Developing a framework and methodology to carbon sinks from the forestry sector in Samoa

Deliverable 3.7_Presentation of the Model

NATIONAL INSTITUTE OF GREEN TECHNOLOGY

MINISTRY OF NATURAL RESOURCES AND ENVIRONMENT

KU-Samoa Workshop
for the Capacity Building

How to Build National Inventory using Earth Observation: Focusing on Forest and Land-use Classification

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NATIONAL INSTITUTE OF GREEN TECHNOLOGY

Ministry of Natural Resources and Environment
Matagaluega o Punaoa Faalenatura ma le Siosiomaga

Contents

01. IPCC guidelines and LULUCF

- Importance of NDC and National GHGI
- Estimation of LULUCF using IPCC Guideline
- Major considerations for Estimation: Approach and Tier

Importance of NDC and National GHGI (Greenhouse Gas Inventory)

Nationally Determined Contribution

- Paris Agreement has every parties report the Nationally Determined Contribution (NDC) to UNFCCC every five years.
- NDC includes the national strategy and plan for climate change mitigation and adaptation.
- "Land use and Forest management" become highlighted as one of ways to achieve mitigation target in NDC because according to IPCC 6th report, one of the main three carbon emission drivers was deforestation and forest degradation.
- Therefore, appropriate "Land use and Forest management" could contribute to climate change mitigation.

National Greenhouse Gas Inventory

- National Greenhouse Gas Inventory (GHGI) is one of methods to estimate national carbon emissions into five categories.
- LULUCF, one of inventory categories and the only one including carbon sink, is considered as key contributions for preventing climate change.
- Under LULUCF, it is essential to identify individual land use representations such as Forest land, Cropland, Grassland, Settlements, Wetland and Other land.
- Land cover classification is one of commonly used methods to distinguish each land use and it helps to estimate land-based inventory, correctly based on land use sectors.

Estimation of LULUCF using IPCC Guideline

IPCC Guideline

- IPCC Guideline(GL) provides "Methodologies for estimating anthropogenic emissions by sources and removals by sinks of greenhouse gases".
- Therefore, if any country does not have its own methodologies, IPCC GL could be a good reference to estimate national GHGI.
- For estimating LULUCF, area of individual land uses should be clear, and it is related to 'Approach (level of Activity data)'. Improved Approach means Land Use and Land-Use Change spatially explicit.
- The other key factor is levels of methods 'Tier'. Higher Tier means country-specific and uses models to estimate LULULCF.

- It is essential to develop national land use data for improving level of Approach and Tier.
- Also, national land use data is helpful to estimate LULUCF itself, establish MRV* system and design climate change mitigation strategy under NDC.

*MRV: Monitoring, Reporting, and Verification

Major considerations for Estimation: Approach and Tier

Methodology for National Greenhouse Gas Inventory

Approach - Activity Data

Approach 1

Basic <Land-Use> data (Statistical or survey data)

Approach 2

Survey of <Land Use> and <Land-Use Change>

Approach 3

Spatially explicit <Land Use> and <Land-Use Change> data

using "Time-series Land Cove map"

Tier – Method and Carbon Emission Factor

Tier 1

Equations and default parameter values are provided.

Tier 2

Same as Tier 1 but applies country- or region-specific emission and stock change

Tier 3

Higher order methods are used, including models and inventory measurement systems tailored to address national circumstances

02. Research on LULUCF

- Research in Korea University
- Other Developing Countries

Research in Korea University

Choi et al., 2023

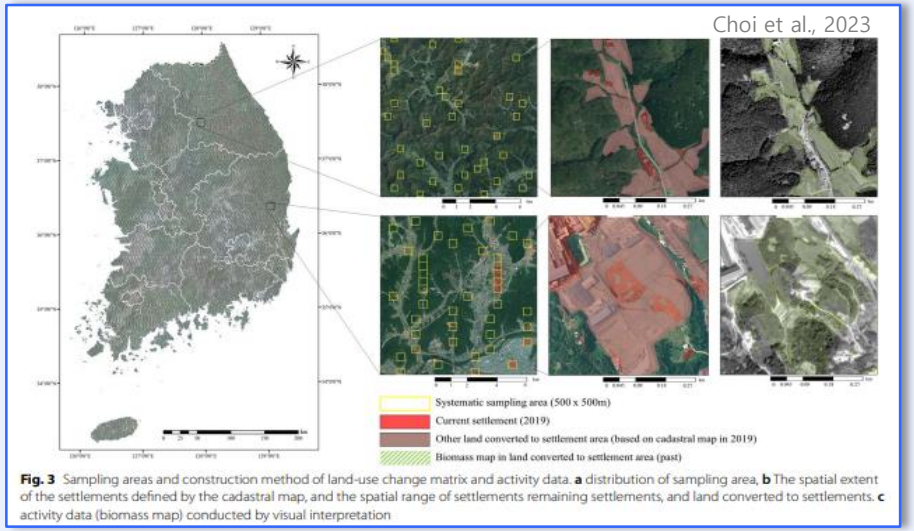


Fig. 3 Sampling areas and construction method of land-use change matrix and activity data. **a** distribution of sampling area, **b** The spatial extent of the settlements defined by the cadastral map, and the spatial range of settlements remaining settlements, and land converted to settlements. **c** activity data (biomass map) conducted by visual interpretation

National Greenhouse Gas Inventory for the LULUCF
(Land Use, Land Use Change and Forest)

- Construction of land-use change matrix and estimation of greenhouse gas inventory focusing on settlements in South Korea (Choi et al., 2023)
- Comparing Sampling and Wall-To-Wall Methodologies to produce geographically explicit land use data for the report on GHG Inventory of the LULUCF Sector in South Korea (Park et al., 2018)

Kim et al., 2019

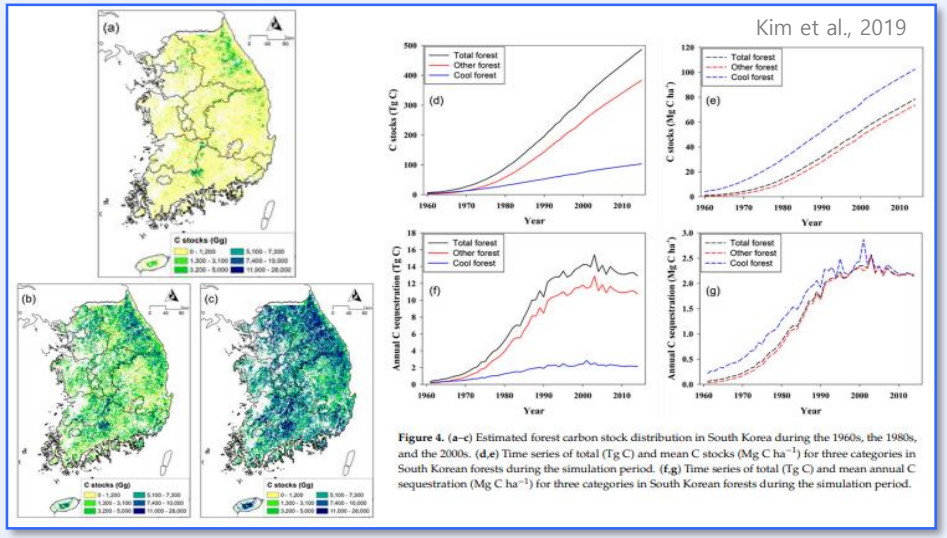


Figure 4. (a–c) Estimated forest carbon stock distribution in South Korea during the 1960s, the 1980s, and the 2000s. (d,e) Time series of total (Tg C) and mean C stocks (Mg C ha^{-1}) for three categories in South Korean forests during the simulation period. (f,g) Time series of total (Tg C) and mean annual C sequestration (Mg C ha^{-1}) for three categories in South Korean forests during the simulation period.

Estimation of Forest Carbon Budgets
(storage and sequestration) in South Korea

- Quantifying impacts of National-Scale Afforestation on Carbon Budget in South Korea from 1961 to 2014 (Kim et al., 2019)
- Estimation of carbon storage based on individual tree detection in *Pinus densiflora* stands using a fusion of aerial photography and LiDAR data in the central South Korea (Kim et al., 2010)

Research in Korea University

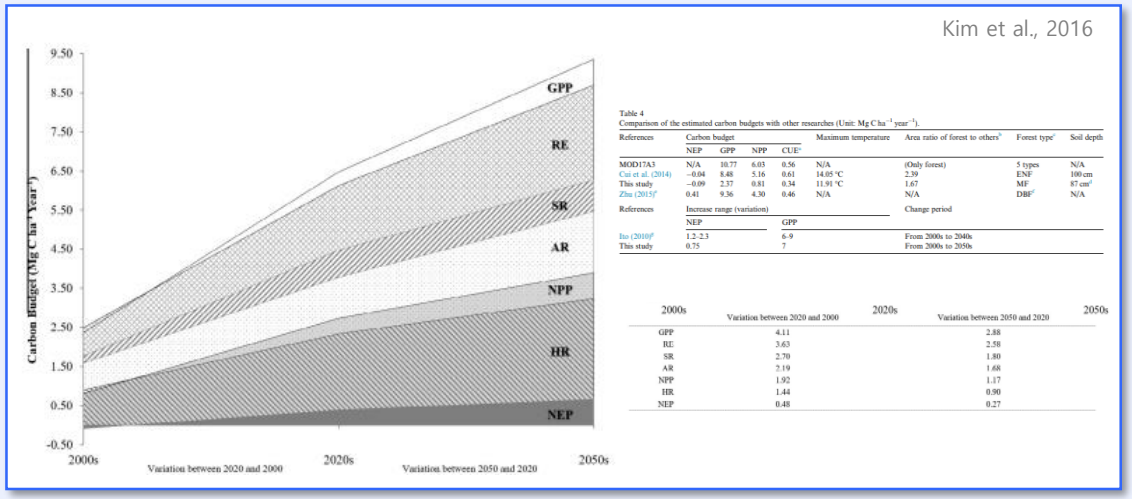
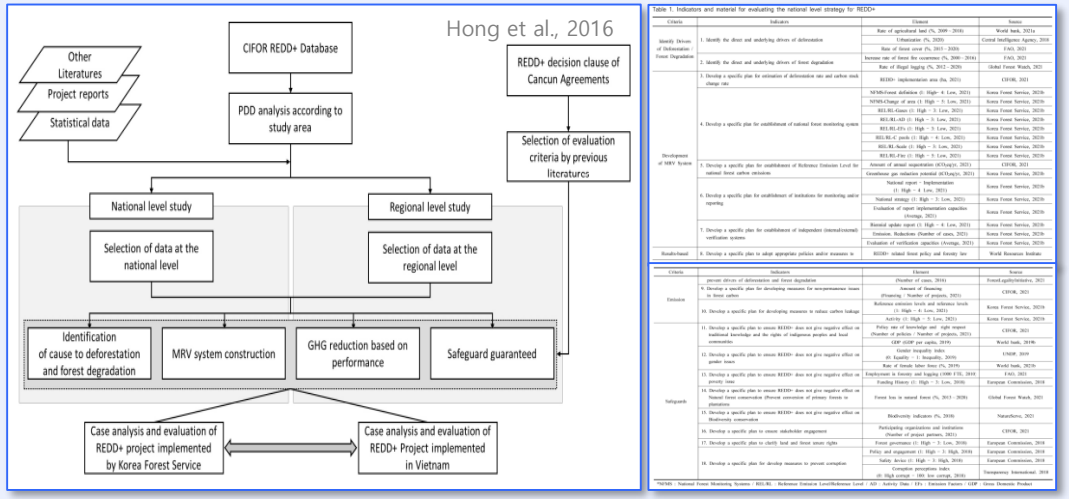


Table 4
Comparison of the estimated carbon budgets with other researches (Unit: Mg C ha^{-1} year^{-1}).

