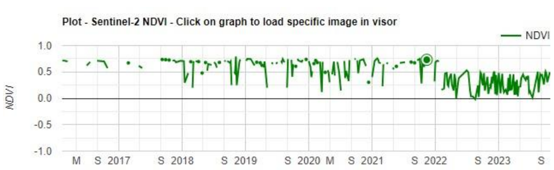
Vegetation picture | **Google Earth Pro image**

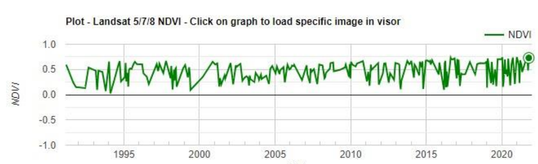
Sentinel 2 image | **Landsat 8 image**





NDVI image Sentinel 2 | NDVI Landsat 5,7,8





Level 3. Secondary Swamp Forest (FSBLSWAMP)

Definition: Broadleaf dominated semi-deciduous/semi-evergreen mature forest that include all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations. The defining characteristic of the secondary swamp forests is that these are inundated seasonally or permanently.

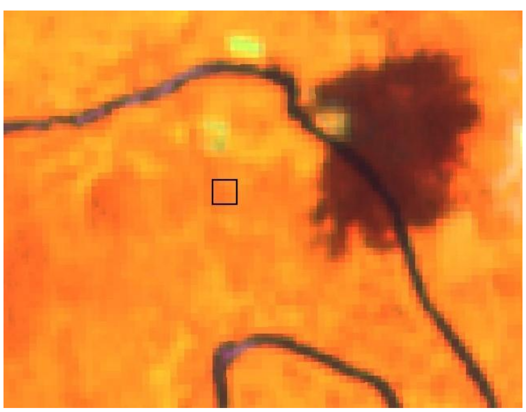
These are forests regenerating largely through natural processes after significant human and/or natural disturbance land use change (with more than 70% mortality) of the original forest vegetation at a single point in time or over an extended period. These forests also display a major difference in forest structure and/or canopy species composition with respect to nearby mature forest on similar sites.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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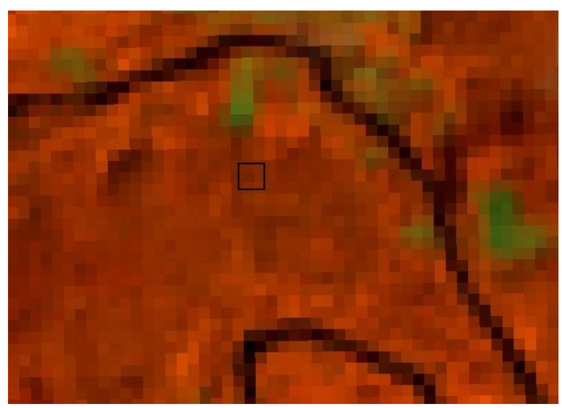

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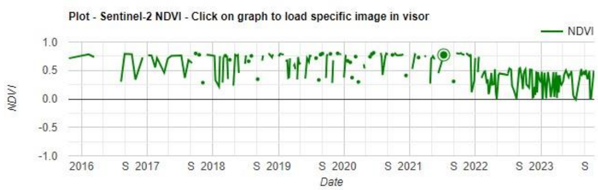
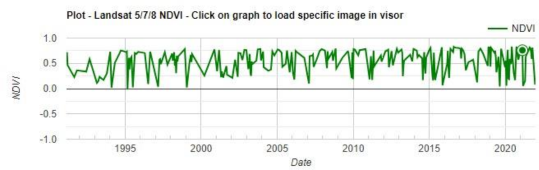


NDVI Landsat 5,7,8



Level 3. Other Secondary Broadleaf Forest (FSBLO)

Definition: Other Broadleaf dominated semi-deciduous/semi-evergreen forest that is 0.5 hectare and include all classes of mixed-species broadleaf trees – including intermittent palms – on all types of soil at all elevations.

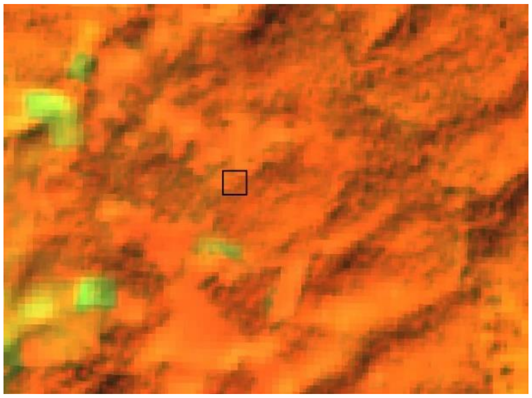
These are forests regenerating largely through natural processes after significant human and/or natural disturbance land use change (with more than 70% mortality) of the original forest vegetation at a single point in time or over an extended period. These forests also display a major difference in forest structure and/or canopy species composition with respect to nearby mature forests on similar sites. If the specific forest class was not Riparian or Swamp, then SBLO was used.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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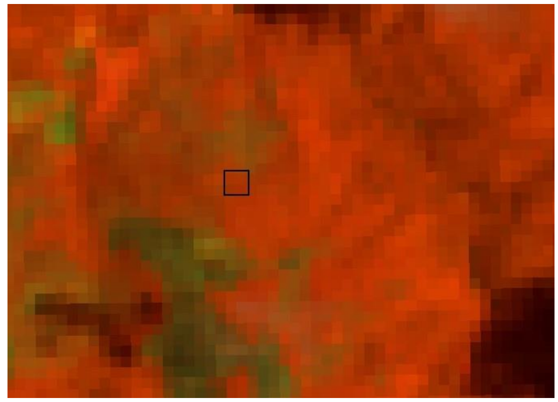

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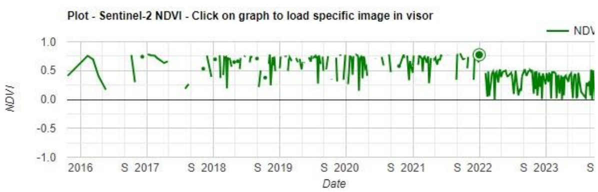


NDVI Landsat 5,7,8

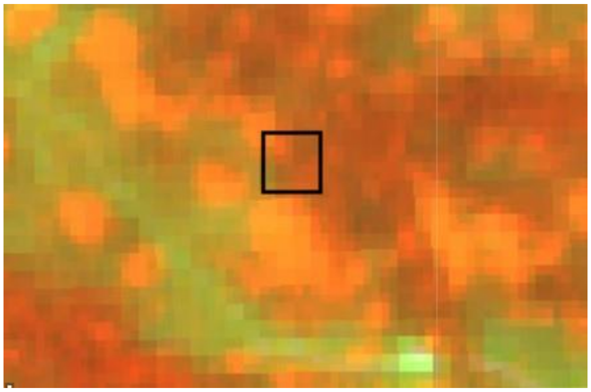
Level 2. Pine Forest (PINE)

Visualization/Interpretation

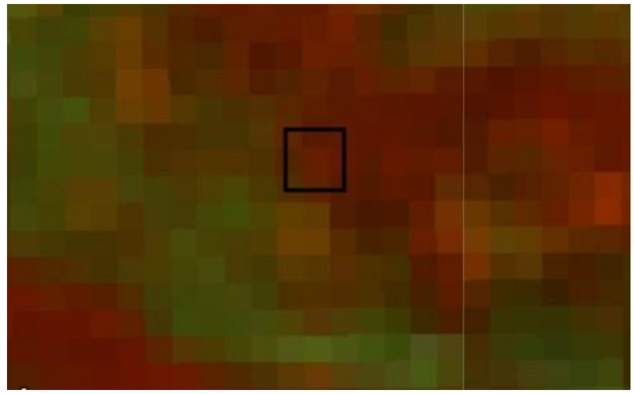
Vegetation picture

Google Earth Pro image

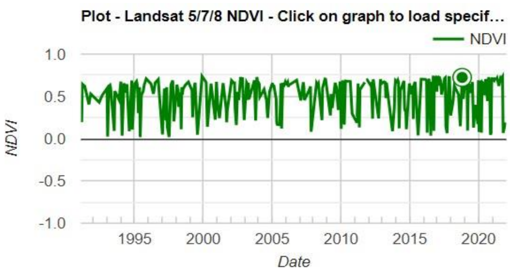
Sentinel 2 image



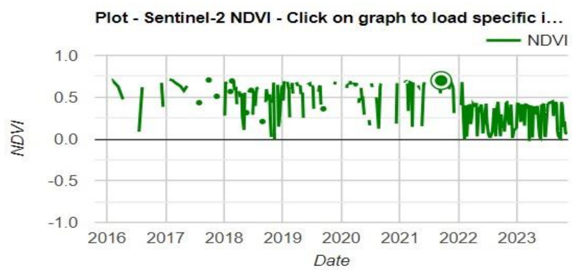
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8

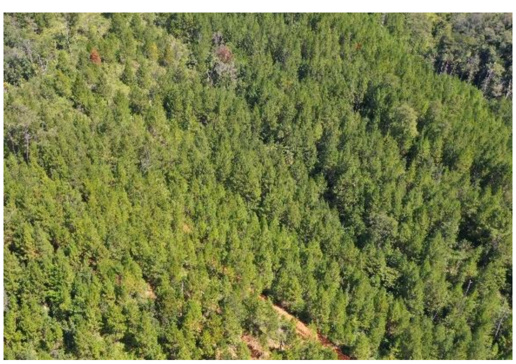


Level 3. Mature Pine Forest (FPINEM)

Definition: pine-dominated evergreen mature trees. Pine forests have some intermittent mixing of broadleaf tree species (oak, craboo). The defining characteristic is an open canopy that is dominated by pine trees with some intermittent small gaps of low broadleaf tree species, grass, or shrubs.

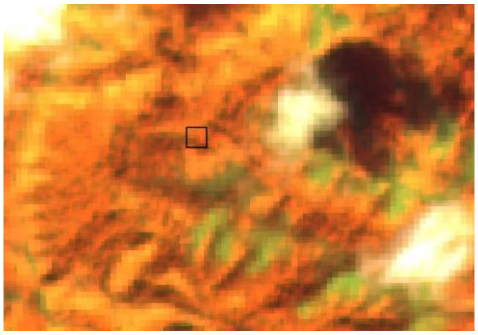
Visualization/Interpretation

Vegetation picture

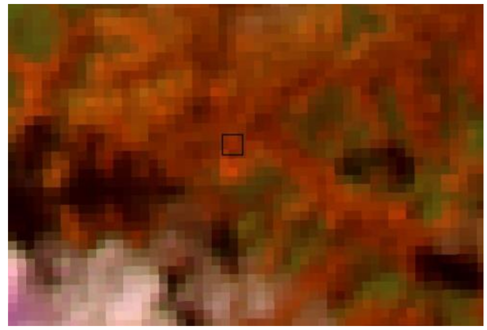


Google Earth Pro image

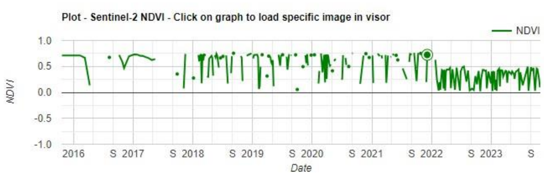
Sentinel 2 image



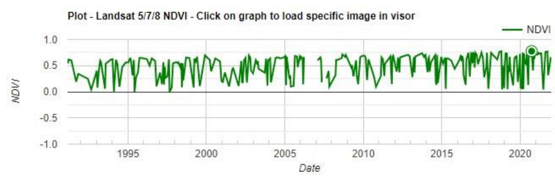
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 3. Secondary Pine Forest (FPINES)

Definition: pine-dominated evergreen trees. Pine forests have some intermittent mixing of broadleaf tree species (oak, craboo). The defining characteristic is an open low canopy that is dominated by pine saplings with some intermittent small gaps of low shrubby vegetation, grass, or small broadleaf trees.

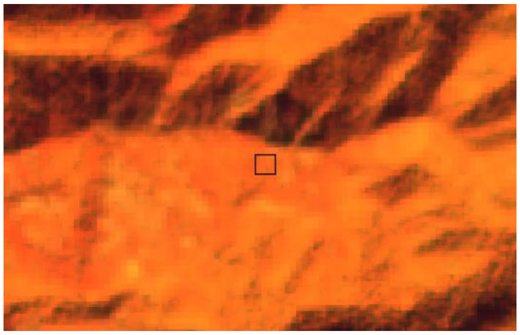
These are pine forests regenerating largely through natural processes after significant human and/or natural disturbance land use change (with more than 70% mortality) of the original forest vegetation at a single point in time or over an extended period.

Visualization/Interpretation

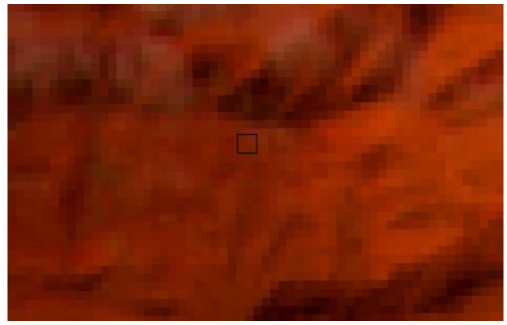
Vegetation picture

Google Earth Pro image

Sentinel 2 image

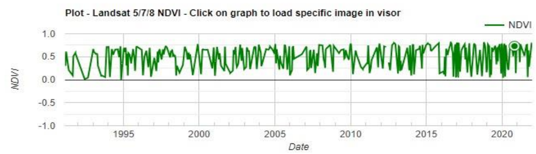


Landsat 8 image



NDVI image Sentinel 2

NDVI Landsat 5,7,8



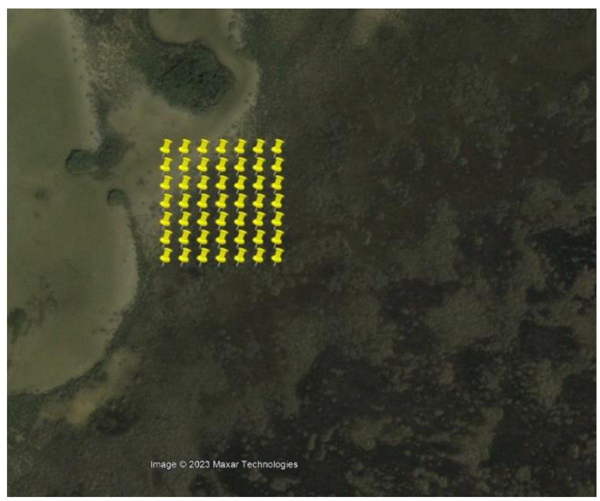
Level 2. Mangrove (MAN)

The term “mangrove” refers to a group of salt-tolerant plant species, including trees, shrubs, palms, or ferns, predominantly found in tropical regions. These species thrive above mean sea level within the intertidal zone of marine environments.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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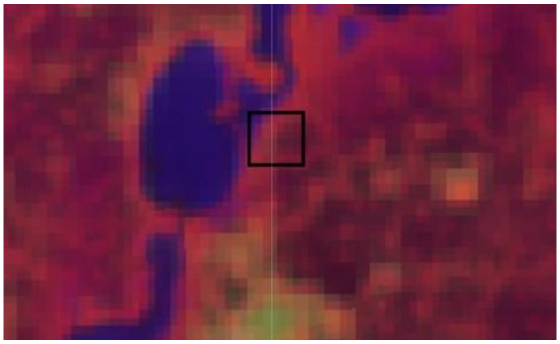
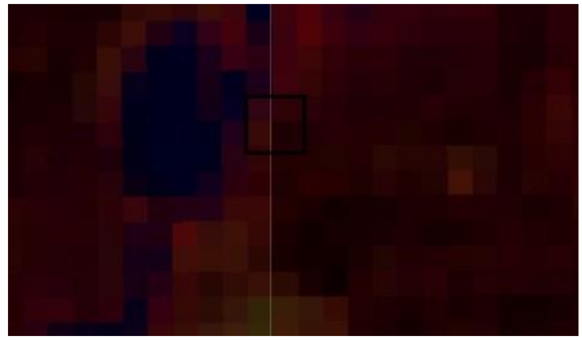


Landsat 8 image



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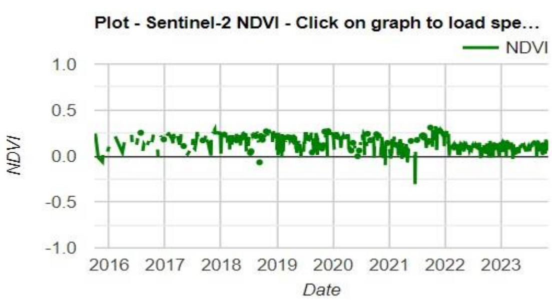
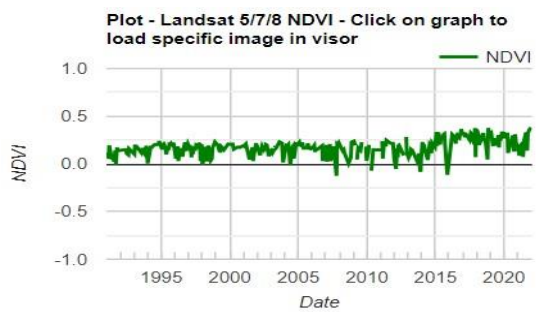


NDVI Landsat 5,7,8



Level 3. Dwarf Mangrove Forest (FMDW)

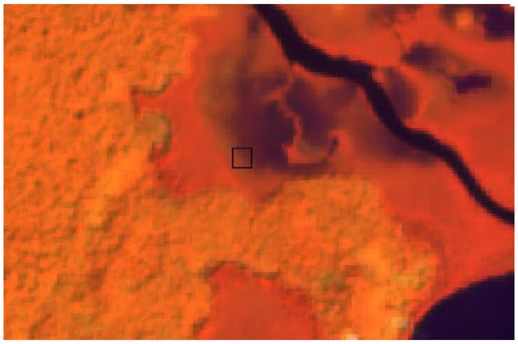
Definition: Composed of mangrove scrubs less than 3-4 m tall and growing at relatively low density. Dwarf mangroves are mostly found along the coastline and on cayes.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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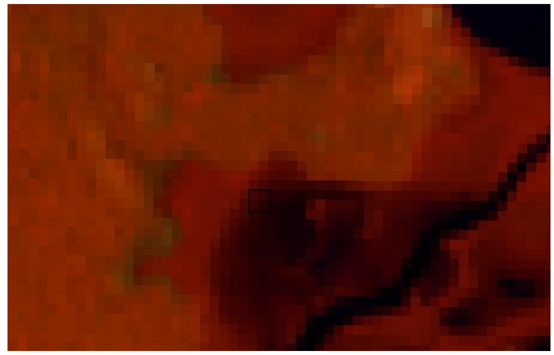

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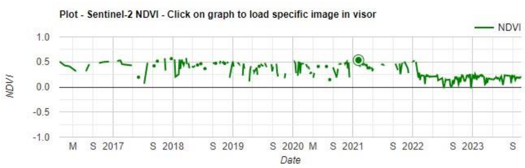
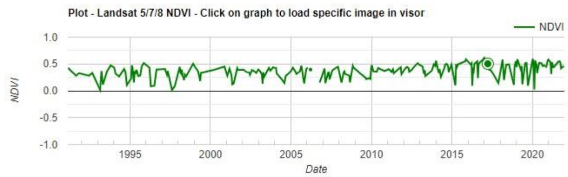


NDVI Landsat 5,7,8



Level 3. Medium Mangrove Forest (FMMED)

Definition: Medium mangrove forest is defined by medium-height vegetation, including mangrove thickets and shorter forest ranging from 3m to 7-8m in height. Additionally, it encompasses mixed-species forests, with heights below 5m, thriving in brackish to saline conditions.

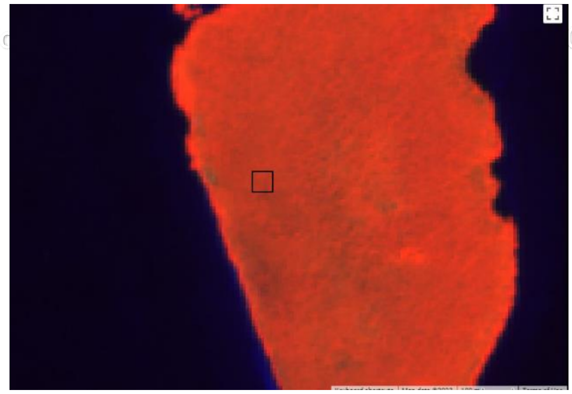
Visualization/Interpretation

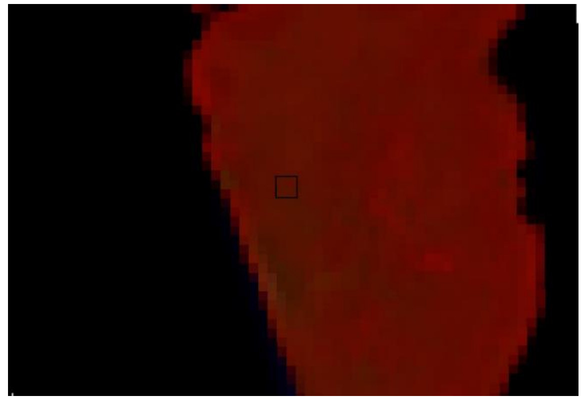
Vegetation picture

Google Earth Pro image

Sentinel 2 image

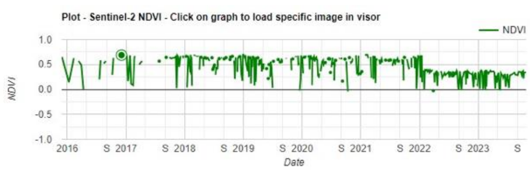
Landsat 8 image

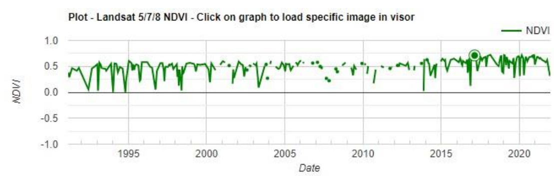




NDVI image Sentinel 2

NDVI Landsat 5,7,8



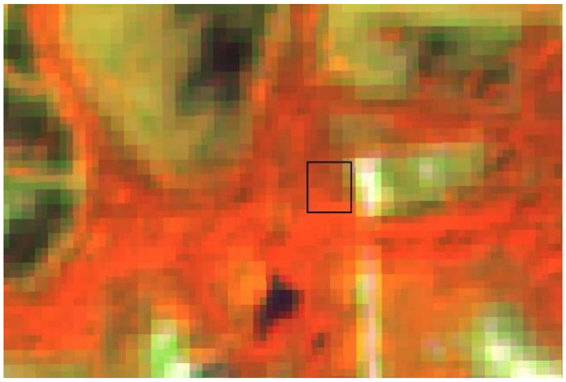


Level 3. Tall Mangrove Forest (FMTA)

Definition: Tall mangrove forest is composed of mangrove forest formations over 7-8m tall.

Visualization/Interpretation	
Vegetation picture	**Google Earth Pro image**

Sentinel 2 image



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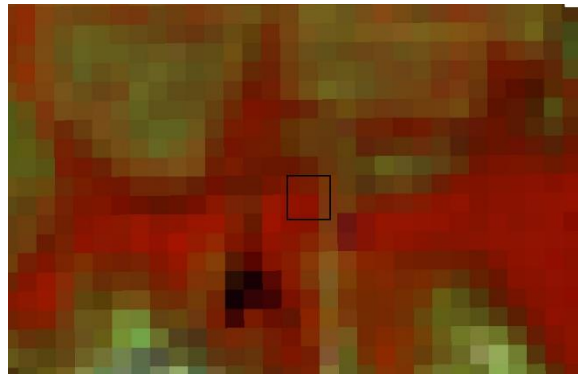
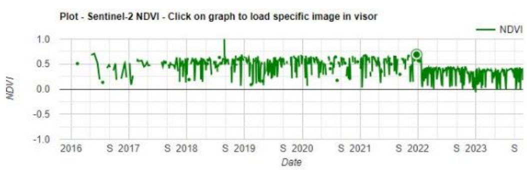


NDVI image Sentinel 2



NDVI Landsat 5,7,8

Level 2. Forest Plantation (FPLANT)

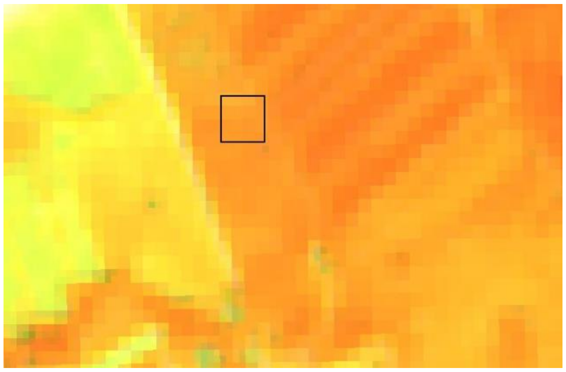
Definition: Planted monoculture stands of broadleaf tree species. The main defining characteristic here is a stand of trees planted in rows with a somewhat open canopy. Common species planted include teak, mahogany, cedar, Melina, and acacia.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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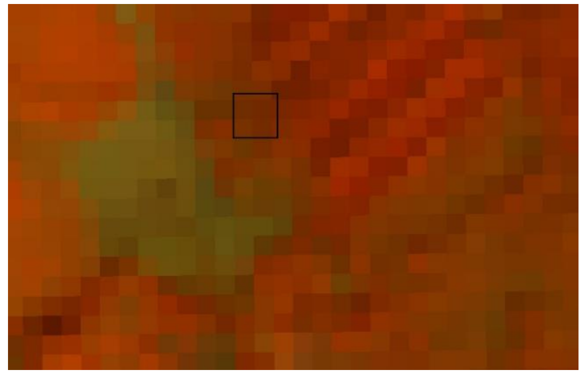

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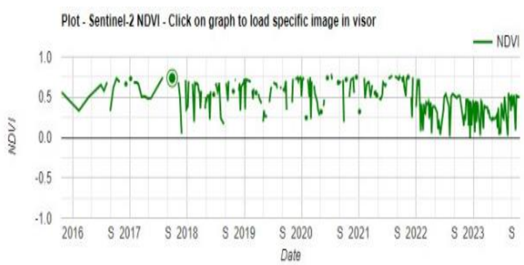
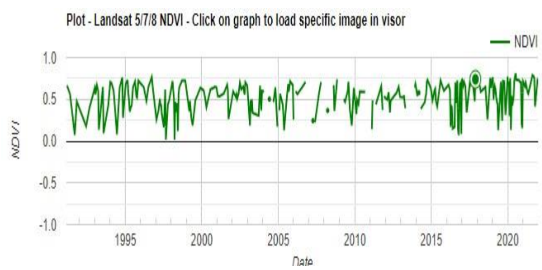


NDVI Landsat 5,7,8



LEVEL 1: Cropland

Agricultural activity is 0.5 hectares of land that has a 20% cover with crops in the sample plot/point. Land that was once used for swidden agriculture and has been abandoned and is ‘regenerating toward a secondary forest’ is also considered cropland under specific class fallow land.

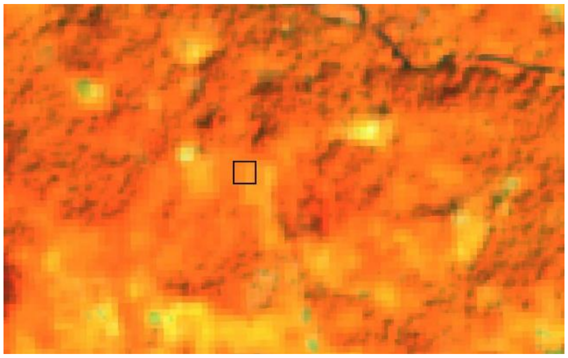
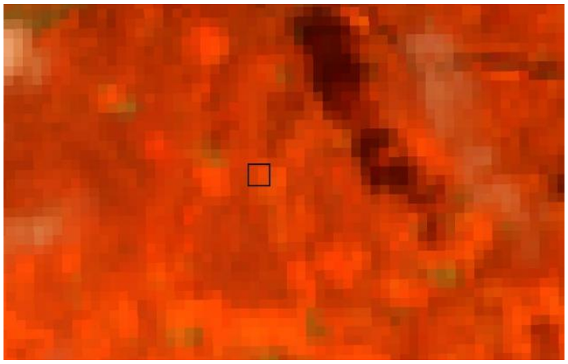
Level 2: Swidden Farming (CSHIFTAGR) [27]

Definition: A system of cultivation where land is cleared (and oftentimes burned) for the production of staple food crops for a short period of time (1 to 3 years), followed by a long fallow period. Only annual crops are planted in swidden farming. Swidden farming is also referred to as milpa farming or slash-and-burn farming.

[27] Definitions of Cropland were provided by the Coordinator for the Research & Innovation Program at the Department of Agriculture. Annual crops are crops that complete their life cycle from seed germination to seed production in one year (e.g. beans, corn, lettuce, sweet pepper, et cetera). Perennial crops are a crops that live year round, producing several crops or harvests during its life time (e.g. fruit trees).

Visualization/Interpretation

Vegetation picture	Google Earth Pro image
	

Sentinel 2 image	Landsat 8 image
	

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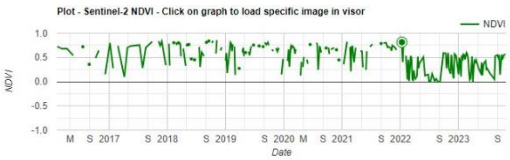
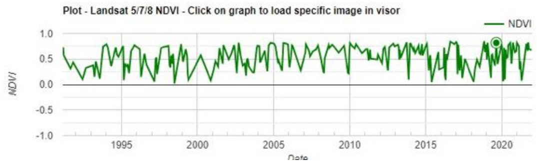


NDVI Landsat 5,7,8



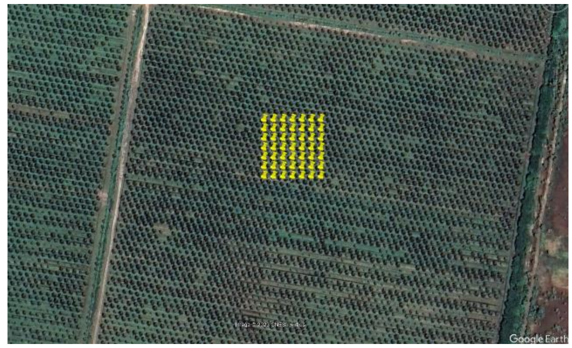
Level 2: *Intensive Agriculture (INTAGR)*

Definition: A production system characterized by having high output per unit of land as a result of an increase in the use of technological inputs (e.g improved seed, irrigation, fertilizer application, pesticides, mechanization and capital). Intensive agriculture can be small-scale or large-scale. It can also be annual crops (eg. Corn, beans, etc.) or perennial crops (citrus, coconut, etc.).

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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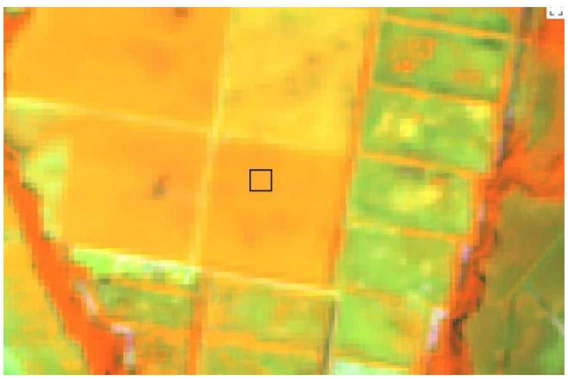
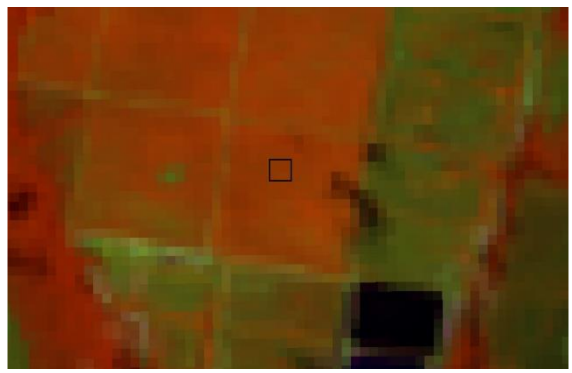


Landsat 8 image



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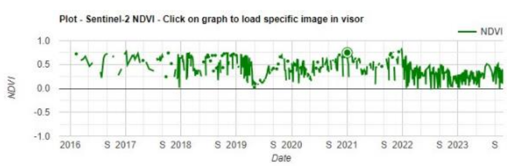


NDVI Landsat 5,7,8

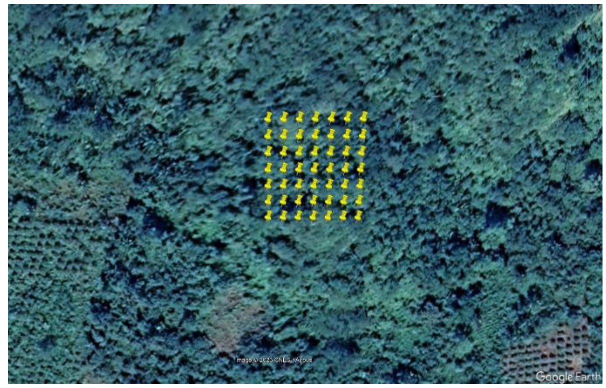
Level 2: *Fallow Land (CFALL)*

Definition: Regeneration immediately after the abandonment of agricultural activity. Fallow land that was mono-crop takes eighteen (18) years to transition to the secondary broad lead forest. During the initial eight (8) years of growth, fallow land has bushes. Consequently, for the next ten (10) years, fallow land is dominated by broadleaf pioneer tree species such as bay cedar, trumpet tree, pole wood, et cetera. At this stage, the defining characteristic of fallow land is an open canopy, with intermittent large trees, low vegetation, and high vine coverage. The canopy is generally lower than 5 meters. Fallow land is referred to as Wamil.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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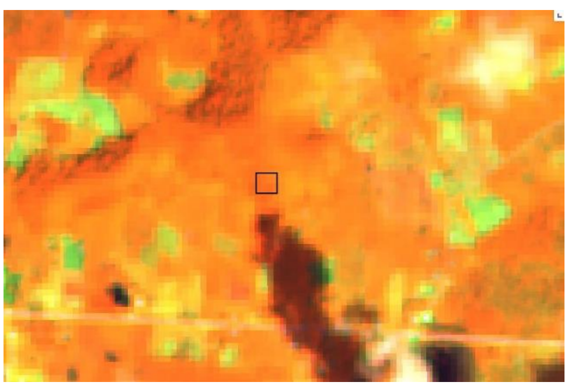
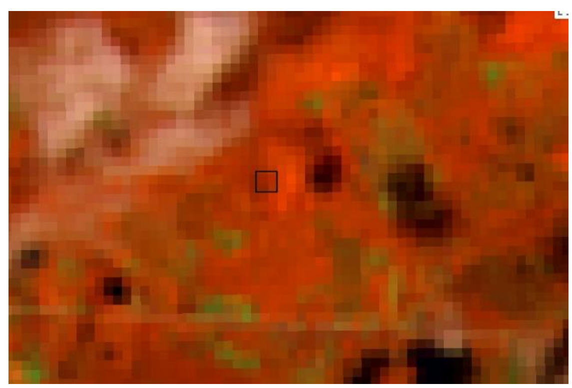
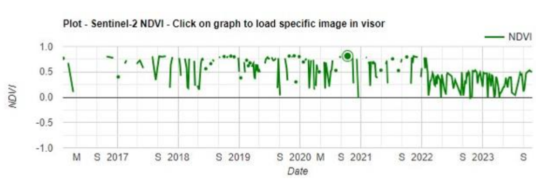


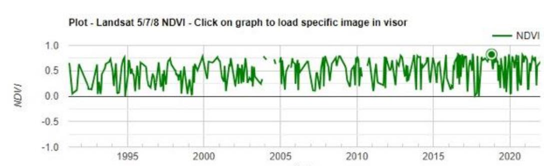
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



LEVEL 1: Grassland (G)

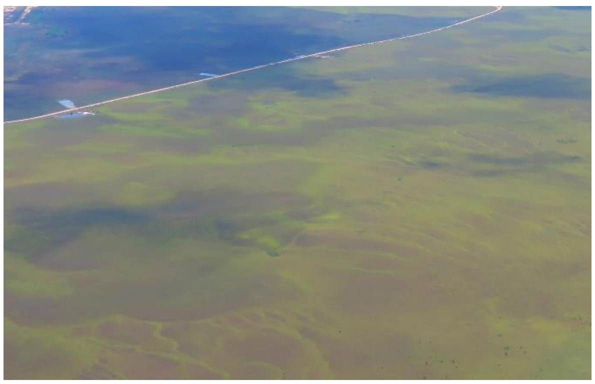
Grassland is 0.5 hectare of land that has a 20% cover of savannah, grass, shrubs, ferns, and tickets in the sample plot/point. [28] Cattle pasture is considered grassland.

Level 2: *Lowland Savannah (SAVG)*

Definition: Savannah is dominated by graminoids (grasses and sedges) with scattered tree species. The dominant species is pine.

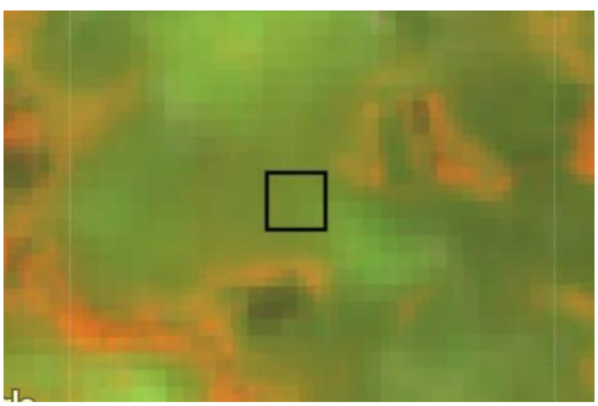
Visualization/Interpretation

Vegetation picture

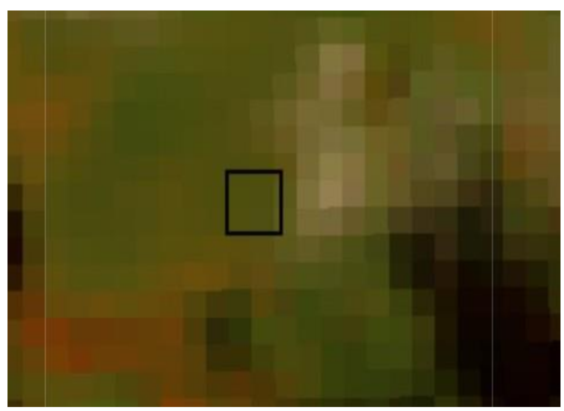


Google Earth Pro image

Sentinel 2 image

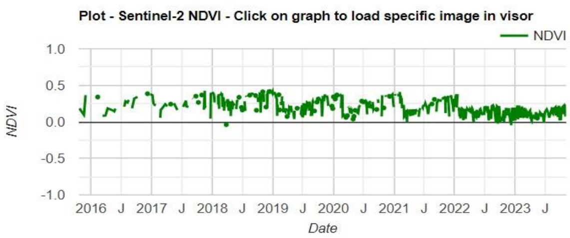


Landsat 8 image

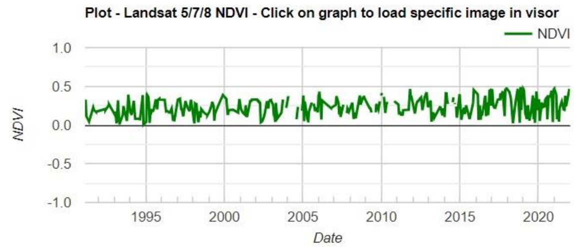


[28] Definition for Grassland relied on the ‘Classification system for the forest and land cover map of Belize 2012/014 based on RapidEye imagery’ of 2016, published by the Forest Department.

NDVI image Sentinel 2



NDVI Landsat 5,7,8



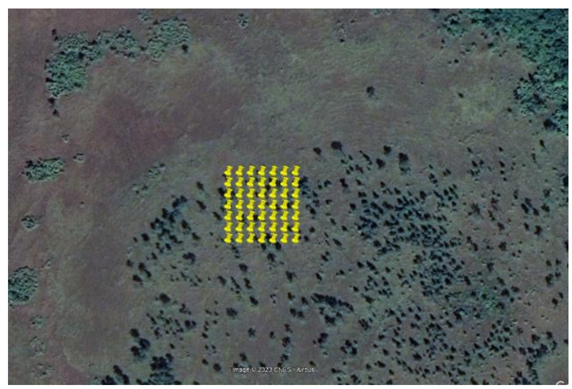
Level 3: *Savannah with scattered trees (GSAVTREE):*

Definition: Dominated by graminoids (grasses and sedges) scattered with various tree species such as Oak, Palmetto Palms, Pines, and Calabash.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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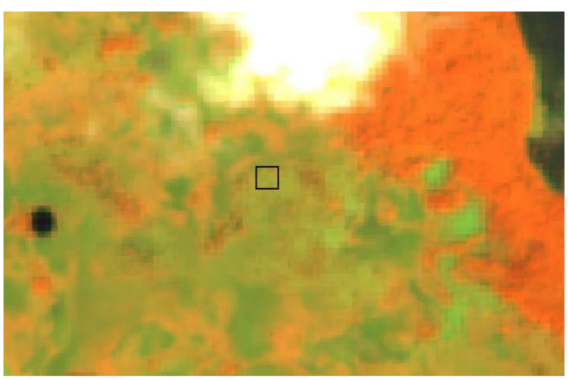
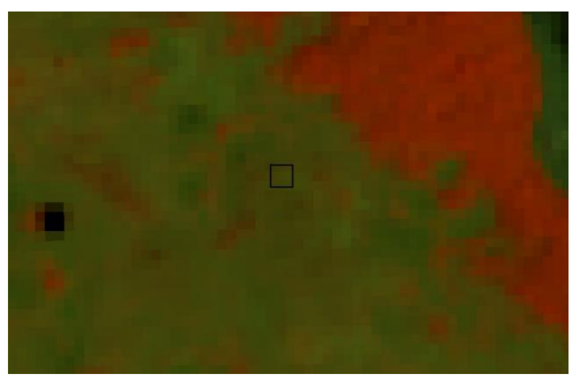


Landsat 8 image



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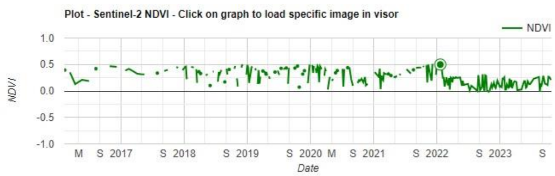


NDVI Landsat 5,7,8

Level 3: *Savannah with Scattered Shrubs (GSAVSHRUB)*

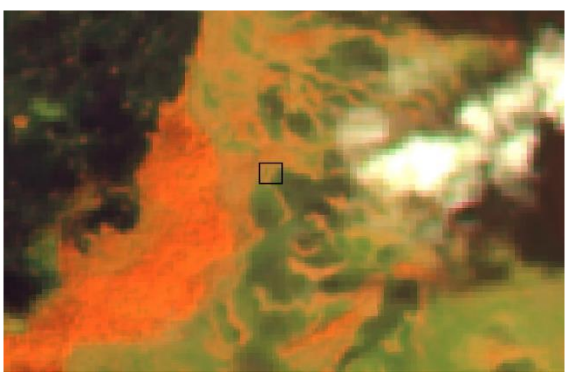
Definition: Dominated by graminoids (grasses and sedges) scattered with various shrub species.

