

# Data analysis of ecosystem services assessment : Primary mangrove classification and species distribution probability

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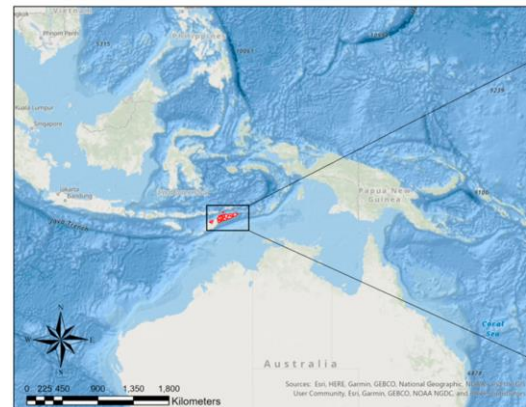
# Mangrove classification – case study in Timor-Leste

## Analysis of forest degradation rate in Timor-Leste using AI algorithm

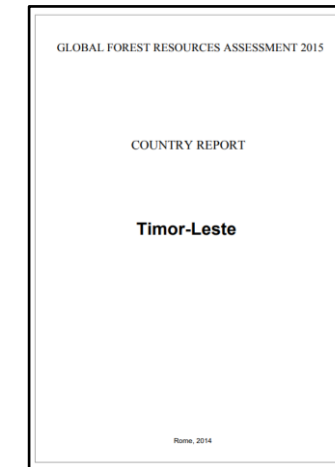
- The lack of infrastructure and sustainable agricultural practices in Timor-Leste has led to land use changes and the use of firewood as an alternative source of energy
- These factors have contributed to an estimated deforestation rate of approximately 1.4% annually in Timor-Lest
- According to FAO, the forest area in Timor-Leste was 966,000 ha in 1990 but reduced to 686,000 ha in 2015
- This study aimed to propose a **Simplified and High Accessibility Deforestation** (or forest degradation) (**SHAD**) assessment approach for countries with limited scientific resources and facilities, while minimizing the cost of constructing a deforestation detecting model, using the U-Net algorithm

Categories		Area (000 hectares)				
		1990	2000	2005	2010	2015
	Forest	966	854	798	742	686
	Other wooded land	0	0	0	0	0
	Other land	521	633	689	745	801
	... of which with tree cover	N/A	N/A	N/A	N/A	N/A
	Inland water bodies	0	0	0	0	0
TOTAL		1487.00	1487.00	1487.00	1487.00	1487.00

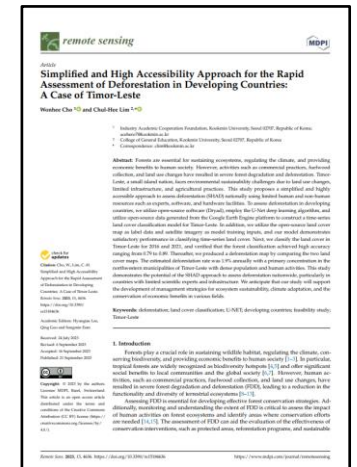
Forest area table in FAO country report



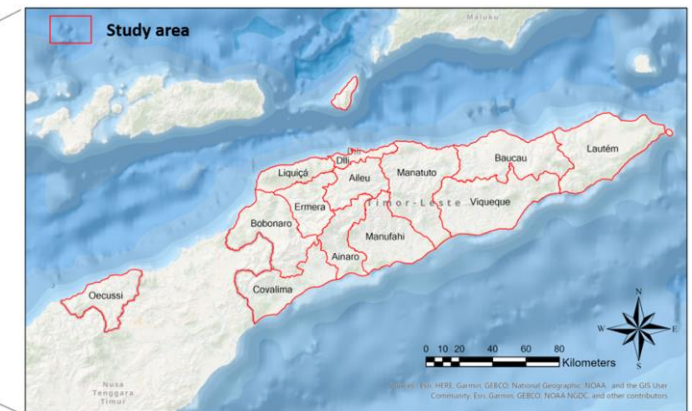
Location of Timor-Leste



FAO. 2015. Global Forest Resources Assessment 2015: Country Report Timor-Leste; FAO: Rome, Italy.