References	Carbon budget				Maximum temperature	Area ratio of forest to others[b]	Forest type[c]	Soil depth
	NEP	GPP	NPP	CUE[a]				
MOD17A3	N/A	10.77	6.03	0.56	N/A	(Only forest)	5 types	N/A
Cui et al. (2014)	−0.04	8.48	5.16	0.61	14.05 °C	2.39	ENF	100 cm
This study	−0.09	2.37	0.81	0.34	11.91 °C	1.67	MF	87 cm[d]
Zhu (2015)[e]	0.41	9.36	4.30	0.46	N/A	N/A	DBF[c]	N/A

References	Increase range (variation)		Change period
	NEP	GPP	
Ito (2010)[f]	1.2–2.3	6–9	From 2000s to 2040s
This study	0.75	7	From 2000s to 2050s

2000s	Variation between 2020 and 2000	2020s	Variation between 2050 and 2020	2050s
GPP	4.11		2.88	
RE	3.63		2.58	
SR	2.70		1.80	
AR	2.19		1.68	
NPP	1.92		1.17	
HR	1.44		0.90	
NEP	0.48		0.27	



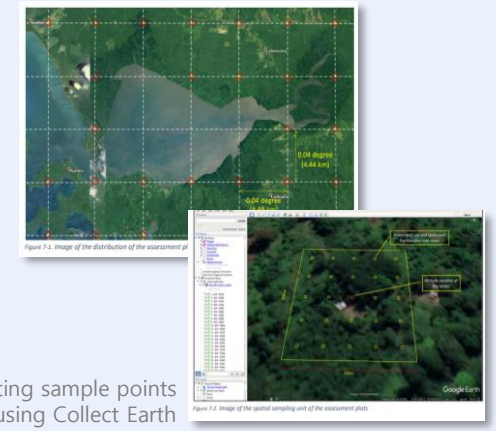
Evaluation on the Carbon Storage in North Korea and Land Cover Change in Other Countries

- Selecting tree species for use in North Korea's forest restoration (Choi et al., 2016) & Estimation of future carbon budget with climate change and reforestation scenario in North Korea (Kim et al., 2016)
- Research on forest structure and carbon dynamics in Brunei Darussalam (Lee et al., 2017) & Research on land cover change in third pole of Asia, Ethiopia, etc.

International Forest Cooperation (REDD+)

- Evaluation on forest cooperation feasibility through REDD+ strategic system in Vietnam (Hong et al., 2022)
- Analysis and evaluation of A/R CDM projects in India for abroad afforestation project (Yoo et al., 2021)

Projects in Other Developing Countries



Selecting sample points using Collect Earth

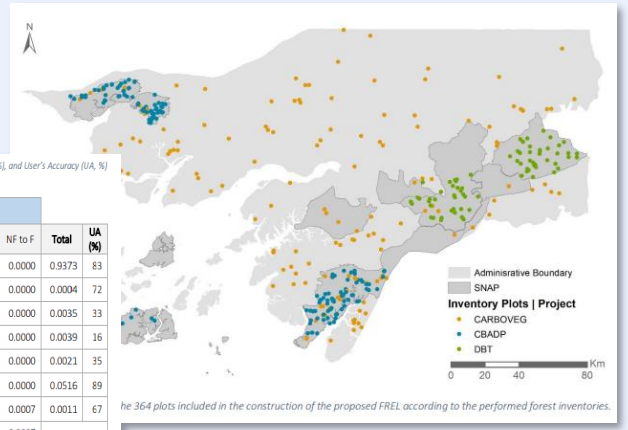
Land Use Change matrix by forest type (2000 – 2018)

Forest types	Cropland (hectares)							Settlement (hectares)			Total
	Permanent	Shifting	Not sure	Palm Oil	Cocoa	Coconut	Other	Village	Hamlet	Large settlement	Hectares	%
Low-altitude forest on plains and fans	5,887	83,535	2,007	83,118	1,978	1,957	3,970	1,988			184,440	52%
Low-altitude forest on uplands		62,100		17,789			1,963	1,978			83,830	24%
Lower montane forest	1,479	60,848	1,959						1,953		66,239	19%
Dry seasonal forest		3,925									3,925	1%
Swamp forest	2,007	5,958									7,965	2%
Savanna										1,315	1,315	0%
Woodland		3,919									3,919	1%
Total	9,373	220,285	3,966	100,907	1,978	1,957	5,933	3,966	1,953	1,315		
%	9,373	220,285	3,966	100,907	1,978	1,957	5,933	3,966	1,953	1,315	351,633	100%

Error Matrix by Forest Cover Change Matrix

Reference

Map: FCC Category	F to F	CF to NF	OF to NF	SA to NF	M to NF	NF to NF	NF to F	Total	UA (%)
F to F	0.7799	0.0000	0.0000	0.0000	0.0000	0.1574	0.0000	0.9373	83
CF to NF	0.0000	0.0003	0.0000	0.0000	0.0000	0.0000	0.0000	0.0004	72
OF to NF	0.0011	0.0000	0.0011	0.0001	0.0000	0.0011	0.0000	0.0035	33
SA to NF	0.0011	0.0000	0.0001	0.0006	0.0000	0.0021	0.0000	0.0039	16
M to NF	0.0006	0.0000	0.0000	0.0000	0.0008	0.0007	0.0000	0.0021	35
NF to NF	0.0054	0.0000	0.0000	0.0000	0.0000	0.0462	0.0000	0.0516	89
NF to F	0.0003	0.0000	0.0000	0.0000	0.0000	0.0001	0.0007	0.0011	67
Total	0.7885	0.0003	0.0013	0.0008	0.0008	0.2077	0.0007	OA = 83%	
PA (%)	99	90	90	81	100	22	97		



364 Plots to construct FREL

Country	Papua New Guinea	Guinea-Bissau
Project	Second National REDD+ Forest Reference Level (2023)	Forest Reference Emission Level (2019)
Activity Data	• **Satellite imagery** **- Land use change: Landsat7 & 8** - supplementary: World-View, QuickBird, Ikonos, SPOT, Sentinel 2A/2B, Global forest change data (Hansen)	• **Satellite imagery** **- Land use change: Landsat7 & 8** - supplementary:
Method	• **Visual interpretation** & Sampling (0.04 degree & 0.02 degree, total 25,279 points) • Software & Tools: Collect Earth	• **Maximum Likelihood classification algorithm,** Visual interpretation & Random stratified sampling (25m * 25m) • Software & Tools: ENVI, Collect Earth

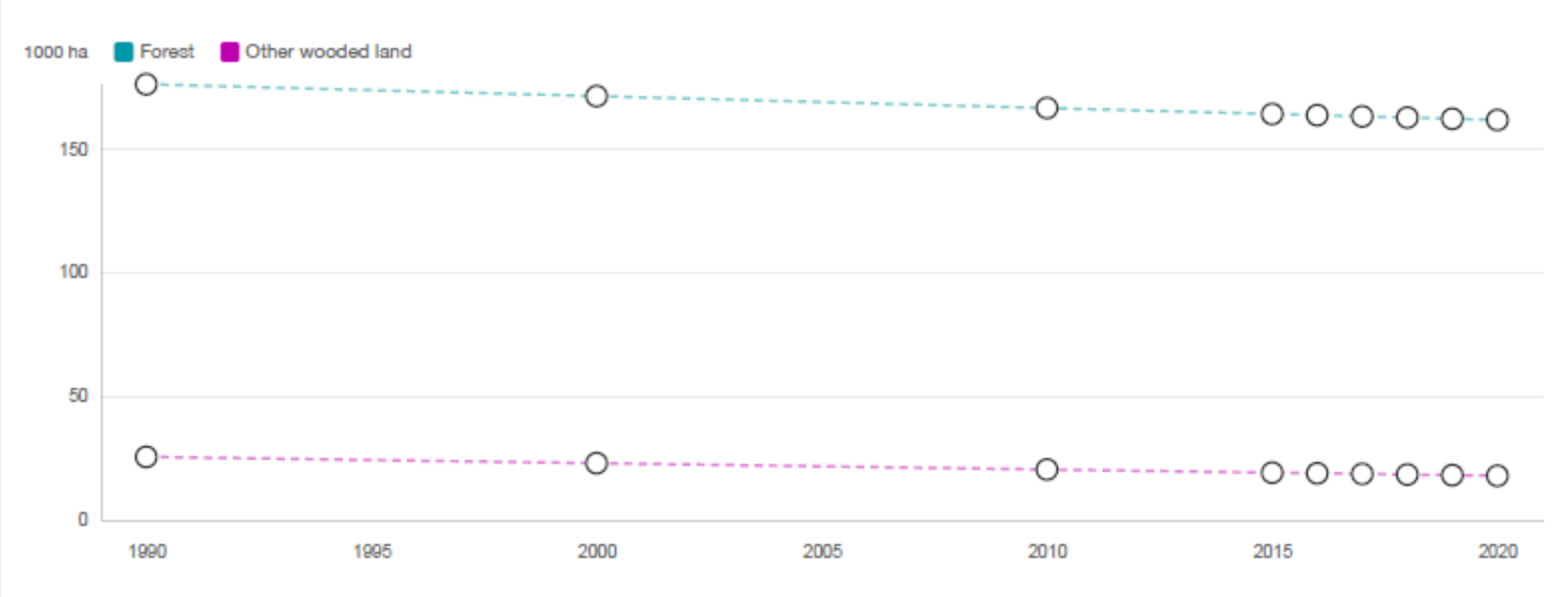
03. Current LULUCF in Samoa

- Activity Data, Tier, and Approach of LULUCF of Samoa
- Limitations

Activity Data, Tier, and Approach of LULUCF of Samoa

1. Forest Resources Assessment (FRA)

- FRA could provide various information related with land cover including forest resources.
- It contains land area in Samoa including forest, other wooded land, and other land.



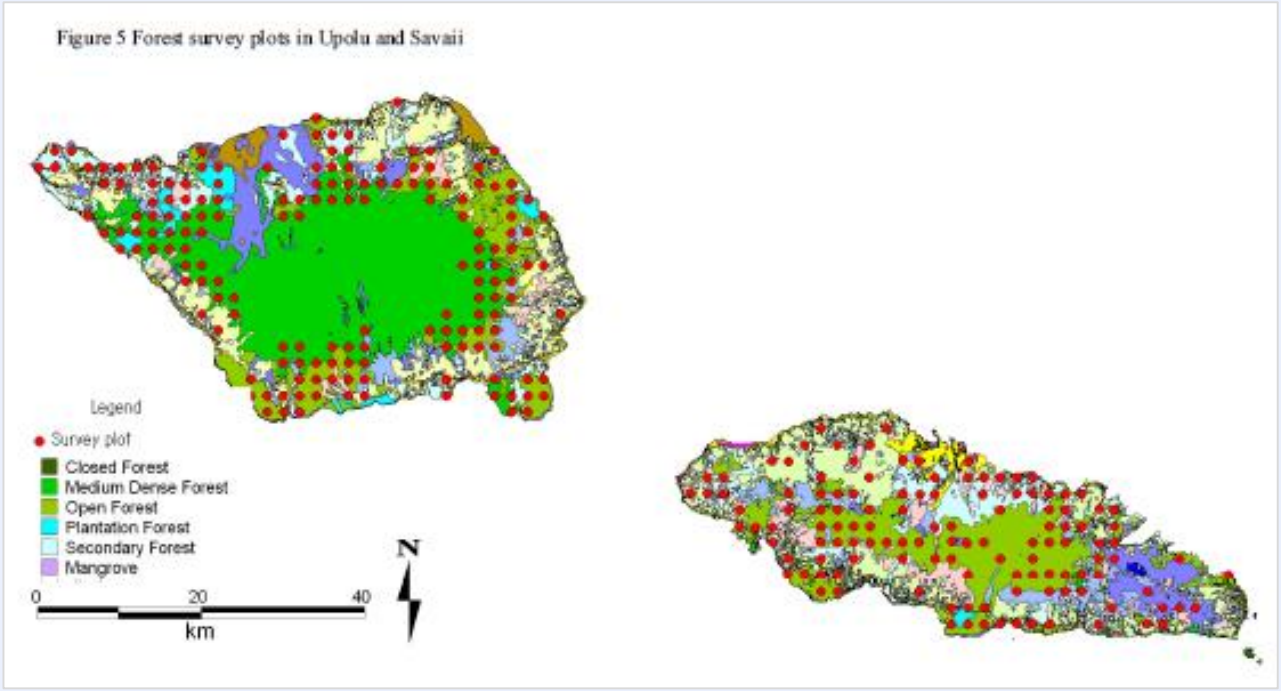
National ClassPdfdaf
Mangrove Forest
Closed Forest
Medium Dense Forest
Open Forest
Secondary Forest
Forest Plantation
Scrub
Coconut Plantation etc.