Visualization/Interpretation

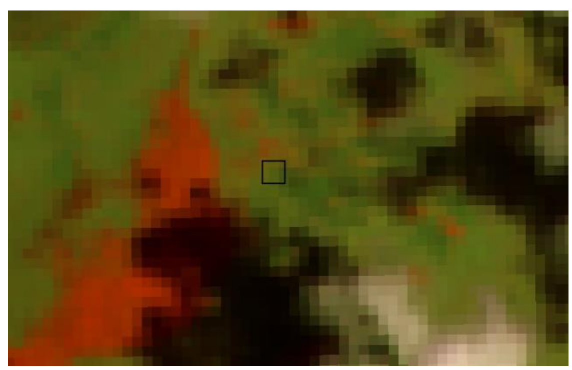
Vegetation picture

Google Earth Pro image

Sentinel 2 image



Landsat 8 image



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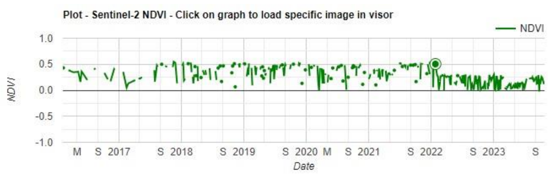
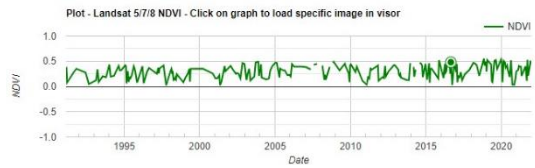


NDVI Landsat 5,7,8



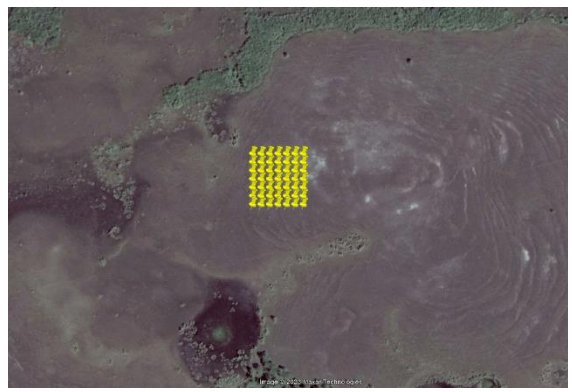
Level 3: *Open Savannah (GSAVOPEN):*

Definition: Large expanse of areas covered by graminoids (grasses and sedges) only.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image



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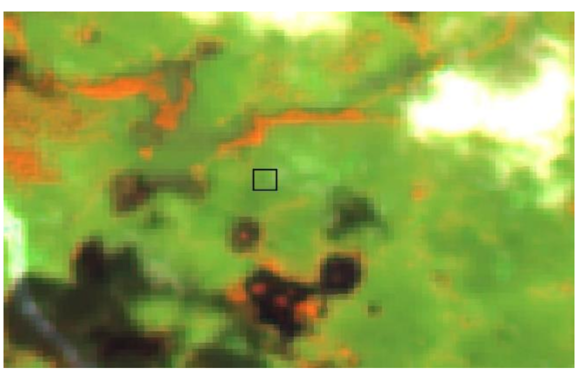
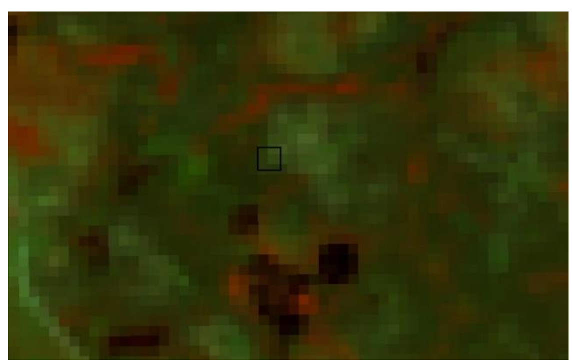


Landsat 8 image



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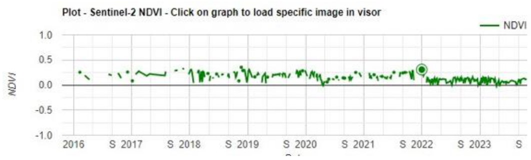
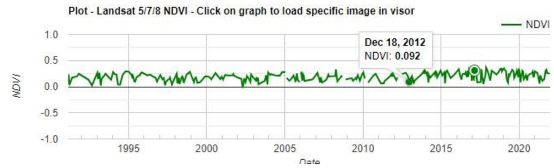


NDVI Landsat 5,7,8



Level 2: *Shrubland (GSHRUB)*

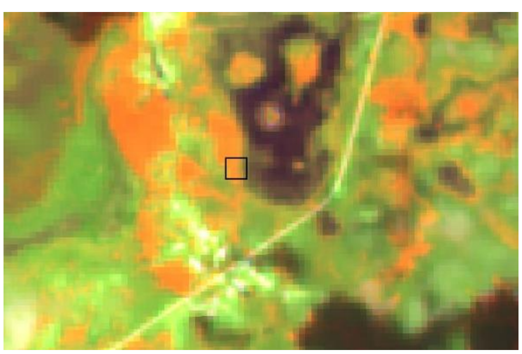
Definition: Includes areas of small trees, herbaceous species, and bushes with sparse and clumped trees. These thick and woody vegetation are less than 5 meters in height because of natural soil conditions, for example, savannah soil, low land areas, poor soils, and waterlogged soils.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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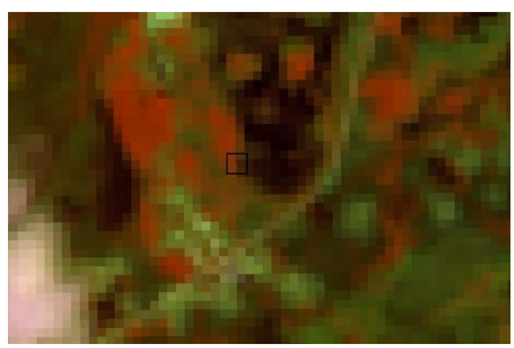

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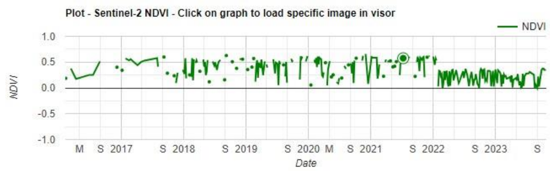


NDVI Landsat 5,7,8

Level 2: *Pasture (GPAST)*

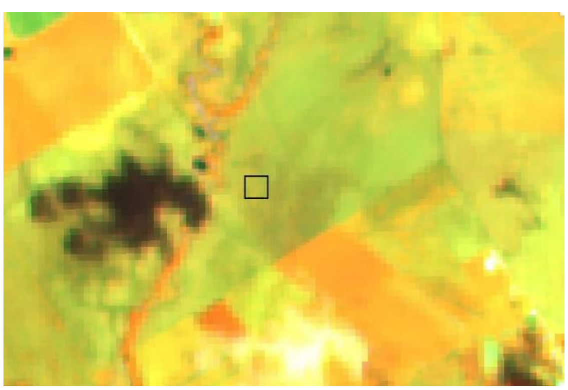
Definition: This includes areas covered with grass and small plants or scattered trees. This includes livestock grazing areas and backyards/lawns, especially backyards in farming communities (e.g. Mennonite communities). The defining characteristic of pasture is that area established by humans.

Visualization/Interpretation

Vegetation picture

Google Earth Pro image

Sentinel 2 image



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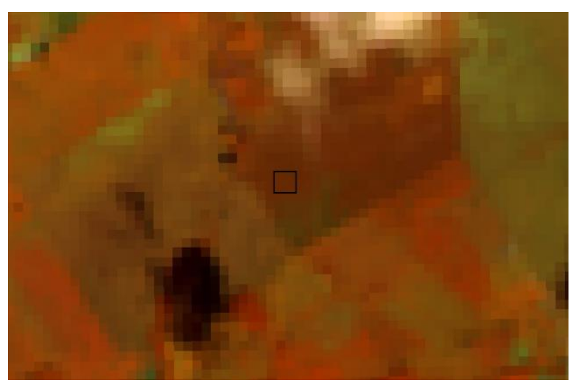
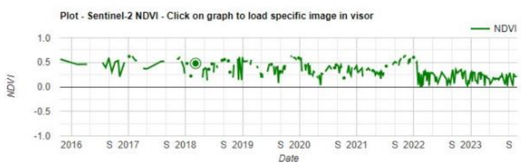
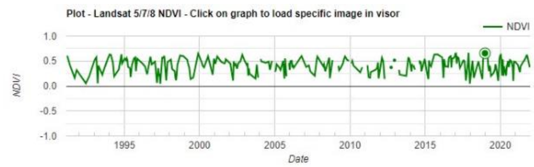


NDVI image Sentinel 2



NDVI Landsat 5,7,8



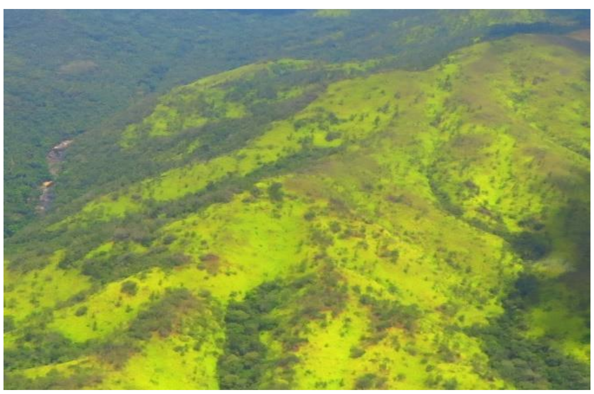
Level 2: *Ferns/Thickets (GFT)*

Definition:

Large patches covered by tiger ferns (bracken) and other fern species. These are generally found in areas of higher elevation. Ferns generally occur after a disturbance such as fire. In the Columbia Forest Reserve, ferns and thickets appeared after hurricane disturbance in forests.

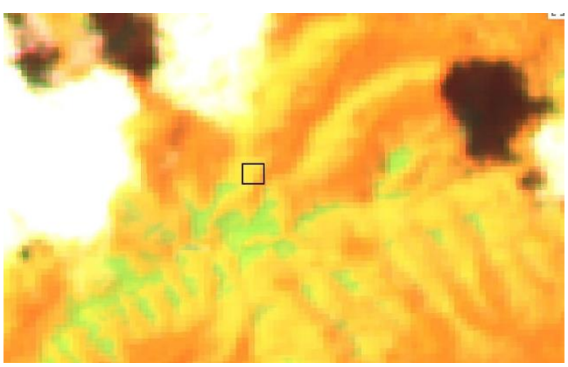
Visualization/Interpretation

Vegetation picture

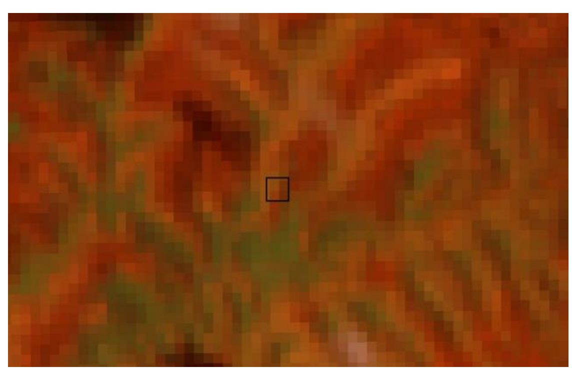


Google Earth Pro image

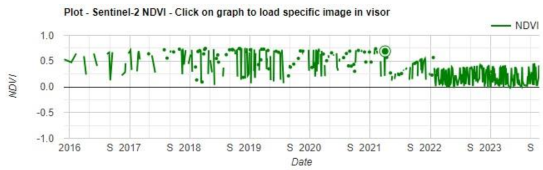
Sentinel 2 image



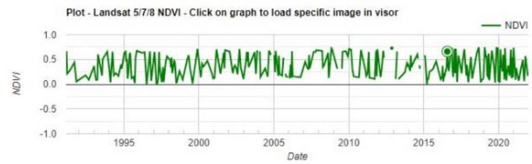
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 2: *Fallow Land (GABDP)*

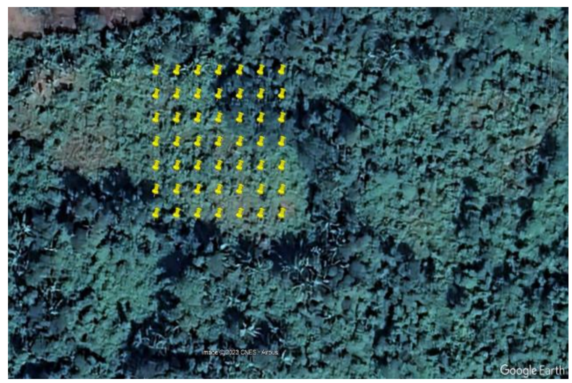
Definition:

Regeneration immediately after the abandonment of agricultural activity. In a grassland ecosystem.

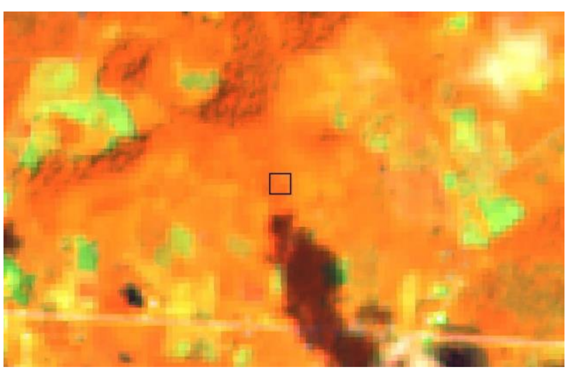
Visualization/Interpretation

Vegetation picture

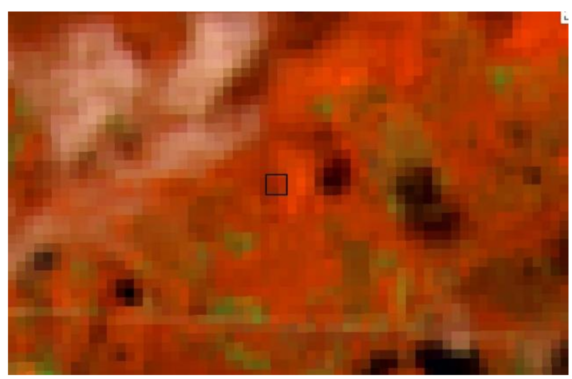
Google Earth Pro image



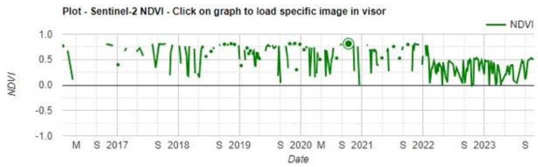
Sentinel 2 image



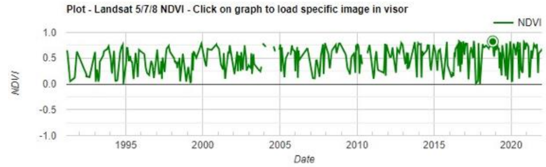
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 2: *Submontanenous Grassland (GSUBM)*

Definition:

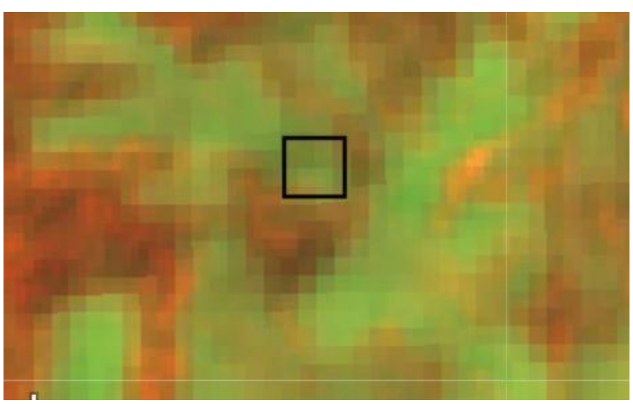
Large expanse of areas covered by graminoids (grasses and sedges) within high elevation environments, such as the Mountain Pine Forest Reserve.

Visualization/Interpretation

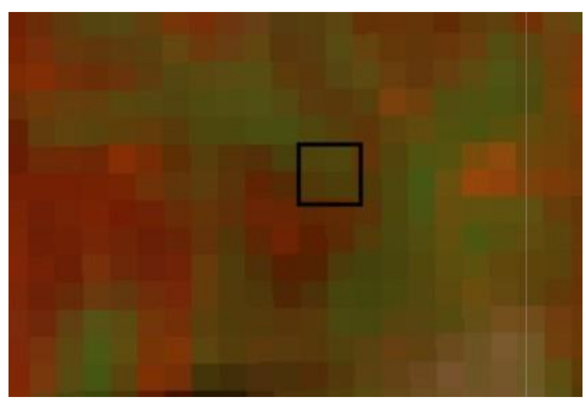
Vegetation picture

Google Earth Pro image

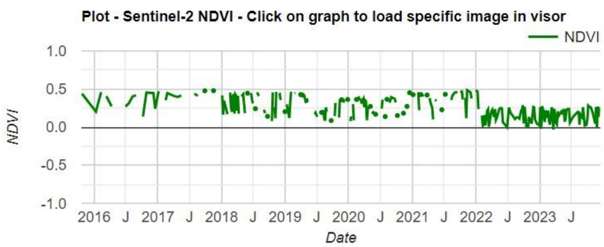
Sentinel 2 image



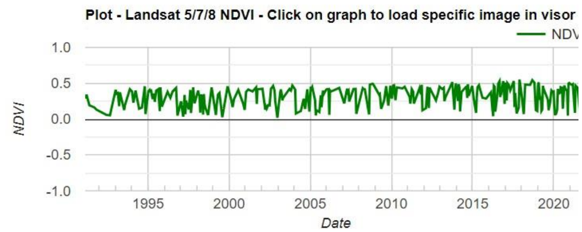
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



LEVEL 1: Wetland (W)

Level 2: *Wetland (WWET)*

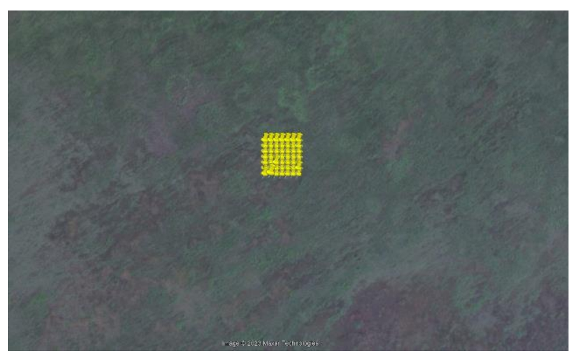
Definition:

Wetland is an area that is 0.5 hectare or more that has 20% permanent or seasonal floods, dominated by herbaceous/graminoid vegetation. Wetlands can have trees such as calabash (Cresentia cujete) or no trees.

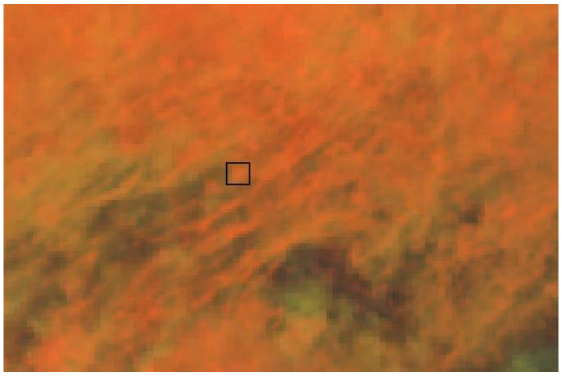
Visualization/Interpretation

Vegetation picture

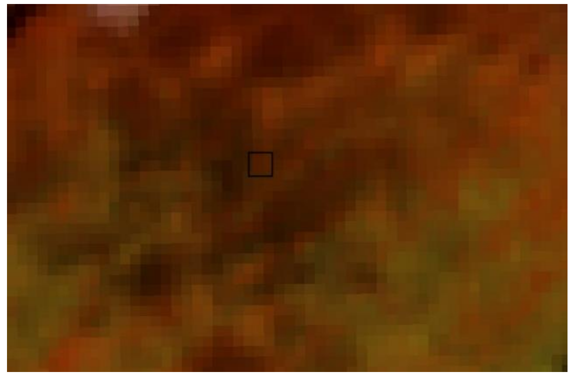
Google Earth Pro image



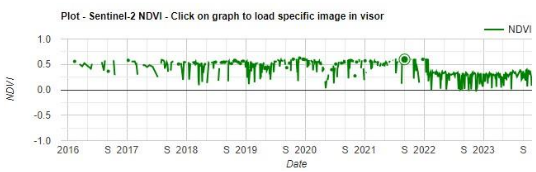
Sentinel 2 image



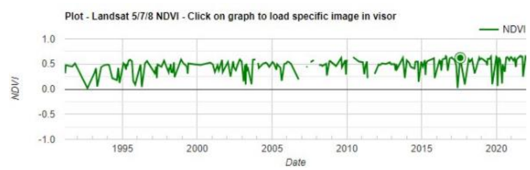
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



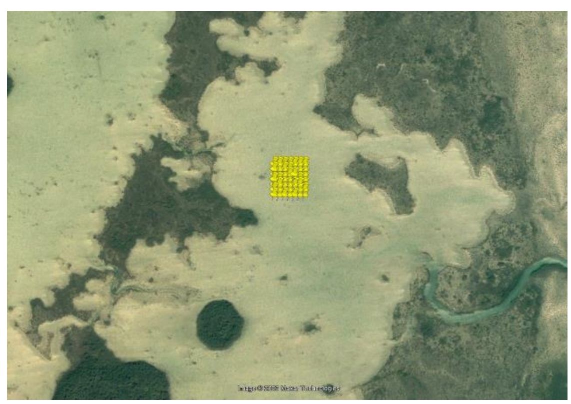
Level 2: Inland Water Bodies (WIWB)

Definition: Area that is 0.5 hectare or more that has 20% of rivers, streams, inland lagoons, lakes, cenotes, and reservoirs that may have aquatic vegetation.

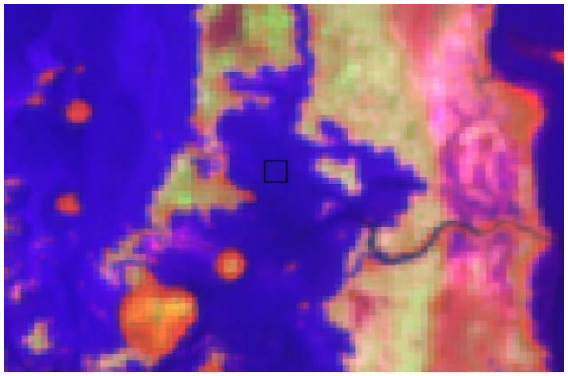
Visualization/Interpretation

Vegetation picture

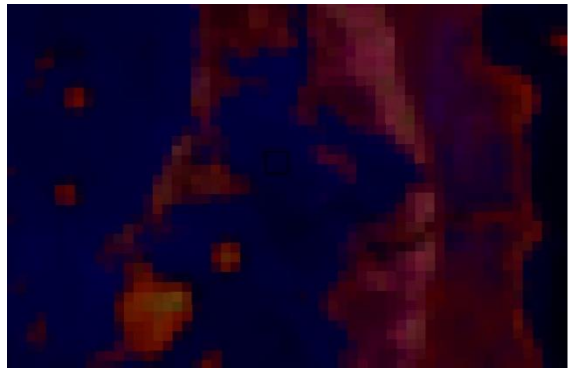
Google Earth Pro image



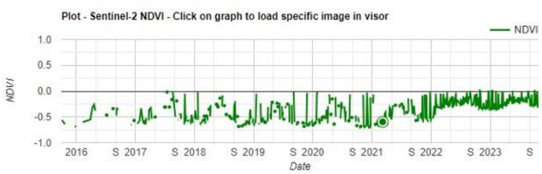
Sentinel 2 image



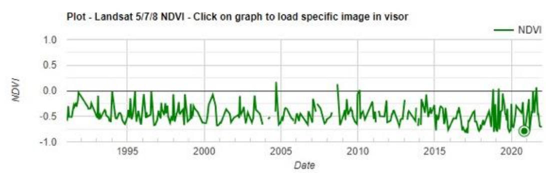
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



LEVEL 1: Settlement (S)

Settlement is an area that is 0.5 hectare or more that has 20% of urban construction that fall within the following subcategories:

Level 2: *City (SC)*

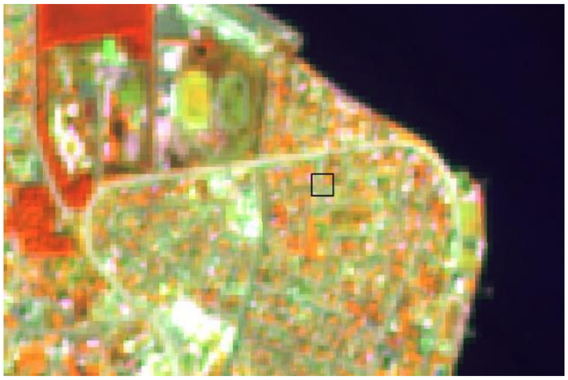
Definition: Plots that fall within either Belize City or Belmopan City.

Visualization/Interpretation

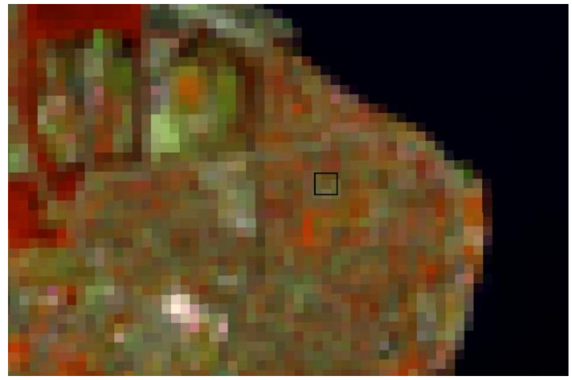
Vegetation picture

Google Earth Pro image

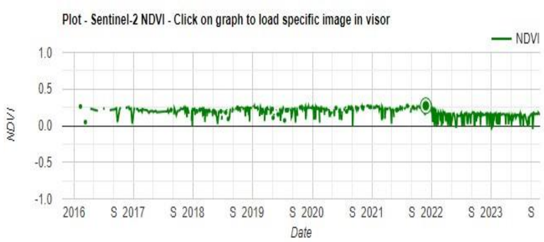
Sentinel 2 image



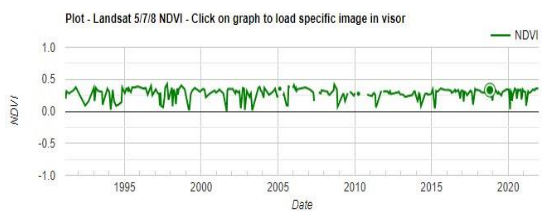
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 2: Town (STOWN)

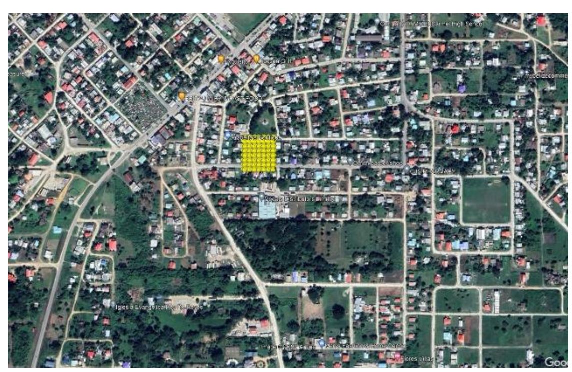
Definition:

Plots that fall within Corozal, Dangriga, Orange Walk, Punta Gorda, San Ignacio, Benque Viejo, San Pedro, or Santa Elena town.

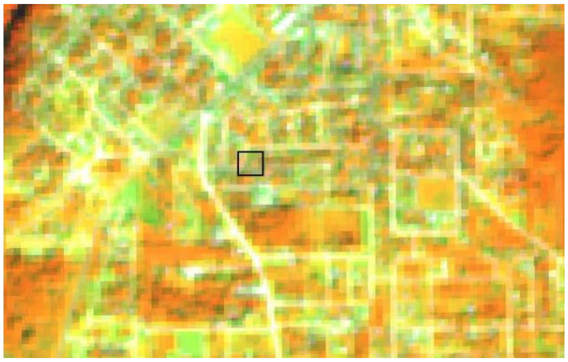
Visualization/Interpretation

Vegetation picture

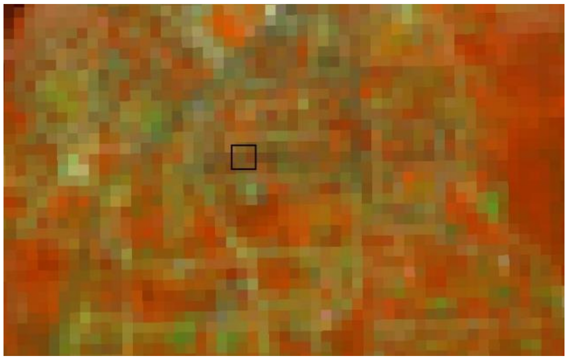
Google Earth Pro image



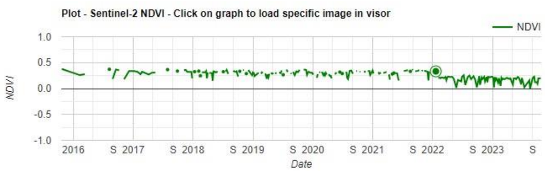
Sentinel 2 image



Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8

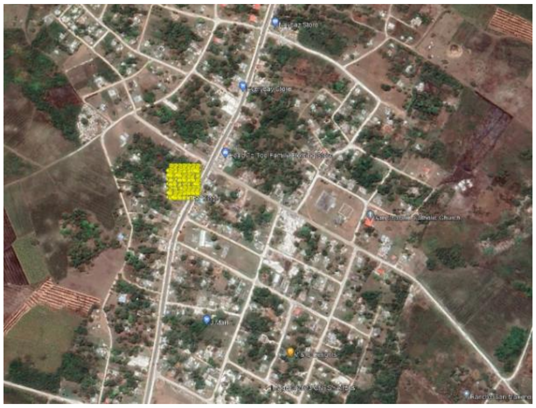
Level 2: Village (SV)

Definition: Settlement that is smaller than a town, having homes and related urban infrastructure.

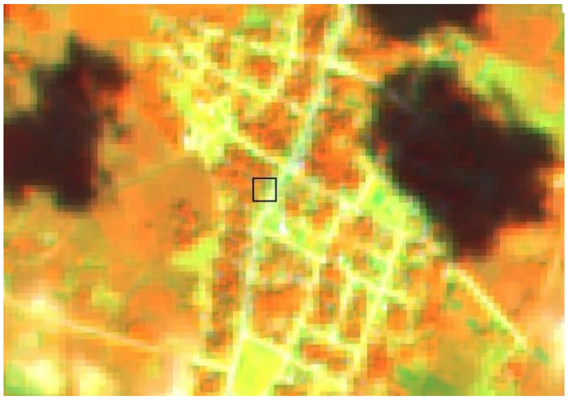
Visualization/Interpretation

Vegetation picture

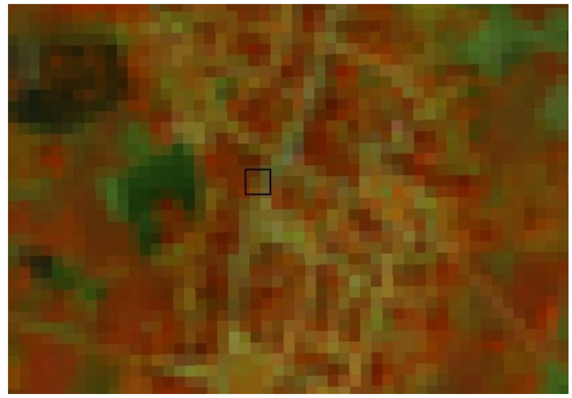
Google Earth Pro image



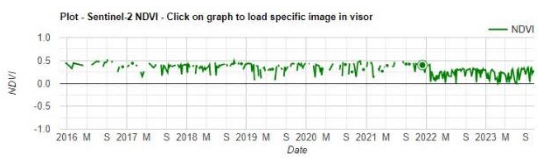
Sentinel 2 image



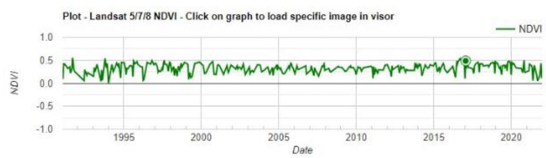
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 2: Road (SR)

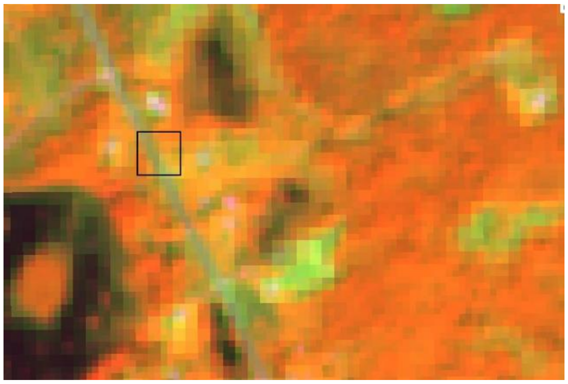
Definition: Paved or unpaved permanently transited roadways.

Visualization/Interpretation

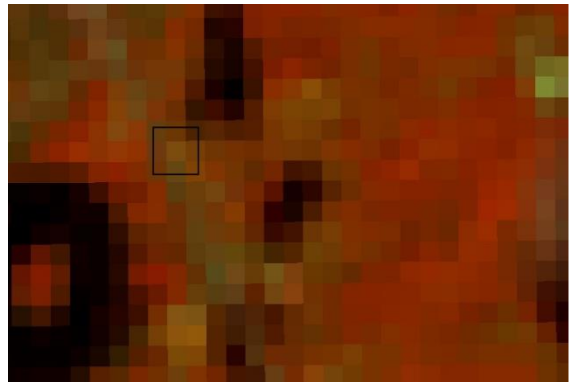
Vegetation picture

Google Earth Pro image

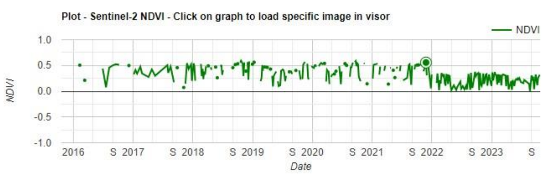
Sentinel 2 image



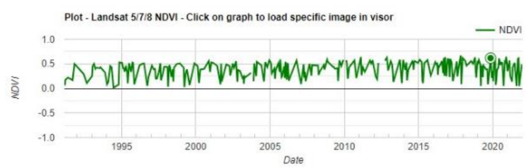
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8



Level 2: Mining (SM)

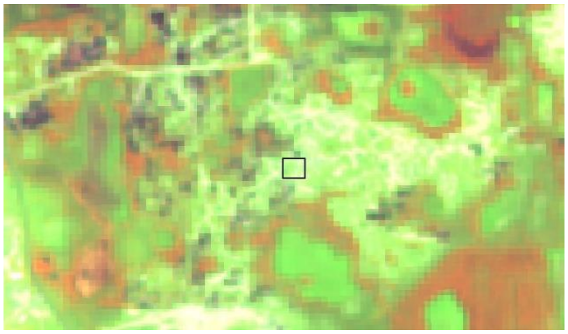
Definition: Areas generally quarried for construction material (white mall for road construction).

Visualization/Interpretation

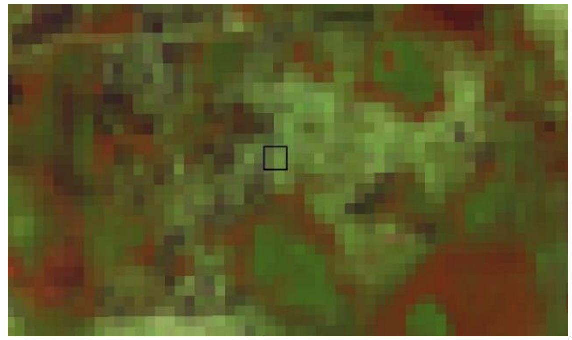
Vegetation picture

Google Earth Pro image

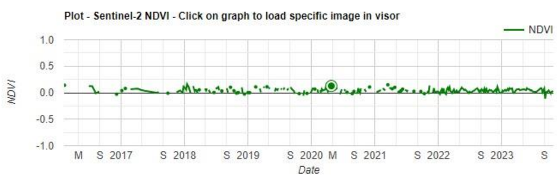
Sentinel 2 image



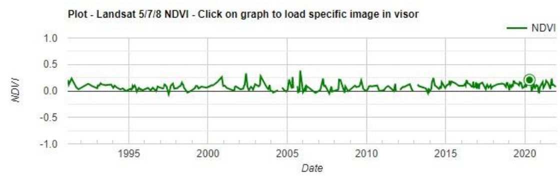
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8

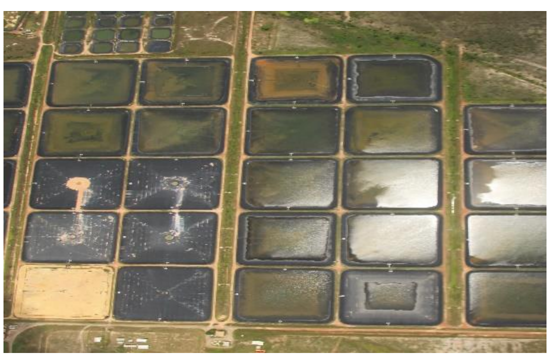


Level 2: Aquaculture (SAQC)

Definition: Areas that are generally shrimp farms/ponds.

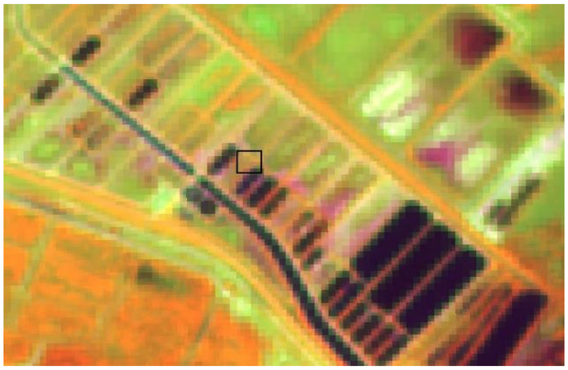
Visualization/Interpretation

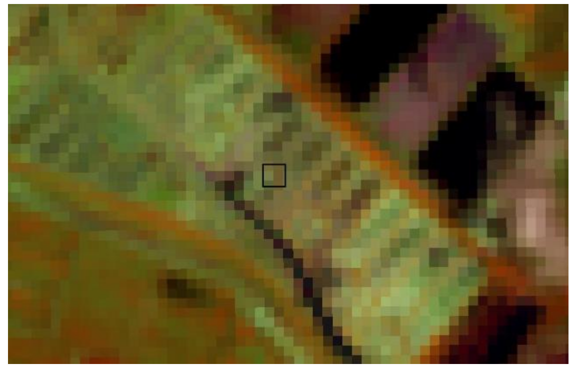
Vegetation picture



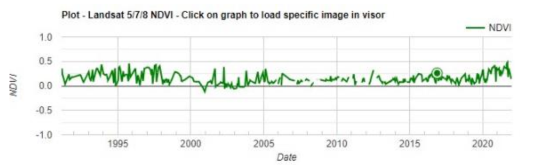
Google Earth Pro image

Sentinel 2 image | **Landsat 8 image**





NDVI image Sentinel 2 | **NDVI Landsat 5,7,8**



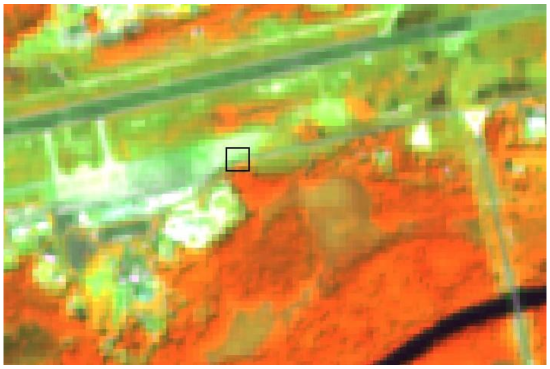
Level 2: Other Settlement (SO)

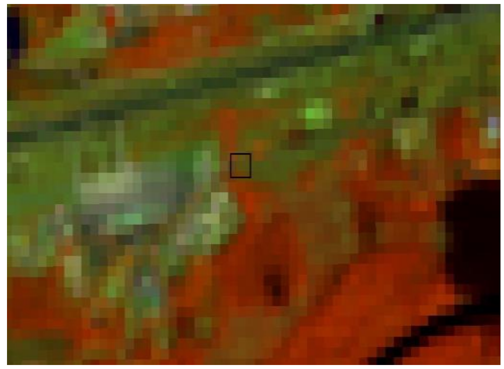
Definition: Urban constructions that do not fall within any of the above (e.g. telephone antennas, power lines etc.).