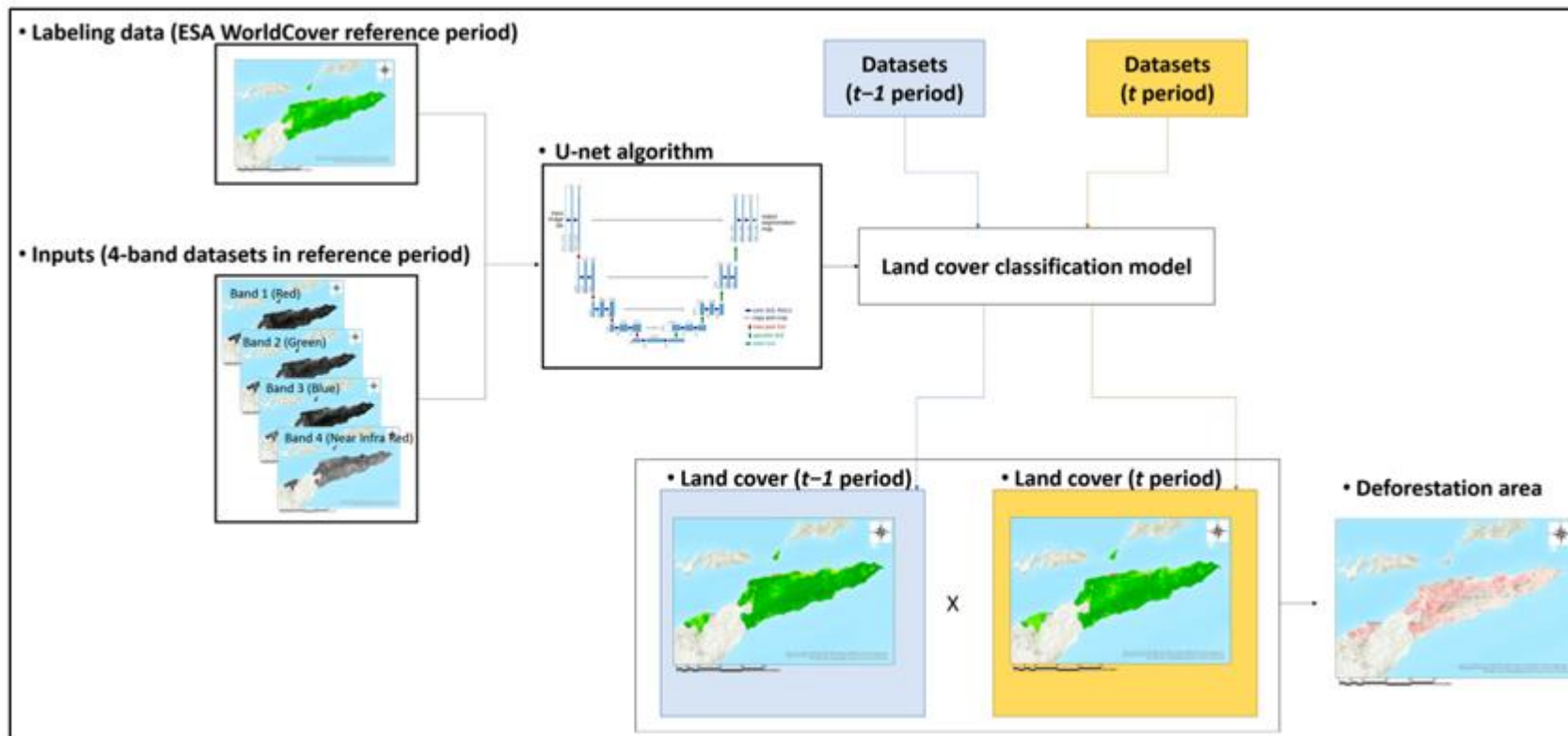


Cho, W.; Lim, C.-H. 2023. Simplified and High Accessibility Approach for the Rapid Assessment of Deforestation in Developing Countries: A Case of Timor-Leste. Remote Sens.