Activity Data, Tier, and Approach of LULUCF of Samoa

2. National Forest Inventory (NFI)

Tier 1

- In 2014, Samoa developed the NFI data with Japan International Cooperation System (JICS).
- It contains the forest survey plots, allometric equation for carbon stock estimation etc.



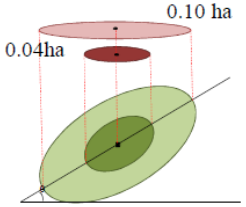
Plot shape	Size		Target DBH
	Large	➢ Horizontal profile radius 17.84 m ➢ Horizontal profile area 0.10 ha ➢ Horizontal profile occupied area 0.06 ha (0.1ha-0.04ha)	DBH ≥ 18 cm
	Small	➢ Horizontal profile radius 11.28 m ➢ Horizontal profile area 0.04 ha ➢ Horizontal profile occupied area 0.04 ha	DBH ≥ 5 cm

Table 7Allometric equations for carbon stock estimation

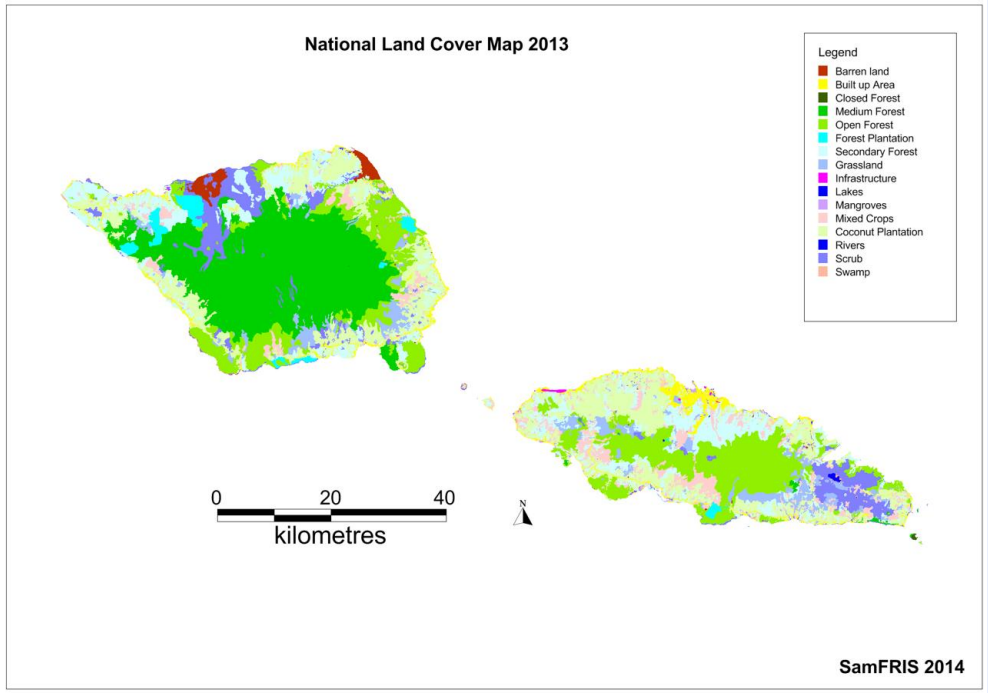
Category	Sub-category	Equation	Remarks
(i) Aboveground tree biomass	(i-1) Aboveground tree biomass (DBH ≥ 5 cm)	$AGB = 0.0509 \times D \times (dbh)^2 \times H$ AGB: aboveground biomass (kg dry matter / tree) D:Basic Wood Density(specific gravity) (oven-dry. tonne / moist m^3) dbh: Diameter at Breast Height (cm) H: Tree height (m)	Chave *et al.* (2005)

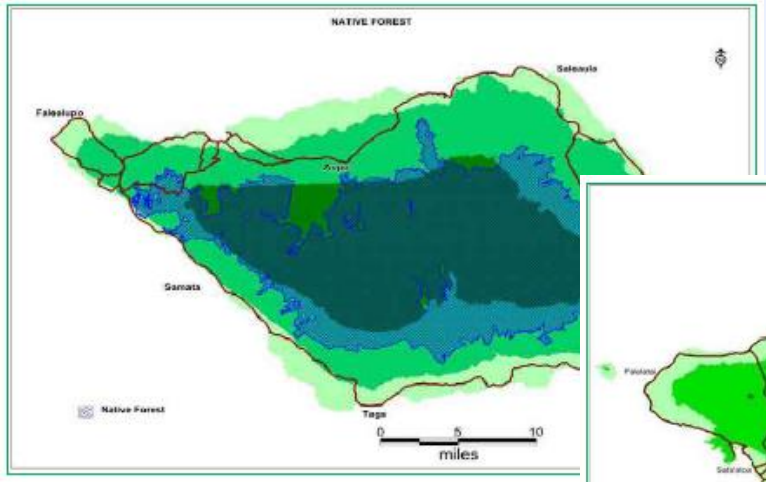
Activity Data, Tier, and Approach of LULUCF of Samoa

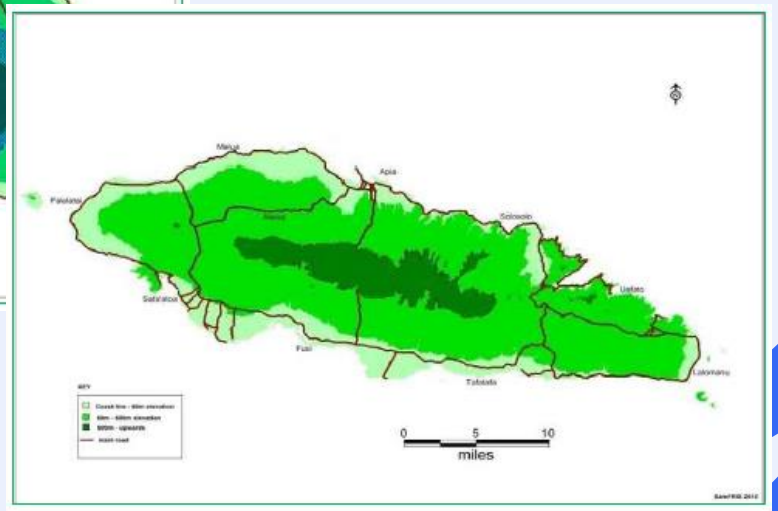
3. National Land Cover Map 2013

Approach 1?

- There is a National Land Cover Map which represents spatial information on land classes in Samoa including forests, mangroves, and plantations etc.
- It is divided with the criteria having homogeneous characteristics on land surface.







Limitations

1. Absence of Spatial data and low consistency
   - In order to use a land cover map in REDD+, it must be able to reflect the past and present situations about land in detail. It could be used for monitoring forest area change.
   - **In Samoa, spatial data for land cover map do not exist after 2013.**
   - In addition, NFMS (National Forest Monitoring System) emphasizes consistency with other statistics and data through TACCC (Transparency, Accuracy, Completeness, Comparability, and Consistency).
   - **It is necessary to figure out the consistency for data convergence at the spatial level.**

Limitations

2. Absence of Technical skills and National systems

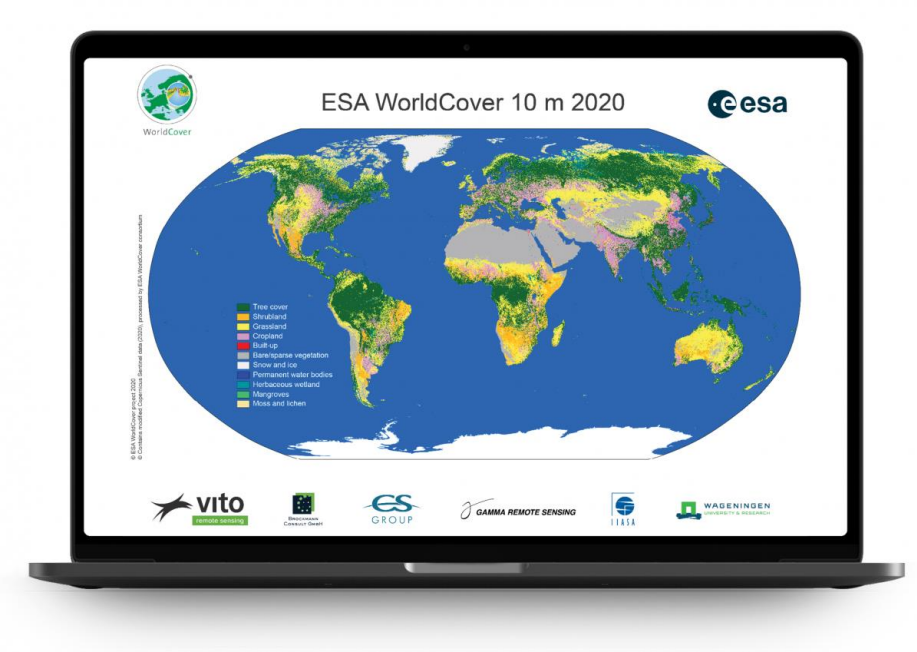
- It should be possible to compare land cover by year. For this, technology to produce land cover map using satellite images or aerial photographs is required.
- **Therefore, it is important to secure land use classification technology through satellite image analysis.**
- A monitoring system using remote sensing techniques suitable for national circumstances is needed.
- **So, Datafication of information for system construction is a crucial process.**

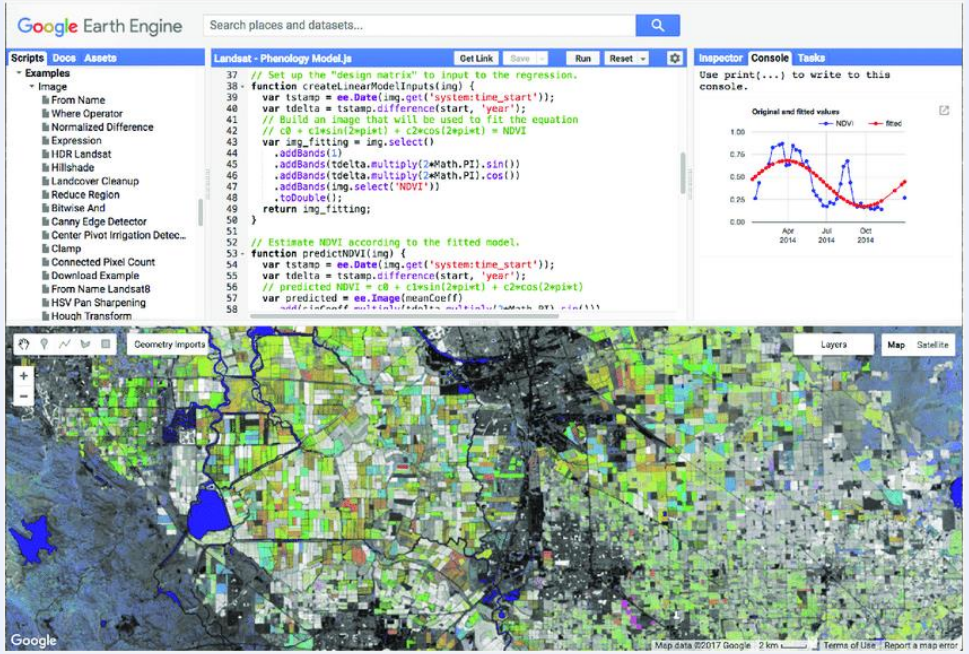
04. Methods to improve LULUCF in Samoa

- Available Data: National Data, Global Open Source Data, and Satellite Imagery
- Available Methods: GIS tool and AI
- Possible Tier & Approach
- Limitations