Visualization/Interpretation

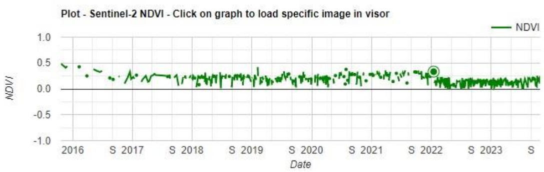
Vegetation picture | **Google Earth Pro image**

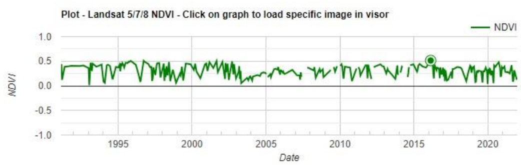
Sentinel 2 image **Landsat 8 image**





NDVI image Sentinel 2 **NDVI Landsat 5,7,8**





LEVEL 1: Other lands (O)

Other lands are areas that are 0.5 hectare or more that has 80% of soils that fall in the following subcategories:

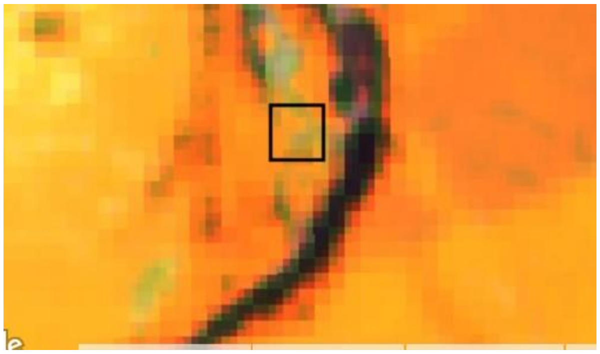
Level 2: *Bare Soil (OBARS)*

Definition: Area that has no vegetation, are not rocks and is not beach.

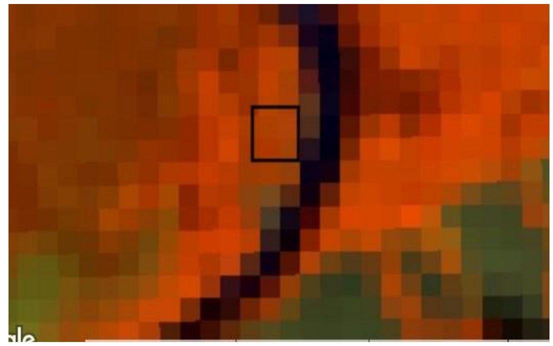
Visualization/Interpretation

Vegetation picture **Google Earth Pro image**

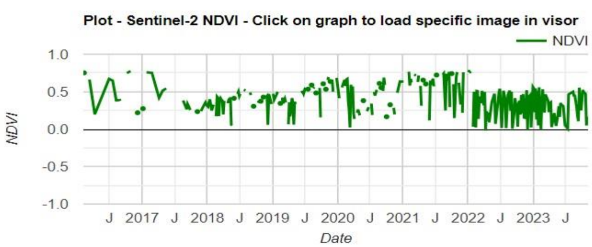
Sentinel 2 image



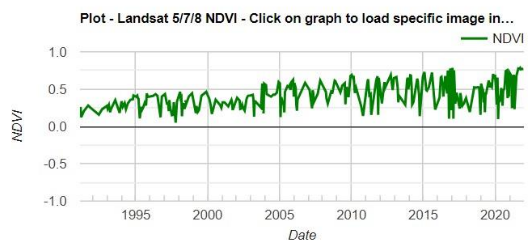
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8

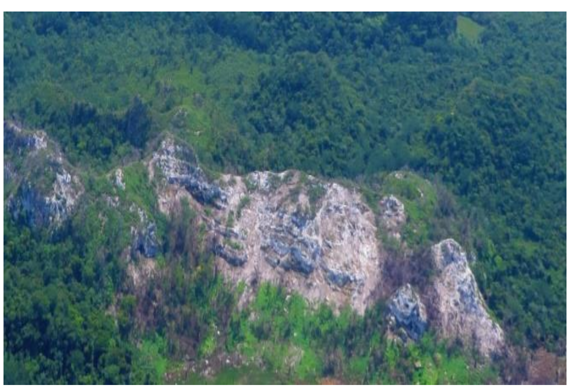


Level 2: Bare Soil Rocks (OROCK)

Definition: Area that is bare and are rocks.

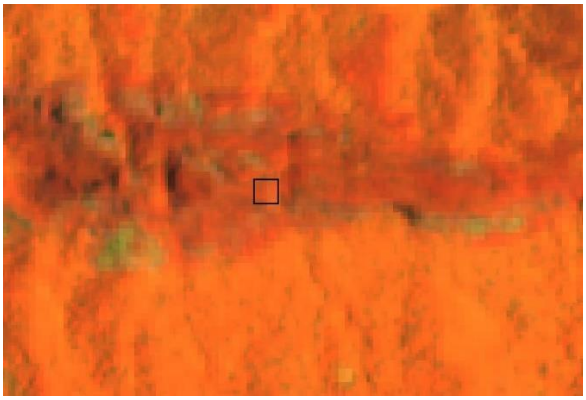
Visualization/Interpretation

Vegetation picture

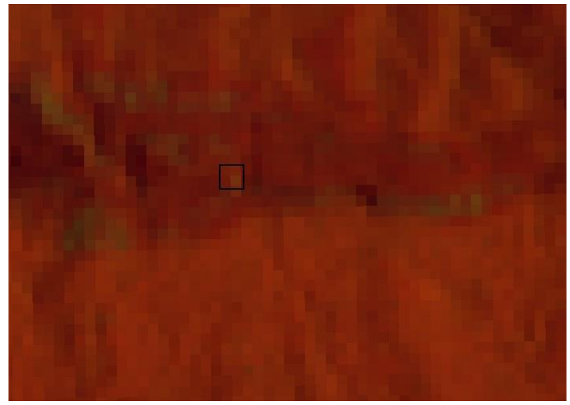


Google Earth Pro image

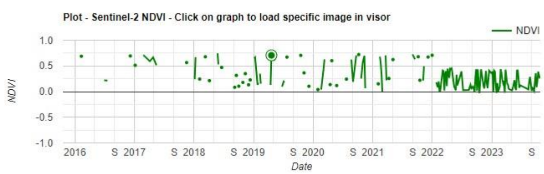
Sentinel 2 image



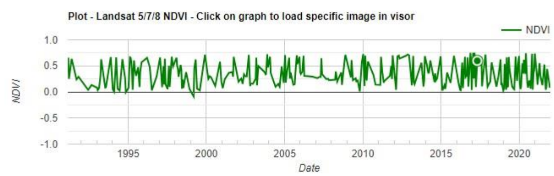
Landsat 8 image



NDVI image Sentinel 2



NDVI Landsat 5,7,8

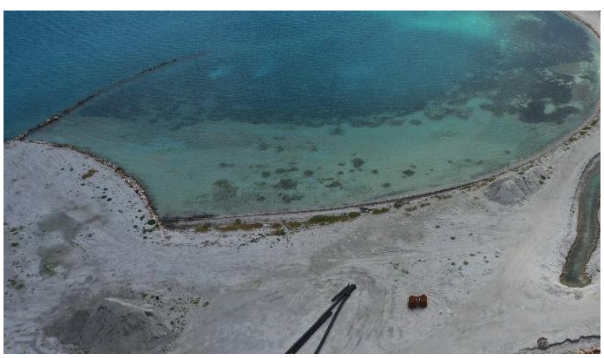


Level 2: BEACHES/ SAND DUNES (OBS)

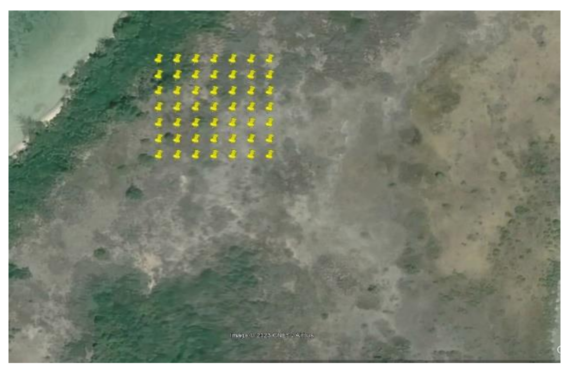
Definition: Area that falls on beaches having no vegetation.

Visualization/Interpretation

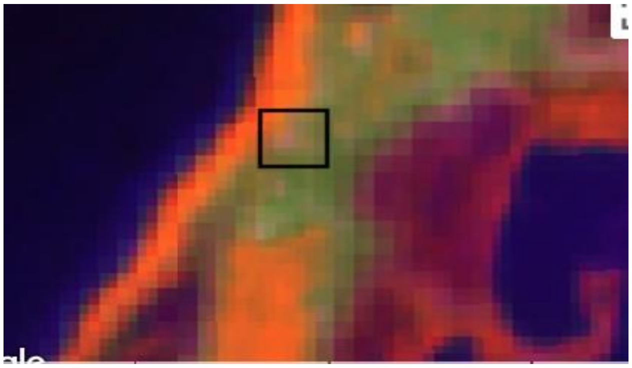
Vegetation picture



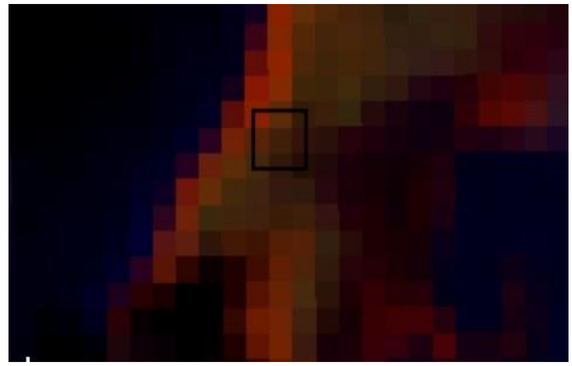
Google Earth Pro image



Sentinel 2 image

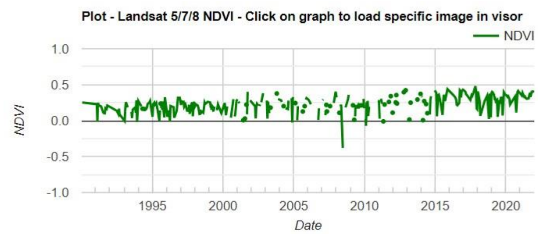


Landsat 8 image



NDVI image Sentinel 2

NDVI Landsat 5,7,8



4.5 Defining Factors for Land Use Determination

4.5.1 Possible and Impossible Land Use Matrix Transitions

In the pursuit of clearly defining and standardizing criteria to enhance interpretability and minimize ambiguity, collaborative discussions were held between our team and national experts. These discussions aimed to address the intricate changes and transitions that occur within various land use categories. Figure 6 has been devised to comprehensively illustrate the feasible and unfeasible transitions from one land use category to another, considering the distinct attributes of each ecosystem, agricultural practices, and other land uses, all within the context of the country.

Land Use and Land Use Change (LULUC) Matrix Vertical: Initial Use Horizontal: Final Use	Forest	Mature Broad-leaf Forest (Riparian, Swamp forest, Other)	Secondary Broad-leaf Forest (Riparian, Swamp forest, Other)	Pine Forest (Mature, Secondary)	Mangroves (Dwarf, Medium, Tall)	Forest Plantation (Teak, Other Plantations)	Croplands	Intensive Agriculture (Corn, Rice, Sugar Cane,	Swidden Farming	Croplands, Fallow land	Grasslands	Grasslands Savannahs (scattered trees, scattered	Shrubland	Pasture	Ferns/Thickets	Sub-mountainous grassland	Grassland, Fallow land	Wetland	Wetland (wetland, Inland Water b	Settlement	City, Town, Village	Other Settlement	Road	Mining	Aquaculture	Other infrastructure	Other Lands	Beaches/Sand dunes	Rocks	Bare Soil
Forest																														
Mature Broad-leaf Forest (Riparian, Swamp forest, Other)			X	X	X	X				X		X	X		X	X	X		X									X		
Secondary Broad-leaf Forest (Riparian, Swamp forest, Other)		X		X	X	X				X		X	X		X	X	X		X									X		
Pine Forest (Mature, Secondary)		X	X		X	X				X		X	X				X		X									X		
Mangroves (Dwarf, Medium, Tall)		X	X	X		X				X		X	X	X	X	X	X											X	X	
Forest Plantation (Teak, Other Plantations)		X	X	X	X					X		X	X		X	X	X		X									X		
Croplands																														
Intensive Agriculture (Corn, Rice, Sugar Cane, Banana,Citrus, Coconut, shifting Crops, Other crops		X	X	X	X							X	X		X	X	X		X									X	X	X
Swidden Farming		X	X	X	X							X	X		X	X	X		X									X	X	X
Croplands, Fallow land		X		X	X							X	X		X	X	X		X									X	X	X
Grasslands																														
Grasslands Savannahs (scattered trees, scattered shrubs, Open Savannah)		X	X	X	X					X			X		X	X	X		X									X	X	X
Shrubland		X	X	X	X			X		X		X			X	X	X		X									X	X	X
Pasture		X	X	X	X					X		X	X		X	X			X									X	X	X
Ferns/Thickets		X	X	X	X			X		X		X	X	X		X	X		X									X	X	X
Sub-mountainous grassland		X	X	X	X					X		X	X	X	X		X		X									X	X	X
Grassland, Fallow land		X		X						X			X		X	X			X									X	X	X
Wetland																														
Wetland (wetland, Inland Water bodies)		X	X	X		X		X	X	X		X	X	X	X	X	X				X	X	X	X				X	X	X
Settlement																														
City, Town, Village		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Other Settlement		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Road		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Mining		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Aquaculture		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Other infrastructure		X	X	X	X	X		X	X	X		X	X	X	X	X			X									X	X	X
Other Lands																														
Beaches/Sand dunes		X	X	X	X	X		X	X	X		X	X	X	X	X	X		X		X	X	X	X	X	X				
Rocks		X	X	X	X	X		X	X	X		X	X	X	X	X	X		X		X	X	X	X	X	X				
Bare Soil		X	X	X	X	X		X	X	X		X	X	X	X	X	X		X		X	X	X	X	X	X				

Figure 6: Showing Possible and impossible transition between different land use change that can occurred within the analysis. The box highlighted in red with the x were all impossible transitions and the blank boxes were possible transitions.

4.5.2 Disturbances

The main disturbances or effects on forests were established/prioritized, reflecting the influence of productive sectors as a priority. Once prioritized, operational definitions were established and a matrix of disturbance effects by land use category was evaluated and established, to facilitate their interpretation within the framework of unique criteria. Figure 7 shows the prioritized disturbances and their relationship to the possibility or impossibility of affecting the different categories of land use defined.

Land Use and Land Use Change (LULUC) Matrix Disturbance **Vertical: Initial Use** **Horizontal: Final Use**	Affected by Fire	Affected by by Grazing	Affected by by Hurricane	Affected by Logging	Affected by Other Human Impact/Infrastructure	Affected by Shifting Cultuvation	Affected by Pest	Affected by Mining
Forest								
Mature Broad-leaf Forest (Riparian, Swamp forest, Other)								
Secondary Broad-leaf Forest (Riparian, Swamp forest, Other)								
Pine Forest (Mature, Secondary)								
Mangroves (Dwarf, Medium, Tall)								
Forest Plantation (Teak, Other Plantations)								
Croplands								
Intensive Agriculture (Corn, Rice, Sugar Cane, Banana,Citrus, Coconut, shifting Crops, Other crops								
Swidden Farming								
Croplands, Fallow land								
Grasslands								
Grasslands Savannahs (scattered trees, scattered shrubs, Open Savannah)								
Shrubland								
Pasture								
Ferns/Thickets								
Sub-mountainous grassland								
Grassland, Fallow land								
Wetland								
Wetland (wetland, Inland Water bodies)								
Settlement								
City, Town, Village								
Other Settlement								
Road								
Mining								
Aquaculture								
Other infrastructure								
Other Lands								
Beaches/Sand dunes								
Rocks								
Bare Soil								

Figure 7: Presenting the Disturbances Matrix Based on Land Use as Documented in the Assessment. Red-highlighted cells signify land uses without recorded disturbances, while white cells indicate land uses with disturbances documented as part of the AD collection.

4.5.3 Hierarchy for land use classification

Another crucial discussion was the national definition of forest. The experts were cognizant that the sample plot to be visually assessed in the LUA app is 0.5 hectare; focused on land-use changes and disturbances for forests and grasslands. Canopy cover percentage, thus, was fundamental to determining its land use. This led to the establishment of a hierarchy for the land use categories (Table 5) for visual interpretation during the Land Use Assessment.

Table 5: Hierarchy of land use classification for Belize for the visual interpretation in the Land Use Assessment.

Categories	% Minimum
Forest	> 30
Cropland	> 20
Grassland	> 20
Wetland	> 20
Settlements	> 20
Other Lands	> 80

According to the ‘hierarchy of land use classification (figure 8), if a sample plot in the LUA app has 30% or more forest canopy, its land use will be classified “s "for”st". If a sample plot has 70% or more of a non-forest IPCC category, a determination is made to classify the sample plot according to the hierarchy. For example, if a plot only has 10 % forest, 20 % grassland, 20 % of cropland, and 50 % of other lands, according to the hierarchy, the classification is cropland.

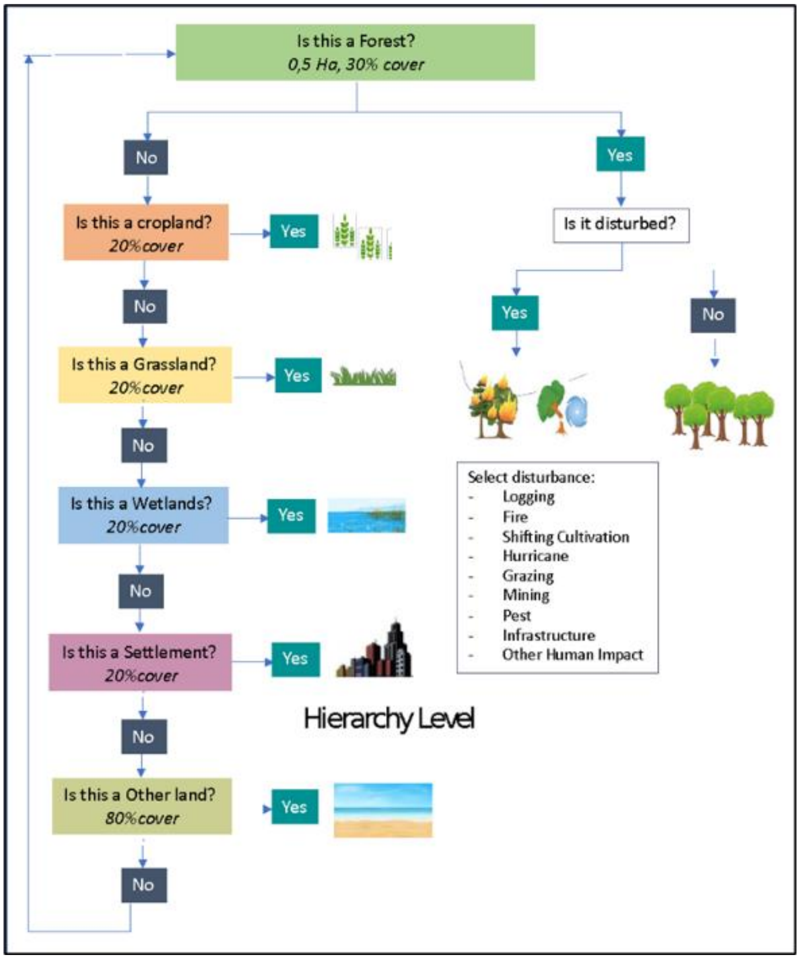


Figure 8: Decision Flowchart Illustrating Hierarchical Decision-Making in the Land Use Assessment

4. 5.4 Survey design

The LUA app enables countries to evaluate land use and land use changes within a portion of their national territory and then extend these findings to the entire country. Utilizing free access to Google Earth Pro and Google Earth Engine images, the app leverages high-resolution imagery, aiding in comprehending the evolution of land use over time. It also integrates interpretations like degradation and disturbances to provide a comprehensive understanding of land use dynamics. Below are examples of the survey application platform Figure 9.

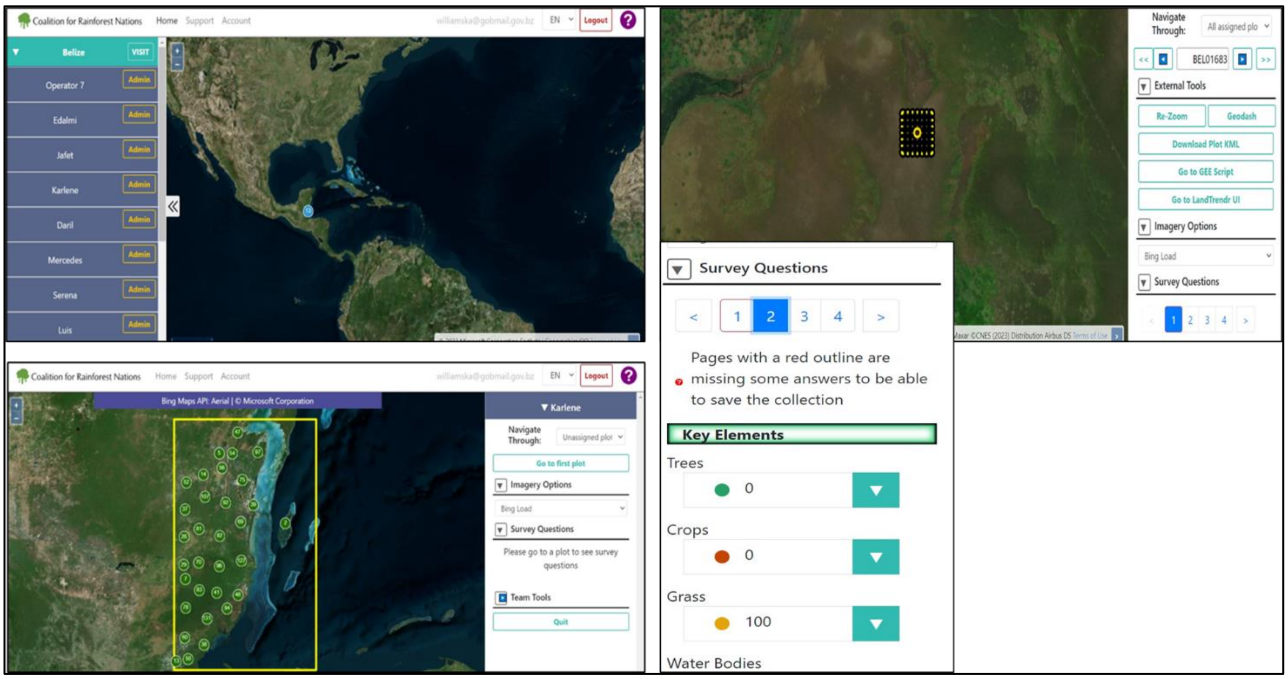


Figure 9: Showing the different pages within the LUA app.

4.5.5 Data Collection Process & Training

Prior to commencing the land use assessment, a comprehensive two-day training session was conducted for the selected operators. This session aimed to elevate their proficiency in GIS knowledge and satellite image interpretation. The training was meticulously structured, focusing on empowering operators with a deep understanding of the LUA app. It revolved around three pivotal elements: facilitating data input, developing forms within the LUA app, and proficiently analysing data collected through this platform.

Following the theoretical training, operators engaged in an immersive three-day hands-on experience with the LUA application. This segment emphasized procedural intricacies and provided practical training in visual interpretation through the LUA app. Prior to this practical session, all operators ensured the installation of essential software, including the LUA app, Google Earth Engine, Google Earth Pro, and Mozilla Firefox, on their laptops. Access to the LUA app was granted through their respective email accounts, enabling operators to familiarize themselves with its launch and the systematic recording of data within the application.

As part of their initiation, new operators were tasked with completing 50 plots. Collaboratively, LUA operators assessed these sample plots, utilizing a comprehensive visual guide aligned with IPCC category definitions. This guide offered explicit instructions on how to assess and classify the sample plots accurately. Furthermore, the Landtrendr UI served as a valuable resource, guiding operators in documenting any changes observed across the various plots under assessment.

Operators were provided with a comprehensive view of sample plots using various platforms, including Google Earth, Bing Maps, Plant NICFI, and Google Earth Engine. This exposure allowed them to examine both high-resolution images and satellite imagery, offering insights into the land use history of each plot. Notably, reliance on Google Earth images for visual interpretation was limited due to inconsistent updates and infrequent time series. The introduction of the Google Earth Engine interface proved invaluable, providing access to NASA Landsat 7 and 8 images and ESA Sentinel 2, boasting resolutions of 30 meters and 10 meters, respectively. Through the Google Earth Engine, operators could analyse Sentinel 2 imagery with a 10m resolution for the years 2015-2023, available at intervals as short as 16 days in some instances.

After undergoing an extensive two-day training workshop, supplemented by an additional three days of practical experience with the LUA app, the operators were methodically assigned the sample plots. With the successful culmination of the preparatory phase, the Land Use Assessment officially commenced. The training and practice sessions meticulously equipped the operators with the necessary skills to proficiently navigate the LUA app, establishing a solid groundwork for a streamlined and efficient assessment process. This phase, known as Phase 1 or the preparation phase, marked an integral step in the Activity Data Collection Process. Significantly, 50% of the operators served as leads during the current year of AD collection, indicating that half of the team comprised experienced individuals who were part of the initial AD collection in 2018. This valuable experience contributed to ensuring transparency and consistency throughout this phase of the process.

4.5.6 Distribution of Sampling Area

The 21,991 sample plots were randomly distributed among twelve (12) operators (table 6), after a systematic calculation each operator was assigned a total of 1,833 plots. This random distribution allowed the operator to gain an understanding and knowledge of the natural and anthropogenic dynamic within the six IPCC main land use categories.

Table 6: Random Distribution of plots to the operator

Operators	Plots Assigned (Random Distribution)
Edalmi	1,833
Jafet	1,833
Karlene	1,833
Daril	1,833
Mercedes	1,833
Serena	1,833
Luis	1,833
Hector	1,833
Jorge	1,833
Jahied	1,833
Koren	1,833
Melvin	1,833

4.6 Disturbance in forests and grasslands in Belize

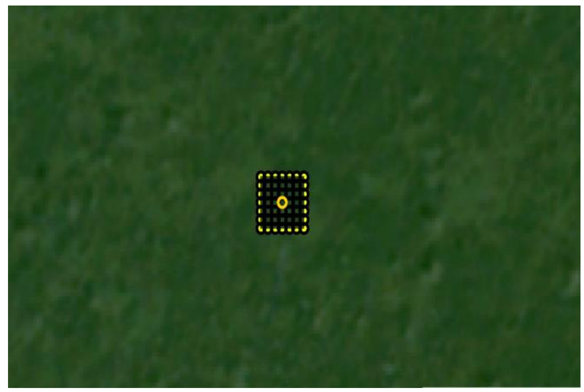
During the plot classification process, the disturbances were observed. The Land Use Application included a MODIS data graph to visualize the presence of fires within and around the plot throughout the years. The Google Earth KML layer (figure 14 below) contained hurricane paths, allowing the observation of plot damages through high-resolution images across different time frames. Furthermore, changes in the canopy were noted within high-resolution imagery. Logging disturbances were noted in the area due to the best expert knowledge of logging roads and barquediers. Pest-related disturbances within Mountain Pine Ridge were also recognized based on expert insight. Infrastructure and mining disturbances could also 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 were along the roadside, buffer zones of Protected Areas, Electrical Boundary Lines, constant maintenance of the property and around urban and rural areas. Below are some examples of disturbances. Overall, disturbances were noted as high and low according to the plot damage.

4.6.1 Hurricane Disturbance

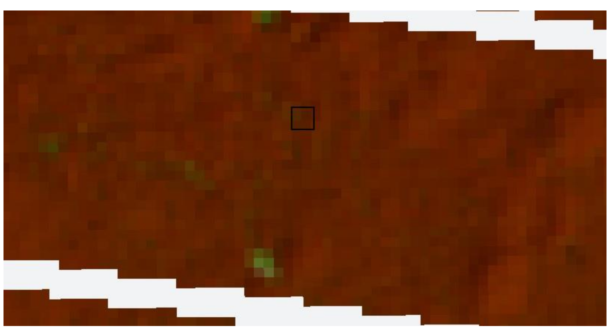
Hurricane disturbances are classified as natural disturbance. Hurricane paths were available as a KML layer in Google Earth and damages of plots could be seen with the high-resolution image over the time frame.

Vegetation picture

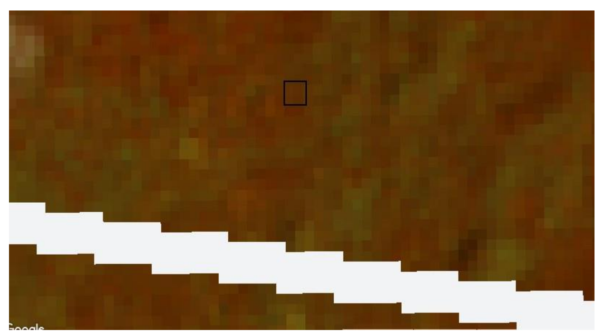
Planet Imagery 2016-2017



Landsat Image Before



Landsat Image After



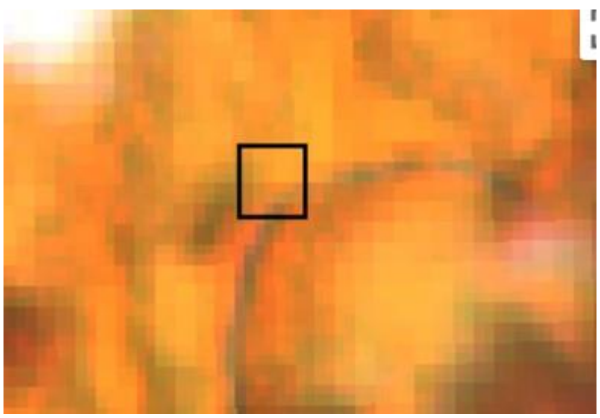
4.6.2 Pest Disturbance

Pest disturbance refers to insects that affect the tree species within its natural ecosystem. Example South Bark Beetle affecting the Pine Forest. Pest disturbance was noted from the area within the Mountain Pine Ridge as seen below from the best expert knowledge.

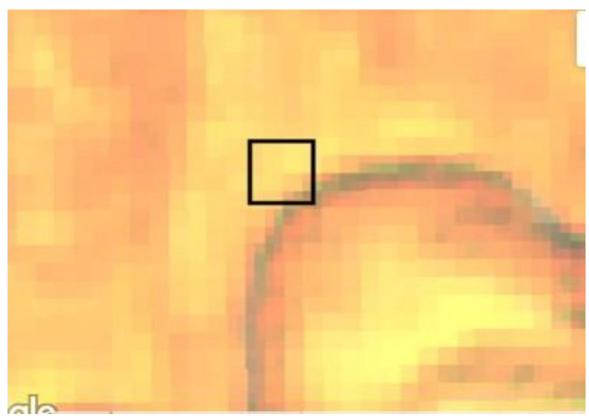
Vegetation picture

Google Imagery 2022

Landsat Image Before



Landsat Image After



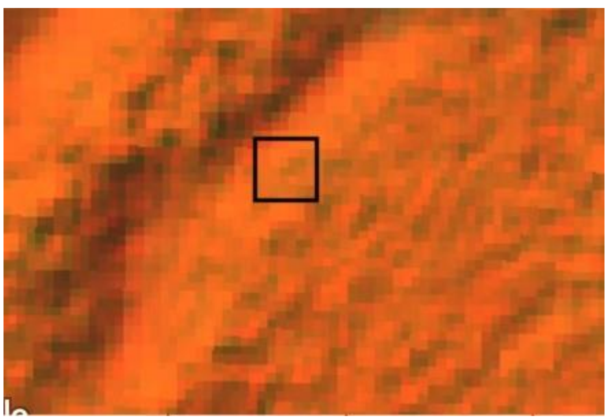
4.6.3 Fire Disturbance

Fire disturbance refers to wildfire affecting forest cover of the Forest. Fire disturbances were noted in Forest plots and also noted in grassland using images from MODIS satellite imageries.

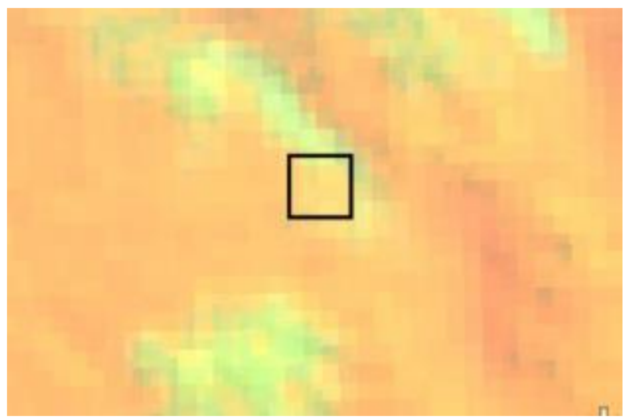
Vegetation picture

Planet Imagery 2023

Landsat Image Before



Landsat Image After



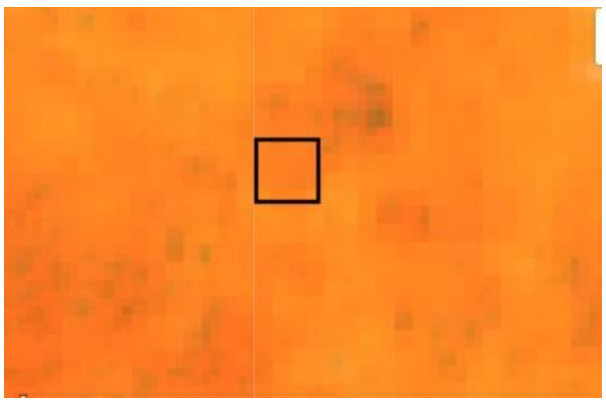
4.6.4 Logging disturbance

Logging disturbance is referring to both legal and illegal unsustainable logging.

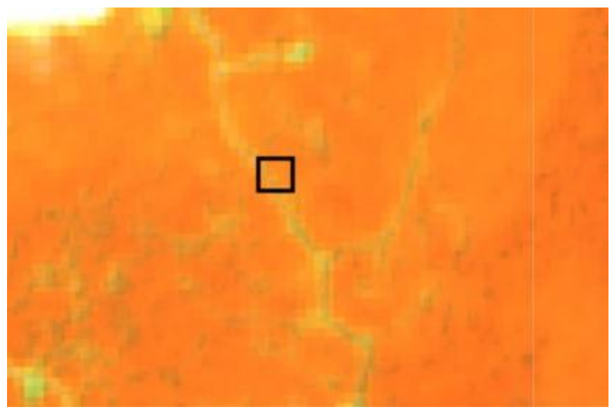
Vegetation picture

Planet Imagery 2019

Landsat Image Before



Landsat Image After



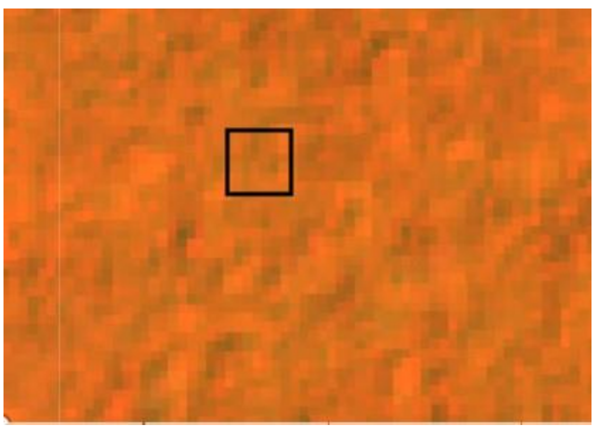
4.6.5 Grazing disturbance

Grazing disturbance refers to livestock affecting a Forest plot over time, where pasture is expanding into the Forest or a mixed plot.

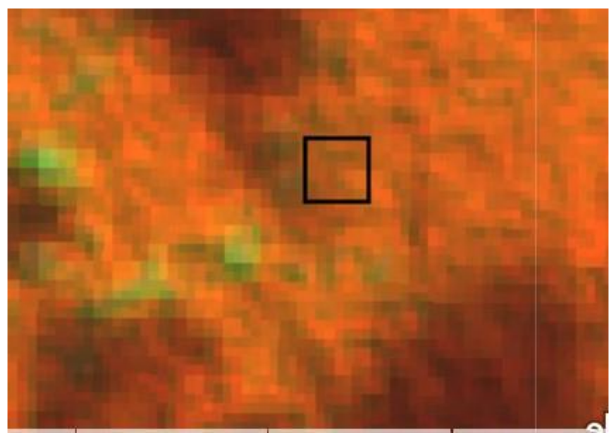
Vegetation picture

Google Earth Imagery

Landsat Image Before



Landsat Image After



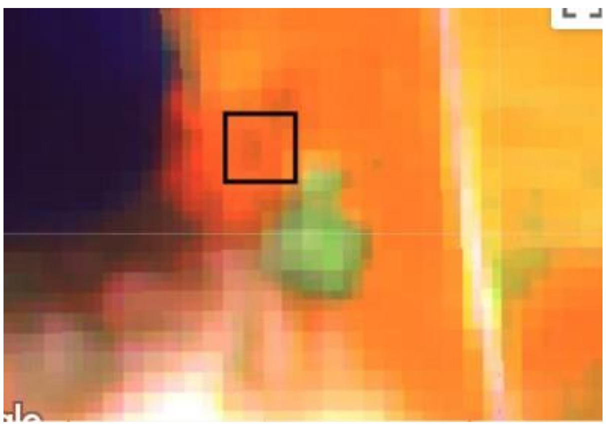
4.6.6 Shifting Cultivation Disturbance

Shifting cultivation disturbance refers to cropland being expanded into a Forest Plot over time or a mixed plot.

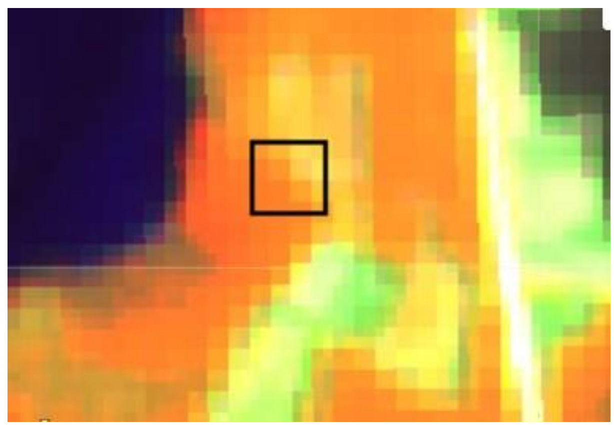
Vegetation picture

Planets 2020 Imagery

Landsat Image Before



Landsat Image After

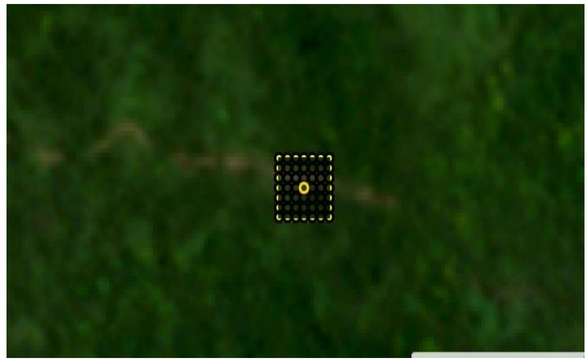


4.6.7 Infrastructure Disturbance

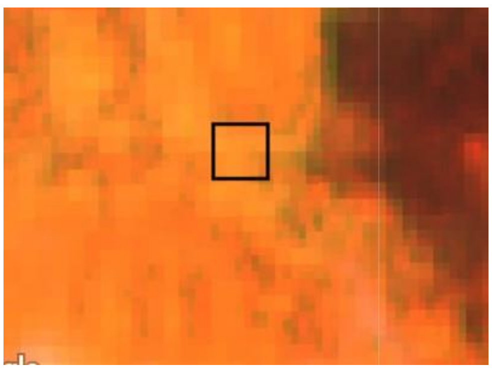
Infrastructure disturbance refers to permanent build-ups such as roads, buildings, or bridges that would affect the Forest cover.

Vegetation picture

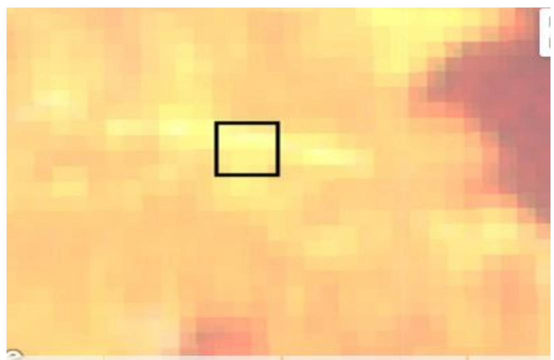
Planet 2023 Imagery



Landsat Image Before



Landsat Image After



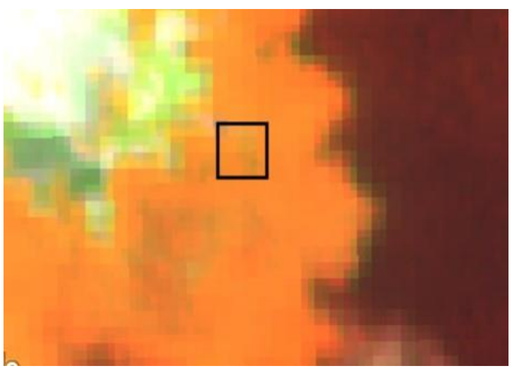
4.6.8 Mining Disturbance

Mining disturbance is referring to the extraction of any minerals within a Forest Plot that affect the Forest Cover.