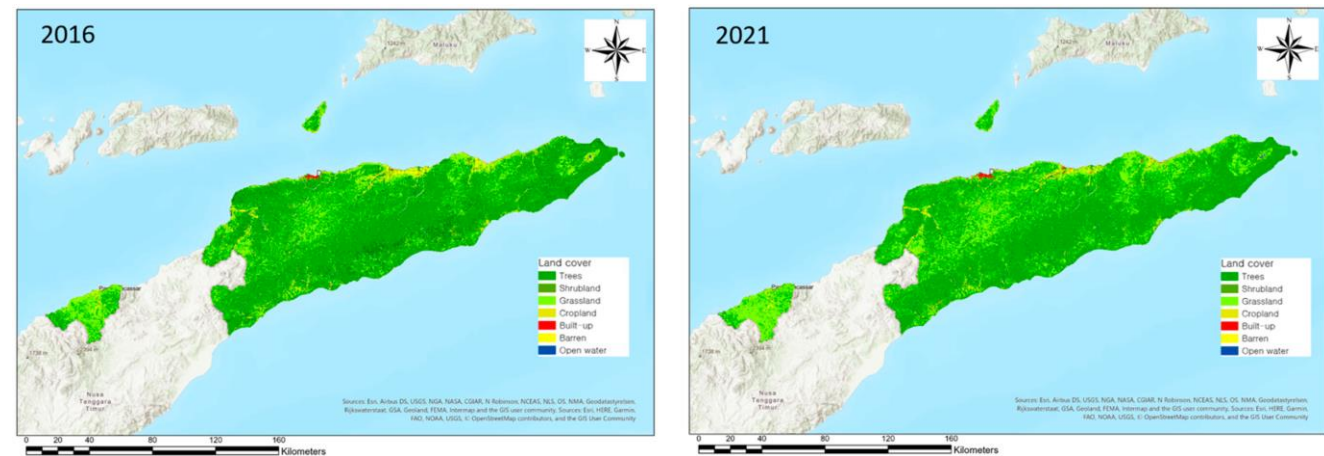
## Mangrove classification – case study in Timor-Leste

- Using Sentinel-2A satellite images with spatial resolution of 10m
- The 4-band dataset consists of red, green, blue, and near-infra red (NIR) bands, based on natural and reflectance characteristics
- Use ESA WorldCover 10m v100, which represents the near-real-time global land cover in 2020 based on Sentinel image
- U-net algorithm is used for land cover classification in this study
- Train the model using data from 2020 and generate land cover maps for 2016 and 2021 to detect areas of deforestation