Available Data: National Data, Global Open Source Data, and Satellite Imagery

1. Available Data
   - ESA World cover map 2020 and 2021
   - Landsat 8 satellite imagery (from Google earth engine)
   - Land Cover Map 2013

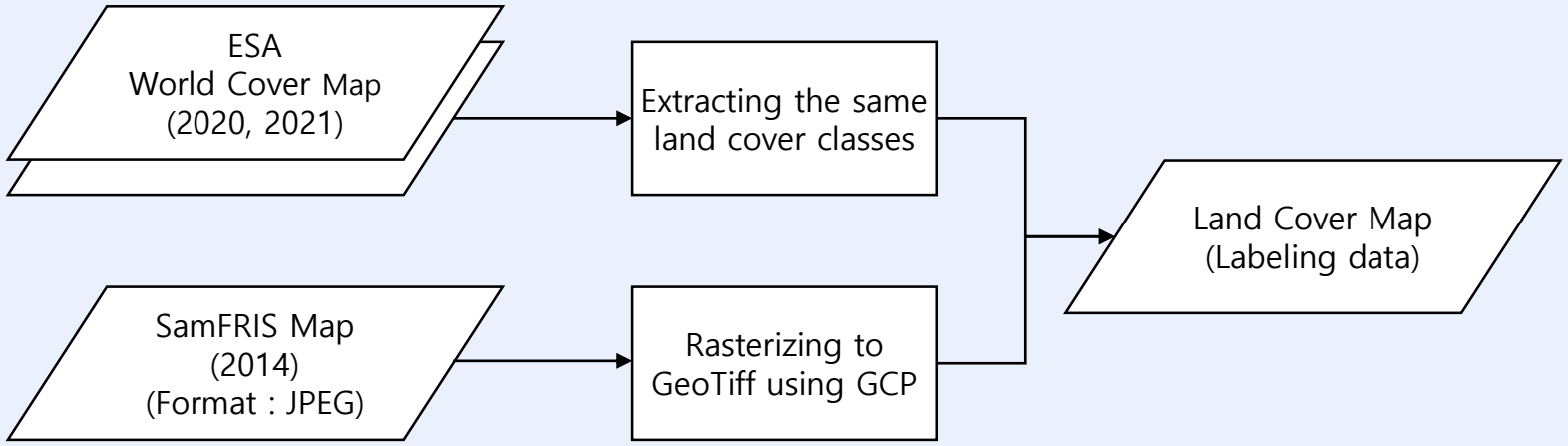




Available Data: National Data, Global Open Source Data, and Satellite Imagery

2. Labeling data preprocessing

- Collecting the existing worldwide land cover data from the ESA
- Rasterizing the former land cover map of SAMOA
- Building an accurate labeling data by combining the aforementioned data
- The land cover map which includes a total of 12 classes



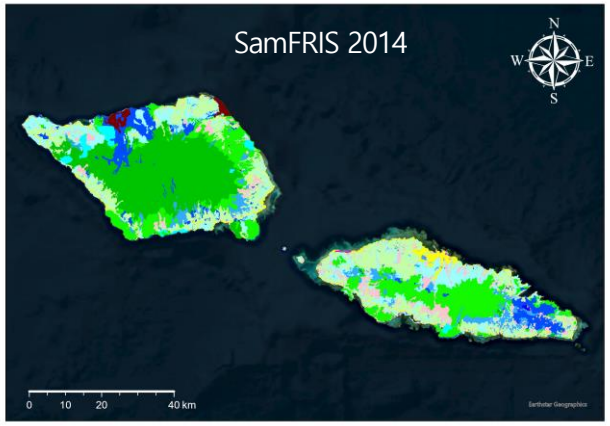
SamFris_2014		ESA_2021		Esa_samfris	
1	Medium Forest	1	Tree cover	1	**Medium Forest**
2	Barren land	2	Shrubland	2	**Open Forest**
3	Open Forest	3	Grassland	3	**Secondary Forest**
4	Built up Area	4	Built-up	4	**Forest Plantation**
5	Forest Plantation	5	Bare/Sparse vegetation	5	**Coconut Plantation**
6	Scrub	6	Permanent water bodies	6	**Mixed Crop**
7	Grassland	7	Herbaceous wetland	7	**Built up Area**
8	Coconut Plantation	8	Mangroves	8	**Scrub / Grassland**
9	Mixed Crop			9	**Permanent water bodies**
10	Secondary Forest			10	**Herbaceous wetland**
11	Closed Forest			11	**Mangroves**
12	Infrastructure			12	**Barren land**
13	Lakes				
14	Mangroves				
15	Rivers				
16	Swamp				

<Research flow to build labeling data>

Available Data: National Data, Global Open Source Data, and Satellite Imagery

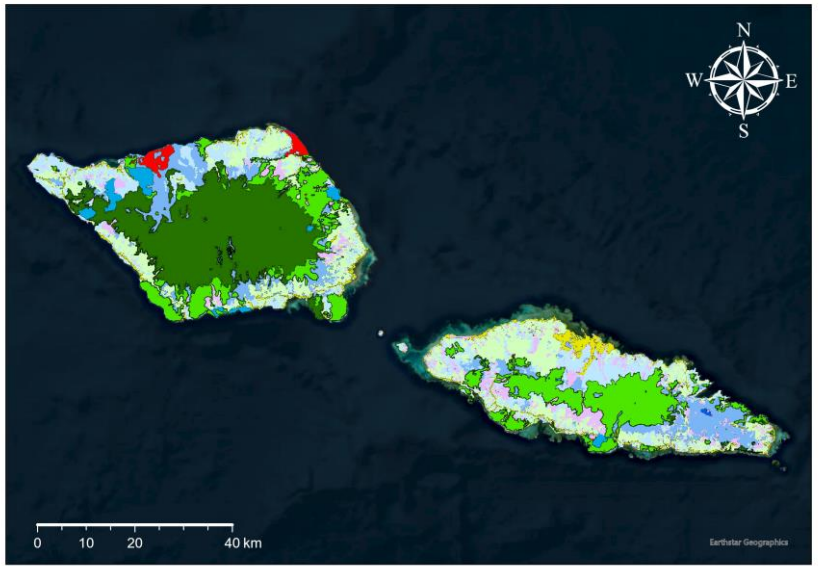
Legend
- Tree Cover
- Shrubland
- Grassland
- Buili-up
- Bare / Sparse vegetation
- Permanent Water Bodies
- Herbaceous wetland
- Mangroves

- Insufficient land cover classes
- Limitation of world cover data



Legend
- Barren land
- Built up Area
- Closed Forest
- Medium Forest
- Open Forest
- Forest Plantation
- Secondary Forest
- Grassland
- Infrastructure
- Lakes
- Mangroves
- Mixed Crops
- Coconut Plantation
- Rivers
- Scrub
- Swamp

- Inaccurate location information
- Limitation of land cover description



Legend
- Medium Forest
- Open Forest
- Secondary Forest
- Forest Plantation
- Coconut Plantation
- Mixed Crop
- Built up Area
- Scrub/Grassland
- Permanent Water Bodies
- Herbaceous Wetland
- Mangroves
- Barren Land

SamFris_2014		ESA_2021		Esa_samfris	
1	Medium Forest	1	Tree cover	1	**Medium Forest**
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14	Mangroves				
15	Rivers				
16	Swamp				

Available Methods: GIS tool and AI

3. Classification – QGIS

- QGIS provides plugin, Semi-Automatic Classification Plugin, for supervised classification of remote sensing images.
- The plugin could be used for analyzing remote sensing images by directly drawing region of interest (ROI).

Semi-Automatic Classification Plugin

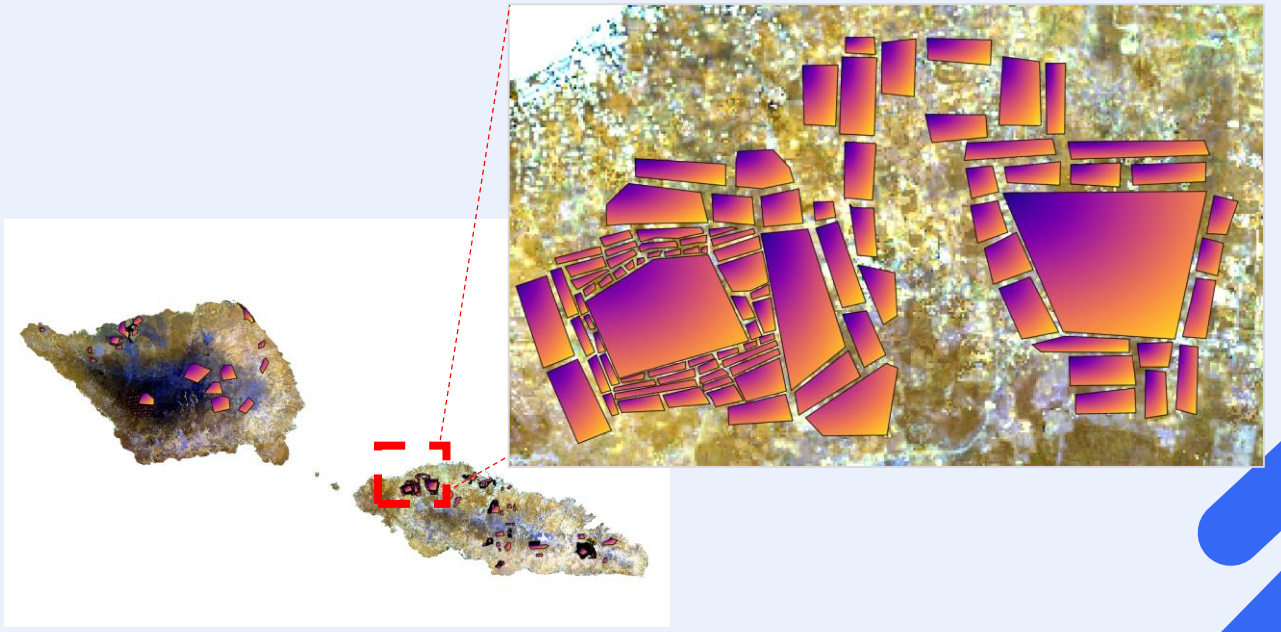
The Semi-Automatic Classification Plugin (SCP) allows for the supervised classification of remote sensing images, providing tools for the download, the preprocessing and postprocessing of images.

Developed by Luca Congedo, the Semi-Automatic Classification Plugin (SCP) allows for the supervised classification of remote sensing images, providing tools for the download, the preprocessing and postprocessing of images. Search and download is available for ASTER, GOES, Landsat, MODIS, Sentinel-1, Sentinel-2, and Sentinel-3 images. Several algorithms are available for the land cover classification. This plugin requires the installation of GDAL, OGR, Numpy, SciPy, and Matplotlib. Some tools require also the installation of SNAP (ESA Sentinel Application Platform). For more information please visit https://fromgistors.blogspot.com .