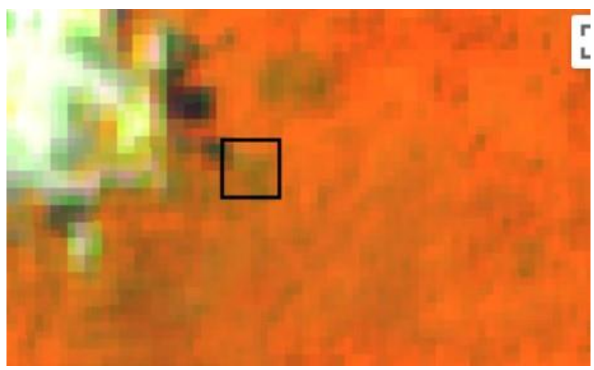
Vegetation picture

Planet 2023 Imagery

Landsat Image Before



Landsat Image After



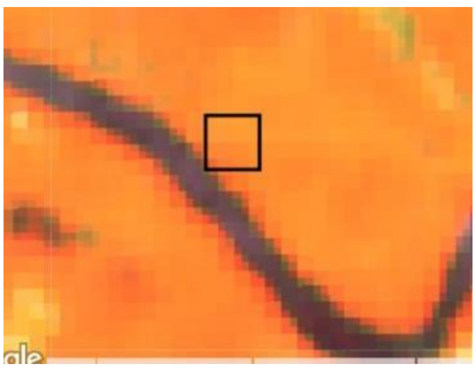
4.6.9 Other Human Impact Disturbances

Other human impact disturbances are those that keeps occurring within a Forest Plot and does not allow an area to grow back into its natural state.

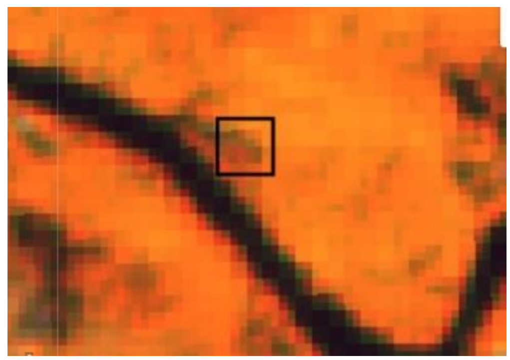
Vegetation picture

Planet 2023 Imagery

Landsat Image Before



Landsat Image After



4.7 Plot analysis with support images

The following images indicate the steps for assessing land use with LUA app and its supporting software (figure 10):

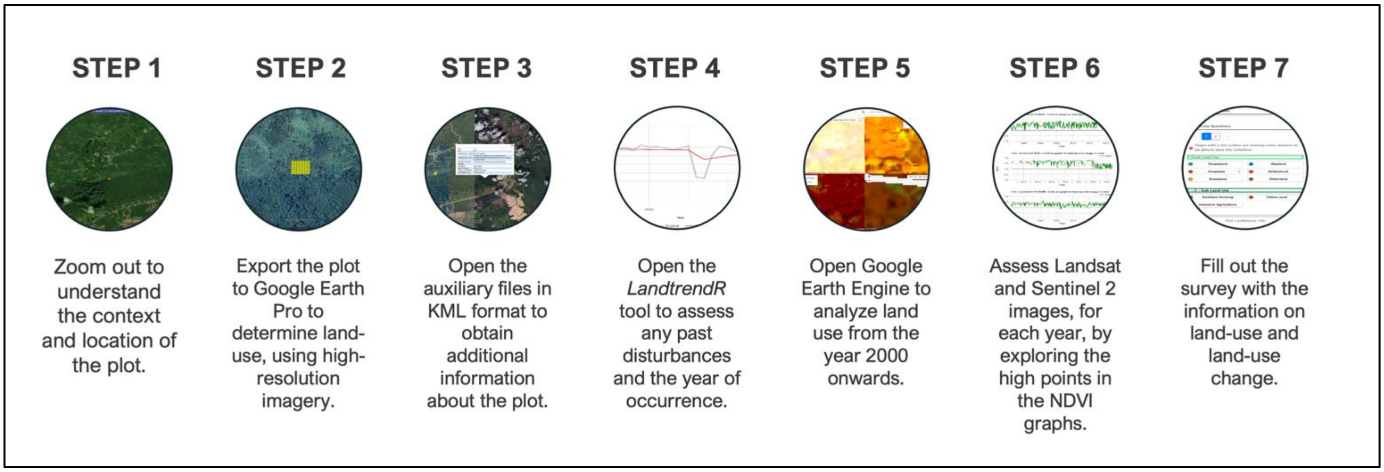


Figure 10 : Showing the steps for assessment of land use using the LUA app.

Step 1:

Microsoft's Bing Maps (figure 11) presents imagery provided by Digital Globe ranging from 3m to 30cm resolution. Collect Earth plot locations have been linked with Bing Maps because the latter web mapping service has slightly different geographic coverage.

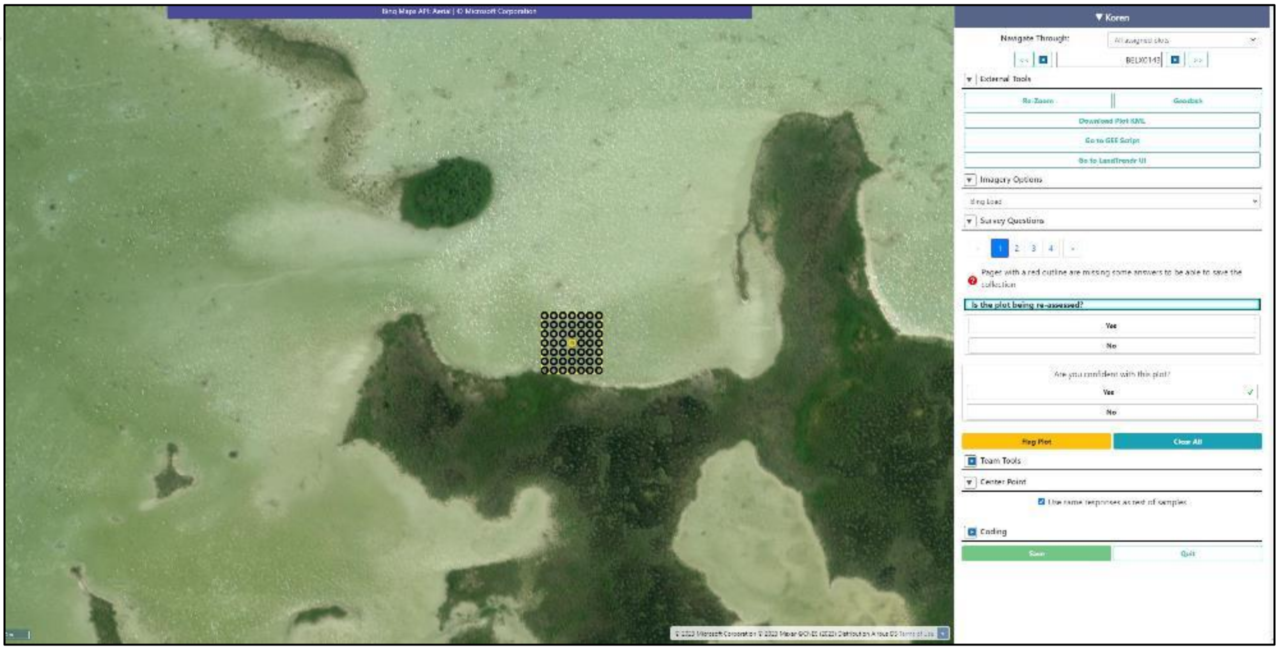


Figure 11: Displaying High-Resolution Bing Map Imagery Available for Assessment via the LUA App.

Step 2:

Through Google Earth Pro (Figure 12), country experts can explore and visualize geographic data in 3D. Country experts can navigate and fly over detailed satellite imagery, terrain models, and 3D buildings. This feature is particularly useful for visualizing landscapes, urban environments, and natural features, providing a realistic and immersive view of the Earth's surface.

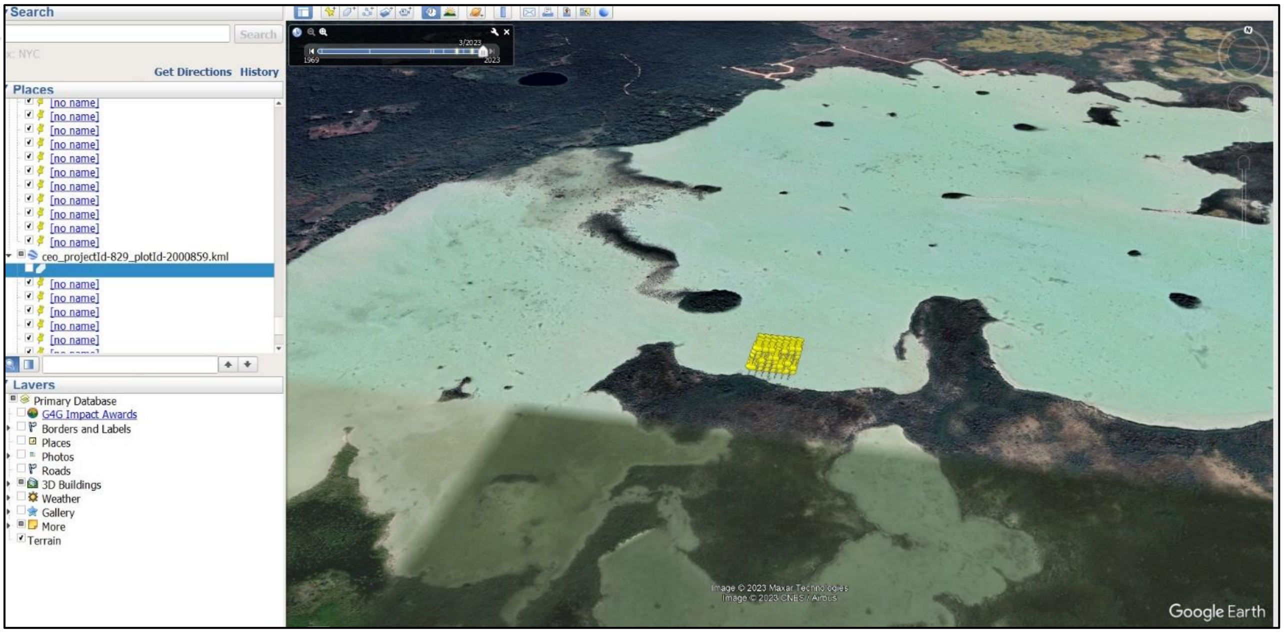


Figure 12: Visualizing Various Years'Ye’rs' Imagery Using Google Earth Pro within the LUA App Interface

In addition, the time slider (Figure 13) allows country experts to navigate through different periods and view the available historical imagery for a specific location. It is a horizontal bar that can be dragged left or right to adjust the time. The leftmost position on the slider represents the oldest imagery, while the rightmost position represents the most recent. The availability of historical imagery depends on the location and the extent of imagery coverage. Some areas may have a long history of imagery dating back several decades, while others may have limited or no historical imagery. When the country experts adjust the time slider or play the time animation, Google Earth Pro will load and display the corresponding historical imagery for the selected time period. The country experts can observe changes in landscapes, urban development, vegetation, and other features over time. The historical imagery in Google Earth Pro is sourced from various providers, including satellite imagery, aerial photographs, and other data sources. The availability and resolution of historical imagery may vary depending on the location and the contributing data source.

Figure 13: Showing Time Slider of available Historically Imagery on Google Earth Pro.

Step 3:

Google Earth Pro also supports the import and integration of external data (Figure 14), such as GPS tracks, spreadsheet data, and GIS files. Users can overlay their data onto satellite imagery or terrain models, enabling them to analyse and visualize geospatial datasets in conjunction with the Earth'sEa’th's surface. To be able to use shapefiles as auxiliary data, the country experts should transform these shapefiles into Keyhole Markup Language (KML), which is an Extensible Markup Language (XML) notation for expressing geographic annotation and visualization within two-dimensional maps and three-dimensional Earth browsers. This is done in QGIS or ArcGIS by loading the shapefile of interest and adding a vectorial layer and then exporting it as KML. Then, this KML file is loaded in Google Earth Pro. When collecting the information of the plot, the auxiliary data added can be displayed and used as a reference. The KML files that the country used are shapefiles of Protected areas, hurricane paths (Figure 14), registered fires, areas of sustainable forest management, ecosystem and mangrove types.

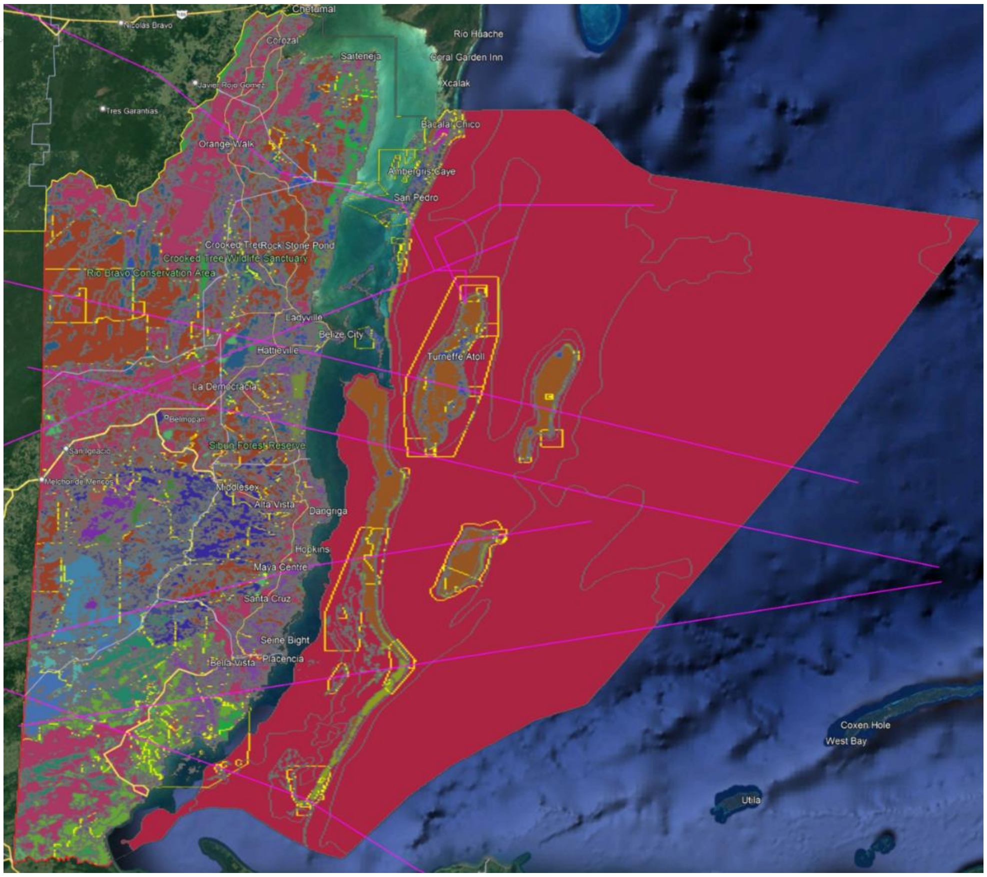


Figure 14: Axillary data layers used throughout the land use assessment displayed within the Google Earth Software.

Step 4:

To detect significant land cover changes over time, Landtrendr was designed to analyze time-series satellite imagery (Figure 15). The primary purpose of Landtrendr (Figure x) is to identify and monitor land cover disturbances, such as deforestation, urbanization, and natural disasters. At its core, Landtrendr utilizes the concept of spectral trajectories to identify and quantify land cover disturbances. A spectral trajectory is the path traced by the spectral values of a pixel across multiple time points. By examining the changes in these trajectories, Landtrendr can detect and characterize significant land cover alterations. Once the breakpoints are identified, Landtrendr generates an output that visualizes the detected disturbances and provides information on the location, timing, and magnitude of the changes. The Landtrendr algorithm works by processing a stack of satellite images captured over a specific time. These images are usually acquired from sensors like Landsat, which provide multi-spectral data. Landtrendr alyseszes pixel values from these images and applies a series of mathematical and statistical techniques to detect temporal trends and changes in land cover. The algorithm involves several key steps. First, Landtrendr preprocesses the satellite images by removing atmospheric interference and calibrating the data. Next, it generates a spectral index, such as the Normalized Difference Vegetation Index (NDVI), which is used to assess vegetation dynamics. Then, Landtrendr employs a statistical approach called Breaks for Additive Seasonal and Trend (BFAST) to identify breakpoints or significant changes in the time series 29.

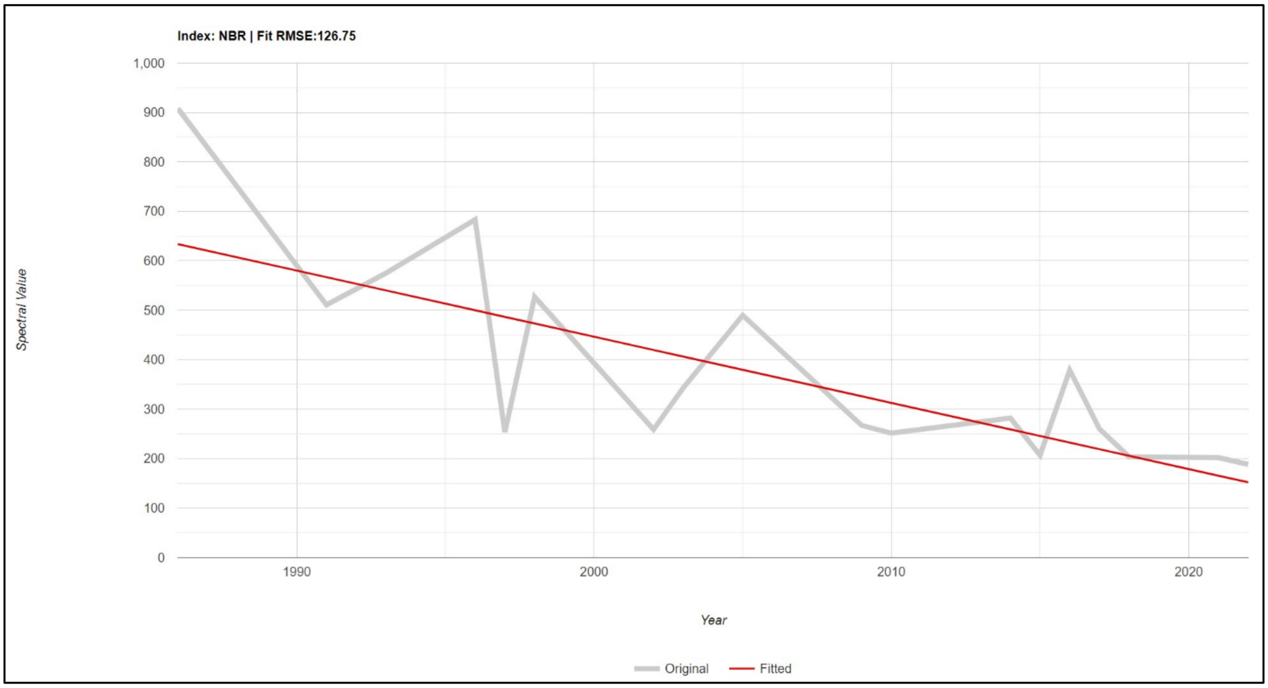


Figure 15: An example of a Landtrendr line graph generated per plot, aiding operators in detecting changes over time.

Step 5:

Through Google Earth Engine (figure 16), country experts have access to Google Earth's virtual globe, which is largely comprised of 15-meter resolution Landsat imagery, 2.5m SPOT imagery and high-resolution imagery from several other providers (CNES, Digital Global, EarthSat, First Base Solutions, GeoEye-1, GlobeXplorer, IKONOS, Pictometry International, Spot Image, Aerometrex and Sinclair Knight Merz).

[29] https://openmrv.org/web/guest/w/modules/mrv/modules_2/landtrendr

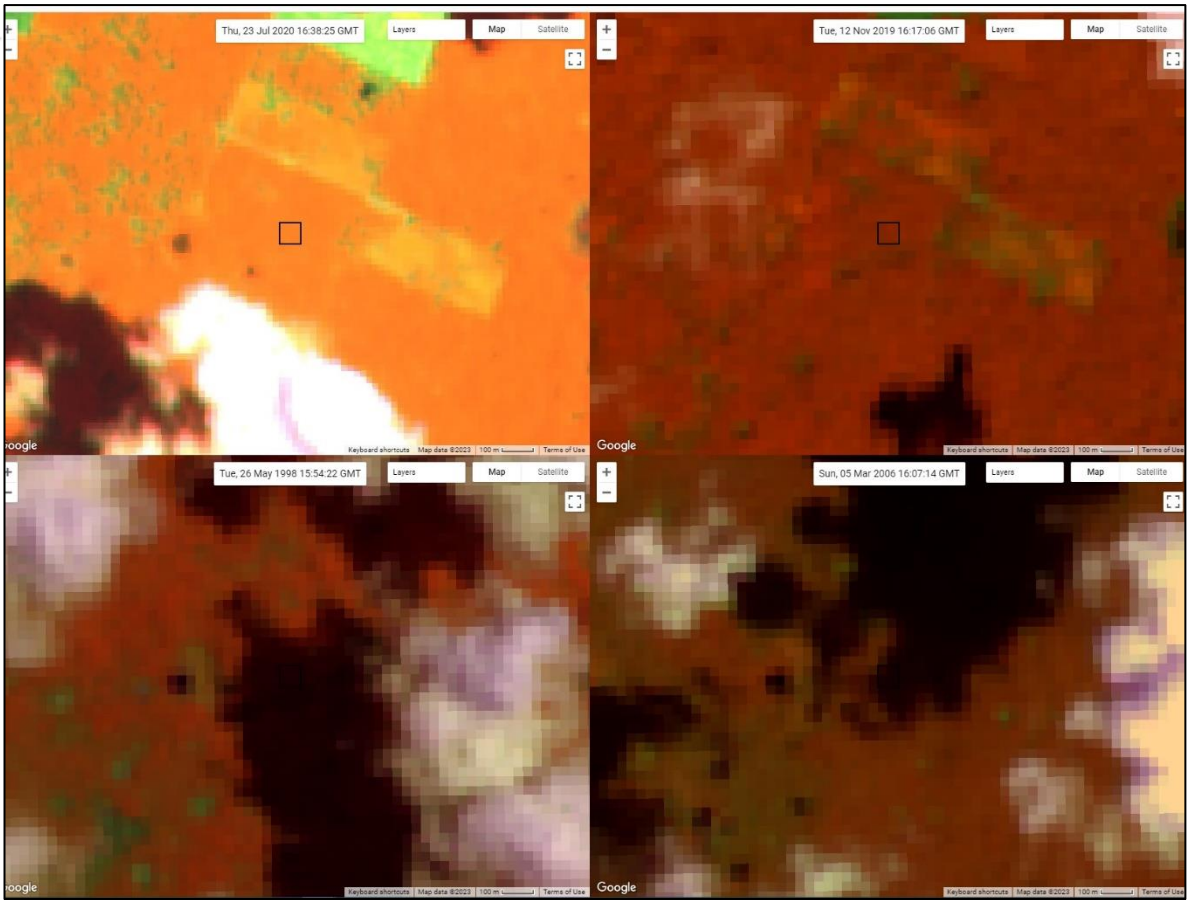


Figure 16: An illustration showcasing the suite of satellite imagery accessible via Google Earth Engine (GEE) within the LUA app.

Landsat satellites capture high-resolution, multispectral imagery of the Earth'sEa’th's surface. Google Earth Engine offers a complete Landsat archive, allowing users to access imagery dating back to the 1970s. Moreover, there is a Landsat Greenest-Pixel top of atmosphere (TOA) reflectance composite. These composites, which are available for Landsat 4, 5, 7 and 8, are created by drawing upon all images of a specific location throughout an entire calendar year. The goal is to identify the greenest pixels in each image, determined by their high normalized difference vegetation index (NDVI) values, and compile them to create a new image. This process helps to minimize the influence of clouds, atmospheric conditions, and other artifacts that can affect individual images, particularly in areas with frequent cloud cover like tropical forests. This infrared color composite presents the forest with a reddish-brown color and agriculture, grass and shrubs in lighter shades of orange. Water appears purple and urban areas are shades of blue and green. These composite pools information from bands that are sensitive to different types of reflectance.

Sentinel-2 satellites, operated by the European Space Agency (ESA), provide high-resolution multispectral imagery with global coverage. Google Earth Engine offers the complete archive of Sentinel-2 imagery.

The Moderate Resolution Imaging Spectroradiometer (MODIS) instruments aboard NASA's Terra and Aqua satellites capture imagery with moderate spatial resolution. MODIS data in Google Earth Engine includes various products such as land surface temperature, vegetation indices, cloud cover, and fire occurrence.

Step 6:

Google Earth Engine also provides access to a wide range of indices that can be derived from satellite imagery for various applications (Figure 17). These indices, among others available in Google Earth Engine, provide valuable information for vegetation monitoring, land cover analysis, water and snow detection, urbanization assessment, and fire analysis.

Normalized Difference Vegetation Index (NDVI): NDVI is a widely used index for assessing vegetation health and density. It measures the difference between near-infrared (NIR) and red-light reflectance, providing information about the presence and vigor of vegetation. NDVI values range from -1 to 1, with higher values indicating healthier and denser vegetation.

Enhanced Vegetation Index (EVI): EVI is another vegetation index that improves upon NDVI by accounting for atmospheric effects and reducing the sensitivity to background noise. It incorporates the blue band to correct for aerosol scattering and the red-edge band to enhance the sensitivity to vegetation changes.

Normalized Difference Water Index (NDWI): NDWI is used to detect and monitor water bodies. It compares the reflectance of green and near-infrared light, allowing for the identification of open water, wetlands, and flooded areas. Higher NDWI values correspond to higher water content.

Normalized Difference Built-Up Index (NDBI): NDBI is employed to detect built-up areas and urbanization. It compares the reflectance of shortwave infrared (SWIR) and near-infrared (NIR) bands. Higher NDBI values indicate a higher proportion of built-up or impervious surfaces.

Enhanced Land Surface Temperature Index (ELSTI): ELSTI is used to estimate land surface temperature by combining thermal infrared bands with visible and near-infrared bands. It provides insights into temperature patterns, urban heat islands, and thermal anomalies.

Burn Severity Index (BSI): BSI is used to assess the severity of fire-affected areas. It compares the reflectance of shortwave infrared (SWIR) and near-infrared (NIR) bands to detect changes caused by fire.

By applying these indices to satellite imagery, country experts can derive meaningful insights and perform advanced geospatial analysis within the Google Earth Engine platform.

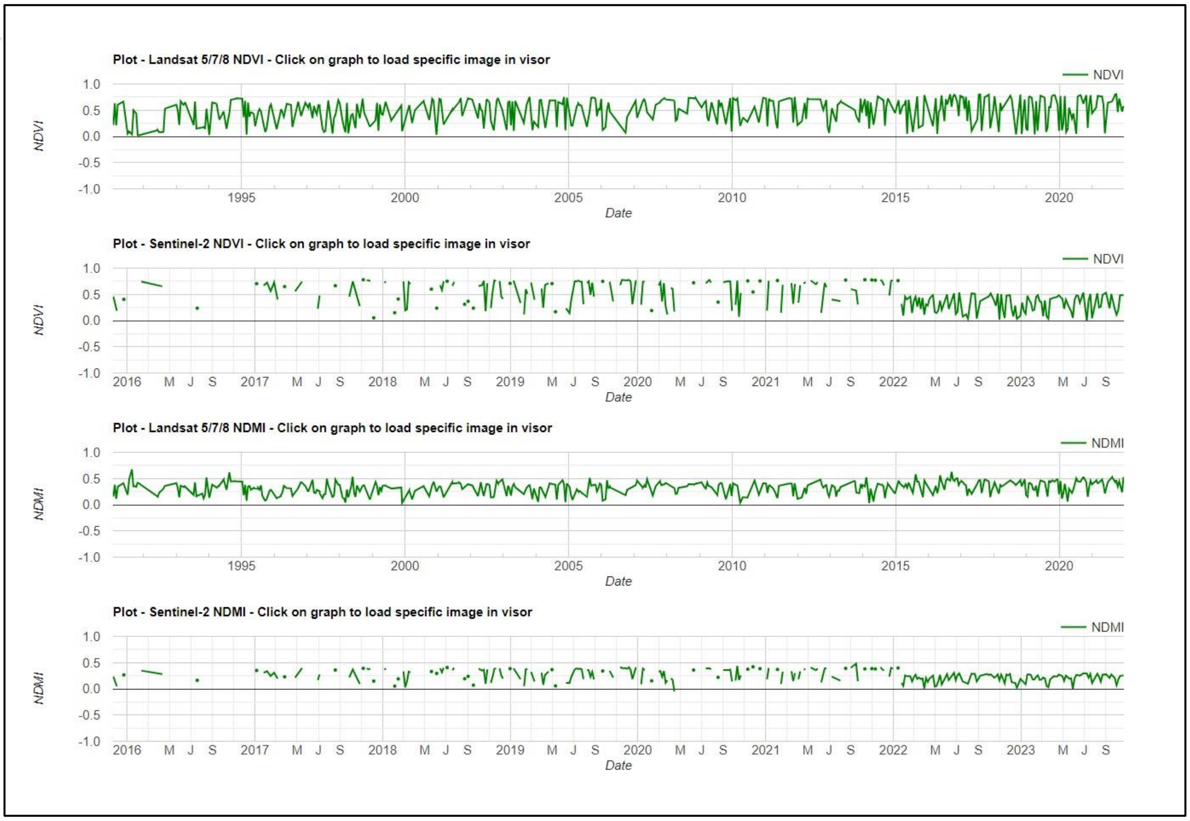


Figure 17: Line graphs depicting NDVI and NDMI generated by the GEE platform within the LUA app, aiding operators in identifying changes or stability within land use assessment plots.

Step 7:

After analysing the different information provided in steps 1-6, country experts allocate the corresponding land use and record if there were one or multiple land use changes or disturbances (Figure x). The methodology of interpretation is based mainly on the recognition of the land key elements and their function, and on the adoption of the “predominant land use” criteria in the classification scheme settled by rules.

The land use representation starts from the assessment of the land cover to observe cover of the Earth’s surface. Land cover refers to the physical characteristics and materials that cover the Earth's surface, referred to as Key land elements. Land cover describes the type and arrangement of natural and artificial features, such as vegetation, water bodies, bare soil, built-up areas, and various landforms. Land cover focuses on the visual representation of the Earth's surface and does not consider how the land is utilized or managed by humans. Once the land cover is assessed, the land use function of the land is expressed through hierarchical relationships among key land elements, and these functional relationships are based on thresholds reflecting the relevance and predominance of key land elements in the observed area. This hierarchy is defined by the country experts (see table 5 above) and is used for consistent interpretation of the land, especially when there are different types of elements in the same plots (e.g infrastructure, crops, trees). Therefore, land use refers to the purpose or activities for which land is employed and functions associated with the land, indicating how it is utilized for economic, social, or environmental purposes. It describes how people utilize the land and its resources, including agriculture, forestry, urban development, industrial areas, transportation infrastructure, recreational spaces, etc. Belize followed the 2006/2019 IPCC guidelines structure for the Zero-FRL, including the six main land uses proposed: Forest lands, Cropland, Grassland, Wetlands, Settlement and other lands (Level 1) and sub-categories of land use at level 2 and 3 (see table 4). All of the above steps were established and understood by all the operators to ensure consistency. These steps and sections were all part of Phase 2 of the implementation of Activity Data Collection.

4.8 Forest Inventories and Carbon Stock Data

4.8.1 Historical Context

Belize's experience with forest inventories began over a centuries ago, during the colonial period. One of the first tasks of the early colonialist government in Belize was to quantify and characterize the country's natural resources. As with all land management endeavors, any decision regarding natural resources used must be informed by good quality information on resource distribution and abundance. The forest estate of the country was divided into different blocks corresponding to production working circles, and initially, logging commenced in the eighteenth century with cursory visual stock assessment. In the latter part of the nineteenth century, colonial foresters began the first commercial stock assessment of timber trees in different areas of the country (Bird, 1998). However, the objective of such inventories did not advance much beyond simply estimating the stock of mahogany (Swietenia macrophylla) until the mid-twentieth century, when colonial foresters began to survey vegetation patterns, document the botany of the forest trees, and also repeat measurements of forest plots to determine growth and mortality. In the mid-to-late twentieth century, colonial foresters began expanding forest inventories to cover full-scale assessments of the forest types within subnational-level management units, cumulatively, these covered close to 50 percent of the national forest estate, to fully categorize the multiple strata into different forest types (see, for instance, Johnson and Chaffy, 1973).

The country's forest estate has traditionally been divided and managed according to distinct geographic blocks, corresponding to the boundaries of public forest reserves or privately owned forests. Within public forests, in some cases, the separation into geographic blocks occurs along ecological lines. Management responsibilities and objectives often vary across the various forest blocks. As a consequence of this, or at least as a contributing factor, there has not been a coordinated attempt to implement the type of national forest inventory promoted in the region by the Food and Agriculture Organization of the United Nations

(FAO). However, several forest blocks have been inventoried over the years for different purposes, with some blocks having multiple inventories at different scales. Some inventories were designed to support forest management planning at the level of 1 to 2 percent sample intensity of an entire block, while others have more diagnostic in nature at the sub-block level. There has also been a permanent forest dynamic inventory since 1998, which currently includes 61 sampling units (SU) spread out over many forest blocks; this inventory is treated in more detail in the following paragraph. The important feature of this multi-inventory approach is that the methods have been standard across blocks and over time, and the data have been digitally archived.

Toward the end of the twentieth century, as an independent nation, Belize began initial work on the first component of a national-level inventory of its forest resource, specifically to measure rates of different processes occurring in the forest commencing in the 1990s with the installation of thirty permanent SUs, each measuring one hectare (ha) in size (Bird, 1998). Until this time, very little research had been conducted on the dynamic processes of tree growth, mortality, and recruitment in the natural broadleaved and pine forests of Belize. The purpose of this new long-term inventory programme was to address the deficiency in the information needed for forest management. The results of these permanent forest plot surveys provide the most comprehensive long-term data set to date on tree diversity, forest structure, forest growth, mortality, and yield for the forest in Belize. Since 2010, the permanent forest inventory has expanded from the original 30 sample SUs, established in the 1990s, concentrated mainly in the moist upland forests, to the current 61 SUs spanning the entire length and breadth of the country. The expanded network now encompasses forests in the three life zones in Belize: dry, moist, and wet. The second component of the National Forest Inventory commenced in 2018, with the specific aim of measuring the area and distribution of different forest types across Belize. This component involved a remote sensing assessment of forest cover and cover changed from 2001 to 2020 by applying virtual permanent SUs established in the LUA app. This virtual forest cover inventory, coupled with the 61 permanent forest dynamics SUs, jointly comprise the National Forest Inventory of Belize and will also serve as the National Forest Monitoring System (NFMS) of Belize.

4.8.2 Broad leaf Mature Forest

Information on Belize's mature broadleaf forests is rooted in several national studies which collectively contribute valuable insights into the characteristics and dynamics of these ecosystems. This includes 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[30]. The methodology used for Permanent Sample plots is derived from Neil Bird's work, "Sustaining the Yield:

[30] Percival Cho (2013). An investigation of tropical forest response to hurricane disturbance with evidence from long-term plots and earth observation in Central America.

improved timber harvesting practices in Belize" published in 1998[31], Dr. Percival Cho's paper, "Diversity, dynamics, and carbon budget of tropical forests subject to hurricane and anthropogenic disturbance: Field Research Methods" finalized in 2013[32] .

During the period 1992 to 1998, 32 one-hectare permanent forest plots were established in mature, hurricane-disturbed (See Figure 18). These plots, collectively form the Forest Monitoring Network of Belize (FORMNET-B), and represent 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).[33] Measurements were quality-controlled and well-documented (e.g. Bird, 1998), which provides a robust basis for evaluating growth rates (Clark and Clark, 2000)[34].

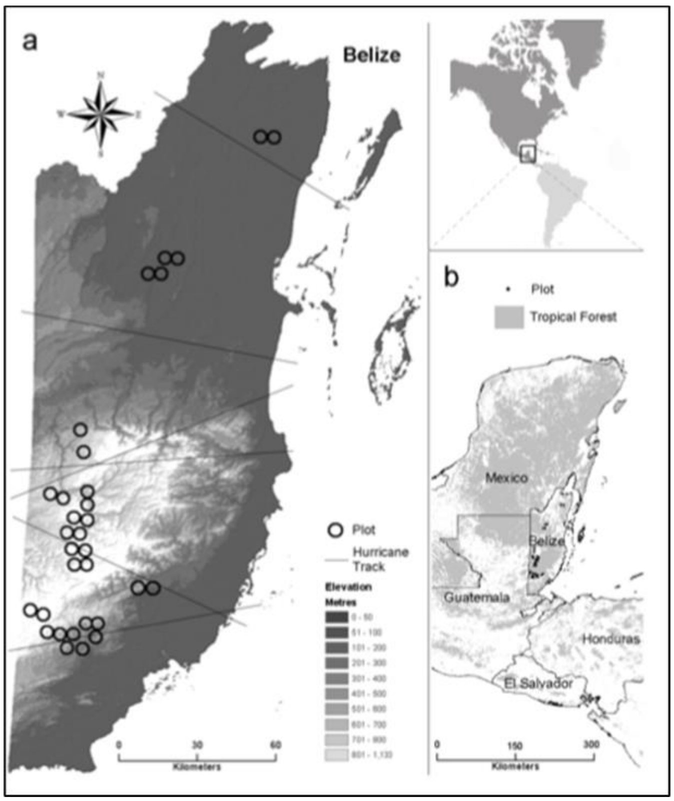


Figure 18: Map showing the location of the thirty-two FORMNET-B plots.

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31 Neil Bird (1998). Sustaining the Yield: improved timber harvesting practices in Belize 1992-1998.
32 Percival Cho (2013). Diversity, dynamics and carbon budget of tropical forests subject to hurricane and anthropogenic disturbance: Field Research Methods.
33 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.
34 David Clark and Deborah Clark (2000). Landscape-scale variation in forest structure and biomass in a tropical rain forest. Forest Ecology and Management.

Expanding on this, an additional 29 PSPs have been established in mature broadleaf forest ecosystems across Belize. This expansion reflects a commitment to comprehensively understand forest dynamics, covering a range of ecological conditions and adheres to the standardized methodologies and the rigorous documentation and quality control measures employed in previous establishments, contributing to the robustness of the dataset. The resulting wealth of information allows for greater insights into the long-term growth rates of these forests, as well as their response to both natural and anthropogenic disturbances. The dataset from this network continues to contribute invaluable information that is critical for shaping effective conservation and sustainable forest management strategies.

Plots were divided into 25 quadrats or subplots each measuring 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)[35] 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.

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 Colombia River Forest Reserve (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

[35]Trevor Beetson, Marks Nester and Jerry Vanclay (1992). Enhancing a Permanent Sample Plot System in Natural Forests. The Statistician.

(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 an 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 (Figure 19). Map of the study area showing the location of the study plots along hurricane Iris Track) Maximum sustained winds were estimated at around 225 km hr^{-1}. Hurricane tracks in the North Atlantic Hurricane Database (Landsea et al., 2004)[36] 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 before Hurricane Iris (Bird, 1998). Seven (7) of the disturbed plots 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.

[36] 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.

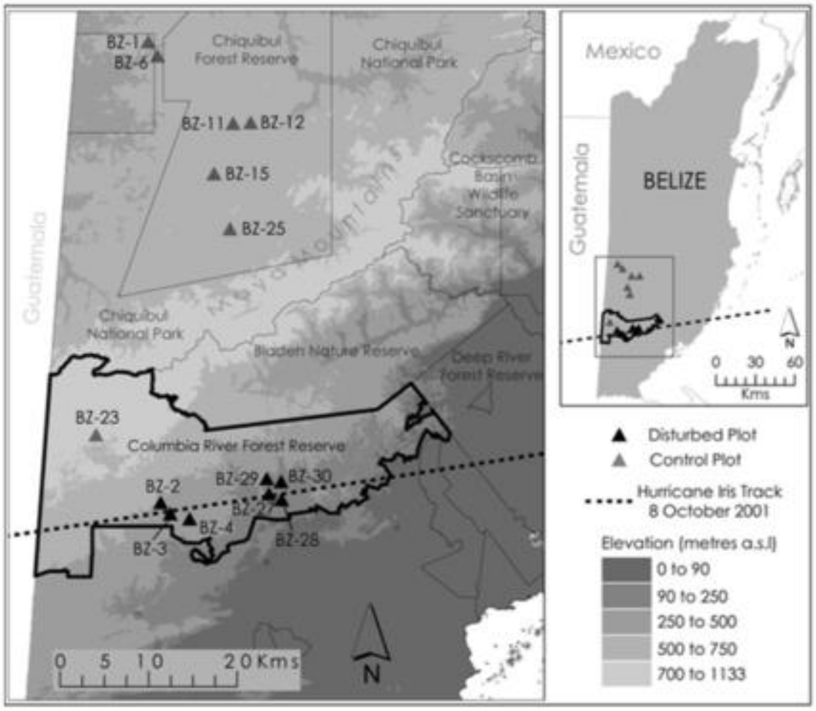

Figure 19: Map of the study area showing the location of the study plots along hurricane Iris Track.

As part of Cho *et al* (2013) studies of forest recovery after hurricane degradation, data from all 85 censuses in the 1990s was compiled and 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)[37]. The data were digitized and validated following methods outlined in Peacock et al. (2007)[38] and Fox et al. (2010)[39].

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 kilometres to prevent overlap.

A relational database was constructed in Microsoft Access to house and link individuals to their respective repeat measurements. The database aims to store and make available long- term forest monitoring data

[37] Jesse Kalwij (2012). Review of 'The Plant List, a working list of all plant species'. Journal of Vegetation Science.
[38] 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.
[39] 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.

from the forest ecosystems of Belize and to facilitate linkages to other databases of permanent forest plot measurements such as 'Forestplots.net' (Lopez- Gonzalez et al., 2011)[40]. 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 paper "*The FORMNET-B database: monitoring the biomass and dynamics of disturbed and degraded tropical forests*"[41].

4.8.3 Mangroves

The updated mangrove emission factors for Above Ground Biomass (AGB), Below Ground Biomass (BGB), and Soil Organic Carbon (SOC) have been derived by synthesizing multiple mangrove studies conducted in Belize. For AGB, the included studies were Belize Blue Carbon, Belize Rookeries, Beer Twin Caye, ERI University of Belize, and the Forest Department (Table 7). Biomass calculation for the different studies, resulting in an average AGB of 60.6 t.d.m/ha with a confidence interval of 35.05%. (Table 9). Overall mangrove biomass values by carbon pool)

The BGB data comprises studies from Belize Blue Carbon, Belize Rookeries, Beer Twin Caye, and ERI University of Belize (See Table 4), yielding an average BGB of 19.0 t.d.m/ha with a confidence interval of 96.36%. (Table 6). Overall mangrove biomass values by carbon pools).