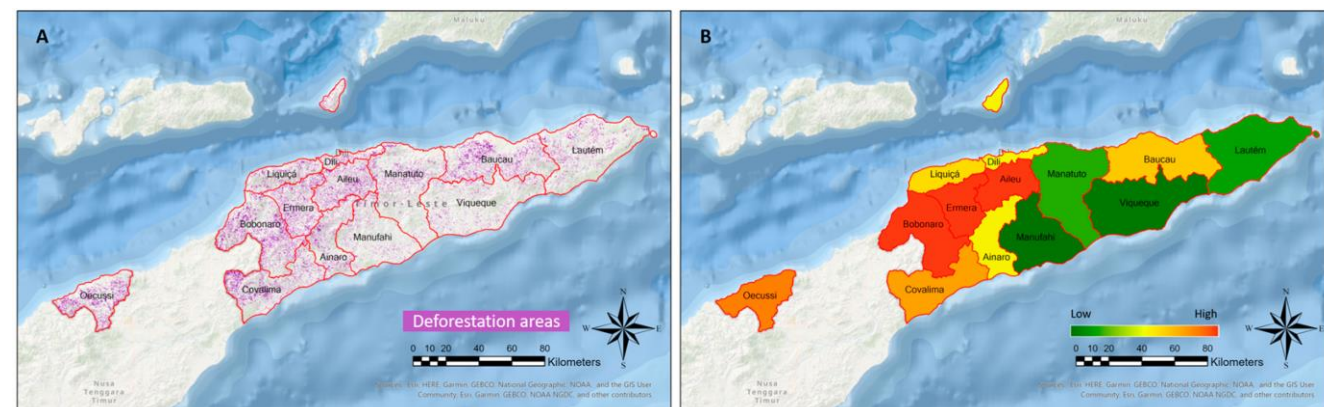


## Mangrove classification – case study in Timor-Leste

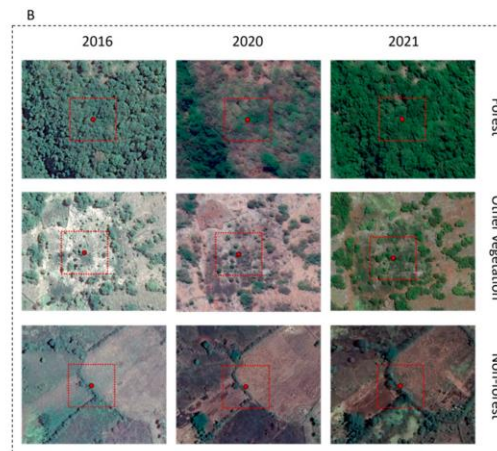
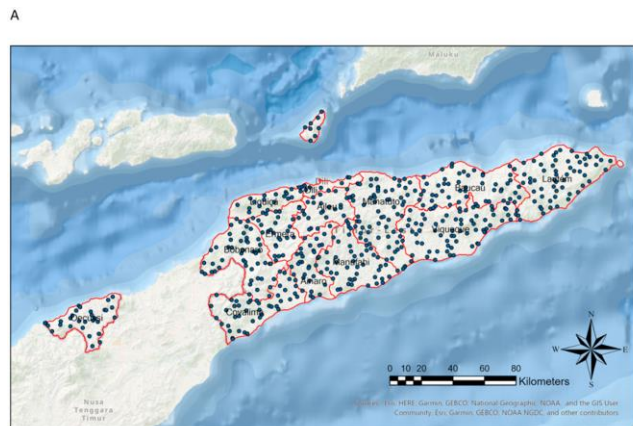
- To assess our estimation, we dispersed 250 random points on the forest area in the 2016 land cover classification map
- Utilized Google Earth Pro's time-series map as the reference images and evaluated the forest transition by comparing land cover changes
- The overall accuracy for the evaluation of the land cover classification by comparing the classified land cover map and reference images ranged from 0.68 to 0.79
- Deforestation was detected by comparing the changed forest area in 2016 to other types of land cover in 2021
- The forest area in Timor-Leste has steadily decreased from 2016 to 2021, with a reduction in the forest cover from **68.8 to 59.2%**
- The deforestation rate based on the change in forest cover during this period is estimated to be **1.9%** annually



2016 and 2021 land cover classification result



Deforestation area in 2016 to 2021; Level of deforestation by municipalities in Timor-Leste



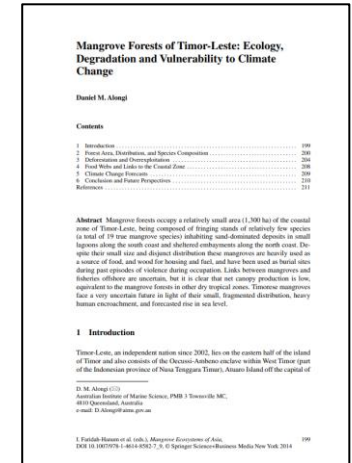
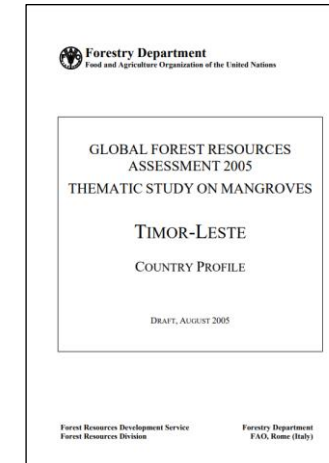
Land cover accuracy test sampling points and test images

## Mangrove classification – case study in Timor-Leste

According to FAO reports and articles on mangroves in Timor-Leste...