496 rating vote(s), 1476049 downloads

Category Raster

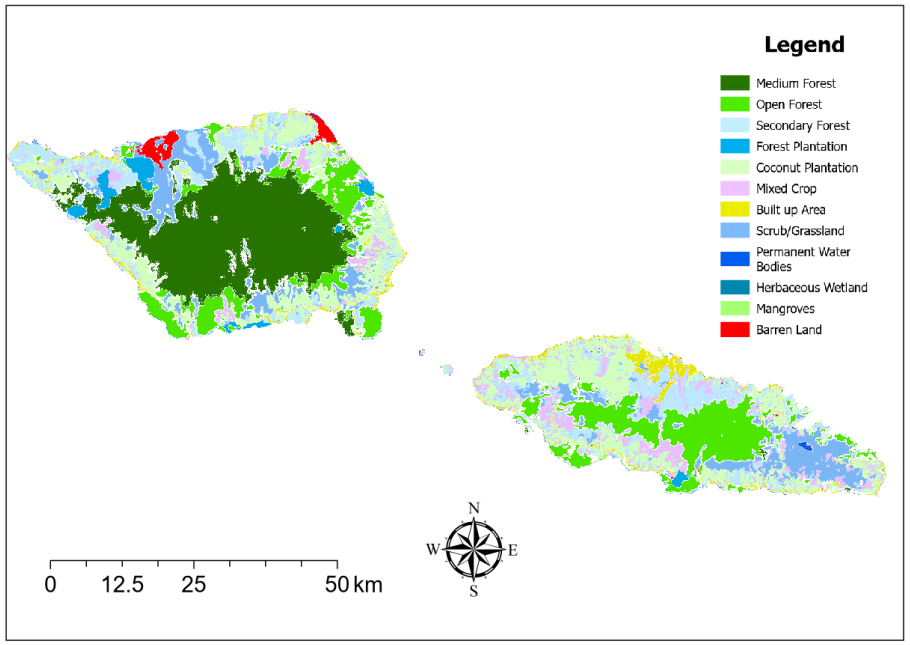
Tags raster, classification, land cover, remote sensing, analysis, aster, goes, landsat, sentinel, supervised classification, spectral signature, mask, clip, accuracy, landscape, copernicus, random forest, snap, processing

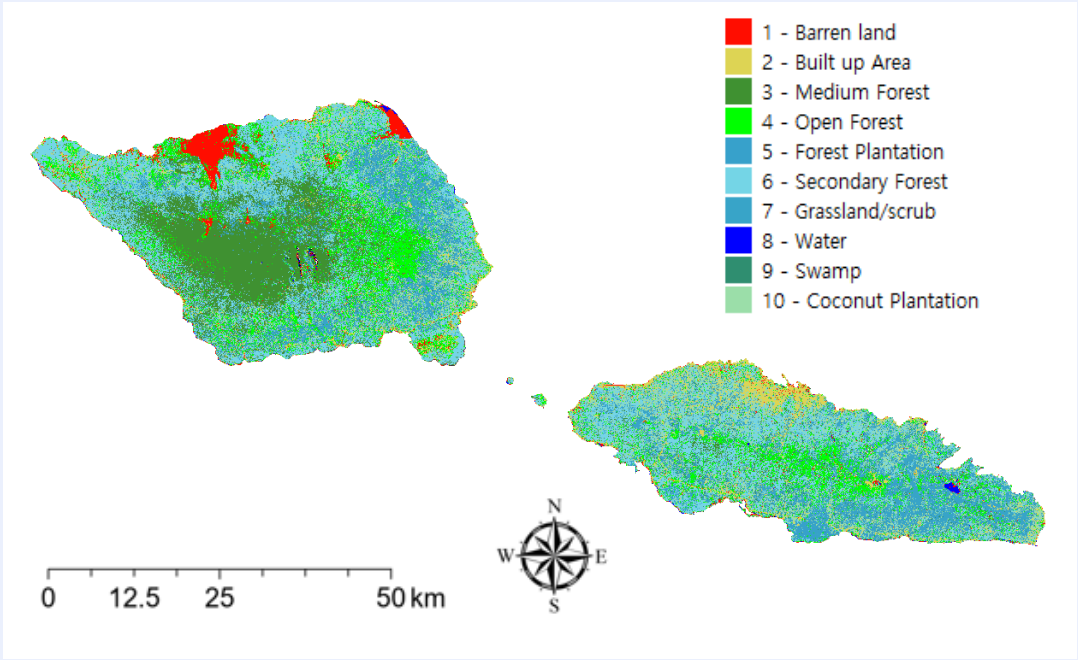


Available Methods: GIS tool and AI

3. Classification – QGIS

- There are limitations to classify land covers in Samoa where it has complex land cover and forest type.
- Therefore, state-of-the-art techniques are needed such as AI and Machine Learning etc.

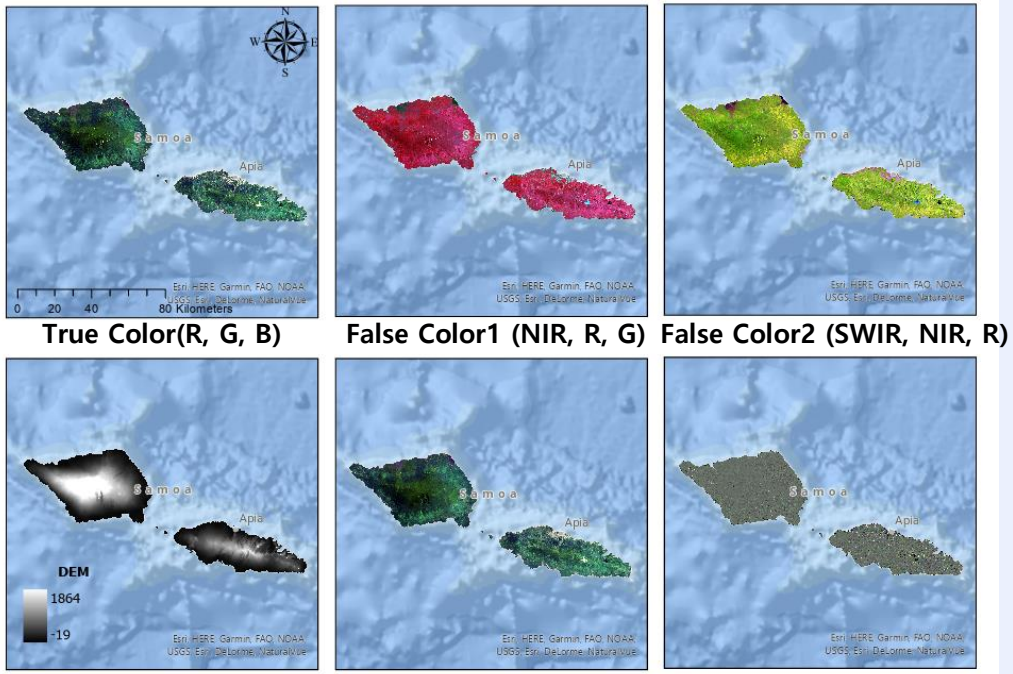


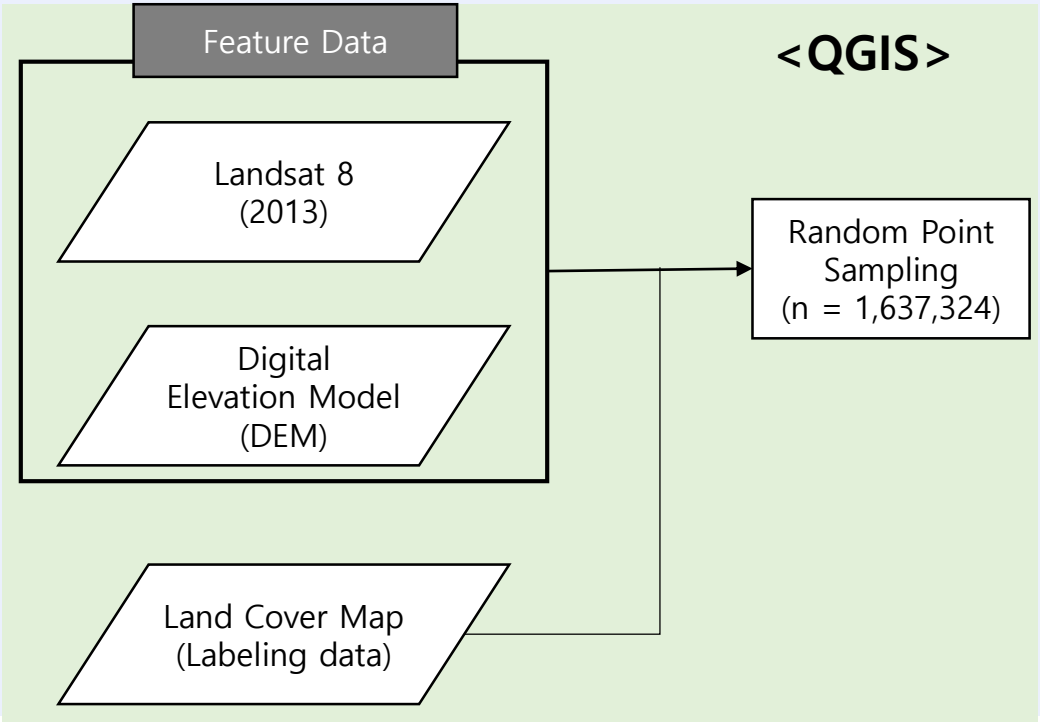


Available Methods: GIS tool and AI

4. Classification – ML

- Landsat 8 has 6 spectral bands and 2 types of filter on each band are applied for this study
- A total of 18 spectral bands and DEM were used as a feature data

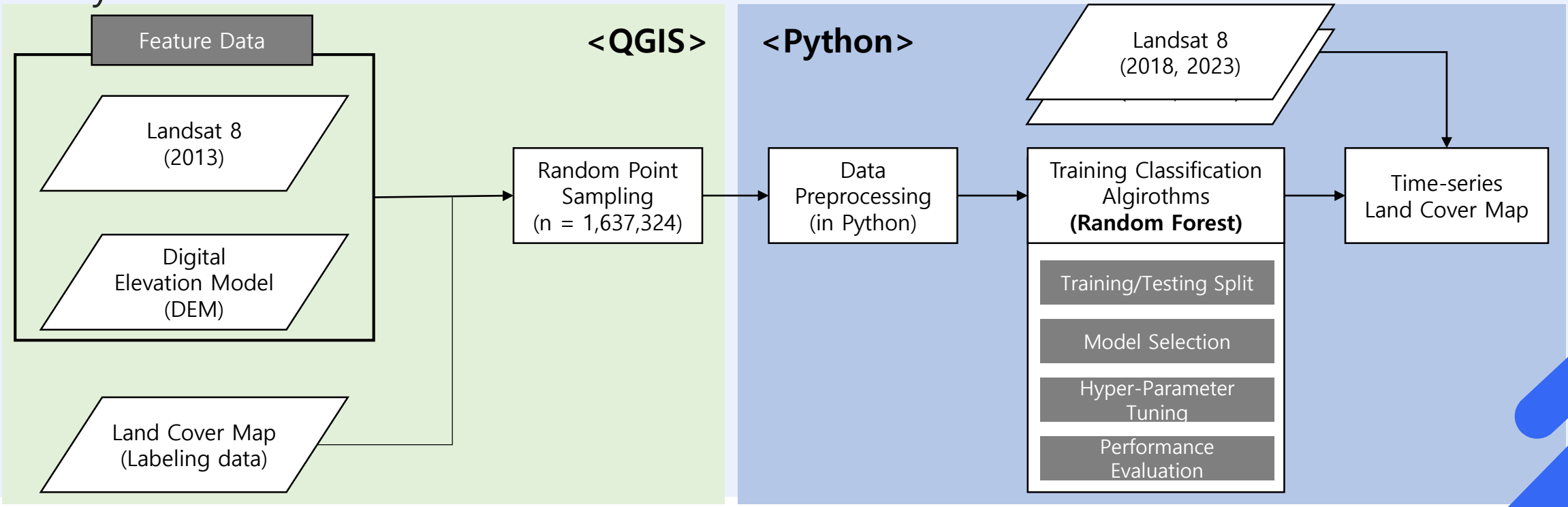




Available Methods: GIS tool and AI

4. Classification – ML

- The whole analysis is processed in QGIS and Python
- Python provides various ML algorithms and Random Forest classifier is applied in this study