Concerning SOC (up to a depth of 1m), the relevant studies considered are Belize Blue Carbon[42] and Beer Twin Caye (Table 7), and they indicate an average SOC of 319.5 tC/ha with a confidence interval of 16.57%. (Table 9 Overall mangrove biomass values by carbon pools)

The carbon pool biomass was estimated by using the weighted average concept. The average biomass per carbon pool as can be seen in (Table 9). Overall mangrove biomass values by carbon pool) from all studies per species was multiplied by the percent mangrove cover of the same species in (Table 8). Mangrove cover by species) from Cherrington 2019 study.

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[40] 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.

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

[42] Belize Blue Carbon: Establishing a national carbon stock estimate for mangrove ecosystem.

Table 7: Biomass calculation for the different studies.

Carbon Pool	Unit	Class	Belize Blue Carbon	Belize Rookeries	UB ERI CARICOM	Beers Twin Cayes	Forest Department	Avg carbon stock/ha
AGB	Mg/ha	Tall	135.60		95.08			115.3
		Medium	97.56	105.87	65.92	104.46	86.32	92.0
		Dwarf	48.66			18.07	62.94	43.2
BGB	Mg/ha	Tall	114.68		84.60			99.6
		Medium	44.76	65.35	48.98	78.60		59.4
		Dwarf	23.47			50.65		37.1
SOC	tC/ha	Tall	431.49					431.5
		Medium	429.12			417.45		423.3
		Dwarf	151.03			386.5		268.8

Table 8: Mangrove covers by species.

Class	2019 Mangrove Cover (ha)	2019 Mangrove Cover (%)
Tall mangrove	4,092.30	0.066120966
Medium Mangroves	16,004.16	0.258585765
Dwarf Mangroves	41,794.65	0.675293269

Table 9: Overall mangrove biomass values by carbon pools.

Carbon pool	Unit	Statistic	Class	Avg carbon stock/ha	95% CI
AGB	Mg/ha	Average (all types)	All Types	60.6	35.05%
BGB	Mg/ha	Average (all types)	All Types	19.0	96.36%
SOC	tC/ha	Average (all types)	All Types	319.5	16.57%

Belize adopted a multifaceted strategy, blending diverse methodologies derived from national studies. This initiative entailed the application of the "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" protocol, specifically to gauge the mangrove biomass.

This study was done in partnership with several stakeholders, including the Environmental Research Institute (ERI) of the University of Belize. The ERI proved key as it has maintained a long-term monitoring presence in five study sites on the Turneffe Atoll, located 32 kilometres east of Belize City. Turneffe Atoll is an integral part of the Mesoamerican Barrier Reef System, situated within a marine reserve co-managed by the Turneffe Atoll Sustainability Association and the Belize Fisheries Department. The five study sites include Calabash, Northeast Turneffe, Zone V, West Turneffe, and Northwest Turneffe, with the former three on the eastern coast and the latter two on the western coast.

MBRS Methodology:

Five sites were selected for the study and each study site encompasses three mangrove plots, amounting to a total of fifteen plots, each measuring 10 meters by 10 meters. The ERI conducts annual monitoring using the CARICOMP Methods Manual[43]. General methods for measuring mangrove ecosystem structure and function are consistent with established practices (Lugo and Snedaker, 1975[44]; Pool et al., 1977[45]; Snedaker and Snedaker, 1984[46]). The standardized procedure for mangrove communities involves recording specific parameters such as forest characterization, stress recognition, plot establishment, trunk diameter at breast height (DBH), height range for trees within the plot, salinity of sub-surface water, biomass within the plot, standing crop, community description (within the plot), tidal range, abundance, and percentage cover. Subplots are designated for seedlings and saplings, with tagging, identification, mapping, and measurement of root seedlings (<2.5 cm dbh) and new leaf biomass growth.

Belize Blue Carbon Methodology:

Following the methods outlined by Kauffman & Donato (2012) and the Coastal Blue Carbon Manual (Howard et al., 2014), Belize aligned its research efforts with other Total Ecosystem Carbon Stock (TECS) projects. The study involves one-time plots not intended for remeasurement. Specific parameters recorded at the plots include mangrove height, canopy width, and dbh for all plants with a dbh ≥ 5 cm within a 7 m radius of the plot centre. Within a nested 2 m radius plot, all plants with a dbh < 5 cm are measured, and all seedlings are counted. In cases where the dominant mangrove ecotype is dwarf, the entire plot has a 3 m radius, with all plants measured within the plot. Each plot within each transect undergoes a survey of woody debris, establishing four 12 m sub-transects at 90-degree angles from the centre of the plot. Along these intersections, coarse woody debris is identified to species and graded according to decay class, following Howard et al. (2014). Allometric equations from Komiyama et al.,2005 were used for BGB and Smith and Whelan,2006 were used for AGB and species-specific wood densities from Howard et al. (2014) are utilized to calculate above-ground biomass (AGB) and below-ground biomass (BGB) estimates. The study sites for the Belize Blue Carbon mangrove plots are the following: Hicks Caye, Drowned Caye range, Shipstern lagoon, New River, Gra Gra lagoon, channel Caye, Big Creek, Paynes Creek, Frenchman Caye and Turneffe Atoll. The total number of study sites for the Belize Blue Carbon is nineteen. From the nineteen sites, eighteen sites encompass six plots per site and one site encompassed three plots, amounting to a total of one hundred and eleven plots.

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[43] 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.

[44] 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.

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

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

Belize Forest Department's Direct Sampling Method:

The Belize Forest Department developed a direct sampling method for biomass data collection, implemented across the country and focusing on the most dominate mangrove class on the mainland-dwarf mangrove. Each site comprises five mangrove plots measuring 1x2m and positioned 20m apart along a 100m transect. Within each 1x2 m plot, the DBH and height of all plants are measured, and all plant material inside the vertical 1x2 m column is cut and separated into crowns, stems, and prop roots, with weight recorded. Propagules are collected and weighed, and a representative sample from each plant component is extracted and placed inside a sealed Ziplock bag and then weighed in the field. These samples are taken to a drying lab, re-weighed on a high-precision, calibrated laboratory balance, and dried until a constant mass at 80 degrees Celsius. The data was then calculated to account for the dry matter and then converted to tonnes of carbon. The basal method was implemented to analyse the correlation between the function of Diameter at Breast Height (DBH) and height.

The study sites included in this research are located in Fresh Water Creek Forest Reserve, Burden Canal Nature Reserve, Manatee Forest Reserve, and Gra Gra Lagoon, selected for the establishment of permanent sample plots due to their long-term institutional protection. The study included four sites; each site encompasses five plots per site amounting to a total of 20 plots for this study.

Belize Rookeries:

The Belize Rookeries study employed the Kauffman & Donato (2012) methodology. Specific parameters recorded at the plots include mangrove height, canopy width, and dbh for all plants with a dbh ≥ 5 cm within a 7 m radius of the plot centre. Within a nested 2 m radius plot, all plants with a dbh < 5 cm are measured, and all seedlings are counted. In cases where the dominant mangrove ecotype is dwarf, the entire plot has a 3 m radius, with all plants measured within the plot. Each plot within each transect undergoes a survey of woody debris, establishing four 12 m sub-transects at 90-degree angles from the centre of the plot. Along these intersections, coarse woody debris is identified to species and graded according to decay class, following Howard et al. (2014). Allometric equations from Komiyama et al.,2005 were used for BGB and Smith and Whelan,2006 were used for AGB and species-specific wood densities from Howard et al. (2014) were utilized to calculate above-ground biomass (AGB) and below-ground biomass (BGB) estimates. The study sites for Belize Rookeries mangrove plots are the following: Hicks Rook, Hick Nonrook, DC Rook; Cayo Negro, DC Nonrook; Swallow Caye, TA Rook; Bird Caye and TA Nonrook.

Beers Twin Caye Study:

Finally, the Beers Twin Caye study employed the Kauffman et al., 2020; methodology. Specific parameters recorded at the plots include mangrove height, canopy width, and dbh for all plants with a dbh ≥ 5 cm within a 7 m radius of the plot centre. Within a nested 2 m radius plot, all plants with a dbh < 5 cm are measured, and all seedlings are counted. In cases where the dominant mangrove ecotype is dwarf, the entire plot has a 3 m radius, with all plants measured within the plot. Each plot within each transect undergoes a survey of woody debris, establishing four 12 m sub-transects at 90-degree angles from the centre of the plot. Along these intersections, coarse woody debris is identified to species and graded according to decay class, following Howard et al. (2014). Allometric equations from Komiyama et al.,2005 were used for BGB and Smith and Whelan,2006 were used for AGB and species-specific wood densities from Howard et al. (2014) were utilized to calculate above-ground biomass (AGB) and below-ground biomass (BGB) estimates. The Beer Twin Caye Study included six sites, encompassing one plot per site amounting to a total of six plots. The plot ID for the mangrove are the following; BZE.Fringe. A, BZE.Fringe. B, BZE.Fringe. C and for dwarf mangrove is BZE.Dwarf. A, BZE.Dawrf. B, BZE.Dwarf. C. The distribution of these plots is Offshore.

4.8.4 Pine Forest

The methodology for establishing and conducting a permanent sample plot (PSP) in pine forests closely aligns with the approach outlined by Bird (1998) for broadleaf forests[47]. However, certain variations in data collection exist, specifically in the assessment of seven parameters: crown form, crown position, climbers, codes, diameter, stumps, and logs. Additionally, it is imperative to incorporate the measurement of non-pine trees within the sampling process.

Pine trees exhibit a conical or pyramid-shaped crown, contrasting with the diverse crown forms observed in broadleaf trees (e.g., oval, rounded, vase-shaped). Crown form grading for pine trees should follow a scale of 1 to 3: a grading of (1) being a crown of very poor form or badly damaged; (2) having a crown of satisfactory form while (3) having a crown form with the best size and development generally seen.

The crown position is graded on a scale of 1 to 3. A grading (3) is a crown plan fully exposed vertically at least within the 90 ° inverted cone subtended by the base. While a grading of (2) is a crown plan partly exposed vertically but partly shaded by other crowns. On the other hand, a grading of (1) is a crown plan entirely shaded.

Climbers relate to mistle-toe presence range from 1 to 3, with (1) being no mistle-toe, (2) being some mistle-toe, and (3) being smothered with mistle-toe.

Codes differ from a broadleaf. E.g. Specific codes, such as Parasites Present (PP) and Cones Present (CN), are used, with adaptations for pine forests.

[47] Neil Bird (1998). Sustaining the Yield: improved timber harvesting practices in Belize 1992-1998.

Diameter is taken over bark without cleaning of flakes. Stumps and snags are measured, and the decay class is considered for a comprehensive assessment. Non-pine trees are also measured, but these are measured similarly to any tree in the broadleaf plot with the same methodology.

The data collection process for pine forests in Belize derives from meticulous procedures across four (4) plots: BZ-45 Mountain Pine Ridge Forest Reserve: Privassion Line (MPR Priv) established in 2017, BZ-54 Mountain Pine Ridge: Flores Line (MPR Flor) established in 2019, BZ-56 Rio Bravo Conservation and Management Area (RBCMA) established in 2020, and BZ-57 Swasey Bladen Forest Reserve (SBFR) established in 2020.

Plot BZ-45 Privassion Line is characterized as a submontane pine moist forest, experiencing adverse effects from fire, logging, and bark beetle infestation in 2017. This logged-over pine forest, affected by ground fires, upland terrain, well-drained soil, and slope, underwent a revaluation in 2018. In contrast, BZ-54 Flores Line was identified as an upland pine mature moist forest, undergoing a prescribed burn in February 2020.

The updated emission factor for pine above-ground biomass was calculated by the sum of all four pine permanent sample plots (MPR Privassion remeasurement, MPR Flor establishment, SBFR remeasurement and RBCMA establishment data) including the broadleaf species found within the plot and biomass data obtained from grass, shrub and ferns plots were used in the calculation, resulting in an average of 117.28 t.d.m/ha, with a 40.45% confidence interval (See Table 10) Above ground biomass calculation for Pine and other carbon pools). Litter data was not collected for any of the pine forest plots. Dead wood was estimated to be 1.46 t.d.m/ha (See Table 11). Above ground biomass calculation for Pine and other carbon pools), which was then converted to (tC/ha) by multiplying by 0.47, resulting in a value of 0.68 tC/ha, with a confidence interval of 53.2%.

Table 10: Above ground biomass calculation for Pine and other carbon pools

Carbon Stock	Variable	Unit	Statistic	MPR Priv 2	MPR Flor	SBFR 2	RBCMA	Avg AGB/ha	95% CI	Comments
Live AGB Tree	AGB / plot	Mg/ha	Sum Total	65.72	156.61	69.80	110.23	100.59	41.3%	
Live AGB Saplings	AGB / plot	Mg/ha	Sum Total	1.25	0.00	0.00	0.01	0.31	194.4%	
Live AGB HDWDS Tree	AGB / plot	Mg/ha	Sum Total	2.11	17.53	0.64	0.88	5.29	151.6%	
Live AGB HDWDS Sapling	AGB / plot	Mg/ha	Sum Total	0.00	5.25	16.25	0.25	5.44	137.0%	
Grass, Shrubs, Ferns	AGB / plot	Mg/ha	Sum Total	5.65	5.65	5.65	5.65	5.65	42.6%	*in order to account for understory - assume all understory is grass and that pine basal area is negligible
Live AGB	**AGB / plot**	**Mg/ha**	**Sum Total**	**74.73**	**185.04**	**92.34**	**117.02**	**117.28**	**40.4%**	
Litter	AGB / plot	Mg/ha	Sum Total	na	na	na	na	na	na	
FWD	AGB / plot	Mg/ha	Sum Total	na	na	na	na	na	na	
DW Tree/Stump AGB	AGB / plot	Mg/ha	Sum Total	1.11	2.40	0.57	1.77	1.46	53.2%	
DW Sapling AGB	AGB / plot	Mg/ha	Sum Total	0.00	0.00	0.00	0.00	0.00	na	
DW	**AGB / plot**	**Mg/ha**	**Sum Total**	**1.11**	**2.40**	**0.57**	**1.77**	**1.46**	**53.2%**	

Table 11: Pine annual Increment

Carbon Stock	Variable	Unit	Statistic	MPR Priv 1	MPR Priv 2	SBFR 1	SBFR 2	ΔAGB yr-1	95% CI
Live AGB Tree	AGB / plot	Mg/ha	Sum Total	65.23	65.72	66.41	69.80	1.94	146.5%

The annual biomass increment for pine was calculated using the data from plot BZ-45 Mountain Pine Ridge Forest Reserve: Privassion Line (MPR Priv 1) established in 2017 and remeasured in 2020 (MPR Priv 2), and plot BZ-57 Swasey Bladen Forest Reserve (SBFR 1) established in 2020 and remeasurement in 2021(SBFR 2), resulting in ΔAGB yr-1 of 1.94 t.d.m/ha/yr and a confidence Interval of 146.5% (See Table 11. Pine annual Increment).

4.8.5 Secondary Broadleaf Forest

The plot layout and data collection procedures for a secondary forest survey are detailed systematically. The plots measure 20mx100m and involve confirming the plot location, marking plot boundaries, and aligning them with cardinal points using true bearings. Vegetation cutting is limited to the plot boundary to minimize disturbance. Pegs are strategically placed to mark internal quadrat lines at 20-meter intervals. Borderline trees on the plot boundary undergo a verification process, and only those meeting specific criteria are included. Bird. (1998), tree census methodology was applied for this process[48].

The survey encompasses additional assessments, including data collection on woody debris and litter. The condition of the plot was recorded, and vegetation was cut only outside the plot to minimize disturbance. Woody debris and litter are collected along a transect line adjacent to the western plot boundary, with precautions to avoid interference near the southern end. Pegs are cut from the plot's outside and placed at 20 m intervals along each boundary, marking the start of internal quadrat lines. Stems under 1 cm are addressed through destructive sampling and weight measurement. This comprehensive methodology ensures a thorough and standardized approach to forest inventory, taking into account various ecological factors and potential challenges in tree identification and measurement.

Simultaneous with living biomass measurement, coarse woody debris (CWD) was surveyed in each secondary permanent sample plot, measuring pieces with a diameter of ≥10 cm. Narrowing pieces below 10 cm were measured to the point and classified as fine woody debris (FWD). CWD extending beyond plot boundaries will be measured only up to the plot border. Fine woody debris and leaf litter will be sampled from a 1 x 100 m transect along the immediate plot border, extending from quadrat 1-5 along the northern edge. Additionally, all stumps and snags will be surveyed across the entire plot, covering all five larger quadrats of 20m x 20m.

Coarse woody debris (CWD) is classified into four forms: logs, stumps, snags (including whole trees), and blobs. The 'blob' category encompasses irregularly shaped pieces, branches, and lianas. Distinguishing between CWD and fine woody debris (FWD) relies on diameter, with length used to differentiate CWD types. Logs are pieces ≥10 cm in diameter and ≥1 m in length, >45° from vertical. Stumps are ≥10 cm in

[48] Neil Bird (1998). Sustaining the Yeild: improved timber harvesting practices in Belize 1992-1998.

diameter at the midpoint and <1 m in height and rooted in the ground. Snags are standing pieces or whole trees ≥10 cm diameter at 1.3 m above the ground, ≤45° from vertical.

The study recognizes five decomposition classes to capture the temporal resolution of decay without blurring criteria. This scale, based on physical changes during decomposition, includes the following primary variables: appearance, intact bark, resistance to a nail, and structural integrity.

Class 1: Recently fallen, solid wood with intact bark and fine branches.

Class 2: Solid wood without fine branches, with bark starting to fall off.

Class 3: Non-solid wood in poorer condition, still resisting a nail being pushed by hand.

Class 4: Soft, rotten wood where a nail can be easily pushed into the wood.

Class 5: Soft, rotten wood that collapses easily when pushed by hand.

Fine woody debris (FWD) sampling is conducted in a subset of each permanent sample plot, specifically in the 1m x 100m transect line used for the coarse woody debris (CWD) census. However, not the entire area will be used. Starting from the northern end of the plot, the first meter of the 1m x 100m transect will be censused for FWD. Subsequently, every other meter will be measured for FWD up to the 100-meter mark, resulting in a total of 50 samples. All FWD from a 1-meter section was collected, weighed, and placed inside a construction bag. A representative handful from all 50 samples was collected in one paper bag for drying, facilitating the estimation of total dry mass per plot-level fresh mass. The primary objective of estimating FWD stocking is to determine the fate of coarse woody debris (CWD).

Leaf litter sampling involves census in a 1-meter x 1-meter area for every 10 meters along the 1m x 100-meter transect, up to the 100-meter mark, resulting in 10 leaf litter samples for each plot. The collected samples will be weighed using a hanging scale, and the initial weight will be recorded in the provided field sheet. The samples will be labeled and oven-dried until a constant weight is achieved, and subsequent weights, along with the final constant weight, will be recorded as the final dry weight for the litter in the plot.

During the period 2019 to 2020, Three (3) permanent sample plots in secondary forest were established. The data obtained and analyzed for the secondary broadleaf forest originates from three (3) distinct plots: BZ-55 Honey Camp National Park (established in 2019), BZ-59 Golden Stream National Park (established in 2020), and BZ-60 Vaca Forest Reserve (established in 2020)[49]. Plot BZ-55 Honey Camp was classified as a lowland secondary dry broadleaf forest while BZ-59 Golden Stream and BZ-60 Vaca Forest Reserve are considered regular secondary forests, with all 3 having no disturbances recorded.

[49] Belize Forest Department

The updated emission factor for secondary broadleaf forest above-ground biomass resulted in an average of 239.53 t.d.m/ha, with a 32.78% confidence interval (See Table 12). Secondary Broadleaf Forest carbon pool biomass calculation). Litter data was collected from the three secondary broadleaf plots resulting in a 3.02 t.d.m/ha (See Table 12). Secondary Broadleaf Forest carbon pool biomass calculation), which was then converted to (tC/ha) by multiplying by 0.47 (carbon fraction), resulting in a value of 1.42 tC/ha and a 33.25% confidence interval. Dead wood was estimated to be 27.37 t.d.m/ha (See Table 12). Secondary Broadleaf Forest carbon pool biomass calculation), which was then converted to (tC/ha) by multiplying by 0.47, resulting in a value of 12.86 tC/ha, with a confidence interval of 22.03%.

Table 12. Secondary Broadleaf Forest carbon pool Biomass calculation.

Carbon Stock	Variable	Unit	Statistic	VFR	GSCP	HCNP	Mean SBL Plot level AGB	SBL AGB Mg/ha	Unit
Litter	AGB within plot	kg/m2	Mean	0.2115	0.4136	0.282	**0.30**	**3.02**	**tons/ha**
		%	95% CI	25.6%	16.5%	16.2%	**33.2%**	33.25%	95% CI
FWD	AGB within plot	kg/m2	Mean	0.35	0.37	0.52	**0.41**	**4.13**	**tons/ha**
		%	95% CI	25.7%	22.7%	31.6%	**22.0%**	22.03%	95% CI
CWD	AGB within plot	Mg/2000m2	Mean	3.31	1.28	2.38	**2.32**	**23.23**	**tons/ha**
		%	95% CI	na	na	na	**42.9%**	42.86%	95% CI
DW	AGB within plot	kg/m2	Mean	1.7202	0.7755	1.363	**1.29**	**12.86**	**tons/ha**
		%	95% CI				**22.0%**	22.03%	95% CI
Understory	AGB within plot	kg/m2	Mean	0.117	0.265	0.106	**0.16**	**1.63**	**tons/ha**
		%	95% CI	69.8%	158.0%	102.1%	**53.5%**	53.49%	95% CI
Saplings	AGB within plot	Mg/50m2	Total	0.742	0.386	0.1635	**0.43**	**4.31**	**tons/ha**
		%	95% CI	na	na	na	**66.4%**	66.43%	95% CI
Trees	AGB within plot	Mg/2000m2	Total	14.42	26.77	28.89	**23.36**	**233.60**	**tons/ha**
		%	95% CI	na	na	na	**32.8%**	32.78%	95% CI
Age (yrs)				16	29	30			
Understory, Saplings & Trees	AGB within plot	Mg/2000m2	Total	15.279	27.421	29.1595	**23.95**	**239.53**	**tons/ha**
		%	95% CI				**32.8%**	32.78%	95% CI
								SBL EFs	AGB/ha
								AGB	**239.53**
								Litter	**3.02**
								DW	**27.37**

4.8.6 Category-level data analysis methodologies for 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[50]; Chave et al., 2005[51]).

[50] 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.

[51] 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.

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[52]). For species not represented in this local database, mean values were obtained from the Global Wood Density Database (Chave *et al*., 2009a[53]; Chave *et al*., 2009b[54]) 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[55]). 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[56]).

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 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.

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

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

[53] Chave, J., Coomes, D., Jansen, S., Lewis, S.L., Swenson, N.G. and Zanne, A. E.: Towards a worldwide wood economics spectrum. Ecol. Lett., 12, 351–366, 2009a.

[54] Chave, J., Coomes, D. A., Jansen, S., Lewis, S. L., Swenson, N. G. and Zanne, A.E.: Data from: Towards a worldwide wood economics spectrum. Dryad Digital Repository, doi:10.5061/dryad.234, 2009b

[55] 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

[56] 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

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 due to model and measurement error following the methods outlined in Chave *et al.* (2004)[57].

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)[58].

To estimate net hurricane-related C flux, the approach used was to estimate the total C removed by Hurricane Iris and subtract this from the total C sequestered following the hurricane.

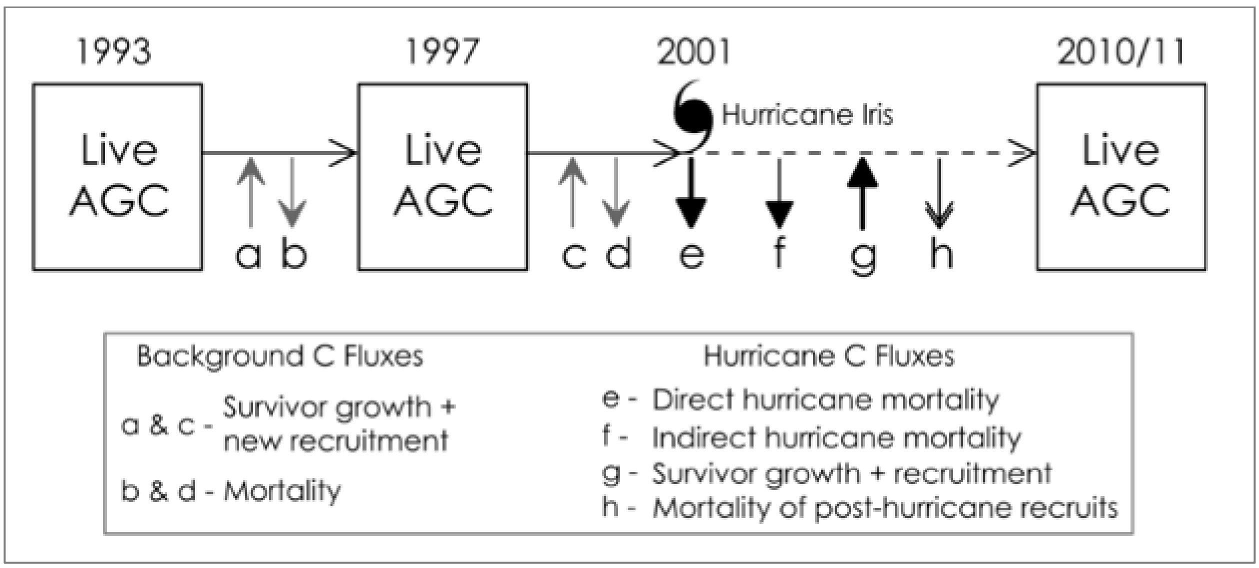

Figure 20: Sketch of forest dynamics over the study period from 1993 to 2010/2011.

Live aboveground carbon stocks (AGC) are represented by rectangles (See Figure 20). Sketch of forest dynamics over the study period from 1993 to 2010/2011). Horizontal arrows represent changes in AGC

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[57] 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.

[58] 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.

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.

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

Biomass (g) = dbh (cm) x 3,390

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

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).

Belize Blue Carbon, Rookeries, UB ERI CARICOM and Beers Twin Caye

Allometric equation to calculate Average Ground Biomass (AGB) and Below Ground Biomass (BGB) of the three mangrove species found in Belize. (See Table 13). An allometric Equation per mangrove species was used to calculate the ABG and BGB)

Table 13: Allometric Equation per mangrove species was used to calculate the ABG and BGB

Species	Equation	Source
Avicennia germinans	$AGB = 0.403 * DBH^{1.934}$	(Smith and Whelan, 2006)
	$BGB = 0.199 * 0.72^{0.899} * DBH^{2.22}$	(Komiyama et al., 2005)
Rhizophora mangle	$AGB = 0.722 * DBH^{1.731}$	(Smith and Whelan, 2006)
	$BGB = 0.199 * 0.87^{0.899} * DBH^{2.22}$	(Komiyama et al., 2005)
Laguncularia racemosa	$AGB = 0.362 * DBH^{1.93}$	(Smith and Whelan, 2006)
	$BGB = 0.199 * 0.60^{0.899} * DBH^{2.22}$	(Komiyama et al., 2005)

[a] Species-specific wood densities are from (Howard *et al.*, 2014)

Pine:

Pine in Biomass was estimated using the equation:

The AGWB was calculated for each standing tree using the allometric equation [AGWB = 0.0407 × dbh 2.8131] (Viergever et al. 2009).

Hardwoods*

$$\text{Biomass} = 0.5 + \frac{25{,}000\,dbh^{2.5}}{dbh^{2.5} + 246{,}872}$$

$R^2 = 0.99$
$n = 454$
Min. diameter = 1.3 cm
Max. diameter = 85.1 cm
Mean diameter = 21.6 cm

Figure 21: Schroeder hardwood equation used for the broadleaf species.

The allometric equation from Vierger et al 2009 was used to calculate the average ground biomass for Pine trees and saplings. For the broad-leaf species, the allometric equation from Paul Schroeder 1997 (See Figure 21). Schroeder hardwood equation used for the broadleaf species) was used to calculate the average ground biomass. For CWD and FWD an equation that converts volume to density was used to calculate the biomass for Blob, Branch, Log and Snug (DT). The density value from the different decay classes was used from two mature forest plots that are established within the Chiquibul Forest.

4.8.7 Category-level methodologies for GHG emissions and absorptions estimations

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 for national greenhouse gas inventories and are to the extent possible, in line with international practice. IPCC methodology tiers 1, 2 and 3 were applied.

For the estimation of GHG emissions and removals for the Forest and Land Use Change Sector, Belize has followed the methodologies proposed in the 2006 IPCC guidelines, Volume 4, Chapter 2 “Generic Methodologies Applicable to Multiple Land-use Categories”, for change in biomass carbon stocks (above-ground biomass and below-ground biomass) and non-CO2 emissions. It includes the analysis for Land remaining in a land-use category and Land converted to a new land-use category. All definitions, methods and assumptions are described in (Excel file> BEL Foundational Platform).

4.8.8 Overview of carbon stock change estimation for the GHG

Methods are described as follows:

Annual increase in biomass carbon stocks due to biomass increment in land remaining in the same land-use category (Table 14).

$$\Delta C_G = \sum_{i,j} (A_{i,j} \bullet G_{TOTAL\,i,j} \bullet CF_{i,j})$$

Where:

ΔCG= annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C yr-1

A = area of land remaining in the same land-use category, ha

GTOTAL= mean annual biomass growth, tonnes C ha-1 yr-1

i = ecological zone (*i* = 1 to *n*)

j = climate domain (*j* = 1 to *m)*

CF = carbon fraction of dry matter, tonne C $(\text{tonne d.m.})_{-1}$

Table 14. IPCC Categories & Sub-Category Carbon Fraction Values & Sources

CF: Carbon Fraction				
LU	Sub-Category	Value	Range / Error	Source
FL	Broad-leaf Mature Forest	0.47	(239 – 295) %	Martin & Thomas, 2011
	Broad-leaf Secondary Forest	0.47	(161.10 – 318.05)	IPCC 2006, V4, Ch4, Table 4.3.
	Pine Forest	0.47	(69.90 – 164.66)	IPCC 2006, V4, Ch4, Table 4.3.
	Mangroves	0.45	(39.36 – 81.86)	2013 IPCC Wetlands Supplement. Table 4.2
	Plantations	0.47	(85 - 160)	IPCC 2006, V4, Ch4, Table 4.3. Tropical / all
CL	Croplands, Swidden farming	0.50		IPCC 2006, V4, Ch4, Table 4.3. Tropical / all

	Croplands, Intensive agriculture	0.50		IPCC 2006, V4, Ch4, Table 4.3. Tropical / all
	Fallow Lands	0.47		IPCC 2006, V4, Ch4, Table 4.3. Tropical / all
GL	Pasture	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.2
	Shrubs	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.3
	Savannah Open	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.4
	Savannah with shrubs	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.5
	Savannah with trees	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.6
	Sub-mountainous	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.7
	Ferns and thickets	0.50		IPCC 2006, V4, Ch5, Section 5.3.1.8
	Grassland abandoned (GABDP)	0.50		IPCC 2006, V4, Ch4, Table 4.3.Tropical / all
WL	Wetlands	-	-	-
SL	Settlements	-	-	-
OL	Other lands	-	-	-

Notes:

Martin & Thomas (2011) indicated that carbon fraction was taken from a total of 190 wood samples from 59 native tree species across 46 genera, 26 families, and 12 orders sampled at the Soberania National Park (SNP), a lowland tropical moist forest located in central Panama. This was the value selected as the most representative for Belize in Cho et al (2013) study.

Table 15: IPCC Categories & Sub-Categories AGB & BGB Values and Sources

R: Ratio-t BGB dm/ (t AGB dm)				
LU	Sub-Category	Value	Range / Error	Source
FL	Broad-leaf Mature Forest	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
	Broad-leaf Secondary Forest	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
	Pine Forest	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
	Mangroves	0.49	Range: 0.04 - 1.1; 95%CI 0.47 - 0.51	2013 IPCC Wetlands Supplement. Table 4.5
	Plantations	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
CL	Croplands, Swidden farming	-	-	-
	Croplands, Intensive agriculture	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
	Croplands, Follow land	0.37		2006 IPCC, V4, Ch 4. Table 4.4. Tropical rainforest
GL	Pasture	-	-	-
	Shrubs	-	-	-
	Savannah Open	-	-	-
	Savannah with shrubs	-	-	-
	Savannah with trees	-	-	-
	Sub-mountainous	-	-	-
	Ferns and thickets	-	-	-
	Grassland abandoned (GABDP)	-	-	-
WL	Wetlands	-	-	-

SL	Settlements	-	-	-
OL	Other lands	-	-	-

Table 16: Growth rates in undisturbed forests by forest type.

IPCC	Forest Type	Values	Tier	Error & Range values	Source
FL	Primary/Mature Broadleaf Forest (+50years)	3.18	3	Range: -5.29 - 5.45; 95% CI: -0.316 - 6.676 (±3.496)	Cho et al (2013)
	Secondary Broad-leaf Forest > 20 and < 50 years (old/mature)	2.3	3		IPCC 2019 Refine, V4, Ch4, Table 4.9
	Secondary Broad-leaf Forest < 20 years (Young/Renegeration)	5.90	3	Range: -0.90 - 3.41	IPCC 2019 Refine, V4, Ch4, Table 4.9
	Pine Forest > 20 years (old/mature)	1.94	3	Range: 0.1 - 1.8	FORMNET-BZ
	Mangroves > 20 years (old/mature)	9.90	1	Range: 0.1 - 27.4; 95%CI 9.4 - 10.4	2013 IPCC Wetlands Supplement. Table 4.4
	Forest Plantations (old/mature)	15	1	Range: 9 - 50	2006 IPCC V4, Ch4, Table 4.10

Notes:

The growth rate in undisturbed forests uses values from the FORMNET-B and Measurement. Table 16 presents the values used by forest type with their respective source.

Annual increase in carbon stock in biomass due to biomass growth in undisturbed forests [Eq. 2.9, 2.10] (See Table 15).

$$\mathbf{\Delta G\ [tC/ha/year]} = Area * Gtotal\_Remaining \quad [eq.\ 2.9]$$

$$\mathbf{Gtotal\_Remaining\ [tC/ha/year]} = Gw\_Remaining\ (1 + R) \quad [eq.2.10]$$

Where:

Area: Area of forest that remains as undisturbed forest [ha]

GTOTAL= average annual growth of aboveground and belowground biomass, ton C ha-1 year-1

GW = average annual growth of aboveground biomass for a specific type of forest vegetation, ton d.m. ha-1 year-1

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1.

Losses in forests that remain as forests were assessed due to various disturbances, both anthropogenic and natural. These include:

- Fires
- Shifting cultivation
- Infrastructure/Other Human Impact
- Mining
- Pest
- Logging
- Hurricanes
- Grazing

Disturbances were divided in groups based on whether regeneration after disturbance is expected or not, and if there were specific modifications to the general growth rate. Groups were allocated like this:

- Group 1, No expected regeneration: Agriculture, Infrastructure, Grazing, Mining (Table 17)
- Group 2, Expected Regeneration: Hurricanes, Logging
- Fire, Expected Regeneration, different Gw
- Pest, Expected Regeneration, different Gw

Each time a disturbance was identified, the year and disturbance fraction were assigned. In the end, averages were estimated for each disturbance.

Table 17: Fraction of biomass affected due to the first disturbance of group 1.

	First Disturbance Average	**First Disturbance SD**
Infrastructure/Other Human impact	27.9	24.2
Mining	20	
Shifting cultivation	31.3	20.0
Grazing	38.6	21.2
Average	31.1	21.7

To facilitate the calculation process, the value of 0.31 is taken as the fraction of biomass affected due to the first disturbance of group 1 (Table 17). This value is calculated based on the average of all the first disturbances in all plots across all years.

Annual increase in carbon stock in biomass due to biomass growth in forests that remain with the first disturbance of group 1 [Agriculture, Infrastructure, Grazing, Mining] [Eq. 2.9]

ΔG [tC/ha/year] = Area • (1-FirstD) • Gtotal_Remaining

Gtotal_Remaining [tC/ha/year]= GW_Remaining • CF • (1 + R)

Where:

Area: Area of forest that remains as undisturbed forest, [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass, tonnes C ha-1 year-1

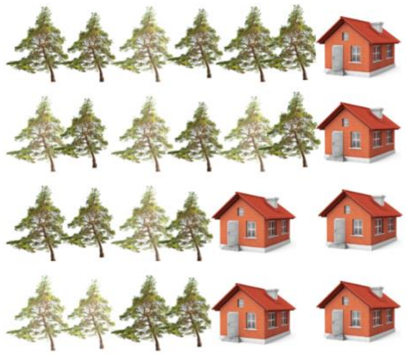
GW_Remaining = average annual growth of aboveground biomass for a specific type of forest vegetation, ton d.m. ha-1 year-1

CF = Carbon Fraction [t C / (t d.m.)]

FirstD= Fraction of biomass was affected due to the first disturbance of group 1, dimensionless

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1.

In many cases, additional disturbances were identified. For the case of group 1, these additional disturbances are added to the previous disturbance. These additional losses were considered as disturbances until the forest definition threshold was reached. When that happened, it was considered land use change, otherwise it was still a forest remaining forest land affected by different disturbance (figure 22) .



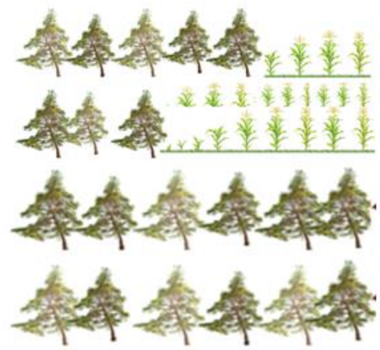


Figure 22: Examples from disturbance in forest

A disturbance due to Infrastructure

Example: F/MBL/Dinfra_2005

A disturbance due to agriculture

Example; F/MBL/DAgri_201

Annual increase in carbon stock in biomass due to biomass growth in forests that remain with additional disturbances of group 1 [Agriculture, Infrastructure, Grazing, Mining] [Eq. 2.9]

$$\Delta G \text{ [tC/ha/year]} = \text{Area} \bullet (1 - \text{FirstD} - \text{AddD}) \bullet \text{Gtotal\_Remaining}$$

$$\text{Gtotal\_Remaining [tC/ha/year]} = \text{GW\_Remaining} \bullet \text{CF} (1 + R)$$

Where:

Area: Area of forest that remains as undisturbed forest [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass, tonnes C ha-1 year-1

GW_Remaining = average annual growth of aboveground biomass for a specific type of forest vegetation, ton d.m. ha-1 year-1

FirstD= Fraction of biomass affected due to additional disturbances of group 1, dimensionless

AddD = Fraction of biomass affected due to additional disturbances of group 1, dimensionless

CF = Carbon Fraction [t C / (t d.m.)]

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1.

To facilitate the calculation process, the value of 0.10 is taken as the fraction of biomass affected due to additional disturbances of group 1. This value is calculated based on the average of all additional disturbances across all plots and years.

This equation also allows the combination of various disturbances.

Example: F/MBL/Dinfra_2005/DAgri_2015

Annual increase in carbon stock in biomass due to biomass growth in forests that remain with the first disturbance of group 2 [Hurricanes/logging] [Eq. 2.9] (Table 18)

ΔG [tC/ha/year] = Area • (1) • [Gtotal_Remaining (1 - FirstD) + Gtotal_regeneration • (FirstD)]

Gtotal_Remaining [tC/ha/year]= GW_Remaining • CF • (1 + R)

Gtotal_regeneration [tC/ha/year]= GW_regeneration • CF • (1 + R)

Where:

Area: Area of forest that remains as undisturbed forest [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass, tonnes C ha-1 year-1

GTotal_Regeneration= average annual growth of aboveground and belowground biomass in the fraction of the forest affected by the disturbance, tonnes C ha-1 year-1

GW_Remaining = average annual growth of aboveground biomass for a specific type of forest vegetation, ton d.m. ha-1 year-1

GW_Regeneration = average annual growth of aboveground biomass for a specific type of forest vegetation affected by the disturbance, ton d.m. ha-1 year-1

FirstD= Fraction of biomass was affected due to the first disturbance of group 2, dimensionless

CF = Carbon Fraction [t C / (t d.m.)]

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1.

The (1) is left as an indicator that there is no loss of forest for another use; that is, the forest is affected but regeneration is allowed.

Caption: Fraction of biomass affected due to the first disturbance of group 2.

Table 18: Fraction of biomass affected due to the first disturbance of group 2.

	First Disturbance Average	First Disturbance SD
Logging	21.4	17.9
Hurricanes	42.0	31.0

Average	37.1	29.7

To facilitate the calculation process, the value of 0.37 is taken as the fraction of biomass affected due to the first disturbance of group 2. This value is calculated based on the average of all first disturbances across all plots and years.

For the year of the disturbance, only half of the regeneration rate [Gtotal_regeneration/2] is applied, assuming that the disturbance can occur at different times of the year—either at the beginning, middle, or end of the year. Therefore, to avoid overestimating the regeneration removals for that year, only half is considered. From the following year onward, the full regeneration rate is applied.

- **Year of the disturbance:** ΔG [tC/ha/year] = Area • (1) • [Gtotal_Remaining (1-FirstD) + Gtotal_regeneration/2 • (FirstD)]
- **Year after the disturbance:** ΔG [tC/ha/year] = Area • (1) • [Gtotal_Remaining (1-FirstD) + Gtotal_regeneration/2 • (FirstD)]

Example: F/MBL/DHur_2010 or F/MBL/DLog_2010

Annual increase in carbon stock in biomass due to biomass growth in forests that remain with additional disturbances of group 2 [Hurricanes/logging] [Eq. 2.9]

ΔG [tC/ha/year] = Area • (1) • [Gtotal_Remaining (1-FirstD-AddD) + Gtotal_regeneration • (FirstD + AddD)]

Gtotal_Remaining [tC/ha/year]= GW_Remaining • CF • (1 + R)

Gtotal_regeneration [tC/ha/year]= GW_regeneration • CF • (1 + R)

Where:

Area: Area of forest that remains as undisturbed forest [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass, tonnes C ha-1 year-1

GTotal_Regeneration= average annual growth of aboveground and belowground biomass in the fraction of the forest affected by the disturbance, tonnes C ha-1 year-1

GW_Remaining = average annual growth of aboveground biomass for a specific type of forest vegetation, ton d.m. ha-1 year-1

GW_Regeneration = average annual growth of aboveground biomass for a specific type of forest vegetation affected by the disturbance, ton d.m. ha-1 year-1

FirstD= Fraction of biomass was affected due to the first disturbance of group 2, dimensionless

AddD = Fraction of biomass affected due to additional disturbances of group 2, dimensionless

CF = Carbon Fraction [t C / (t d.m.)]