- In Timor-Leste, mangroves are used for fuelwood, tannin extractions, and other products
- There are cases where mangrove forests are destroyed to establish shrimp farms
- Currently, significant mangrove loss has occurred in Timor-Leste
- The mangrove area, which was **9,000 hectares in 1940**, decreased to **1,802 hectares by 2005**
- Need of their protection has also been recognized by the Timor-Leste's authorities
- In the case of mangrove, there are undetected information from existing global data

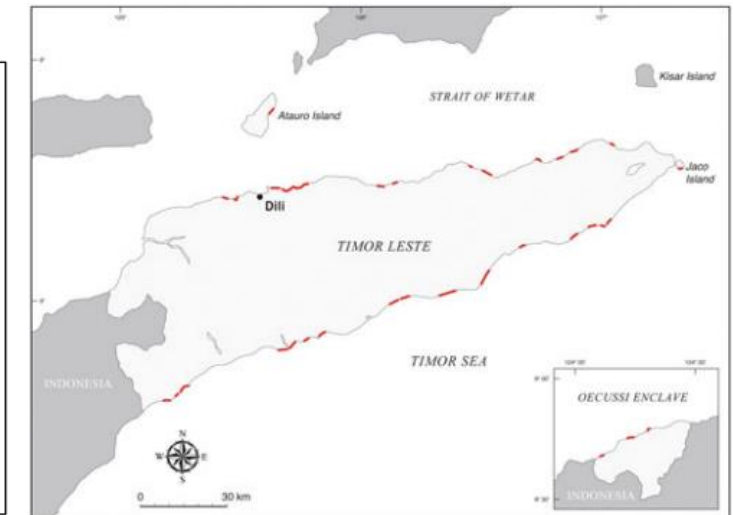
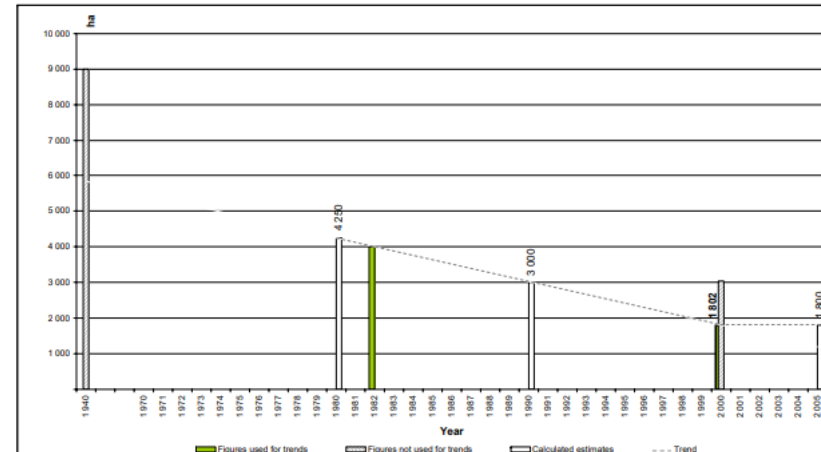
→ Given the destruction of mangrove forests in Timor-Leste, it is imperative to assess current mangrove distribution and areas of destruction for conservation and reforestation efforts



Saenger, P., Hegerl, E.J. & Davie, J.D.S. (1983). Global status of mangrove ecosystems. Commission on ecology papers No. 3. Gland, Switzerland, IUCN

Alongi, Daniel. (2013). Mangrove Forests of Timor-Leste: Ecology, Degradation and Vulnerability to Climate Change.

Year	Area (ha)	Source	Trend	Methodology/Comments
1940	9 000	Mackinnon, J.; Beudels R.C, Robinson A.H. 1982. <i>National conservation plan for Indonesia. V. 4: Nusa Tenggara</i> . FAO-FO-INS/78/061 Field report 44.		Secondary reference, no primary source provided. "Original" mangroves extent.
1982	4 000	Mackinnon, J.; Beudels R.C, Robinson A.H. 1982. <i>National conservation plan for Indonesia. V. 4: Nusa Tenggara</i> . FAO-FO-INS/78/061 Field report 45	X	Secondary reference, no primary source provided. The "Year" is the publication year.
2000	3 035	The World-Web Virtually Library-East Timor. 2000. <i>Flora and Fauna The obscure history of East Timor - Flora and fauna</i> Universidade de Coimbra. <a href="http://www.uc.pt/timor/flora/fauna.html#THE.MAN.GROVE">http://www.uc.pt/timor/flora/fauna.html#THE.MAN.GROVE</a>		Secondary reference, no primary source provided. The "Year" is the publication year.
2000	1 802	GOTL. 2001. <i>Rapid Rural Land Use Assessment and Model For Land Use Classification and Mapping</i> . Agricultural Land Use and Geographical Information System unit. Timor-Leste.	X	Cited in: FAO. 2005. <i>Global Forest Resources Assessment 2005 - Timor-Leste</i> . By da Silva, M. FRA 2005 Country Report No. 218. Unpublished.