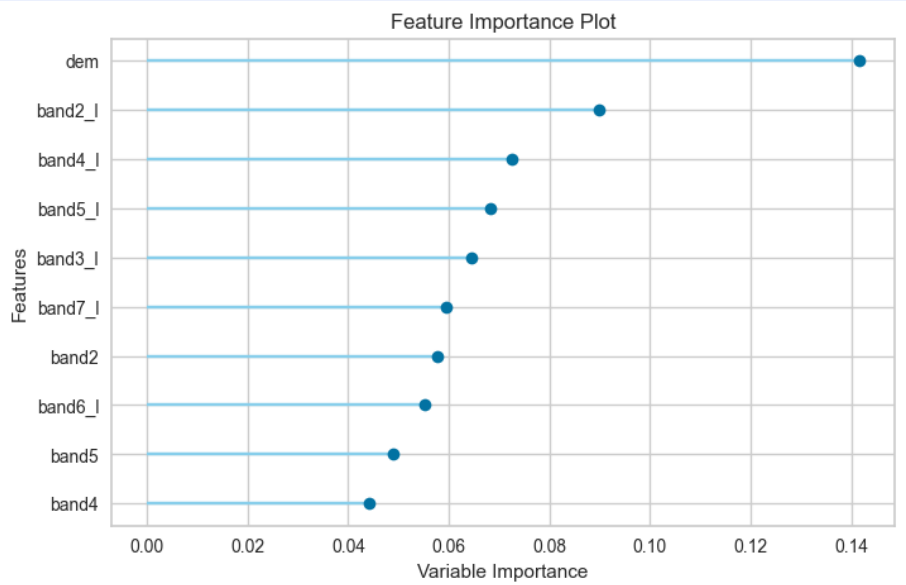


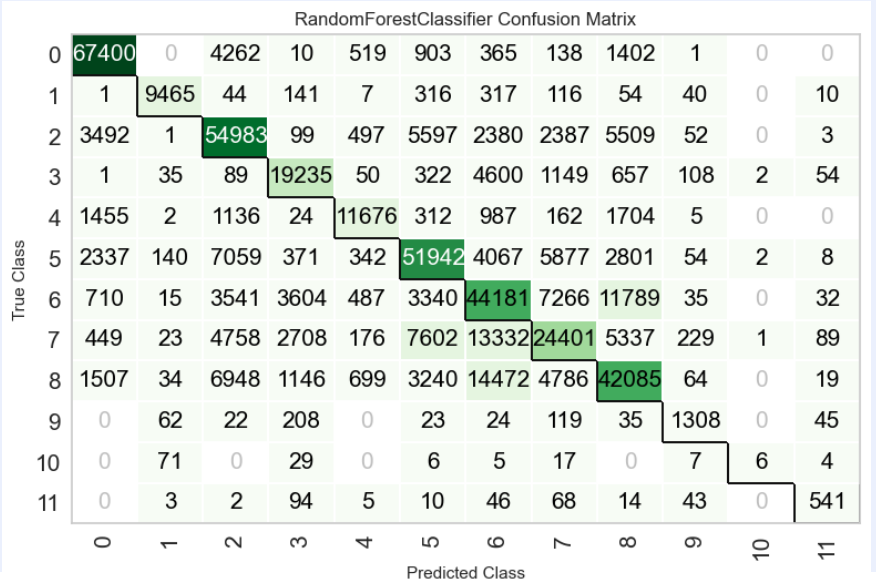
Available Methods: GIS tool and AI

4. Classification – ML

- Random Forest algorithms show about 0.65 values on all performance indicator
- This results are triggered by imbalance classes ratio of labeling data

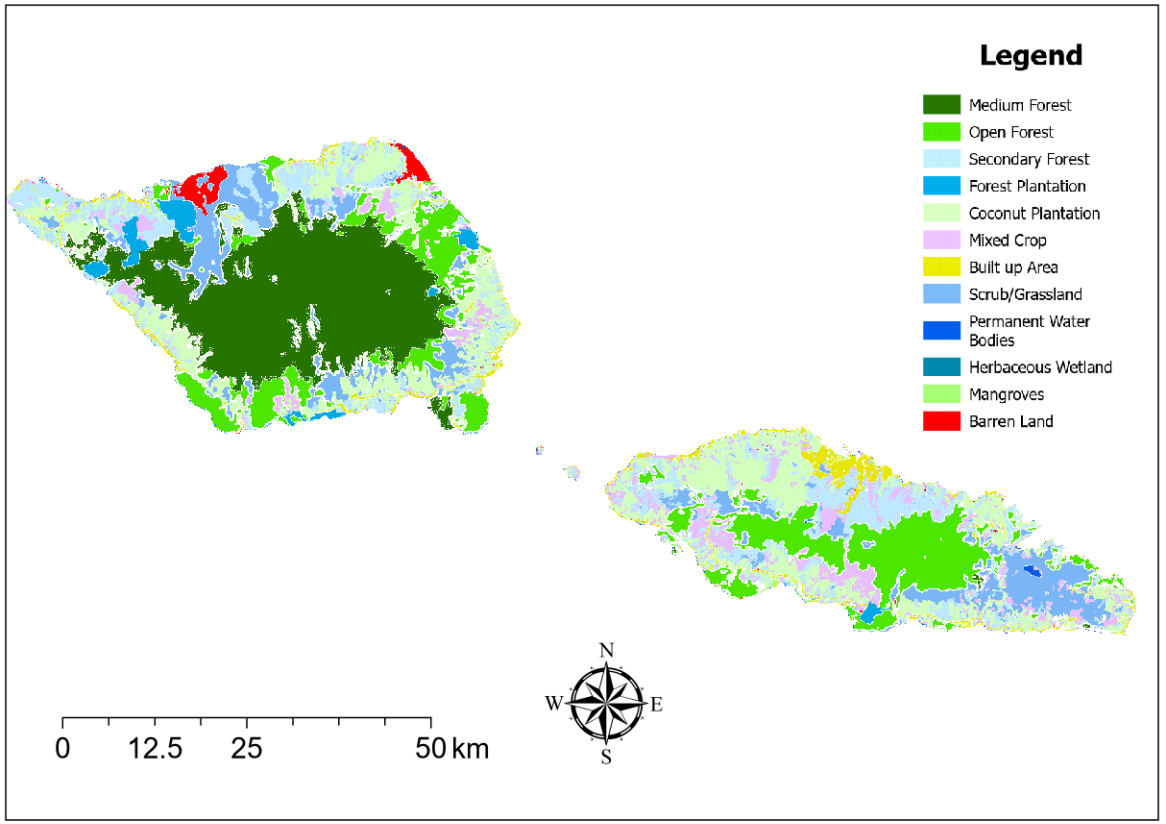
	Accuracy	AUC	Recall	Precision	F1	Kappa
Mean	**0.6658**	**0.9277**	**0.6658**	**0.6649**	**0.6634**	**0.6126**
Std	0.0013	0.0003	0.0013	0.0014	0.0014	0.0015





Available Methods: GIS tool and AI

4. Classification – ML



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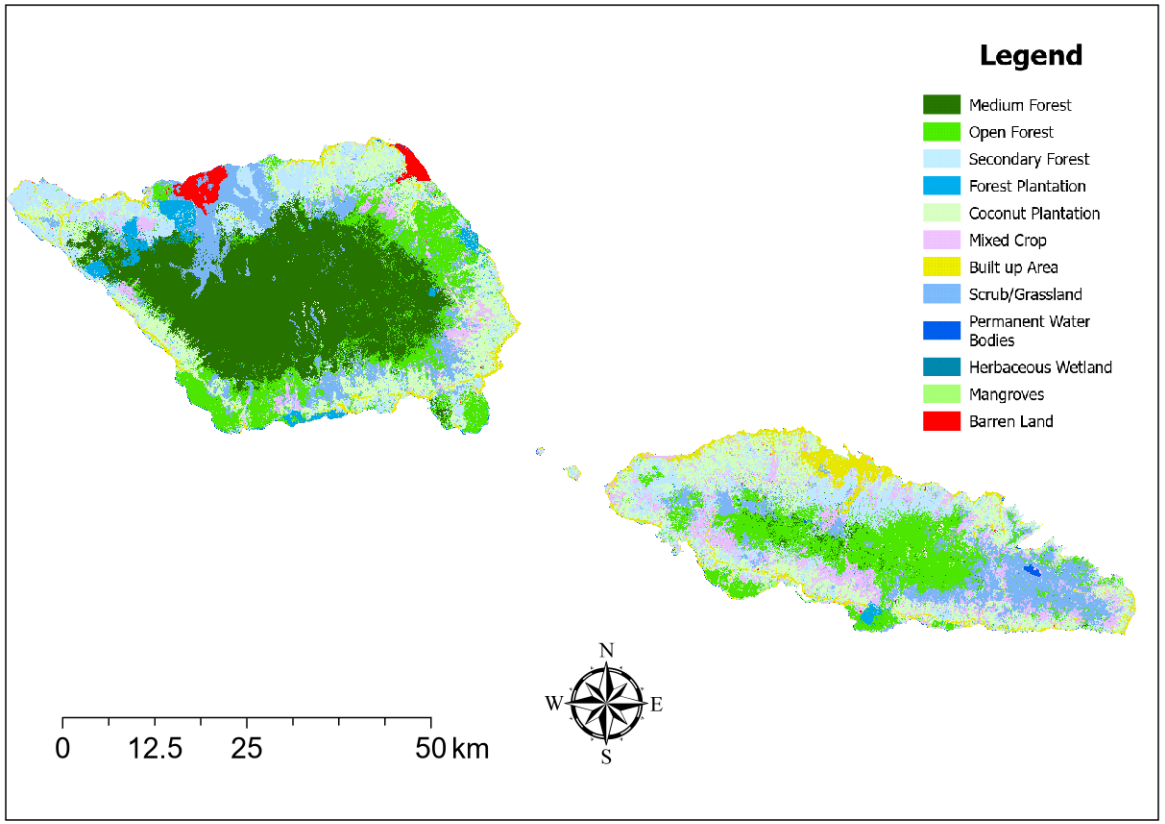
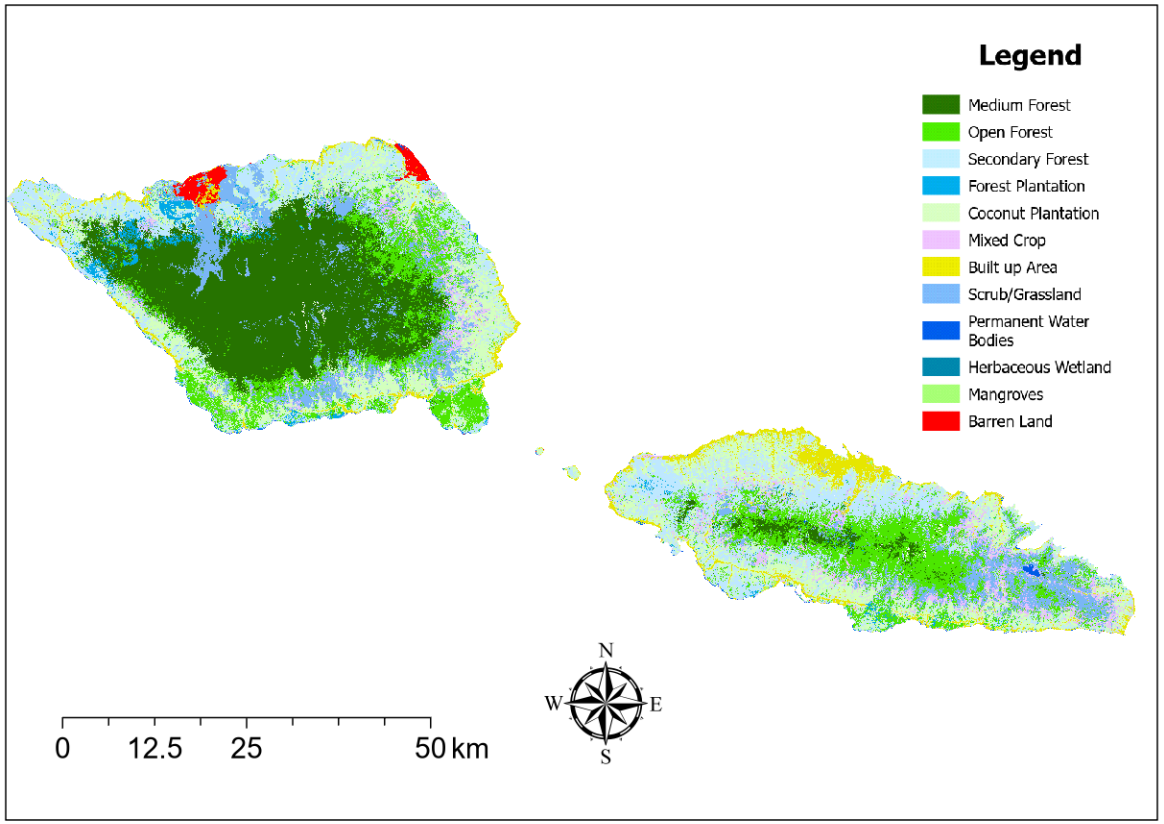