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1

The (1) is left as an indicator that there is no loss of forest for another use; that is, the forest is affected but regeneration is allowed.

The fraction of biomass lost due to the additional disturbance of group 2 is the same value as the first disturbance.

Unlike group 1, this disturbance fraction is not cumulative; that is, every time a storm occurs, the same disturbance fraction is applied, expecting regeneration.

Growth rate in forests regenerating after being affected by disturbances of Group 2 [Logging/Hurricanes) [Gw_Regeneration]

The growth rate in regenerating forests uses values from the FORMNET-B and Measurement. Table 13 presents the values used by forest type with their respective source.

Table 19: Display the approximate age for each forest type.

CATEGORIES	AGE	Source
Primary/Mature Broadleaf Forest (+50years)	+50years	Forest Monitoring Network Belize (FORMNET-B)
Secondary Broad-leaf Forest > 20 and < 50 years (old/mature)	> 20 and < 50	
Secondary Broad-leaf Forest < 20 years (Young/Regeneration)	< 20 years	
Pine Forest > 20 years (old/mature)	> 20 years	
Mangroves > 20 years (old/mature)	> 20 years	

Young or early-age forests have a higher growth rate than that of primary, mature, or stable forests, mainly due to the presence of pioneer and dominant species. This high growth rate is maintained until a calculated age is reached, at which point the forest is considered to transition from an early age to a middle age, and values are assigned for Forest lands remaining Forest lands, which are of lower value.

Based on discussions with national experts from the Forest Department, the approximate age for each forest type is indicated in **(See Table 19 above),** and the relationship between underground and aboveground biomass for each vegetation type is provided in **(See Table 15).**

Annual increase in carbon stocks in biomass due to biomass growth in forests affected by Fire disturbance of Fires [Eq. 2.9] (Table 20)

ΔG [tC/ha /year] = Area •* (1) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire (FirstDFire)]

GTotal_Fire **[tC/ha /year]= Gw_Regeneration • CF • (1+R).**

Where:

Area: Surface area of forest that remains as undisturbed forest [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass in the fraction of the remaining forest, ton dry matter ha-1 year-1

GTotal_Fire = average annual growth of aboveground and belowground biomass in the fraction of the affected forest by fire, ton dry matter ha-1 year-1

Growth rate after a fire, tC ha-1 year-1

FirstDFire = Fraction of biomass affected by fire, [dimensionless]

CF = Carbon Fraction [t C / (t d.m.)]

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1

The (1) is left as an indication that there is no loss of forest for other uses; that is, the forest is affected but regeneration is allowed.

Forest fires in Belize primarily affect the understory, litter, and dead material, but in broadleaf areas, the impact extends to trees. Expert assessments, notably by (Cho, 2022), categorize most fires in Belize as high-frequency occurrences.

Different forest types exhibit distinct responses to fires. Pine and Savannah ecosystems display rapid recovery, aligned with their natural ecological patterns. In contrast, broadleaf forests, unaccustomed to fires, experience severe impacts on trees, leading to prolonged recovery and notable changes in forest composition.

Secondary Broadleaf (SBL) forests often emerge from fires originating in adjacent savannahs. In contrast, Mature Broadleaf (MBL) forests, characterized by increased dead wood, face higher risks during slow-burning fires that penetrate deep into roots. However, SBL forests tend to recover comparatively faster.

Hurricanes exacerbate fire risks by increasing debris accumulation on the forest floor. In Mature Broadleaf (MBL) forests, fires during dry seasons can be detrimental to trees, potentially causing their demise. Additionally, fires in MBL forests may transfer carbon from Dead Organic Matter (DOM) to another carbon pool rather than releasing it into the atmosphere. To understand the percentage corresponding to the understory, the following analysis was conducted (see Figure 23)[59]:

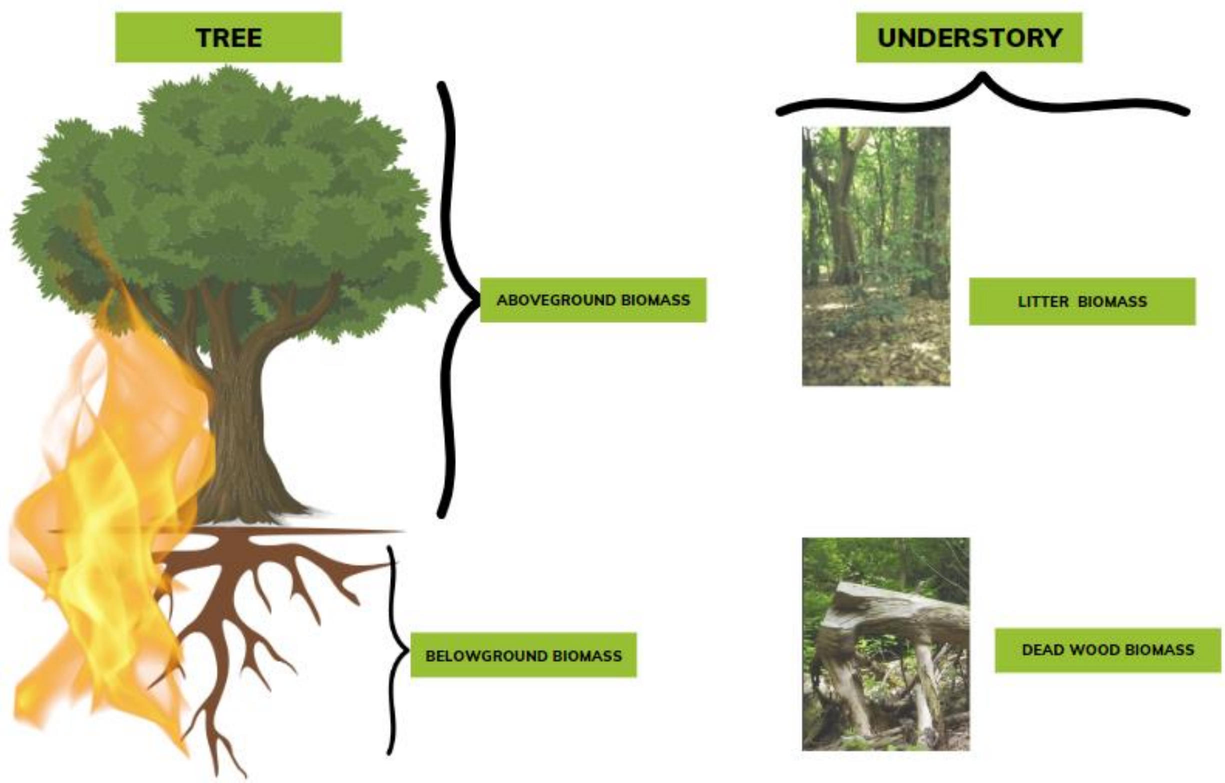


Figure 23. Representation of total biomass by pool in forests and its relationship with the impact or loss of biomass due to forest fires in the conditions of the national context.

From this diagram, it was deduced that aboveground biomass represents 70%, belowground biomass 30%, litter and regeneration biomass, and dead wood and stumps biomass 50%.

[59] Forest department: Chief Forest Officer-Wilber Sabido, Deputy Chief Forest Officer- John Pinelo, MRV & GSMU Manager (Edgar Correa), MRV program(Edalmi Pinelo, Luis Balan,Sumeet Betancourt, Mercedes Carcamo, Karlene Williams),GSMU(Jorge Nabet, koren Sanchez), Fire Management(Raul Chun, Edwardo Pott,Shanelly Balan), Landscape Restoration Desk (Minerva Gonzales), Sustainable Forest Management (Florencia Guerra). Science for Sustainability-Dr. Pevical Cho, CfRN (Milena Nino, Lucila Balam, Javier Fernandez, Marcial Arias), MRV Hub (Brittany Meighan).

Most fires have a high impact, affecting trees such as Mature Broadleaf and secondary forests, with an estimated impact of 32%, while pine forests are estimated to be at 7%, highlighting that the trees generally survive. Therefore, 68% of the corresponding percentage of aboveground biomass remains after the fire and pine at 73 %.

For understory, it is also estimated that at the time of the fire, 27% was lost for MBL and SBL. While for Pine Forest 30% is lost.

To calculate emissions from fires and removals after the fire due to regeneration, these percentages were Fractions of biomass loss due to fires and remaining (see Table 20).

Table 20: Tree and understory component for fraction of biomass loss due to fires

	Tree component	Burn	Fraction of biomass loss due to Fires	Remaining	DOM_FireTransfer
MBL	70%	45%	32%	68%	0.32
SBL	70%	45%	32%	68%	0.32
PINE	70%	10%	7%	93%	
Understory (MBL/SBL)	30%	90%	27%	73%	
Understory (Pine)	30%	100%	30%	70%	

Based on these new percentages, it is estimated that the fraction of aboveground and belowground biomass that burns is 0.59 for MBL and SBL and 0.37 for Pine. This fraction is applied each time a fire occurs (see Table 21).

Table 21: Fraction of biomass loss due to Fires

Fires		
Notation	*First Fire*	*Additional Fire*
Parameter	**Fraction of biomass loss due to Fires**	**Fraction of biomass loss due to Fires**
Units	**Dimensionless**	**Dimensionless**
Forestland		

Mature Broadleaf Forest (MBL)	0.59	0.59
Secondary Broadleaf Forest (SBL)	0.59	0.59
Pine Forest (PINE)	0.37	0.37
Mangroves (MAN)	1.00	1.00
Forest Plantations (PLANTF)	0.50	0.50

Growth rate in forests affected by fire [Gw_Fire]

Table 22: Regeneration after fire

Notation	*Gw after fire*	*Time to reach max Stock*
Parameter	**Annual Above Ground-Carbon increase**	**years**
Units	**[tC/ha/yr]**	**[Years]**
Forest Land	**Dato Nacional (Anexo II)**	
Mature Broadleaf Forest (MBL)	3.80	17
Secondary Broadleaf Forest (SBL)	3.80	15
Pine Forest (PINE)	27.94	2
Mangroves (MAN)	6.64	6
Forest Plantations (PLANTF)	9.66	4

Gw after fire is the same value as Gw_ regeneration, except for the case of pine, as mostly the understory is what is burnt, which corresponds to 30% of the total AGC, and only 7% is affected from the rest of the tree (see table 22), the Gw is estimated as

Gw Fire_Pine [tC/ha /year] = AGC • % affected

This differentiation is done because the biomass lost will recover within the same year of disturbance and the following year, due to the adaptation that pine has to fires.

The estimated recovery times after a fire vary: 17 years for MBL, 15 years for secondary broadleaf forests, 2 years for pine forests, and 4 years for forest plantations. This is attributed to rain cycles preceding dry seasons.

Therefore, the equations are applied as follows:

Disturbance year = ΔG [tC/ha/year] = Area • (1) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire/2 • (FirstDFire)]

Year after disturbance = ΔG [tC/ha/year] = Area • (1) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire • (FirstDFire)]

When Belize forests return to their initial state at their different recovery time, the general equation for gains in undisturbed forests is applied.

In cases where the fire occurred in a forest previously affected by another disturbance from group 1 or 2, the Gw_fire rate is applied only to the remaining forest fraction:

Disturbance year = ΔG [tC/ha/year] = Area • (1-FirstD) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire/2 • (FirstDFire)]

Year after disturbance = ΔG [tC/ha/year] = Area • (1-FirstD) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire • (FirstDFire)]

Example: F/MBL/DAgri_2001,DFire_2013

If there were multiple previous disturbances from Groups 1 or 2, the equation is adjusted based on the number of additional disturbances:

Disturbance year = ΔG [tC/ha/year] = Area • (1- FirstD– AddD) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire/2 • (FirstDFire)]

Year after disturbance = ΔG [tC/ha/year] = Area • (1-First D – AddD) • [GTotal_ remaining • (1-FirstDFire) + GTotal_Fire • (FirstDFire)]

Example: F/MBL/DAgri_2001, Dinfra 2008, DFire_2013

In the case of fires after Pest disturbances, the same equations (1 and 2) are used since pests affected the tree biomass and not the understory.

For consecutive fires, equation 1 is applied successively. This reflects the dynamics that only the recovered percentage is burned.

Annual increase in carbon stocks in biomass due to biomass growth in forests affected by pests [Eq. 2.9](Table 23)

ΔG [tC/ha/year] = Area • (1) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest • (FirstDPest)]

Gtotal_Remaining [tC/ha/year]= GW_Remaining • CF • (1 + R)

Gtotal_Pest [tC/ha/year]= GW_Pest • CF • (1 + R)

Where:

Area: Surface area of the forest that remains undisturbed [ha]

GTotal_Remaining= average annual growth of aboveground and belowground biomass in the fraction of the remaining forest, ton dry matter ha-1 year-1

GTotal_Pests: Growth rate after pests, tC ha-1/year

FisrtDPests: Fraction of biomass affected by Pests, dimensionless

CF = Carbon Fraction [t C / (t d.m.)]

R = ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass, (t.d.m. of aboveground biomass)-1

The (1) is left as an indicative that there is no loss of forest for another use; that is, the forest is affected but regeneration is allowed.

The Belize bark beetle infestation in 1998 had a dual impact on the country's economy and environment. Economically, the infestation posed a severe threat to the forestry sector, affecting valuable timber resources and leading to substantial economic losses within industry. The decline in timber quality and quantity had a direct negative influence on revenue generation and employment opportunities. Environmentally, the infestation resulted in widespread tree mortality, contributing to deforestation, and disrupting the ecological balance of Belize's forest ecosystems. The loss of trees not only affected biodiversity but also compromised the ecosystem services provided by healthy forests, such as carbon sequestration and watershed protection. The 1998 bark beetle infestation underscored the interconnectedness of economic and environmental factors, emphasizing the importance of integrated management strategies to address both aspects simultaneously.

In 2000 and 2001, over 26,000 ha. of mature pine stands (*Pinus caribaea* and *P. tecunumanii*) in the Mountain Pine Ridge Forest Reserve suffered nearly 100% mortality from an outbreak of *Dendroctonus spp.* (Billings and Schmidtke 2002, Midtgaard and Thunes 2002). This was the first bark beetle outbreak in Belize in 50 years. The causal agent is an undescribed species, closely related to both *D. frontalis* and *D. vitei* (Midtgaard and Thunes 2002), with attack dynamics like those of *D. frontalis.* The devastated area represents about 70% of the entire Forest Reserve and about 85% of its pine forests. Little direct control was applied, and, by March 2002, the beetle outbreak had largely subsided (Billings and Schmidtke 2002)[60].

[60] Billings, R.F. and P. Schmidtke. 2002. Central American Southern Pine Beetle/Fire Managment Assessment.

Bark beetle infestation phases:

• Phase 1 Pines with recent attacks (last 5-10 days). A pine tree under attack by *Dendroctonus frontalis* (phase 1) is recognized by the green crown and fresh resin clumps in the bark.

• Phase 2 Pines with *Dendroctonus frontalis* larvae (last 25-35 days). A pine tree infested with weevil larvae (phase 2) will have a yellowish crown with drier and harder resin clumps.

• Phase 3 Dead pines abandoned by the weevil. Pine trees are characterized by a red crown.

Table 23: Fraction of biomass lost in the first Pest disturbance[61]

	Tree Component	Affected	Lost	Fraction of biomass lost in the first Pest disturbance	Remaining	DOM_FireTransfer
PINE	70%	100%		7%	93%	0.18
Understory (Pine)	30%	0%				

The growth rate in forests affected by pests [Gw_Pests]

Following the distribution percentages, the growth rate value used for regeneration after pests is 1.94 tC/ha. The time to reach max Stock for pine is 28 years.

Therefore, the equations are applied as follows:

Disturbance year = ΔG [tC/ha/year] = Area • (1) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest/2 • (FirstDPest)]

Year after disturbance = ΔG [tC/ha/year] = Area • (1) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest • (FirstDpest)]

The half-year correction is applied to represent the forest's recovery in the disturbance year, avoiding overestimating removals compared to applying the entire regeneration rate. In cases where the pest occurred in a forest previously affected by another disturbance from group 1 or 2, the Gw_Pest rate is applied only to the remaining forest fraction:

[61] Forest department: Chief Forest Officer-Wilber Sabido, Deputy Chief Forest Officer- John Pinelo, MRV & GSMU Manager (Edgar Correa), MRV program(Edalmi Pinelo, Luis Balan,Sumeet Betancourt, Mercedes Carcamo, Karlene Williams),GSMU(Jorge Nabet, koren Sanchez), Fire Management(Raul Chun, Edwardo Pott,Shanelly Balan), Landscape Restoration Desk (Minerva Gonzales), Sustainable Forest Management (Florencia Guerra). Science for Sustainability-Dr. Pevical Cho, CfRN (Milena Nino, Lucila Balam, Javier Fernandez, Marcial Arias), MRV Hub (Brittany Meighan).

Disturbance year = ΔG [tC/ha] = Area * (1- FirstD) * [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest/2 • (FirstDPest)]

Year after disturbance = ΔG [tC/ha] = Area • (1-First D) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest • (FirstDpest)]

Example: F/MBL/DAgri_2001, DPest_2013

If there were multiple previous disturbances from Groups 1 or 2, the equation is adjusted based on the number of additional disturbances:

Disturbance year = ΔG [tC/ha] = Area • (1- FirstD – AddD) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest/2 • (FirstDPest)]

Year after disturbance = ΔG [tC/ha] = Area • (1-FirstD – AddD) • [GTotal_ remaining • (1-FirstDPest) + GTotal_Pest • (FirstDpest)]

Example: F/MBL/DAgri_2001, DInfra_2008, DPest_2013

Annual increase in carbon stocks in biomass due to biomass growth in other land uses converted to forest land [Eq. 2.9, 2.10] (Table 24)

ΔG [tC/ha] = Area • (1) • GTotal_Conversion [eq. 2.9]

Gtotal [tC/ha] = GW_Conversion • CF • (1 + R) [eq.2.10]

Where:

Area: Surface area of the forest that remains undisturbed [ha]

GTotal_Conversion: Average annual growth of aboveground and belowground biomass after conversion, tonnes C ha-1 year-1

GW_Conversion: Average annual growth of aboveground biomass for a specific type of forest vegetation after conversion, ton d. m. ha-1 year-1

CF = Carbon Fraction [t C / (t d.m.)]

R: Ratio between belowground and aboveground biomass for a specific type of vegetation in t.d.m. of belowground biomass (t.d.m. of aboveground biomass)-1.

The same values described in Table 20 for regeneration are applied as the growth rate after conversion. The (1) represents that the whole plot was converted to another lad use. If the plot is affected by one or multiple disturbances from groups 1, the area is subtracted as follows:

$$\Delta G\ [tC/ha] = Area \bullet (1 - FirstD) \bullet GTotal\_Conversion \quad [eq.\ 2.9]$$

$$\Delta G\ [tC/ha] = Area \bullet (1 - FirstD - AddD) \bullet GTotal\_Conversion \quad [eq.\ 2.9]$$

If after the conversion the forest is affected by disturbance of Group 2, Fire or pest, the same logic and set of equations is applied, however, GTotal_Remaining is replaced by GTotal_Conversion_

Annual Losses in carbon stocks in biomass on lands remaining in the same land use category (Equation 2.11)(Table 21)

$$\Delta CL = \Delta Lwood\text{-}removals + \Delta Lfuelwood + \Delta Ldisturbance$$

Where:

ΔCL= annual loss of carbon stocks due to biomass loss on lands remaining in the same land use category, ton C year-1

ΔL_wood-removals = annual loss of carbon due to forest removal, ton C year-1 (equation 2.12)

ΔL_fuelwood = annual loss of carbon in biomass due to fuelwood removal, ton C year-1 (equation 2.13)

ΔL disturbance = annual losses of carbon in biomass due to disturbances, ton C year-1 (equation 2.14)

Belize does not have a complete annual time series from 2000 to 2020 on national roundwood or fuelwood statistics. Therefore, all wood extraction was captured as Logging disturbances in equations 2.14.

Annual losses of carbon in biomass due to disturbances (Equation 2.14)

$$\Delta L\_disturbance = Adisturbance \bullet AGB \bullet (1+R) \bullet CF \bullet FirstD$$

Where:

Ldisturbance = annual carbon losses due to disturbances, ton C year-1

Adisturbance= area affected by disturbances, ha year-1

ABG = average aboveground biomass, t.d.m. ha-1

R = ratio between belowground and aboveground biomass in t.d.m. of belowground biomass (t.d.m. of aboveground biomass)-1

CF = carbon fraction of dry matter, ton C (t.d.m.) -1

FirstD = fraction of biomass lost due to disturbances

In the case of additional disturbances, the equation is applied as follows:

ΔL_disturbance [ton C ha-1] = Adisturbance • AGC• AddD

AGC [ton C ha-1] = AGB • (1+R) • CF

If there was a disturbance of Group 2, Fire or Pest after a disturbance of Group 1, the area is subtracted as follows:

ΔL_disturbance = Adisturbance • AGC • (1-FirstD) • AddD

If there was a disturbance of Group1, Group 2 or Pest after fire, the AGB is replaced by the Gw_Fire * by the number of years the forest has been recovering.800 Specifically for MBL and SBL, which have longer periods of recovery.

ΔL_disturbance = Adisturbance • (Gw_Fire • (1+R) • CF) • Year Recovery • AddD

In the cases of fires after fires

ΔL_disturbance = =Area•AddFire• (AGC_Before conversion• (1-FisrtDFires) + (GTotal_Regeneration•FirstDFire*•Years Recovery))

In the case of losses after conversion, the AGB is replaced by Gw_Conversion multiplied by the years growing after the conversion.

ΔL_disturbance = Adisturbance • (Gw_Conversion • (1+R) • CF) • Years after conversion • FirstD

Table 24: The carbon stocks by forest type [tC/ha]

Forest Type	Forest Type (Age)	Aboveground Carbon (tC/ha)	Tier	Standard Deviation	Source
Mature Broadleaf Forest (MBL)	+50years	125.67	3	Range: 119.58 – 395.85	Cho et al 2013
Secondary Broadleaf Forest (SBL)	> 20 and < 50	112.57	3	Range: 161.10 – 318.05	FORMNET - B
Pine Forest (PINE)	< 20 years	55.12	2	Range: 69.90 – 164.66	FORMNET - B
Mangroves (MAN)	> 20 years	27.27	2	Range: 39.36 – 81.86	Morrissette et al., 2023; Belize Blue Carbon Project, Smithsonian-UBERI eDNA Cayes Project 2023, UB ERI CARICOM Data 2010-2019, Kauffman et al., 2020; Beer Data from Twin Caye, Forest Department.
Forest Plantation (PLANTF)		56.4	1	Range: 85 - 160	Expert Judgement (Forest Department team + CEO)

Annual change in biomass carbon stocks on land converted to other land-use category (tier 2) (Equation 2.15, Ch2, V4)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

ΔC_B= annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_G= annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr^{-1}

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr^{-1}

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuelwood gathering and disturbances on land converted to other land-use category, in tonnes C yr^{-1}

Initial change in biomass carbon stocks on land converted to another land category (Equation 2.16, Ch2, V4)

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER} - B_{BEFORE}) \bullet \Delta A_{TO\_OTHERS} \} \bullet CF$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C yr^{-1}

B_{AFTER_i} = biomass stocks on land type *i* immediately after the conversion, tonnes d.m. ha^{-1}

B_{BEFORE_i} = biomass stocks on land type *i* before the conversion, tonnes d.m. ha^{-1}

$\Delta A_{TO\_OTHERS_i}$ = area of land use *i* converted to another land-use category in a certain year, ha yr^{-1}

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)$^{-1}$
***i* =** type of land use converted to another land-use category

Change in biomass carbon stocks on land converted to another land category was estimated using the values of Area, Biomass and Carbon Fraction as described above for lands remaining in a category.

In the case of forest converted to another land use, but the forest has had a previous disturbance, the biomass is subtracted as follows:

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER} - B_{BEFORE} \bullet (1\text{-DFirst}) \bullet \Delta A_{TO\_OTHERS} \} \bullet CF$$

Example: FG/MBL>GPAST_2015/DAgri_2011

If the forest was previously affected by Disturbance G2, fires or pest, the BBefore is replaced by the biomass recovered until the moment of the disturbance:

Example: FG/MBL>GPAST_2013/DFire_2010

$\Delta C_{CONVERSION}$ =Area*(Bafter-(AGC*(1-FirstDFire)+(GTotal_Fire*years of recovery after fire)))

Annual change in Carbon Stocks in dead wood or litter (Gain-Loss Method)

$$\Delta C_{DOM} = A \bullet \{(DOM_{in} - DOM_{out}) \bullet CF\}$$

Where:

ΔC DOM = annual change in carbon stocks in the dead wood/litter pool, tonnes C yr-1

A = area of managed land, ha

DOMin = average annual transfer of biomass into the dead wood/litter pool due to annual processes and disturbances, tonnes d.m. ha-1 yr-1.

DOMout = average annual decay and disturbance carbon loss out of dead wood or litter pool, tonnes d.m.ha-1 yr-1

CF = carbon fraction of dry matter, tonne C (tonne d.m.)-1

The Tier 1 approach was applied for F>F, following, the assumption that the carbon contained in all biomass components that are transferred to dead organic matter pools will be released in the year of the transfer, whether from annual processes (litterfall and tree mortality), land management activities, such as fuelwood gathering, except for F>F affected by disturbances. For this estimation, it was necessary to estimate the amount of biomass that is transferred to dead organic matter, which was done by expert judgement.

Different national experts[62] gathered to discuss on possible percentages of AGB that could be transferred to DOM, specifically after hurricanes and pest. For the case of hurricanes, it was indicated that 90% of what was estimated as AGB loss would be transferred to DOM because the steam and branches could have been broken and there was defoliation, and maybe some trees were uprooted; therefore, most of this biomass component would remain in forest areas, unless washed out but heavy rains and floods. In the case of Pest, some of the affected trees were extracted for other uses. It was agreed that about 25% of the tree component would remain as dead tree and would be transferred to DOM. The understory was not affected by pest, therefore, by weighted average, the percentage of AGB to be transferred was estimated to be 18%.

In the case of disturbances by Group1, the fraction affected by the disturbance (FirstD or AddD) was accounted as a loss in the DOM C pool. In the case of fires, all DOM was considered to be lost.

In the case of Forest lands converted to other land uses, the difference between new Land Use – previous Land use was estimated.

$$\Delta C_{DOM} = A \bullet (DOM_{AFTER} - DOM_{BEFORE}) \bullet CF$$

[62] Forest department: Chief Forest Officer-Wilber Sabido, Deputy Chief Forest Officer- John Pinelo, MRV & GSMU Manager (Edgar Correa), MRV program(Edalmi Pinelo, Luis Balan,Sumeet Betancourt, Mercedes Carcamo, Karlene Williams),GSMU(Jorge Nabet, koren Sanchez), Fire Management(Raul Chun, Edwardo Pott,Shanelly Balan), Landscape Restoration Desk (Minerva Gonzales), Sustainable Forest Management (Florencia Guerra). Science for Sustainability-Dr. Pevical Cho, CfRN (Milena Nino, Lucila Balam, Javier Fernandez, Marcial Arias), MRV Hub (Brittany Meighan).

In the case of lands uses converted to forest land, the difference between new Land Use – previous Land use was estimated, but the recovery of DOM C stocks in forest lands was estimated to take 20 years, as per Tier 1 assumptions.

$$\Delta C_{DOM} = (A \bullet (DOM_{AFTER} - DOM_{BEFORE}) \bullet CF) / 20$$

Once the 20 years are met, the Tier 1 assumption of F>F is applied.

Change in Carbon stock in soils in land converted to a new land category (IPCC Equation 2.25, Ch2, V4)

$$\Delta CMineral = \frac{(SOCo - SOC_{o-t})}{D}$$

$$\Delta SOC = \sum_{c,s,i} \{(SOC_{REF} * F_{LU} * F_{MG} * F_I * A)\}$$

Where,

ΔCMineral = annual change in carbon stocks in mineral soils, tonnes C yr-1

SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C

SOC$_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C

T = number of years over a single inventory time period, yr

D = Time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr.

c = represents the climate zones, s the soil types, and i the set of management systems that are present in a country.

SOC_{REF} = the reference carbon stock, tonnes C ha-1 FLU = stockchangefactorforland-usesystemsorsub-systemforaparticularland-use,dimensionless

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha.

The soil information was obtained from the Global Soil Organic Carbon Map -GSOCmap-, from FAO (2019) through the following portal web address: https://earthmap.org/. The country was selected, and the information was downloaded. The result of the process is a TIFF file. TIFF image processing was performed in QGIS Desktop version 3.1.6(Figure 24).

Belize has land use information obtained through the Land Use Assessment described in the activity data section. Thus, the objective is to link the SOC information for each of the plots, which will then allow the SOC ref value to be assigned by land use and land use subcategories. The TIFF image was processed with the Samples Raster Values tool for the process of linking the Collect Earth plots to the SOC raster (TIFF).

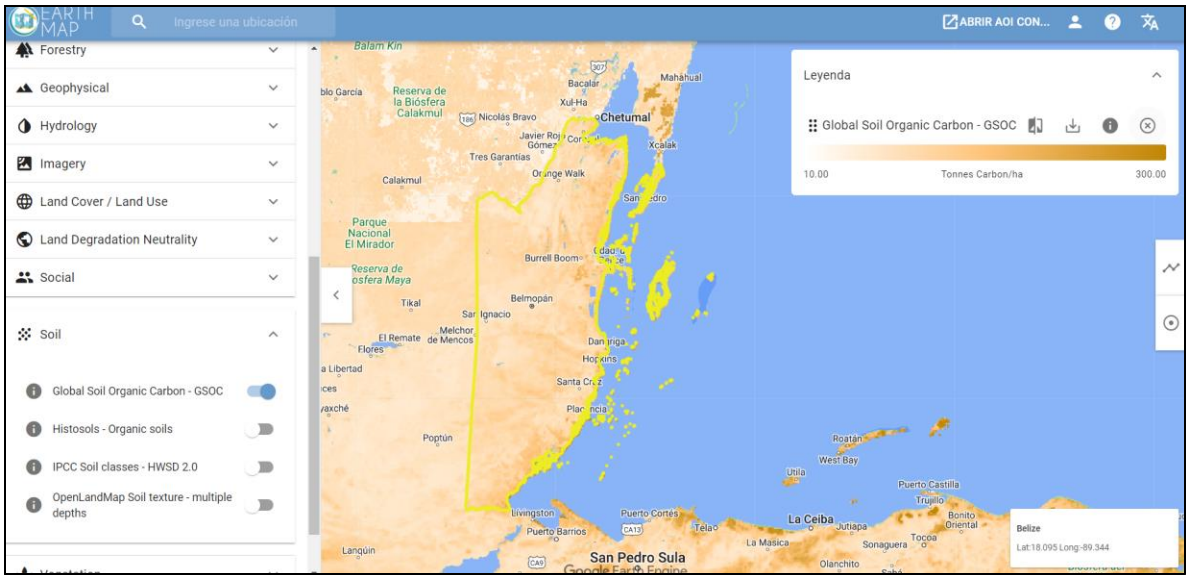


Figure 24: Global Soil Organic Carbon Map -GSOCmap-, from FAO (2019)

As a result, a CVS file containing the SOC reference values (Table 25) for each sampling point is generated. The information was saved as a CSV file. The information is then organized by land use and subcategory and an average value is estimated.

Mangroves use the value provided by Belize Blue Carbon, Belize Rookeries, Beer Twin Caye, ERI University of Belize, and the Forest Department studies (section 4.8)

The following stock change factor for management regime, input and land use were used, taken from the default values of the IPCC 2006, Vol 4, Ch 4, pg 4.40.

Table 25: SOC reference values

Notation	*SOC*	*FLU*	*FMG*	*FI*	*SOC_0+1*

Parameter	Soil	Factor for land use systems	Factor for management regime	Factor for input of organic matter	*to use in eq. 2.25
Units	**t C ha-1**	**Dimensionless**	**Dimensionless**	**Dimensionless**	**Dimensionless**
Forestlands					
Mature Broadleaf Forest (MBL)	105.40	1.00	1.00	1.00	105.40
Secondary Broadleaf Forest (SBL)	97.28	1.00	1.00	1.00	97.28
Pine Forest (PINE)	87.69	1.00	1.00	1.00	87.69
Mangroves (MAN)	319.5	1.00	1.00	1.00	131.24
Forest Plantations (PLANTF)	102.69	1.00	1.00	1.00	102.69
Croplands					
Croplands, Swidden farming-Remaining , Annual (CSHIFTAGR)	96.41	0.83	1.00	1.00	80.02
Croplands, Intensive agriculture-Remaining, Perennial, (INTAGR)	90.75	1.01	1.00	1.00	91.66
Croplands, Follow land -Remaining (CFALL)	94.20	0.82	1.04	0.92	73.90
Grasslands					
Pasture (GPAST)	84.78	1.00	1.00	1.00	84.78
Shrubs (GSHRUB)	104.35	1.00	1.00	1.00	104.35
Savannah Open (GSAVOPEN)	107.93	1.00	1.00	1.00	107.93
Savannah with shrubs (GSAVSHRUB)	103.48	1.00	1.00	1.00	103.48
Savannah with trees (GSAVTREE)	100.86	1.00	1.00	1.00	100.86
Sub-mountainous (GSUBM)	102.76	1.00	1.00	1.00	102.76
Ferns and thickets (GFT)	87.66	1.00	1.00	1.00	87.66
Grassland abandoned (GABDP)	84.78	1.00	1.00	1.00	84.78
Wetlands					
Wetland (WWET)	0.00	0.00	0.00	0.00	0.00
Inland Water Bodies(WIWB)	0.00	0.00	0.00	0.00	0.00
Settlements					
City (SC)	0.00	0.00	0.00	0.00	0.00
Town (STOWN)	0.00	0.00	0.00	0.00	0.00
Village (SV)	0.00	0.00	0.00	0.00	0.00
Other (SO)	0.00	0.00	0.00	0.00	0.00
Road (SR)	0.00	0.00	0.00	0.00	0.00
Mining (SM)	0.00	0.00	0.00	0.00	0.00
Aquaculture (SAQC)	0.00	0.00	0.00	0.00	0.00
Other Infrastructure (SOI)	0.00	0.00	0.00	0.00	0.00
Other lands					
Other lands (OBS)	0.00	0.00	0.00	0.00	0.00
Other lands (OROCK)	0.00	0.00	0.00	0.00	0.00

Equation 2.25 was only applied in land use conversions. For lands converted to Forest or Forest lands converted to other land uses, the D was considered to be 20 years, as per Tier 1 assumptions (IPCC 2006, Vol 4, Ch 2).

4.8.9 Non- CO2 Emissions

This section provides information for estimating carbon stock changes and non-CO2 emissions resulting from fires in the Forest Land (including those resulting from forest conversion) and non-CO2 emissions in the Grasslands. Emissions in croplands were not estimated (Table 26).

Estimation of Greenhouse Gas Emissions from Fire (IPCC Equation 2.27, Ch2, V4)

$$L_{fire} = A \bullet MB \bullet C_f \bullet G_{ef} \bullet 10^{-3}$$

Where:

Lfire = amount of greenhouse gas emissions from fire, tonnes of each GHG (CH_4, N_2O).
A = area burnt, ha
MB = mass of fuel available for combustion, tonnes ha^{-1}.
Cf = combustion factor, dimensionless
Gef = emission factor, g kg-1 dry matter burnt

Table 26: Estimation of GHG from Fires

		*MB * Cf*	*Gef CH4*	*Gef N2O*
LU	**Sub-Category**	**Mass of fuel available for combustion * Combustion factor**	**Emission factor- CH4**	**Emission factor- N2O**
		t c ha^{-1}	g kg-1 dry matter burnt	g kg-1 dry matter burnt
FL	Broad-leaf Mature Forest	100.72	6.80	0.20
	Broad-leaf Secondary Forest	90.23	6.80	0.20
	Pine Forest	55.12	6.80	0.20
	Mangroves	60.60	6.80	0.20

	Plantations	60.00	6.80	0.20
GL	Pastures/	5.61	2.30	0.21
	Shrubs (GSHRUB)	4.74	2.30	0.21
	Savannah Open (GSAVOPEN)	2.88	2.30	0.21
	Savannah with shrubs (GSAVSHRUB)	4.74	2.30	0.21
	Savannah with trees (GSAVTREE)	9.14	2.30	0.21
	Sub-mountainous (GSUBM)	2.60	2.30	0.21
	Ferns and thickets (GFT)	2.00	2.30	0.21
	Grassland abandoned (GABDP)	22.18	2.30	0.21

Clarification Notes:

- *MB* Cf* was calculated as Biomass (Bw) multiplied by the Fraction of Disturbance due to fires (Fd)
- Emission factors for CH4 and N2O were taken from 2006 IPCC, V4, Ch2, Table 2.

5. RESULTS

Through the land use assessment campaign, Belize identified annual land use changes for the six IPCC land use classes and sub-categories of land use. Areas are presented in table 27.

Table 27: Annual land use area [Ha].

For the improved resolution see the FP.

Area per land use [ha]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Mature Broadleaf Forest	1,391,034	1,388,922	1,383,192	1,378,266	1,374,145	1,370,626	1,366,102	1,361,277	1,354,642	1,349,213	1,341,372	1,328,806	1,319,959	1,313,223	1,305,985	1,296,837	1,286,683	1,279,043	1,272,408	1,263,059
Secondary Broadleaf Forest	60,419	59,715	59,212	58,408	57,503	56,397	55,493	54,688	53,985	53,080	51,672	50,667	48,858	47,752	45,942	44,434	42,524	41,318	43,228	43,429
Forest Plantations	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,407	1,307	1,307	1,307	1,307	1,307	1,307	1,307	1,206	1,206	1,206
Mangrove	73,890	73,890	73,890	73,789	73,890	73,890	73,789	73,789	73,990	73,990	73,890	73,890	73,890	73,890	73,990	73,990	73,990	74,091	74,091	73,890
Pine Forest	37,196	36,593	36,191	36,090	36,090	36,090	36,090	35,990	35,990	35,990	35,789	35,185	35,185	35,185	35,085	35,085	35,085	34,884	34,884	34,783
Swidden farming	30,762	31,365	32,773	34,281	35,588	36,693	37,598	38,503	39,106	40,111	40,815	42,022	42,826	43,127	43,831	44,334	45,942	47,350	48,254	49,059
Intensive Agriculture	105,054	106,160	107,567	108,773	109,980	110,885	112,191	114,202	116,916	119,329	121,842	127,774	133,001	137,927	142,049	144,361	147,980	149,991	151,901	155,419
Fallow land	1,608	1,608	2,212	2,815	3,016	3,519	4,021	4,825	7,841	8,344	9,550	11,360	12,667	13,270	15,180	19,000	21,111	22,619	22,117	22,921
Pasture	104,652	105,657	107,869	110,281	112,191	114,001	116,213	118,625	119,530	121,943	126,768	131,694	135,213	137,324	140,038	143,758	148,583	152,605	154,615	158,335
Shrubland	39,408	39,408	39,408	39,307	39,106	39,106	38,905	38,905	38,905	38,604	38,503	38,201	38,000	37,900	37,900	37,799	37,799	37,799	37,799	37,799
Open Savannah	38,000	38,000	37,900	37,799	37,799	37,799	37,598	37,799	37,799	37,799	37,799	37,799	37,699	37,297	36,794	36,794	36,593	36,593	36,593	36,492
Savannah with scattered shrubs	94,699	94,699	94,498	94,197	94,197	94,197	94,096	94,197	94,197	94,197	94,197	94,297	94,197	93,895	93,694	93,493	93,493	93,493	93,493	93,593
Savannah with scattered trees	34,180	34,180	34,180	34,180	34,180	34,180	34,180	34,180	34,180	34,180	34,080	34,080	34,080	34,080	33,979	33,979	33,879	33,879	33,678	33,476
Sub-mountainous grassland	3,016	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116	3,116
Ferns/Thickets	12,064	12,466	12,868	12,968	12,968	12,968	12,968	13,069	13,069	13,069	13,169	13,672	13,672	13,672	13,773	13,773	13,773	13,974	13,974	13,974
Wetland	103,847	103,847	103,847	103,847	103,747	103,747	103,747	103,646	103,445	103,445	103,345	103,345	103,345	103,345	103,244	103,244	103,244	103,144	103,043	103,043
Inland Water Bodies	43,228	43,228	43,328	43,328	43,328	43,328	43,328	43,328	43,328	43,328	43,328	43,328	43,328	43,228	43,127	42,926	42,926	42,926	42,926	42,926
City	2,413	2,413	2,513	2,513	2,614	2,614	2,614	2,614	2,614	2,614	2,614	2,614	2,614	2,714	2,714	2,714	2,815	2,815	2,815	2,815
Town	4,021	4,021	4,021	4,021	4,021	4,021	4,021	4,021	4,122	4,122	4,222	4,222	4,222	4,222	4,222	4,222	4,323	4,323	4,323	4,423
Village	18,095	18,095	18,296	18,397	18,498	18,498	18,699	18,699	18,900	19,000	19,201	19,302	19,302	19,402	19,603	20,005	20,307	20,307	20,609	20,910
Other infrastructure	1,508	1,508	1,508	1,508	1,608	1,810	2,413	2,413	2,413	2,513	2,513	2,513	2,513	2,714	2,915	3,016	3,016	3,016	3,217	3,317
Road	1,106	1,106	1,106	1,106	1,106	1,106	1,106	1,206	1,206	1,206	1,206	1,206	1,206	1,206	1,307	1,407	1,407	1,407	1,407	1,407
Mining	603	603	603	603	704	704	804	804	804	804	804	905	905	905	905	905	1,005	1,005	1,106	1,206
Aquaculture	3,116	3,317	3,820	4,323	4,323	4,222	4,222	3,317	3,116	3,116	3,217	2,815	2,915	3,217	3,116	3,116	2,714	2,614	2,513	2,312
Other Settlement	5,127	5,127	5,127	5,127	5,328	5,529	5,730	5,831	5,831	5,831	6,032	6,233	6,333	6,434	6,534	6,736	6,736	6,836	7,037	7,439
Beaches/Sand dunes	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503	503
Rocks	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101	101
Total general	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**	**2,210,956**

Forestland changed from 1,563,841 Ha in 2001 to 1,416,317 Ha in 2020. Forestlands represents 71% cover in 2001 to 64% in 2020.