Location of mangrove forests in article

# Mangrove classification – case study in Timor-Leste

## Satellite image pre-processing and input materialization

- Using Landsat-8 satellite images with spatial resolution of 30m
- Mangrove forests are characterized by high humidity and low temperatures resulting from periodic tidal flooding
- Mangrove Index has been developed with association to the SWIR band.
- MI\*, NDMI\*, and SIAD\*, which are effective indices, were used in previous studies

→ Combining these, we create false-color images and aim to identify only mangrove habitats

\* MI: Mangrove Index; NDMI: Normalized Mangrove Index; SIAD: Shortwave Infrared Absorption Depth

Landsat-7 ETM+ Bands (µm)			Landsat-8 OLI and TIRS Bands (µm)		
			30 m Coastal/Aerosol	0.435 - 0.451	Band 1
Band 1	30 m Blue	0.441 - 0.514	30 m Blue	0.452 - 0.512	Band 2
Band 2	30 m Green	0.519 - 0.601	30 m Green	0.533 - 0.590	Band 3
Band 3	30 m Red	0.631 - 0.692	30 m Red	0.636 - 0.673	Band 4
Band 4	30 m NIR	0.772 - 0.898	30 m NIR	0.851 - 0.879	Band 5
Band 5	30 m SWIR-1	1.547 - 1.749	30 m SWIR-1	1.566 - 1.651	Band 6
Band 6	60 m TIR	10.31 - 12.36	100 m TIR-1	10.60 - 11.19	Band 10
			100 m TIR-2	11.50 - 12.51	Band 11
Band 7	30 m SWIR-2	2.064 - 2.345	30 m SWIR-2	2.107 - 2.294	Band 7
Band 8	15 m Pan	0.515 - 0.896	15 m Pan	0.503 - 0.676	Band 8
			30 m Cirrus	1.363 - 1.384	Band 9

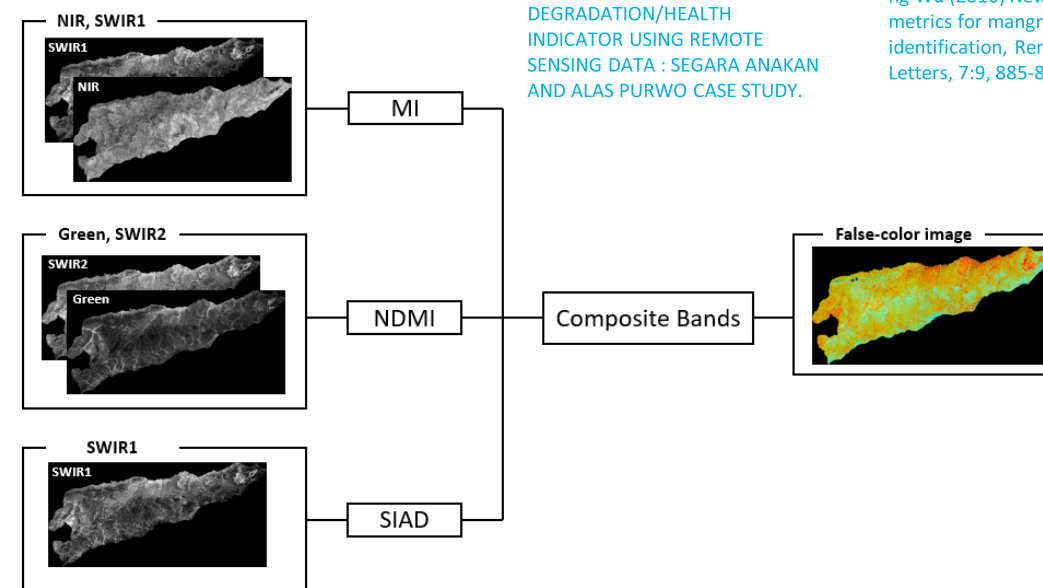
Landsat-7 ETM+ and Landsat-8 OLI spectral band