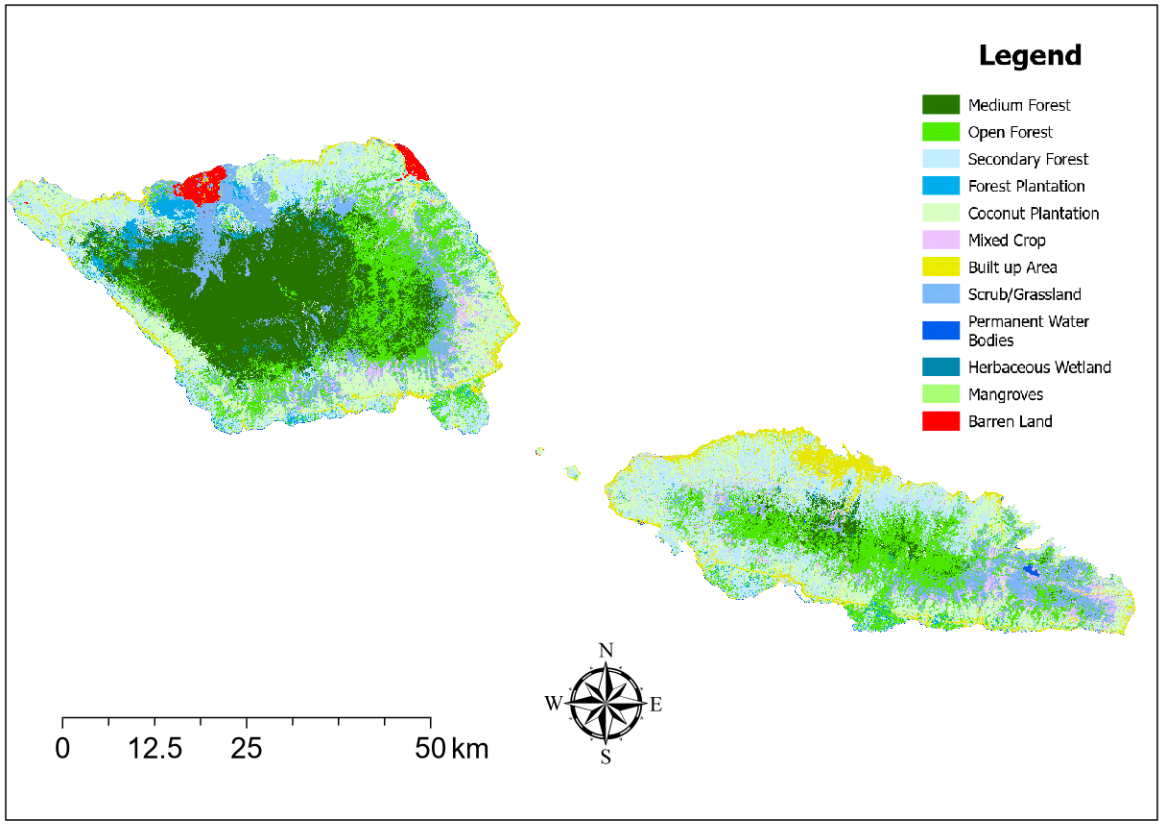
<Land Cover Map 2013>

Available Methods: GIS tool and AI

4. Classification – ML



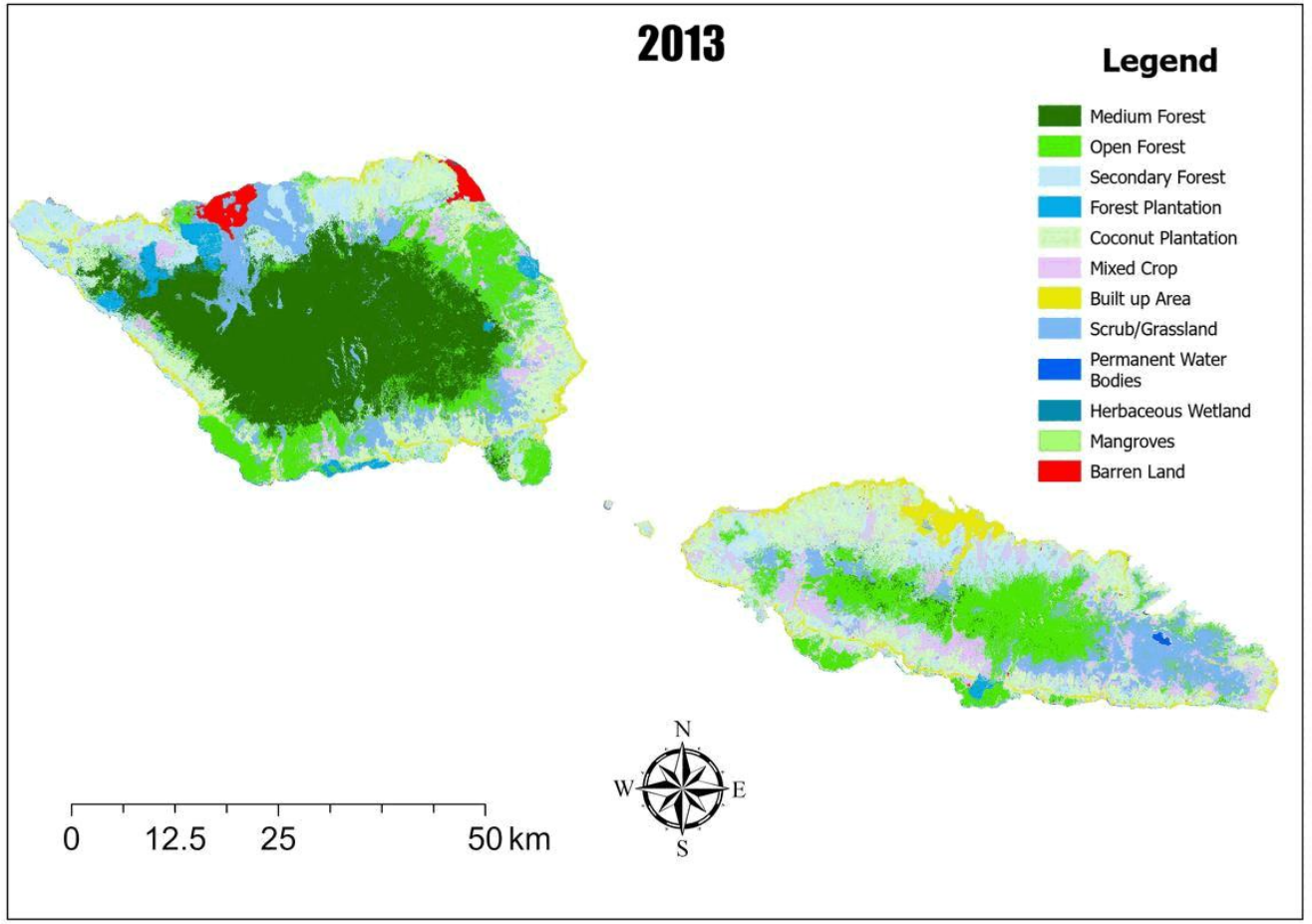
<Land Cover Map 2018>



<Land Cover Map 2023>

Available Methods: GIS tool and AI

4. Classification – ML



Available Methods: GIS tool and AI

4. Classification – ML

<Land Cover Change Matrix Table>

		2013			2018			2023		
	Land Cover Classes	Area(ha)	Ratio	Var vs last 5 yrs	Area(ha)	Ratio	Var vs last 5 yrs	Area(ha)	Ratio	Var vs last 5 yrs
1	Medium Forest	68248.8	0.23	-	69135.84	0.24	↑	58024.71	0.20	↓
2	Open Forest	52897.14	0.18	-	48745.8	0.17	↓	56837.43	0.19	↑
3	Secondary Forest	40964.67	0.14	-	51804.09	0.18	↑	52975.26	0.18	↑
4	Forest Plantation	6322.32	0.02	-	5375.43	0.02	↓	7981.65	0.03	↑
5	Coconut Plantation	48503.07	0.17	-	52835.85	0.18	↑	54478.89	0.19	↑
6	Mixed Crop	23316.66	0.08	-	15081.57	0.05	↓	13510.17	0.05	↓
7	Built up Area	11825.64	0.04	-	13818.06	0.05	↑	13481.64	0.05	↓
8	Scrub / Grassland	35829.81	0.12	-	31729.59	0.11	↓	30904.56	0.11	↓
9	Permanent water bodies	846.54	0.00	-	922.23	0.00	↑	953.46	0.00	↑
10	Herbaceous wetland	28.17	0.00	-	2.88	0.00	↓	1.53	0.00	↓
11	Mangroves	315.81	0.00	-	255.87	0.00	↓	331.11	0.00	↑
12	Barren land	3326.31	0.01	-	2717.73	0.01	↓	2985.3	0.01	↑
	Total	292424.9	1		292424.9	1		292465.7	1	

05. Suggestion for LULUCF of Samoa

- National DB and management system for LULUCF
- International Cooperation: REDD+

Suggestion 1: National DB and management system for LULUCF

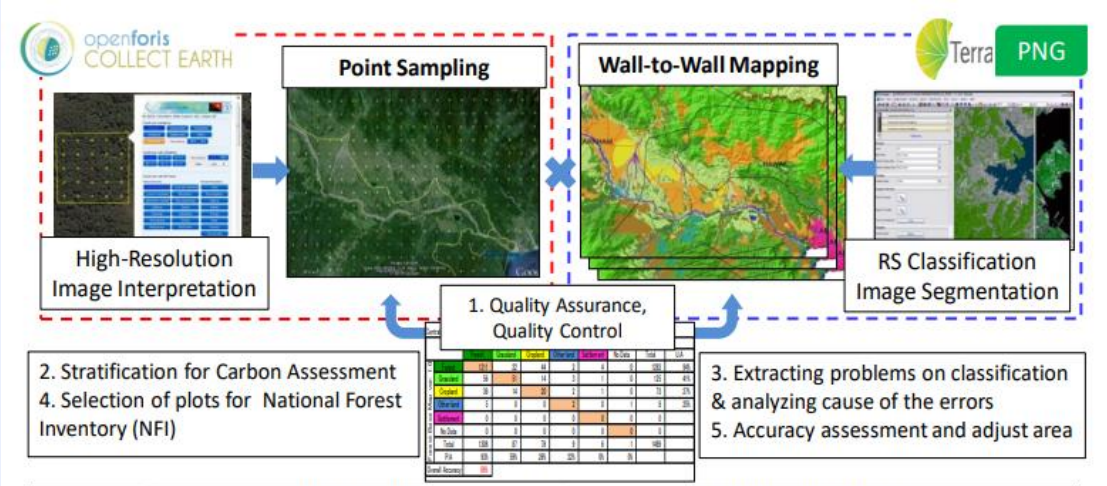
Methodologies for Monitoring LUC

1. Sampling

- Sampling is a method based on statistical sampling to estimate greenhouse gas emissions and sequestration in the LULUCF sector.
- It involves collecting and analyzing data only from selected areas, rather than including all regions or land-use categories. This helps reduce the time and cost involved in creating the inventory.