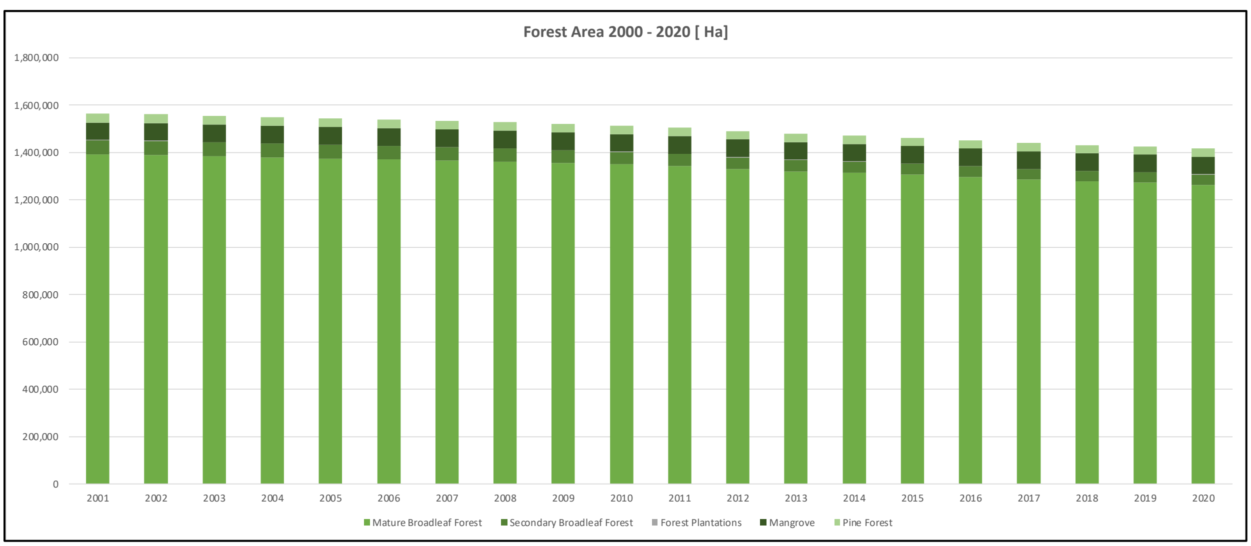


Figure 25: Forest Area 2000-2020 per [ha]

Belize boasts extensive and diverse forests, encompassing tropical rainforests, pine forests, and hardwood forests. The forestry sector plays a crucial role, involving activities such as timber extraction and the collection of non-timber forest products. The government is committed to sustainable forest management, recognizing the ecological importance of these ecosystems. The forests are home to a rich biodiversity, including various species of flora and fauna. Conservation efforts, ecotourism initiatives, and community involvement contribute to the preservation of Belize's forests. Sustainable forestry practices are aimed at balancing economic interests with environmental conservation, ensuring the long-term health and viability of these valuable natural resources.

The average deforestation rate is 8,022 Ha, with the highest deforestation in 2011 (14,878) and the lowest in 2001. The total area of forest lost in 20 years was 160,446 Ha (Table 25). The main drivers of deforestation were forest lands converted to Croplands (80,355 Ha) and Grasslands (68, 461 Ha) ((Figure 28).

Table 28: Forestland converted to Otherland.
For the improved resolution see the FP.

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Area [ha]	F>C	F>G	F>W	F>S	F>O
2001	1,709	1608	0	101	0
2002	3,317	3,016	0	402	0
2003	3,217	2,513	0	201	0
2004	2,513	2,011	0	503	0
2005	2,312	2,011	0	302	0
2006	2,614	2,413	0	704	0
2007	2,915	2,714	0	201	0
2008	4,624	2,513	0	201	0
2009	3,619	2,714	0	201	0
2010	3,921	5,630	0	302	0
2011	8,143	6,333	0	402	0
2012	6,836	3,921	0	101	0
2013	5,630	2,513	0	302	0
2014	5,429	3,820	0	101	0
2015	5,529	5,027	0	402	0
2016	6,736	5,328	0	302	0
2017	4,624	4,624	0	0	0
2018	4,122	2,714	0	201	0
2019	5,630	3,921	0	704	0
2020	2,915	3,116	0	0	0

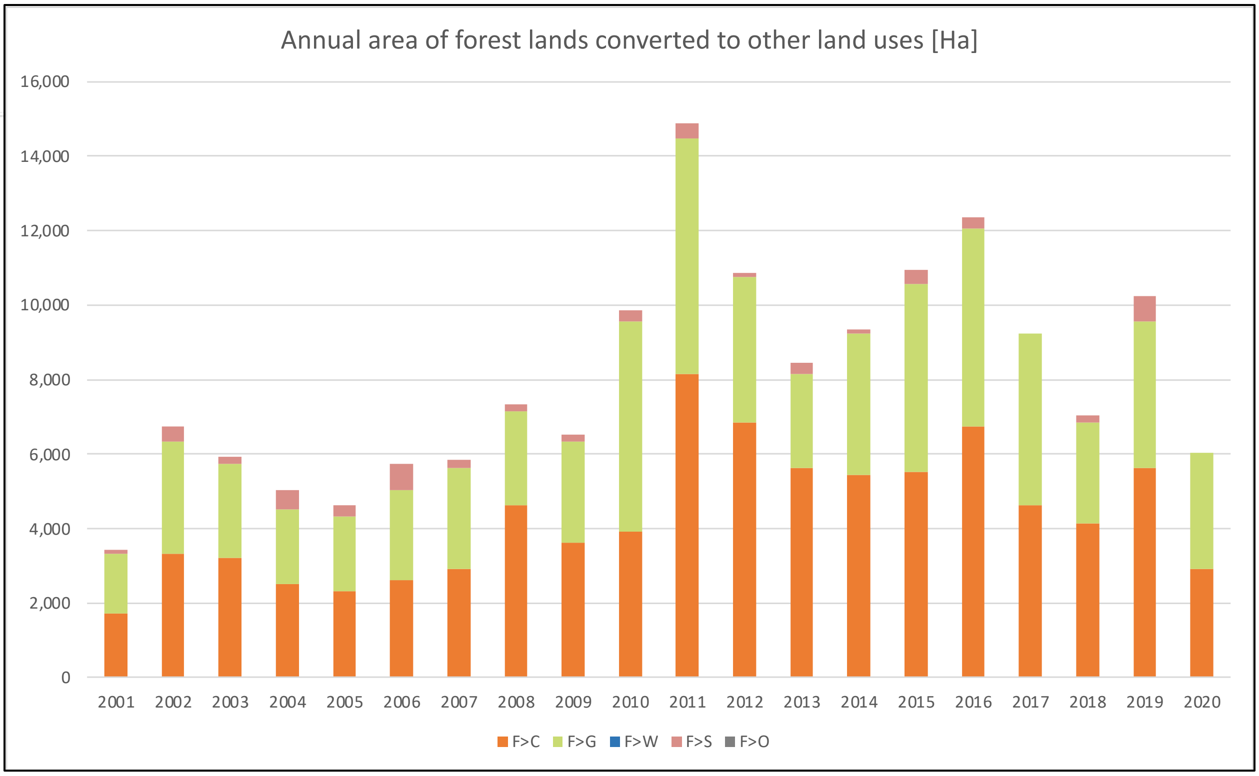


Figure 26: Annual area of Forest lands converted to other land uses.

Belize's economy is characterized by a variety of socio-economic activities, with agriculture playing a significant role through the cultivation of products such as sugar, citrus fruits, and livestock. The tourism industry is on the rise, drawing visitors with its diverse ecosystems and historical sites. Fisheries contribute to both local consumption and exports, while forestry focuses on the sustainable management of the country's extensive forests. Belize is exploring its energy resources, including limited oil reserves and renewable sources. Manufacturing is a smaller sector, with products like food, textiles, and clothing. The government is actively working on policies to foster sustainable development and economic diversification, recognizing the susceptibility of the economy to global factors.

Figure 26 also shows the correlation that exists between hurricanes and land use conversions. As previously explained, Hurricanes exacerbate fire risks by increasing debris accumulation on the forest floor. Once the fires happen, the land is cleared and people tend to use the land for agriculture or livestock.

The following figure shows where the main land use changes happened between 2000 and 2020 (figure 27).

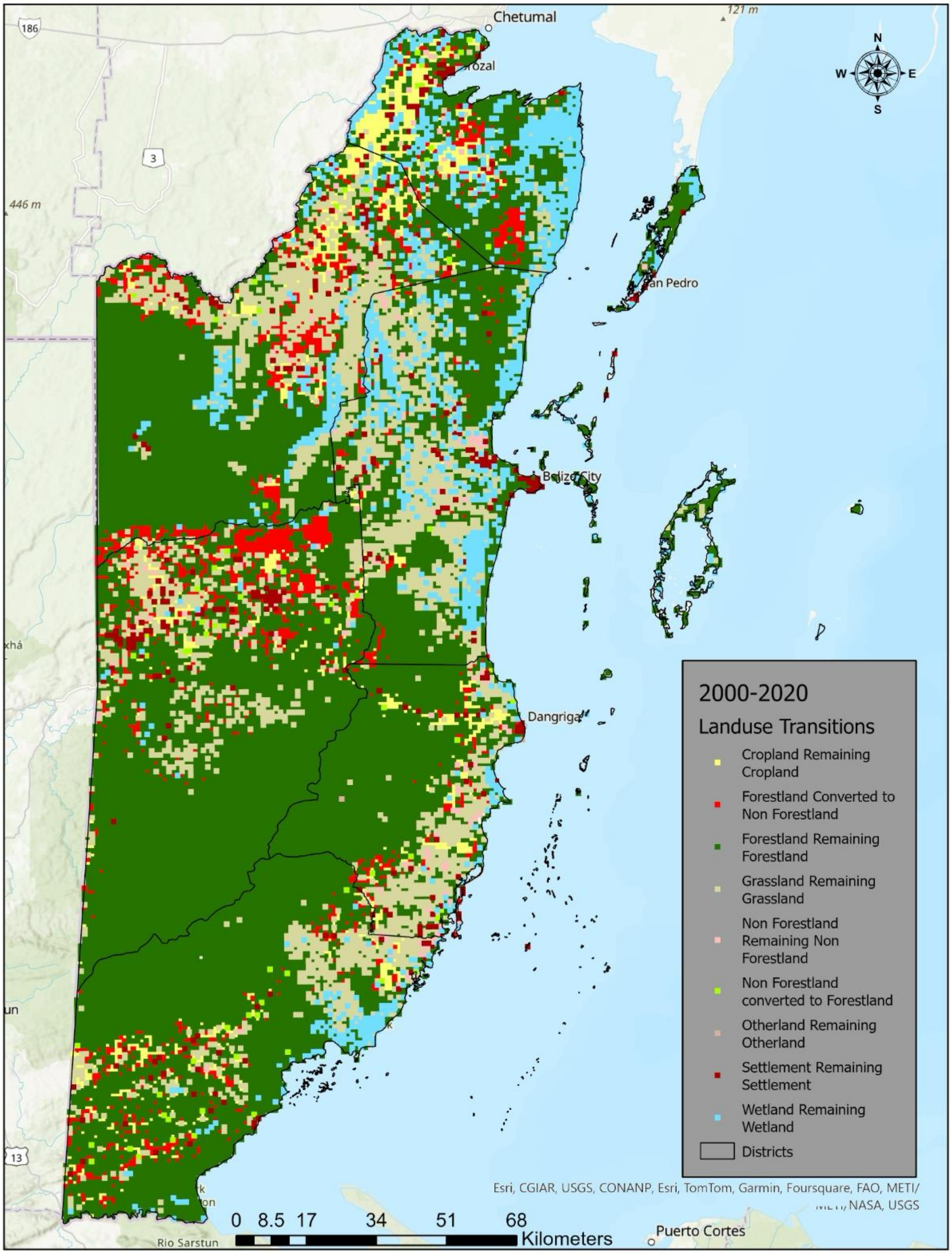


Figure 27: Landuse Transitions between 2000-2020.

Table 29: The area of Forest Land affected by disturbances.

For the improved resolution see the FP.

Area of Forest lands affected by disturbances 2000 - 2020 [Ha])	Fire	Grazing	Hurricane	Infraestructura/ Other Human Impact	Logging	Mining	Pest	Shifting Cultivation
2000	3116	302	503	1910	603	0	503	2815
2001	5730	101	37397	603	603	0	804	1307
2002	13672	704	1810	1206	503	0	0	3016
2003	10757	402	0	1206	402	101	0	2815
2004	2614	201	101	704	201	0	0	704
2005	6736	402	0	905	603	0	0	804
2006	7138	101	101	1307	402	0	0	1608
2007	10757	101	5831	905	503	0	0	1307
2008	4725	302	101	603	402	0	0	2915
2009	3820	603	101	1106	704	0	0	1106
2010	8746	603	29254	1206	1106	0	0	1910
2011	36593	503	905	1206	1206	0	0	2614
2012	6937	302	0	804	905	0	0	1407
2013	5630	302	0	302	804	0	0	3016
2014	3921	201	0	402	704	0	0	1910
2015	3418	302	0	804	1810	0	0	2011
2016	6836	503	5328	1206	2815	0	0	2513
2017	10656	905	0	1005	2714	0	0	2413
2018	3820	503	101	804	1508	0	0	1910
2019	9550	905	0	2614	2915	0	101	3619
2020	17693	201	2413	1608	1508	0	0	3016

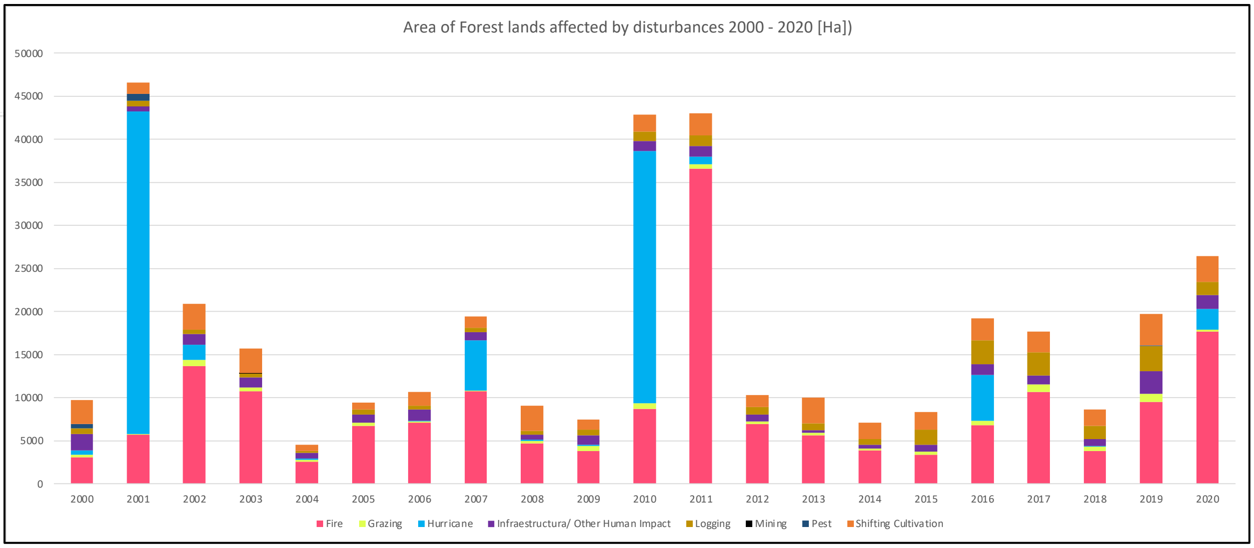


Figure 28 Area of Forest lands affected by disturbances 2000-2020.

In Belize, deforestation and forest degradation are driven by a combination of factors. Agricultural expansion for crops and livestock, unsustainable logging practices, and infrastructure development, including roads and tourism projects, contribute significantly to forest loss. Urbanization and the expansion of cattle ranching further exacerbate deforestation, as does the potential impact of climate change on the health of the forests. Illegal logging, land encroachment, and uncontrolled wildfires, often linked to human activities, pose additional threats. Efforts to address these challenges involve a mix of policies, regulations, and sustainable land-use practices, with an emphasis on responsible forestry, biodiversity conservation, and community engagement. The government and conservation organizations strive to balance economic development with the preservation of Belize's diverse and valuable ecosystems through measures aimed at promoting sustainable development and international collaborations.

Over the years, several hurricanes have impacted the country, causing varying degrees of damage. Notable hurricanes include Hurricane Janet in 1955, which struck as a Category 5 storm, causing extensive destruction. In 2000, Hurricane Keith hit Belize as a Category 4 hurricane, leading to severe flooding and infrastructure damage. In October 2010, Hurricane Richard, a Category 2 hurricane, made landfall just south of Belize City. With maximum sustained winds of around 90 mph, the storm brought heavy rainfall, strong winds, and storm surge to Belize. Widespread flooding occurred, affecting communities and causing damage to homes, infrastructure, and agriculture. In 2016, Hurricane Earl, a Category 1 storm, caused significant damage to crops and infrastructure(Table 26). Belize has experienced other hurricanes and tropical storms, highlighting the country's vulnerability to these weather events. The government and local communities implement measures to enhance preparedness and resilience in the face of tropical cyclones, recognizing the importance of mitigating the impact of these natural disasters on the population and infrastructure(Figure 28).

Historical GHG emissions of CO2, CH4 and N2O are reported for the period 2001–2020 associated with Forest land remaining forest land, land converted to Forest land, and Forest land conversion(Table 27). AGB, BGB, DOM, SOC and non-CO2 gases (CH4, N2O) from biomass burning were included (see table 28).

Table 30: Historical GHG emissions of CO2, CH4 and N2O & AGB, BGB, DOM, SOC and non-CO2 gases (CH4, N2O). **For the improved resolution see the FP.**

Land use categories & GHGi coverage in terms of C pools and gases

FOREST LANDS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

CROPLANDS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

GRASSLANDS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

WETLANDS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

SETTLEMENTS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

OTHER LANDS

CARBON POOLS INCLUDED	ABG	BGB	Litter	DW	SOC
	x	x	x	x	x

GASES INCLUDED	CO2	CH4	N2O	HFC	PFC	SF6	NF3	NOx	SO2	COVNM	CO
	x	x	x	NA	NA	NA	NA	NA	NA	NA	NA

Notation Key	
NA	NOT APLICABLE
NE	NO ESTIMATED
NO	NOT OCCUR
IE	INCLUDED ELSEWHERE

6. DESCRIPTION FOR GHGI TOOL

The foundational platform tool for Belize's National Greenhouse Gas (GHG) inventory comprises multiple sheets, encompassing an introduction, manual, activity database, emission factors, calculation sheets (Gains, Losses, Conversions), carbon pools, and a results sheet. This calculation spreadsheet serves as an annex to Belize's National GHG Inventory Report (NIR), which is included in the country's Second Biennial Update Report (BUR) and, concurrently, establishes the cornerstone for the nation's singular GHG inventory dataset.

All greenhouse gas data is precisely compiled within this unified spreadsheet, ensuring comprehensive consistency in terms of data, methodologies, and national expert’s input. Utilizing MS Excel, the chosen platform maximizes transparency, providing a clear and accessible overview of every calculation integral to Belize's national inventory totals. This strategic approach not only aligns with international reporting standards but also fosters a robust foundation for transparency and accuracy in Belize's greenhouse gas accounting processes.

6.1 Introductory Sheet

The introductory sheet (Figure 29) furnishes comprehensive information, encompassing details such as country contacts, covered, and a description outlining the information explanations of the pools and gases incorporated in each respective sheet.

Belize

Land Use, Land Use Change and Forestry Greenhouse gas (GHG) Inventory

and

REDD+ Reference Level and REDD+ Results

Date	29-Dec-23
Version	V2

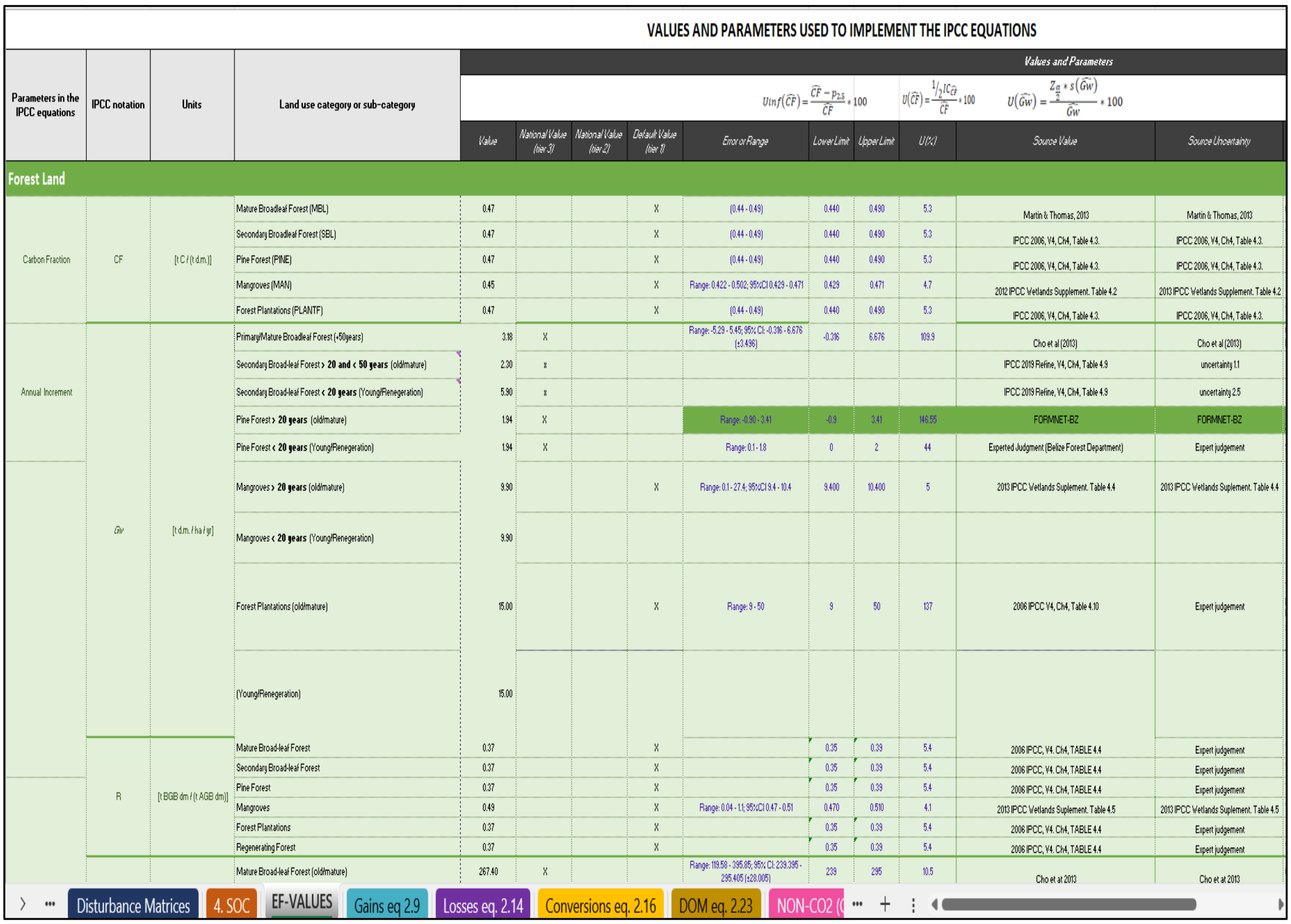
Contact Information and Focal Points

Contact	Name	Email	Institution/Department
Focal point REDD+	Lennox Gladden	coord.cc@environment.gov.bz	National Climate Change Office
Technical Lead FRL/ REDD+TA	Edgar Correa	gsmu.ecorrea@forest.gov.bz	Forest Department
GHG Inventory Officer	Edalmi Grijalva	edalmi.grijalva@environment.gov.bz	Forest Department
Emission Factor Officer	Sumeet Betancourt	sumeet.betancourt@environment.gov.bz	Forest Department
Data/Field Technician	Luis Balan	luis.balan@environment.gov.bz	Forest Department
Activity Data Lead Officer	Karlene Williams	williamska@gobmail.gov.bz	Forest Department
Data/Field Technician	Mercedes Carcamo	mercedes.carcamo@environment.gov.bz	Forest Department

Figure 29: The Introduction sheet in the GHGI Tool of Belize including contact information for focal points. **For the improved resolution see the FP.**

6.2 Emission factor-Values Sheet

EF Values Sheet (Figure 30) serves the purpose of compiling all values and parameters used to implement the IPCC equations necessary for conducting the calculations outlined in the IPCC 2019/2006 guidelines, particularly focusing on specific variables for Chapter 4. An emission factor is a critical component of this sheet, representing the relationship between the amount of greenhouse gases emitted and the activity or process causing those emissions. Information is sourced on a country-specific basis whenever possible; otherwise, default values from the IPCC or scientific papers are employed. The sheet includes carbon factor, Litter Stocks, Ratio, Soil Organic Carbon, source value, source uncertainty and comment/assumptions, providing a comprehensive framework for accurate and transparent calculations.



VALUES AND PARAMETERS USED TO IMPLEMENT THE IPCC EQUATIONS

Values and Parameters

$$Uinf(\widetilde{CF}) = \frac{\widetilde{CF} - p_{2.5}}{\widetilde{CF}} * 100 \qquad U(\widetilde{CF}) = \frac{1/2 IC_{\widetilde{CF}}}{\widetilde{CF}} * 100 \qquad U(\widetilde{Gw}) = \frac{Z_{\frac{\alpha}{2}} * s(\widetilde{Gw})}{\widetilde{Gw}} * 100$$

Parameters in the IPCC equations	IPCC notation	Units	Land use category or sub-category	Value	National Value (tier 3)	National Value (tier 2)	Default Value (tier 1)	Error or Range	Lower Limit	Upper Limit	U(%)	Source Value	Source Uncertainty
Forest Land													
Carbon Fraction	CF	[t C / (t d.m.)]	Mature Broadleaf Forest (MBL)	0.47			X	(0.44 - 0.49)	0.440	0.490	5.3	Martin & Thomas, 2013	Martin & Thomas, 2013
			Secondary Broadleaf Forest (SBL)	0.47			X	(0.44 - 0.49)	0.440	0.490	5.3	IPCC 2006, V4, Ch4, Table 4.3.	IPCC 2006, V4, Ch4, Table 4.3.
			Pine Forest (PINE)	0.47			X	(0.44 - 0.49)	0.440	0.490	5.3	IPCC 2006, V4, Ch4, Table 4.3.	IPCC 2006, V4, Ch4, Table 4.3.
			Mangroves (MAN)	0.45			X	Range: 0.422 - 0.502; 95%CI 0.429 - 0.471	0.429	0.471	4.7	2012 IPCC Wetlands Supplement. Table 4.2	2013 IPCC Wetlands Supplement. Table 4.2
			Forest Plantations (PLANTF)	0.47			X	(0.44 - 0.49)	0.440	0.490	5.3	IPCC 2006, V4, Ch4, Table 4.3.	IPCC 2006, V4, Ch4, Table 4.3.
Annual Increment	Gw	[t d.m. / ha / yr]	Primary/Mature Broadleaf Forest (+50years)	3.18	X			Range: -5.29 - 5.45; 95% CI: -0.316 - 6.676 (±3.496)	-0.316	6.676	109.9	Cho et al (2013)	Cho et al (2013)
			Secondary Broad-leaf Forest **> 20 and < 50 years** (old/mature)	2.30	x							IPCC 2019 Refine, V4, Ch4, Table 4.9	uncertainty 1.1
			Secondary Broad-leaf Forest **< 20 years** (Young/Renegeration)	5.90	x							IPCC 2019 Refine, V4, Ch4, Table 4.9	uncertainty 2.5
			Pine Forest **> 20 years** (old/mature)	1.94	X			Range: -0.90 - 3.41	-0.9	3.41	146.55	FORMNET-BZ	FORMNET-BZ
			Pine Forest **< 20 years** (Young/Renegeration)	1.94	X			Range: 0.1 - 1.8	0	2	44	Experted Judgment (Belize Forest Department)	Expert judgement
			Mangroves **> 20 years** (old/mature)	9.90			X	Range: 0.1 - 27.4; 95%CI 9.4 - 10.4	9.400	10.400	5	2013 IPCC Wetlands Suplement. Table 4.4	2013 IPCC Wetlands Suplement. Table 4.4
			Mangroves **< 20 years** (Young/Renegeration)	9.90									
			Forest Plantations (old/mature)	15.00			X	Range: 9 - 50	9	50	137	2006 IPCC V4, Ch4, Table 4.10	Expert judgement
			(Young/Renegeration)	15.00									
	R	[t BGB dm / (t AGB dm)]	Mature Broad-leaf Forest	0.37			X		0.35	0.39	5.4	2006 IPCC, V4. Ch4, TABLE 4.4	Expert judgement
			Secondary Broad-leaf Forest	0.37			X		0.35	0.39	5.4	2006 IPCC, V4. Ch4, TABLE 4.4	Expert judgement
			Pine Forest	0.37			X		0.35	0.39	5.4	2006 IPCC, V4. Ch4, TABLE 4.4	Expert judgement
			Mangroves	0.49			X	Range: 0.04 - 1.1; 95%CI 0.47 - 0.51	0.470	0.510	4.1	2013 IPCC Wetlands Suplement. Table 4.5	2013 IPCC Wetlands Suplement. Table 4.5
			Forest Plantations	0.37			X		0.35	0.39	5.4	2006 IPCC, V4. Ch4, TABLE 4.4	Expert judgement
			Regenerating Forest	0.37			X		0.35	0.39	5.4	2006 IPCC, V4. Ch4, TABLE 4.4	Expert judgement
			Mature Broad-leaf Forest (old/mature)	267.40	X			Range: 119.58 - 395.85; 95% CI: 239.395 - 295.405 (±28.005)	239	295	10.5	Cho et at 2013	Cho et at 2013

Figure 30: Example of the EF- Values and parameters used to implement the IPCC equations.
For the improved resolution see the FP.

6.3 AD-Database Sheet:

This Database sheet (Figure 31) pertains to extraction of raw data from the Total LUA app, encompassing unique IDs for all plots, information on Land Use per year, Year of Land Use Change, multi-disturbances per plots and years of Disturbance.

extId	projectName	userEmail	long	lat	collectionTime	flagged	QAFlagged	confidence	code	Reassessed	2000-main	2000-sub	2000-disturbance	2000-degradation	2001-main	2001-sub	2001-disturbance	2001-degradation	2002-main
BEL00001	Koren	gsmu.ksanche	-89.0878	15.93171	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00002	Jafet	patja@gobma	-89.1251	15.92231	Mon Aug 07 2(	FALSE	TRUE	TRUE	F/MBL/Cultivation_2000		Forestland	Mature Broad	Shifting Cultiv	70	Forestland	Mature Broadleaf Forest			Forestland
BEL00003	Karlene	williamska@g	-89.1252	15.93135	Mon Jul 10 20	FALSE	TRUE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00004	Daril	daril.avila@g	-89.1252	15.93135	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00005	Koren	gsmu.ksanche	-89.1159	15.93144	Mon Jul 10 20	FALSE	TRUE	TRUE	FC/MBL>CSHIFTAGR_2010/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00007	Jahied	jaharmstrong:	-89.1065	15.93153	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00008	Luis	luis.balan@er	-89.0972	15.93162	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00009	Mercedes	mkarycar@gm	-89.116	15.94047	Thu Aug 03 20	FALSE	TRUE	TRUE	FCC/MBL>CSHIFTAGR_2013>CFALL_2020/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00011	Jahied	jaharmstrong:	-89.1066	15.94057	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00012	Jorge	gsmu.jnabet@	-89.0973	15.94066	Mon Jul 10 20	FALSE	TRUE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00013	Hector	hectorcucul23	-89.1069	15.96767	Mon Jul 10 20	FALSE	TRUE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00014	Hector	hectorcucul23	-89.1163	15.97661	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00015	Jahied	jaharmstrong:	-89.107	15.9767	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00016	Edalmi	edalmigrijalva	-89.173	16.03026	Mon Jul 10 20	FALSE	FALSE	TRUE	FC/MBL>CSHIFTAGR_2005/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00017	Daril	daril.avila@g	-89.1174	16.07599	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/DFire_2002		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00018	Daril	daril.avila@g	-89.108	16.07608	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00019	Hector	hectorcucul23	-89.08	16.07635	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00020	Jorge	gsmu.jnabet@	-89.0707	16.07644	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00021	Jorge	gsmu.jnabet@	-89.0613	16.07653	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00022	Edalmi	edalmigrijalva	-89.052	16.07662	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/Cultivation_2019		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00023	Karlene	williamska@g	-89.1175	16.08502	Mon Jul 10 20	FALSE	FALSE	TRUE	F/SBL/		Forestland	Secondary Broadleaf Forest			Forestland	Secondary Broadleaf Forest			Forestland
BEL00024	Mercedes	mkarycar@gm	-89.0614	16.08557	Mon Jul 10 20	FALSE	FALSE	TRUE	FC/MBL>CSHIFTAGR_2003/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00025	Hector	hectorcucul23	-89.0521	16.08566	Mon Aug 14 2(	FALSE	FALSE	TRUE	F/MBL/Cultivation_2015		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00026	Jafet	patja@gobma	-89.1273	16.1301	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00027	Melvin	xis.melvin@gr	-89.1181	16.13923	Mon Jul 10 20	FALSE	FALSE	TRUE	FC/MBL>CSHIFTAGR_2015/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00028	Koren	gsmu.ksanche	-89.0808	16.14863	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/Cultivation_2008		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00029	Serena	serenareyes68	-89.0714	16.14872	Mon Aug 14 2(	FALSE	FALSE	TRUE	F/MBL/DLogging_2015		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00030	Jorge	gsmu.jnabet@	-89.1463	16.15701	Mon Jul 10 20	FALSE	TRUE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00031	Edalmi	edalmigrijalva	-89.0995	16.15748	Mon Jul 10 20	FALSE	FALSE	TRUE	FC/MBL>CSHIFTAGR_2004/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00032	Koren	gsmu.ksanche	-89.0902	16.15757	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/Cultivation_2008		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00033	Jorge	gsmu.jnabet@	-89.0809	16.15766	Mon Jul 10 20	FALSE	FALSE	TRUE	FC/MBL>CSHIFTAGR_2013/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00034	Karlene	williamska@g	-89.0715	16.15775	Mon Jul 10 20	FALSE	FALSE	TRUE	F/SBL/Cultivation_2000,Cultivation_2010,Cultivation_2017		Forestland	Secondary Bro	Shifting Cultiv	30	Forestland	Secondary Broadleaf Forest			Forestland
BEL00035	Luis	luis.balan@er	-89.0622	16.15784	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00036	Hector	hectorcucul23	-89.1464	16.16605	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/DHuricane_2001		Forestland	Mature Broadleaf Forest			Forestland	Mature Broad	Huricane	100	Forestland
BEL00037	Daril	daril.avila@g	-89.137	16.16614	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00038	Mercedes	mkarycar@gm	-89.1277	16.16624	Mon Jul 10 20	FALSE	FALSE	TRUE	F/MBL/Cultivation_2009		Forestland	Mature Broadleaf Forest			Forestland	Mature Broadleaf Forest			Forestland
BEL00039	Luis	luis.balan@er	-89.1183	16.16633	Tue Oct 03 20:	FALSE	TRUE	TRUE	C/CSHIFTAGR/	TRUE	Cropland	Swidden farming			Cropland	Swidden farming			Cropland
BEL00040	Koren	gsmu.ksanche	-89.109	16.16642	Mon Oct 09 2(	FALSE	FALSE	TRUE	C/CSHIFTAGR/	FALSE	Cropland	Swidden farming			Cropland	Swidden farming			Cropland
BEL00041	Serena	serenareyes68	-89.0996	16.16651	Mon Jul 10 20	FALSE	FALSE	TRUE	C/CSHIFTAGR/		Cropland	Swidden farming			Cropland	Swidden farming			Cropland
BEL00042	Luis	luis.balan@er	-89.0903	16.16661	Thu Jul 13 202	FALSE	FALSE	TRUE	F/MBL/Cultivation_2000		Forestland	Mature Broad	Shifting Cultiv	10	Forestland	Mature Broadleaf Forest			Forestland
BEL00043	Mercedes	mkarycar@gm	-89.0809	16.1667	Mon Jul 10 20	FALSE	TRUE	TRUE	G/GPAST/		Grassland	Pasture			Grassland	Pasture			Grassland
BEL00044	Karlene	williamska@g	-89.0716	16.16679	Tue Oct 03 20:	FALSE	FALSE	TRUE	G/GPAST/	TRUE	Grassland	Pasture			Grassland	Pasture			Grassland

Figure 31: Example of AD-Database Sheet in the GHGI Tool of Belize.

For the improved resolution see the FP.

6.4 AD-PlotSum(Pivot):

This sheet pertains to a coding system designed to consolidate plots with identical land use or land use change characteristics from the LUA app. Its purpose is to account for plots exhibiting similar Land Use and Land Use change transitions, systematically analysed on a national scale, year by year, and for each sampling plot within the timeframe of 2000 to 2020 using the LUA app. The sheet incorporates a Pivot Table that tallies the codes outlined in the AD-Database, providing a detailed description of each code along with the distribution of plots categorized by IPCC classification and status, delineating between Land Remaining in the Same Category, Land Remaining in the Same Category with disturbances and Land Converted to Another Category. In addition, the Pivot table content color code to identify the different land use categories (refer to figure 32).

These codes represent singular trajectories in land use or land use change, specifically crafted to streamline the analysis by significantly reducing the number of plots subject to IPCC equation application. The Pivot Table function within the sheet consolidates the data from 21,993 plots, categorizing them into identical land use and land use change "trajectories" or situations through the application of the assigned codes. To execute this process, one can utilize the "Insert" function, initiate a Pivot Table, select "code" from the AD-Database, and proceed to count the rows, thus providing a consolidated overview of the coded trajectories.

A) LAND REMAINING		
F/MBL/	9913	996553.89
F/SBL/	171	17190.63
F/PINE/	115	11560.95
F/MAN/	711	71476.83
F/PLANTF/	7	703.71
C/CSHIFTAGR/	249	25031.97
C/INTAGR/	934	93895.02
CC/CSHIFTAGR>CFALL_2013/	1	100.53
CC/CSHIFTAGR>CFALL_2014/	3	301.59
CC/CSHIFTAGR>CFALL_2015/	4	402.12
CC/CSHIFTAGR>CFALL_2016/	1	100.53
CC/CSHIFTAGR>CFALL_2017/	4	402.12
CC/CSHIFTAGR>CFALL_2018/	2	201.06
CC/CSHIFTAGR>CFALL_2020/	2	201.06
CC/CSHIFTAGR>CFALL_2021/	2	201.06
CC/CSHIFTAGR>CFALL_2023/	1	100.53
CCC/CSHIFTAGR>CFALL_2003>CSHIFTAGR_2013/	1	100.53
CCC/CSHIFTAGR>CFALL_2005>CSHIFTAGR_2011/	1	100.53
CCC/CSHIFTAGR>CFALL_2010>CSHIFTAGR_2015/	1	100.53
CC/INTAGR>CFALL_2008/	1	100.53
CCC/INTAGR>CFALL_2008>INTAGR_2011/	1	100.53
CCC/INTAGR>CFALL_2008>INTAGR_2015/	1	100.53
CC/INTAGR>CFALL_2009/	1	100.53
CC/INTAGR>CFALL_2011/	1	100.53
CC/INTAGR>CFALL_2012/	1	100.53
CCC/INTAGR>CFALL_2012>INTAGR_2022/	1	100.53
CCC/INTAGR>CFALL_2013>INTAGR_2020/	1	100.53
CC/INTAGR>CFALL_2014/	4	402.12
CCC/INTAGR>CFALL_2014>INTAGR_2023/	1	100.53
CC/INTAGR>CFALL_2015/	20	2010.6
CC/INTAGR>CFALL_2016/	4	402.12
CC/INTAGR>CFALL_2017/	4	402.12
CC/INTAGR>CFALL_2018/	3	301.59
CCC/INTAGR>CFALL_2018>INTAGR_2019/	1	100.53
CCC/INTAGR>CFALL_2018>INTAGR_2023/	1	100.53
CC/INTAGR>CFALL_2019/	4	402.12
CC/INTAGR>CFALL_2020/	5	502.65
CC/INTAGR>CFALL_2021/	3	301.59
CC/INTAGR>CFALL_2022/	1	100.53
CC/INTAGR>CFALL_2023/	1	100.53
G/GPAST/	850	85450.5
G/GSHRUB/	268	26942.04
G/GSAVOPEN/	142	14275.26
G/GSAVSHRUB/	493	49561.29
G/GSAVTREE/	174	17492.22
G/GSUBM/	14	1407.42
G/GFT/	36	3619.08
GG/GPAST>GABDP_2009/	1	100.53

2b. Transitions-Matrix | 2c.Disturbances | 3a. AD- Database | 3c. Pivot AD | LUC Matrices

Figure 32: Example of Pivot activity data Sheet in the GHGI Tool of Belize.

For the improved resolution see the FP.

The subsequent sheets serve as foundational calculation sheets for the six IPCC land use categories. These categories are delineated across distinct sheets, specifically designed for gains (equation 2.9), losses (equation 2.14), conversions (equation 2.16), dead organic matter, non-CO2 emissions (CH4 & N2O), and Soil Organic carbon. Each of these sheets is organized into three primary sections with supporting tables:

1. Land Remaining in the Same Category (Undisturbed)
2. Land Remaining in the Same Category (Disturbed)
3. Land Conversions

These sections systematically examine and categorize the complex dynamics within each land use category, providing a comprehensive framework for a subtle examination of undisturbed and disturbed land scenarios, along with a detailed analysis of land conversions.

The supporting tables in the calculation sheets are as follows:

Emission Factors: The values presented here mirror those in the "EF-Values" sheet. The rationale behind reiterating them in the header of this sheet is to facilitate a more straightforward review of the equations and calculations within the cells.

Activity Data: The values displayed in this section are identical to those found in the "AD-Plot Sum" sheet. This repetition in the header of this sheet aims to enhance the ease of reviewing both equations and calculations within the cells.

Color Code Section: This section is specifically used to identify and differentiate between various land categories. The table below displays the corresponding color codes. This section is specifically used to identify and differentiate between various land categories. The table below displays the corresponding color codes (Table 31).

Table 31: Showing color code for land categories in the GHGI Tool of Belize. (For improved resolution to the FP sheet)

ColorCodes
MBL
SBL
PINE
MAN
PLANTF
CFALL
CSHIFTAGR
INTAGR
GSAVTREE
GSAVSHRUB
GSAVOPEN
GSHRUB
GPAST
GFT
GABDP
GSUBM
WWET
WIWB
SC
STOWN
SV
SO
SR
SM
SAQC
SOI
OBARS
OROCK
OBS

Color Groups Section:

Table 32 below illustrates the color groups within this section, serving the purpose of macro color-coding commands to categorize the levels of disturbances. Group 1 indicates no regeneration, and Group 2 indicates regeneration.

Table 32: Table xxx of group color code for disturbances (For improved resolution to the FP sheet)

CodeGroups			
Group1	Group2	Pest	Fire
DInfra	DHur	DPest	DFire
DMin	DLog		
DAgri			

Table 33: Code code for group 1, group 2, Pest and Fire.

ColorCodes
FirstGroup1
FirstGroup2
FirstPest
FirstFire

Section 1 Emission and Removal Factors (ERF): This is where the application and calculation of emissions and removal factors for forest lands, specifically those remaining as forest lands (in the Remaining/No Disturbance category), are carried out.

Section 2 ERF: Applied Emissions and removal factors for Forest lands remaining Forest lands (Remaining / with disturbance category). This section relates to Forest Land Remaining Forest Land affected by disturbances such as hurricanes, fires, logging, and others. This section is divided into groups:

In Group 1, the fraction of biomass lost in the first disturbance (refer to Table 32 above) includes the ERF code, parameters, and forest categories, detailing the fraction of biomass disturbances for Group 1. It also provides information on the fraction of biomass lost in the second disturbance of Group 1.

In Group 2, the following metrics are outlined: the fraction of forest removed due to the first disturbance of Group 2(refer to Table 32 above), the fraction of forest removed due to additional disturbances in Group 2, and the fraction of biomass lost due to the first disturbance of Group 2. This information encompasses ERF codes, parameters, and forest categories, along with details about the fraction of biomass disturbances for Group 1 and the fraction of biomass for second disturbances.

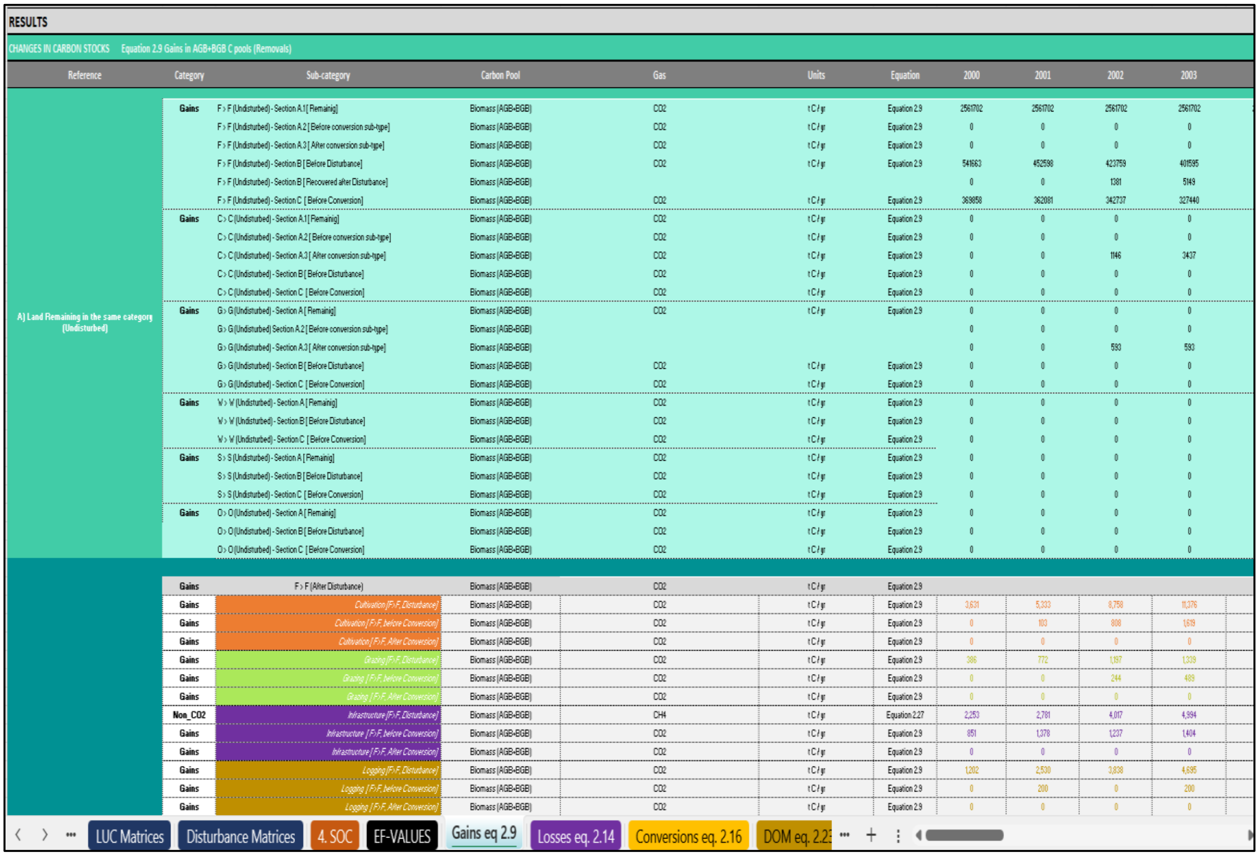
Regeneration from Croplands includes Fallow land - Remaining (CFALL), and for Grassland, it involves Grassland abandonment (GABDP). This considers the percentage regenerated in the first year of disturbance and the percentage regenerated after the year of disturbance.

Pest Section: covers the fraction of forest removed due to the initial pest disturbance, the fraction of forest removed due to additional pest disturbances, the fraction of biomass lost in the initial pest disturbance, and the fraction of AGB transferred to DOM.

Fire Section: covers the fraction of forest removed due to the initial fire disturbance, the fraction of forest removed due to additional fire disturbances, the fraction of biomass lost due to fires, the percentage regenerated after the year of disturbance, and the fraction of DOM loss due to fires.

6.5 Gains equation 2.9 Sheet:

This sheet (figure 33) includes several sections described above, along with calculations for all land remaining in the same category undisturbed, land remaining in the same category with disturbance and land conversion for gains in AGB and BGB carbons pools removals for changes in carbon stock.



RESULTS

CHANGES IN CARBON STOCKS   Equation 2.9 Gains in AGB+BGB C pools (Removals)

Reference	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2000	2001	2002	2003
A) Land Remaining in the same category (Undisturbed)	Gains	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	2561702	2561702	2561702	2561702
		F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	541663	452598	423759	401595
		F > F (Undisturbed) - Section B [Recovered after Disturbance]	Biomass (AGB+BGB)				0	0	1381	5149
		F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	369858	362081	342737	327440
	Gains	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	1146	3437
		C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)				0	0	0	0
		G > G (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)				0	0	593	593
		G > G (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	S > S (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		S > S (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		S > S (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	O > O (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		O > O (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
		O > O (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	F > F (After Disturbance)	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9				
	Gains	Cultivation [F>F, Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	3,631	5,333	8,758	11,376
	Gains	Cultivation [F>F, before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	103	808	1,619
	Gains	Cultivation [F>F, After Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	Grazing [F>F, Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	386	772	1,197	1,339
	Gains	Grazing [F>F, before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	244	489
	Gains	Grazing [F>F, After Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Non_CO2	Infrastructure [F>F, Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	2,253	2,781	4,017	4,994
	Gains	Infrastructure [F>F, before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	851	1,378	1,237	1,404
	Gains	Infrastructure [F>F, After Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0
	Gains	Logging [F>F, Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	1,202	2,530	3,838	4,695
	Gains	Logging [F>F, before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	200	0	200
	Gains	Logging [F>F, After Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.9	0	0	0	0

Figure 33: Example of Gains Eq. 2.9 Sheet in the GHGI Tool for Belize (For improved resolution to the FP sheet)

6.6 Losses equation 2.14:

This sheet (figure 34) includes several sections described above, along with calculations for all land remaining in the same category undisturbed, land remaining in the same category with disturbance and land conversion for losses in AGB and BGB carbons pools removals for changes in carbon stock.

RESULTS - EMISSIONS [AGB, BGB]

CHANGES IN CARBON STOCKS Equation 2.14 Losses in AGB+BGB C pools

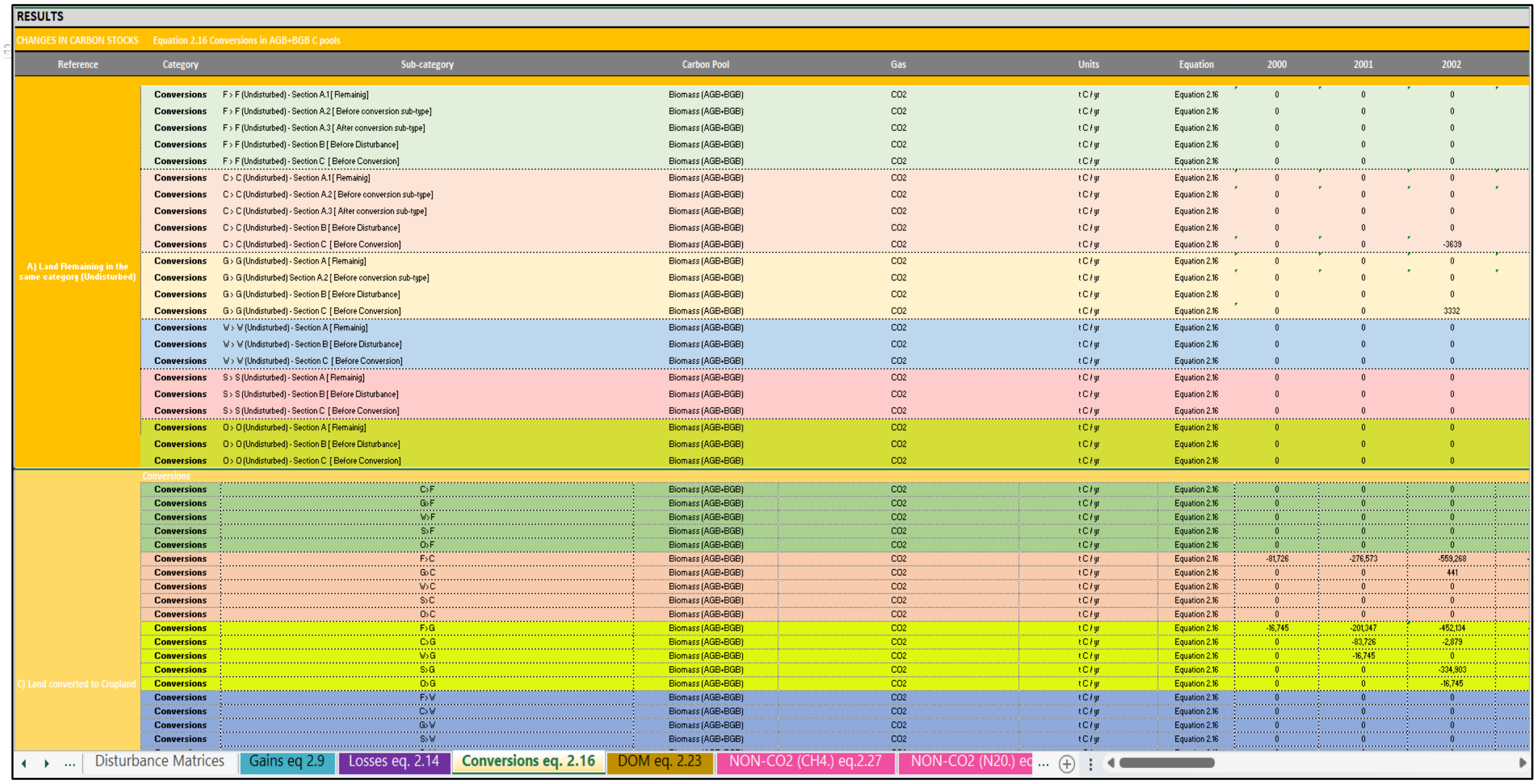
Reference	Category	Sub-category	Carbon Pool	2000	2001	2002	2003	2004	2005
A) Land Remaining in the same category (Undisturbed)	Losses	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0
		F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0
		F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0
		F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0
		F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	5389	0	0
	Losses	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0
		C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0
		C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0
		C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0
		C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0
		G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0
		G > G (Undisturbed) - Section B [Before Disturbance]		0	0	0	0	0	0
		G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0
		W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0
		W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	0	0	0
C) Land converted to Cropland	Losses	C>F	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	G>F	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	W>F	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	S>F	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	O>F	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	F>C	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	G>C	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	W>C	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	S>C	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	O>C	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	F>G	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	C>G	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	W>G	Biomass (AGB+BGB)	0	0	564	0	0	0
	Losses	S>G	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	O>G	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	F>W	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	C>W	Biomass (AGB+BGB)	0	0	0	0	0	0
	Losses	G>W	Biomass (AGB+BGB)	0	0	0	0	0	0

Disturbance Matrices | Gains eq 2.9 | Losses eq. 2.14 | Conversions eq. 2.16 | DOM eq. 2.23 | NON-CO2 (CH4.) eq.2.27 | NON-CO2 (N20.) ec...

Figure 34. Example of Losses Sheet in the GHGI Tool for Belize (For improved resolution to the FP sheet)

6.7 Conversions equation 2.16 section:

This sheet (Figure 35) incorporates several sections as described above, including calculations for all land that remains in the same category undisturbed, land that remains in the same category with disturbance, and land conversion for changes in AGB and BGB carbon pools. This section refers to the IPCC 2006/2019 guidelines, Volume 4, Chapters 2 (Generic methodologies applicable to multiple land-use categories), Conversion Equation 2.16 for all other land use categories.



RESULTS

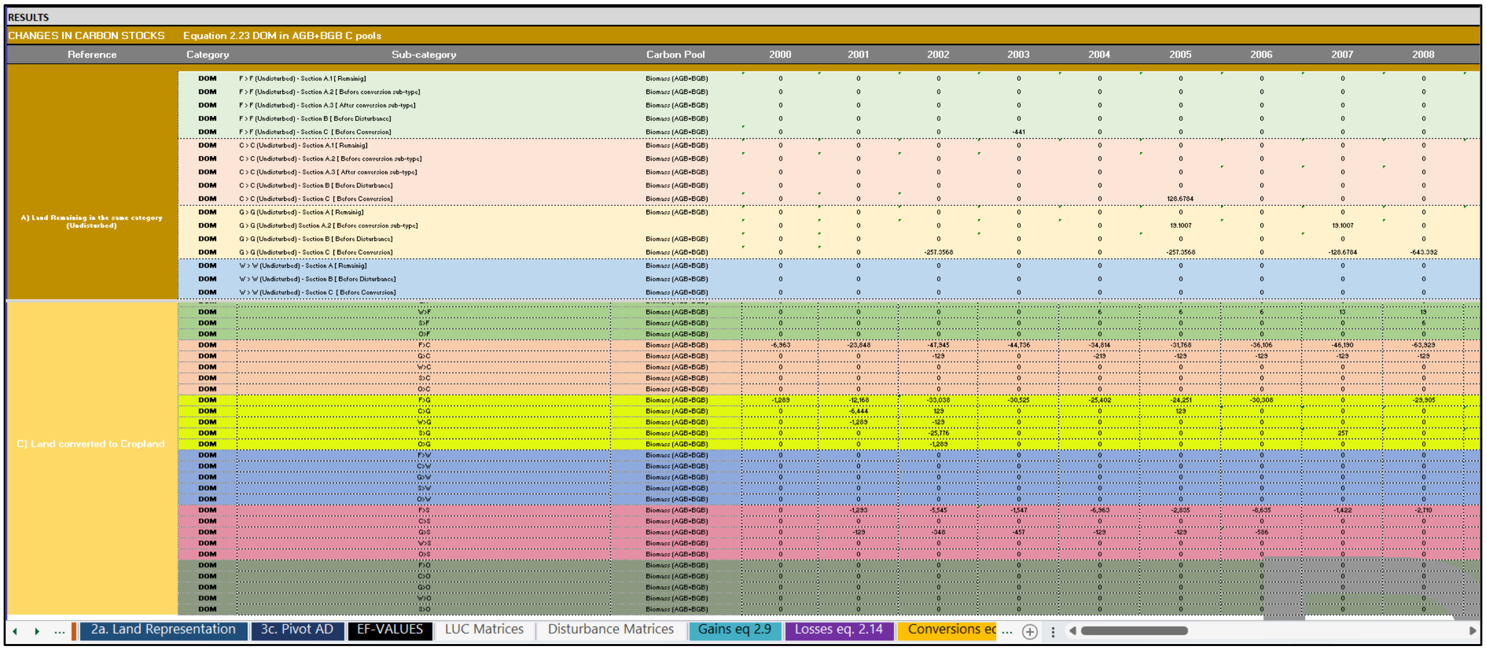
CHANGES IN CARBON STOCKS — Equation 2.16 Conversions in AGB+BGB C pools

Reference	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2000	2001	2002
A) Land Remaining in the same category (Undisturbed)	Conversions	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	-3639
	Conversions	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	G > G (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	3332
	Conversions	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S > S (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S > S (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S > S (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	O > O (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	O > O (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	O > O (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions								
C) Land converted to Cropland	Conversions	C>F	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	G>F	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	W>F	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S>F	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	O>F	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F>C	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	-81,726	-276,573	-559,268
	Conversions	G>C	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	441
	Conversions	W>C	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S>C	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	O>C	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	F>G	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	-16,745	-201,347	-452,134
	Conversions	C>G	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	-83,726	-2,879
	Conversions	W>G	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	-16,745	0
	Conversions	S>G	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	-334,903
	Conversions	O>G	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	-16,745
	Conversions	F>W	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	C>W	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	G>W	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0
	Conversions	S>W	Biomass (AGB+BGB)	CO2	t C / yr	Equation 2.16	0	0	0

Figure 35: Example of Conversions Sheet in the GHGI Tool of Belize
(For improved resolution to the FP sheet**)**

6.8 Dead Organic Matter (DOM) Equation 2.23

This sheet (Figure 36) incorporates several sections as described above, including calculations for all land that remains in the same category undisturbed, land that remains in the same category with disturbance, and DOM for changes in AGB and BGB carbon pools. This section refers to the IPCC 2006/2019 guidelines, Volume 4, Chapters 2 (Generic methodologies applicable to multiple land-use categories), DOM Equation 2.23 for all other land use categories.



RESULTS

CHANGES IN CARBON STOCKS — Equation 2.23 DOM in AGB+BGB C pools

Reference	Category	Sub-category	Carbon Pool	2000	2001	2002	2003	2004	2005	2006	2007	2008
A) Land Remaining in the same category (Undisturbed)	DOM	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	-441	0	0	0	0	0
	DOM	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	0	0	128.6784	0	0	0
	DOM	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	G > G (Undisturbed) Section A.2 [Before conversion sub-type]		0	0	0	0	0	19.1007	0	19.1007	0
	DOM	G > G (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	-257.3568	0	0	-257.3568	0	-128.6784	-643.392
	DOM	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
C) Land converted to Cropland	DOM	W>F	Biomass (AGB+BGB)	0	0	0	0	6	6	6	13	19
	DOM	S>F	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	6
	DOM	O>F	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F>C	Biomass (AGB+BGB)	-6,963	-23,848	-47,945	-44,736	-34,814	-31,768	-36,106	-46,190	-63,929
	DOM	G>C	Biomass (AGB+BGB)	0	0	-129	0	-219	-129	-129	-129	-129
	DOM	W>C	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	S>C	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	O>C	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F>G	Biomass (AGB+BGB)	-1,289	-12,168	-33,038	-30,525	-25,402	-24,251	-30,308	0	-29,905
	DOM	C>G	Biomass (AGB+BGB)	0	-6,444	129	0	0	129	0	0	0
	DOM	W>G	Biomass (AGB+BGB)	0	-1,289	-129	0	0	0	0	0	0
	DOM	S>G	Biomass (AGB+BGB)	0	0	-25,776	0	0	0	0	257	0
	DOM	O>G	Biomass (AGB+BGB)	0	0	-1,289	0	0	0	0	0	0
	DOM	F>W	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C>W	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	G>W	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	S>W	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	O>W	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F>S	Biomass (AGB+BGB)	0	-1,293	-5,545	-1,547	-6,963	-2,835	-8,635	-1,422	-2,710
	DOM	C>S	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	G>S	Biomass (AGB+BGB)	0	-129	-348	-457	-129	-129	-586	0	0
	DOM	W>S	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	O>S	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	F>O	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	C>O	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	G>O	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	W>O	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0
	DOM	S>O	Biomass (AGB+BGB)	0	0	0	0	0	0	0	0	0

2a. Land Representation | 3c. Pivot AD | EF-VALUES | LUC Matrices | Disturbance Matrices | Gains eq 2.9 | Losses eq. 2.14 | Conversions ec ...

Figure 36: Example of Dead Organic Matter Sheet in the GHGI Tool of Belize

6.9 non-CO2 (CH4) Equation 2.27:

This section refers to IPCC 2006/2019 guidelines, Volume 4, Chapters 2 (Generic methodologies applicable to multiple land-use categories), NON-CO2 (CH4) eq. 2.27 for all other land use categories(Figure 37).

RESULTS

CHANGES IN CARBON STOCKS Equation 2.25 SOC in AGB+BGB C pools

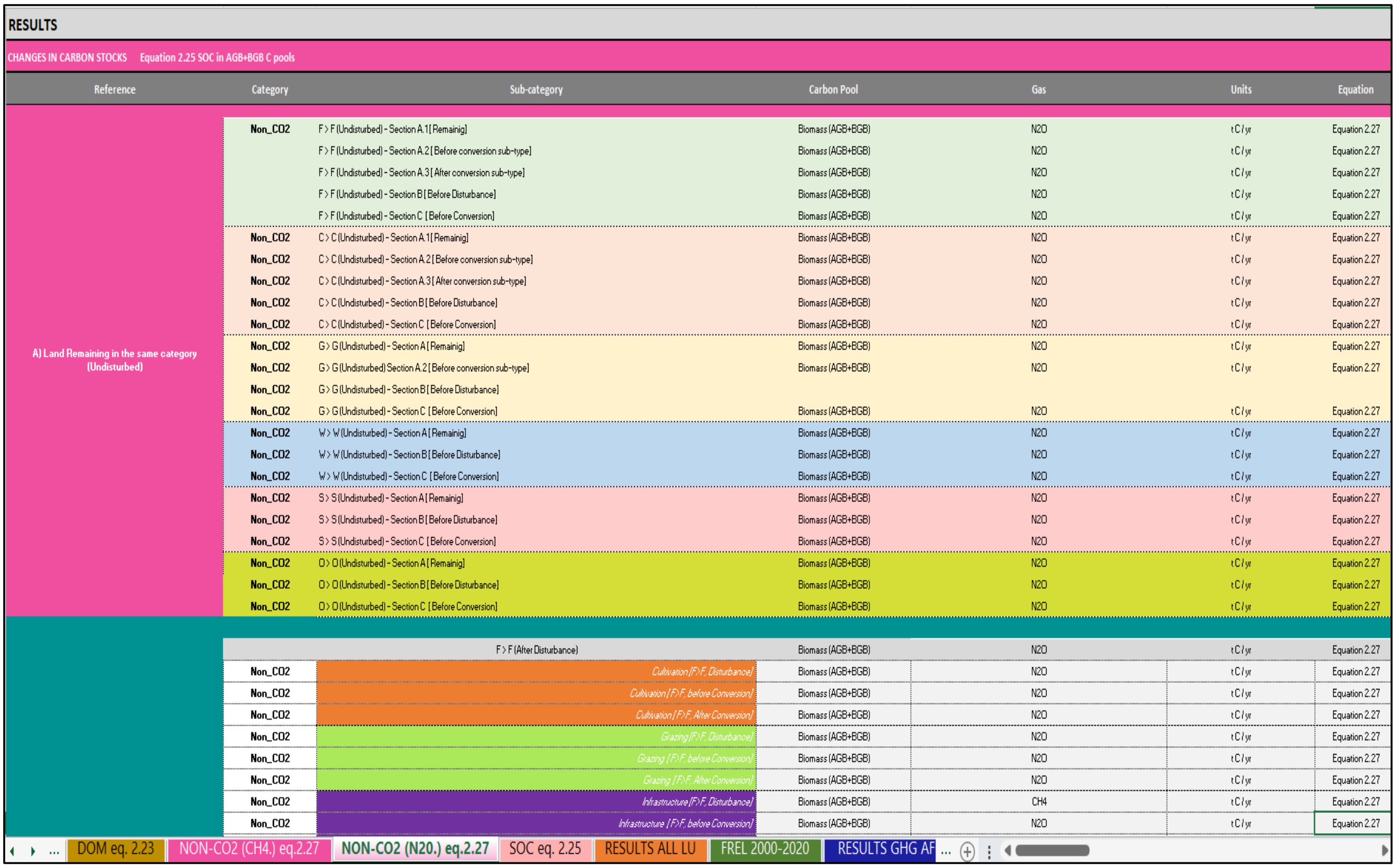
Reference	Category	Sub-category	Carbon Pool	Gas	Units	Equation	2000
A) Land Remaining in the same category (Undisturbed)	Non_CO2	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G > G (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	S > S (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	S > S (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	S > S (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	O > O (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	O > O (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	O > O (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	C>F	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G>F	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	W>F	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	S>F	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	O>F	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F>C	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	G>C	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	W>C	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	S>C	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	O>C	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0
	Non_CO2	F>G	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27	0

2a. Land Representation | 3c. Pivot AD | EF-VALUES | LUC Matrices | Disturbance Matrices | Gains eq 2.9 | Losses eq. 2.14 | Conversions ec ...

Figure 37: Example of Non-CO2 (CH4) eq. 2.27 Sheet in the GHGI Tool of Belize

6.10 Non-CO2 (N2O) eq. 2.27:

This section refers to IPCC 2006/2019 guidelines, Volume 4, Chapters 2 (Generic methodologies applicable to multiple land-use categories), non-CO2 (N2O) eq. 2.27 for all other land use categories (Figure 38).



RESULTS

CHANGES IN CARBON STOCKS Equation 2.25 SOC in AGB+BGB C pools

Reference	Category	Sub-category	Carbon Pool	Gas	Units	Equation
A) Land Remaining in the same category (Undisturbed)	Non_CO2	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
		F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
		F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
		F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
		F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	G > G (Undisturbed) - Section B [Before Disturbance]				
	Non_CO2	G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	S > S (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	S > S (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	S > S (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	O > O (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	O > O (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	O > O (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
		F > F (After Disturbance)	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Cultivation [F>F, Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Cultivation [F>F, before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Cultivation [F>F, After Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Grazing [F>F, Disturbance]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Grazing [F>F, before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Grazing [F>F, After Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27
	Non_CO2	Infrastructure [F>F, Disturbance]	Biomass (AGB+BGB)	CH4	t C / yr	Equation 2.27
	Non_CO2	Infrastructure [F>F, before Conversion]	Biomass (AGB+BGB)	N2O	t C / yr	Equation 2.27

Figure 38: Example of non-CO2 (N2O) Sheet in the GHGI Tool of Belize

6.11 SOC Equation 2.25

This section refers to IPCC 2006/2019 guidelines, Volume 4, Chapters 2 (Generic methodologies applicable to multiple land- use categories), SOC eq. 2.25 for all other land use categories(Figure 39).

RESULTS

CHANGES IN CARBON STOCKS Equation 2.25 SOC in AGB+BGB C pools

Reference	Category	Sub-category	Carbon Pool	2000	2001
A] Land Remaining in the same category [Undisturbed]	SOC	F > F (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	F > F (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0.0
	SOC	F > F (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0.0
	SOC	F > F (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	F > F (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0
	SOC	C > C (Undisturbed) - Section A.1 [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	C > C (Undisturbed) - Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0.0
	SOC	C > C (Undisturbed) - Section A.3 [After conversion sub-type]	Biomass (AGB+BGB)	0	0.0
	SOC	C > C (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	C > C (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0
	SOC	G > G (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	G > G (Undisturbed) Section A.2 [Before conversion sub-type]	Biomass (AGB+BGB)	0	0.0
	SOC	G > G (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	G > G (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0
	SOC	W > W (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	W > W (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	W > W (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0
	SOC	S > S (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	S > S (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	S > S (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0
	SOC	O > O (Undisturbed) - Section A [Remainig]	Biomass (AGB+BGB)	0	0.0
	SOC	O > O (Undisturbed) - Section B [Before Disturbance]	Biomass (AGB+BGB)	0	0.0
	SOC	O > O (Undisturbed) - Section C [Before Conversion]	Biomass (AGB+BGB)	0	0.0

NON-CO2 (CH4.) eq.2.27 | NON-CO2 (N2O.) eq.2.27 | SOC eq. 2.25 | RESULTS ALL LU | FREL 2000-2020 | RESULTS GHG AFOLU 2000-20120

Figure 39: Example of SOC Sheet in the GHGI Tool of Belize

7. Information on Quality Assurance/Quality Control (QA/QC) Procedures

7.1 QA/QC of the data analysis

Quality control process

This section describes the quality control (QC) and quality assurance procedures implemented for the data analysis of the Land use and land use change assessment. For the collection of AD using the Land Use Assessment Application, there were 3 phases identified.

Activity Data Collection

- Phase 1: Having a clear understanding of the quality and the quantity of the data you would like to collect needs to be clear. Having a clear understanding of land use classes and their natural ecological processes is necessary. Furthermore, having a key understanding of the QA/QC activities that would be introduced in the implementation and validation phase. During this phase, a national consultation was done with key stakeholders to endorse this process. The same LU class was used along with its definition as the past FRL/FREL hence national consultation was not necessary for the definitions. As per the land use transition, the national forest experts went over these to ensure the updated transition could be taken into consideration for the development of the survey of the LUA. This phase should clearly be defined and endorsed nationally before moving into phase 2.
- Phase 2: The implementation phase is where the team is assembled, the LUA app is prepared, and the workspace is organized for the Land Use Assessment process. In Belize, a 12-member team focused on classifying total sample plots, including an extra 5% for QA/QC. The lead CFRN consultants reviewed the classification progress after the first week, ensuring accuracy in the operators' work.
- Phase 3: The validation phase served as the primary arena for our Quality Assurance/Quality Control (QA/QC) activities. In Belize, we implemented diverse levels and types of QA/QC processes throughout this phase. In the assessment process, consensus is crucial. The primary validation process involved a weekly routine of extracting data from the LUA app, scrutinizing for impossible transitions and disturbances, and reevaluating inaccurately identified plots. The distribution of plots among team members was implemented to ensure that each member did not validate their own assigned plots for added QA/QC. To rectify misassignments, the data was imported into ArcGIS Pro, enabling the identification of erroneously labelled plots. Through this procedure, 31 plots (table 34) were recognized and subsequently subjected to a re-evaluation process.

Table 34: Plots identified during the QC session with the team using ArcGIS Pro and Planets Imagery.

BEL #	Classification	New Classification
BEL08632	Mangrove	Wetland
BEL09093	Mangrove	Savannah w/ shrub
BEL09468	Mangrove	Savannah w/ shrub
BEL09383	Mangrove	*Ground truthing*
BEL09336	Mangrove	Savannah w/ shrub
BEL09335	Mangrove	Savannah w/ shrub
BEL09234	Mangrove	Savannah w/ shrub
BEL09235	Mangrove	Remain
BEL09236	Mangrove	Remain
BEL09186	Mangrove	Remain
BEL09140	Mangrove	Savannah w/ shrub
BEL11876	Mangrove	Remain
BEL11900	Mangrove	Shrubland
BEL11637	Mangrove	MBL
BEL16941	Mangrove	Remain
BEL16325	MBL	Cropland
BEL11661	MBL	G- Pasture
BEL11758	MBL	G-Pasture
BEL01423	MBL	Remain
BEL01405	MBL	Remain
BEL10464	MBL	Cropland
BEL20358	MBL	G-Pasture
BEL20232	MBL	G-Pasture
BEL20697	MBL	G-Pasture
BEL20751	MBL	G-Pasture

BEL15044	MBL	G-Pasture
BEL13883	MBL	MBL
BEL03403	MBL	MBL disturbed
BEL13517	Open Savannah	Wetland
BEL16977	Open Savannah	Wetland
BEL17606	Open Savannah	Fallow

From the 5% extra plots selected for QC, 795 plots exhibited three different assessments which warranted a reassessment initiative. To streamline this process, the plots were evenly distributed among designated groups, with each group tasked with reassessing 265 plots. In response to this, a distinct "re-assessed" option was integrated into the LUA app. This addition served to clearly distinguish plots that have undergone reassessment from the initial pool of 795, enhancing the overall transparency and efficiency of the assessment procedure (Figure 40).

In the LUA the plots were filtered as follows:

```
// Is there is only 1 value it means that there is no duplicates; return the first one
if (group.length === 1) return group[0];

const code1 = group[0][codeId];
const code2 = group[1][codeId];
const code3 = group[2][codeId];

// If any of the codes from the duplicates match, return one of them
if (code1 === code2 || code1 === code3) return group[0];
if (code2 === code3) return group[1];

const reassessed1 = group[0][reassessedId];
const reassessed2 = group[1][reassessedId];
const reassessed3 = group[2][reassessedId];

// If any of the plots is marked as reassess, return that one
if (reassessed1) return group[0];
if (reassessed2) return group[1];
if (reassessed3) return group[2];

// If all this fails, return the first one from the duplicates, but mark it to be reassessed
return replaceAt(group[0], reassessedId, 'NEEDS REASSESS');
});
```

Figure 40: Quality Control assessment by three operators

The logic follows the following flow:

1. If there is only one plot with the specific extId, that plot is added to the report (it has no duplicates)
2. If at least 2 of the codes of the duplicate plots are the same, the first of those two codes that are the same is taken and added to the report.
3. If the first duplicate plot (sorted by plotId) was marked as Reassessed, this is the one added to the report.

4. If the second duplicate plot (sorted by plotId) was marked as Reassessed, this is the one added to the report

5. If the third duplicate plot (sorted by plotId) was marked as Reassessed, this is the one added to the report.

6. If none of the above is true, the first duplicate plot is added to the report but its value is changed from "Reassessed" to "NEEDS REASSESS"

Table 35: Showing the groups and technical experts selected to do the reassessment

Groups for QC			Number of Plots Assigned
Group 1	Edalmi	Karlene	265
Group 2	Luis	Mercedes	265
Group 3	Koren	Nabet	265

Additionally, 250 plots with impossible transitions and wrongly assigned disturbances were identified and distributed among four of the technical experts for validation (See table 35).

Table 36: Showing the names of technical experts and number of plots assigned to each for reassessment.

Technical Experts	Number of Reassessed Plots Assigned
Mercedes	1 – 63
Luis	64 – 125
Edalmi	126 – 187
Karlene	188 – 250

Simultaneously, 233 plots marked with a "no confidence status" were assigned to technical experts (See Table 36) for cross-validation to reassess the no confidence plots labelled by the operators.

Table 37: Showing the names of technical experts and number of plots assigned to each for reassessment.

Technical Experts	Number of Reassessed Plots Assigned
Mercedes	1 – 60
Luis	61 – 118
Edalmi	119 – 176
Karlene	177 – 233

Finally, upon entering data into the foundational platform, additional plots were identified that warranted re-evaluation as seen in the table below. These steps were essential to ensure the accuracy and reliability of the information captured, further enhancing the integrity of our dataset.

Table 38: Showing the plots extracted from the Foundation Platform for reassessment.

DATE: 10/11/2023		
ID	Code	REASSESSMENT
BEL15451	CC/INTAGR>INTAGR_2012/	C/INTAGR/
BEL13622	CC/INTAGR>INTAGR_2018/	C/INTAGR/
BEL00999	FF/MBL>MBL_2001/	C/CSHIFTAGR/
BEL19621	G/GABDP/	C/INTAGR/
BEL04062	GG/GPAST>GABDP_2002/	G/GPAST/
BEL14207	GG/GPAST>GABDP_2007/	G/GPAST/
BEL14574	GG/GPAST>GABDP_2007/	G/GPAST/
BEL20654	G/GABDP/Grazing _2017	FGG/MBL>GPAST_2015>GABP_2023/
BEL18292	CC/CFALL>INTAGR_2021/	FC/MBL>INTAGR_2019/
BEL12123	CC/CFALL>INTAGR_2023/	GC/GSAVSHRUB>INTAGR_2023
BEL10174	CFC/CFALL>SBL_2010>CSHIFTAGR_2019/	W/WWET/
BEL10171	CF/CFALL>SBL_2011/	C/INTAGR/
BEL10496	CG/INTAGR>GABDP_2018/	CG/INTAGR>CFALL_2018/
BEL20324	CG/INTAGR>GABDP_2019/	CC/INTAGR>CFALL_2019/
BEL01009	CF/CSHIFTAGR>SBL_2011/	F/MBL/Cultivation_2020
BEL11166	CF/CSHIFTAGR>SBL_2011/	F/MBL/
BEL00715	CFF/CSHIFTAGR>SBL_2002>SBL_2021/	FCCF/MBL>CSHIFTAGR_2002>CFALL_2010>SBL_2020/
BEL11466	CGF/CSHIFTAGR>GABDP_2008>SBL_2018/	CCF/CSHIFTAGR>CFALL_2008>SBL_2018/
BEL10943	GF/GPAST>SBL_2006/	F/SBL/
BEL19671	GF/GPAST>SBL_2017/Grazing _2022	G/GPAST/
BEL17814	GCG/GPAST>CSHIFTAGR_2011>GABDP_2023/	G/GPAST/
BEL19327	GC/GABDP>INTAGR_2017/	C/INTAGR/
BEL12936	GW/GPAST>WIWB_2002/	W/WWET/
BEL03201	CC/CSHIFTAGR>CSHIFTAGR_2011/	FC/MBL>CSHIFTAGR_2011/
BEL15416	GG/GPAST>GPAST_2019/	G/GPAST/

8. Improvement Plan

Building off what was presented in Belize's earlier 2001-2015 FRL/FREL, the following updated list of gaps and challenges related to institutional arrangements and legislation for REDD+ has been identified.

8.1 Institutional arrangements

Improve effective and full coordination among institutions involved in REDD+ implementation.

Improved coordination among the range of institutions involved in REDD+ implementation remains a priority, even as progress has been made on that coordination since the publication of the previous FRL.

For instance, the development of the various elements of and inputs to the Zero-FRL has involved coordination with entities outside of the Forest Department and its parent Ministry. That has included coordination with other Ministries and quasi-governmental institutions, as well as with members of the NGO and academic communities. Those institutions have contributed to and participated to some extent in the mapathon activities for the development of the Zero-FRL.

While there is interest by the various institutions in supporting the Zero-FRL activities, collaboration among the institutions has been on an informal basis, and that collaboration could be formalized, and could likely also benefit from the allocation of resources to incentivize that coordination and collaboration.

It is also worth noting that while the Forest Department and the National Climate Change Office maintain key roles for REDD+ implementation, with changes in government administrations, the ministerial home of the Forest Department has changed. The Forest Department currently sits within the Ministry of Sustainable Development, Climate Change, and Disaster Risk Management, but when the previous FRL/FREL was submitted, the Forest Department sat within the Ministry of Forestry, Fisheries, Environment, and Sustainable Development. Some of the mandates for Belize's blue carbon resources, in contrast, are under the auspices of the Ministry of Blue Economy and Civil Aviation which was created in late 2020. As the formalization of the Measuring, Reporting and Verification Program within the Forest Department in 2020, it is important to continue the expansion and of this program that would enhance the collaboration among other institutions as mentioned above.

8.2 Capacity building

Strengthening monitoring and evaluation of national activities

While the Zero-FRL has concentrated on sample-based estimations of land cover and use changes throughout Belize, the Forest Department recognizes the potential of machine learning and AI. This technology presents an opportunity to achieve comprehensive wall-to-wall monitoring, a challenge and priority. Such monitoring holds the promise of early detection and warning systems for changes, aligning to prevent deforestation.

Furthermore, various Forest Department personnel have been trained over the years in land cover mapping and automated monitoring of land cover change. That would allow for supplementing the existing sample-based framework being used.

Institutions in Belize such as the Forest Department have also made use of archives of open data which have allowed for inventorying land cover change across decades. This includes access to the Landsat archive (1972-present), the Copernicus Sentinel-2 archive (2015-present), and access to very high spatial resolution Planet / NICFI bi-annual and monthly mosaics (Dec. 2015-present).

Institutional data exchanges and archiving

While the Forest Department is responsible for implementing Belize's NFMS and components of the GHGI, a range of national institutions contribute data relevant to the NFMS and the GHGI. As indicated in section 7.1 above, institutional arrangements for data sharing could be formalized to ensure smoother collaboration on the collection, sharing, and archiving of the relevant data. Conducting climate change-related research is also a priority.

Partnerships

Since the inception of the earlier FRL/FREL, collaborative opportunities with international partners have significantly expanded. Alongside ongoing capacity-building collaborations with the UN Food & Agriculture Organization (FAO) and the Coalition for Rainforest Nations (CfRN), the Forest Department has actively pursued partnerships with prominent entities such as the NASA/USAID SERVIR program, the U.S. Government's SilvaCarbon program, and the Global Forest Observations Initiative (GFOI) under the intergovernmental Group on Earth Observations (GEO), where Belize holds a founding membership.

Though not directly contributing to the current Zero-FRL development, in late 2023, the Forest Department and its partners conducted a training activity in collaboration with the SERVIR program. This initiative aimed to bolster the capacities of national institutions in monitoring land cover changes. Additionally, plans are underway for a focused capacity-building collaboration with the SilvaCarbon program, set to commence in 2024, albeit with a limited scope.

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