2. Wall-to-Wall

- An approach to construct an inventory that includes all regions or land use categories.
- It involves analyzing all land within the target area to accurately estimate greenhouse gas emissions and sequestration.



	Point Sampling	Wall-to-Wall Mapping
Spatial Coverage	Sampling Plots	Segmented polygons
Area Calculation	Statistical	Geographical
Boundary	No	Yes
Statistical Analysis	Ample	Limited
Driver Analysis	Ample	Limited

Collect Earth Point Sampling and Wall-to-Wall Mapping Method
(Source: PNGFA)

Suggestion 1: National DB and management system for LULUCF

National Database for Monitoring LUC

- The IPCC refers to three general tiers for estimating emissions/removals of GHGs based on data availability and classification criteria
- Appropriate data collection and analysis are essential for methods to estimate greenhouse gas emissions and sequestration effectively
  - ✓ Wall-to-Wall method requires detailed and comprehensive data to analyze all land within the target area
  - ✓ Sampling method focuses on selected sample areas, making specific data for those samples crucial
- Therefore, it is important to collect and produce suitable data for the analysis, and they need to be managed under the National Database system.

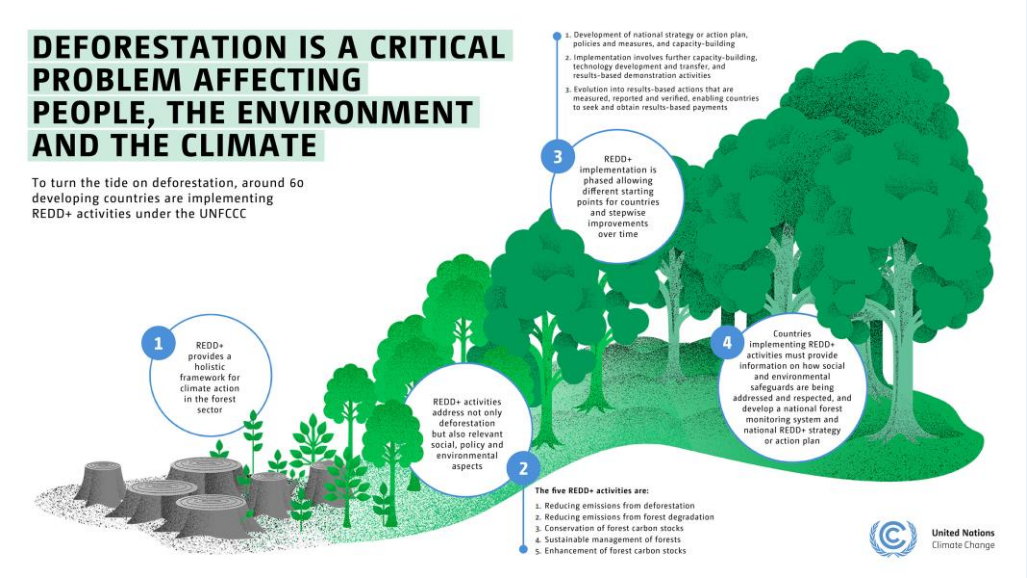
Sector	Data	Description	Year of data taken	Source
Sampling Matrix	Aerial Photography	Aerial photography for 2000s	2001-2003	National Geographic Information Institute
	Orthophoto	Orthophoto for 2010s and additional data for 2000s	2000-2003 2010-2013	National Geographic Information Institute
	National Forest Inventory	NFI location information		Korea Forest Promotion Institute
	Sample Point	Sample Point for visual interpretation (4 km, 2 km,		
Wall-to-Wall Matrix	Land Cover	Land Cover map for 2000s	1999-2000	Ministry of Environment
	Land Cover	Land Cover map for 2010s	2011	Ministry of Environment
Matrix Accuracy	Cadastral Statistics	Accuracy for estimated matrix by Sampling, Wall-to-Wall method	2000, 2011	National Geographic Information Institute
Forest CO_2 storage estimation	National Forest Inventory	NFI data attribute (volume, forest species, etc) (2006-2010, 2011-2015)	2006-2010 2011-2015	Korea Forest Promotion Institute
	Forest Type Map	5th Forest type map		Korea Forest Service
	Carbon Emission Factors	Carbon Emission Factors by species in Korea		National Institute of Forest Science
	Forest Statistics	Accuracy for CO_2 storage estimation	2000, 2011, 2016	Korea Forest Service

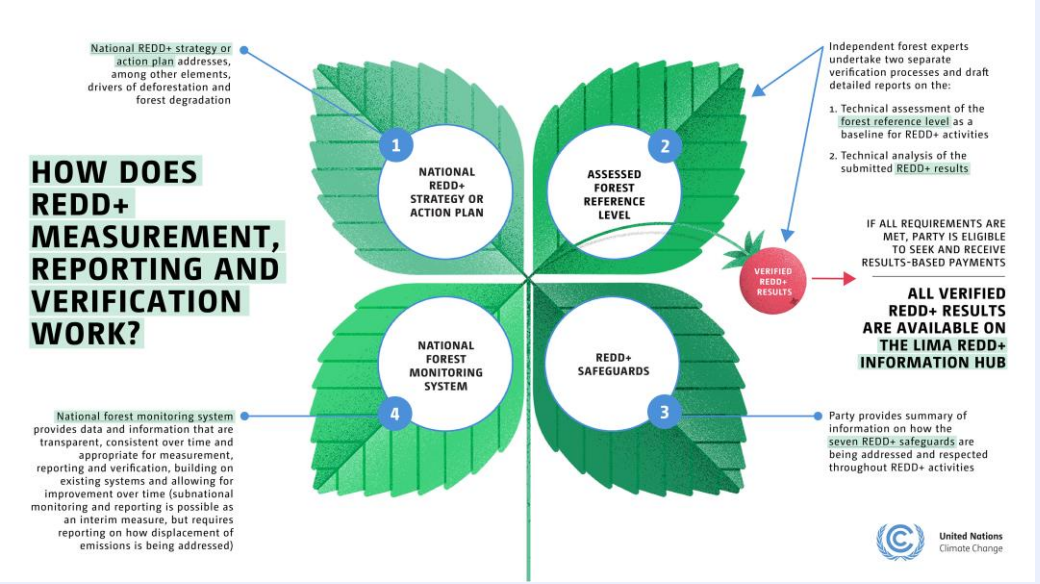
The example of available Data for LULUCF matrix and Forest CO2 storage estimation analysis (Source: Park et al. 2018)

Suggestion 2: International Cooperation: REDD+

Implementation of REDD+ in Samoa

- REDD+ is a voluntary climate change mitigation approach aims to provide incentives to developing countries to reduce emissions from deforestation and forest degradation, conserve forest carbon stocks, sustainably manage forests and enhance forest carbon stocks
- To support the implementation of REDD+ and capacity building for practitioners in Samoa, we will provide a manual that offers instructions for land use classification and forest carbon estimation





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Falealupo
Asau
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Fagafau
Tuasivi
Sala'ilua
바이토오뭄리 Vaito'omuli
사타푸알라 Satapuala
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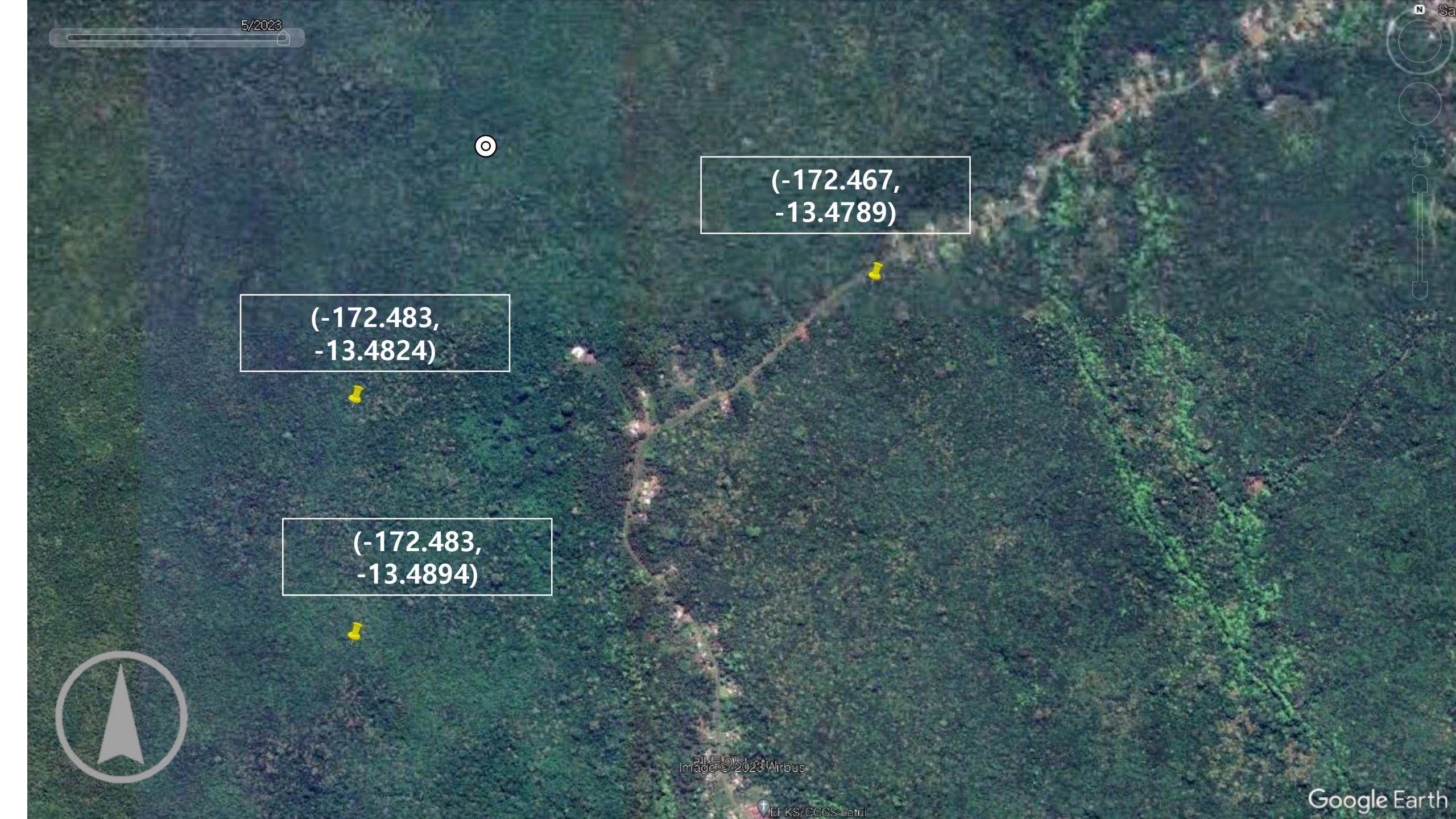
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Developing a framework and methodology to carbon sinks from the forestry sector in Samoa

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