Winarso, Gathot & Purwanto, Anang & Yuwono, Doddy. (2014). NEW MANGROVE INDEX AS DEGRADATION/HEALTH INDICATOR USING REMOTE SENSING DATA : SEGARA ANAKAN AND ALAS PURWO CASE STUDY.



Tiezhu Shi, Jue Liu, Zhongwen Hu, Huizeng Liu, Junjie Wang & Guofeng Wu (2016) New spectral metrics for mangrove forest identification, Remote Sensing Letters, 7:9, 885-894

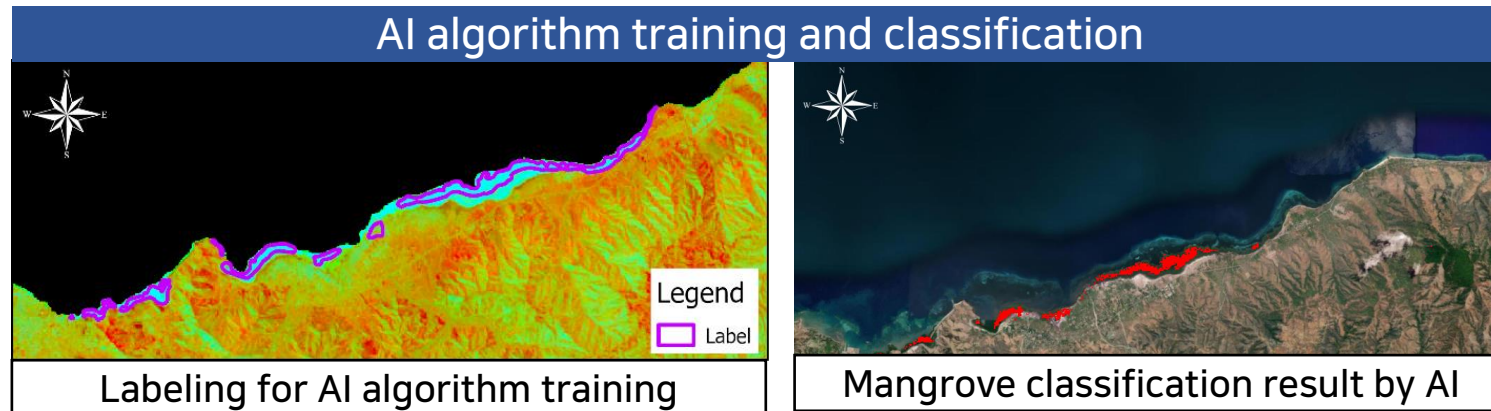


Satellite image pre-processing process

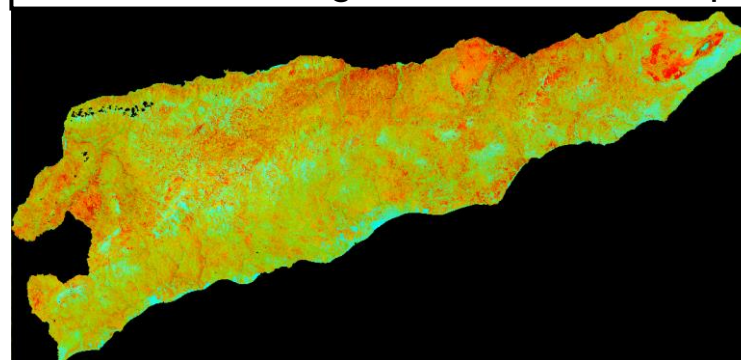
## Mangrove classification – case study in Timor-Leste

### AI Model build

- Utilizing U-NET AI algorithms that have recently attracted attention
- Mangrove detection model trained using mangrove index input data representative of 2020 dry season
- In 2013, 2019, and 2023, the accuracy of the classification results was evaluated to validate the model



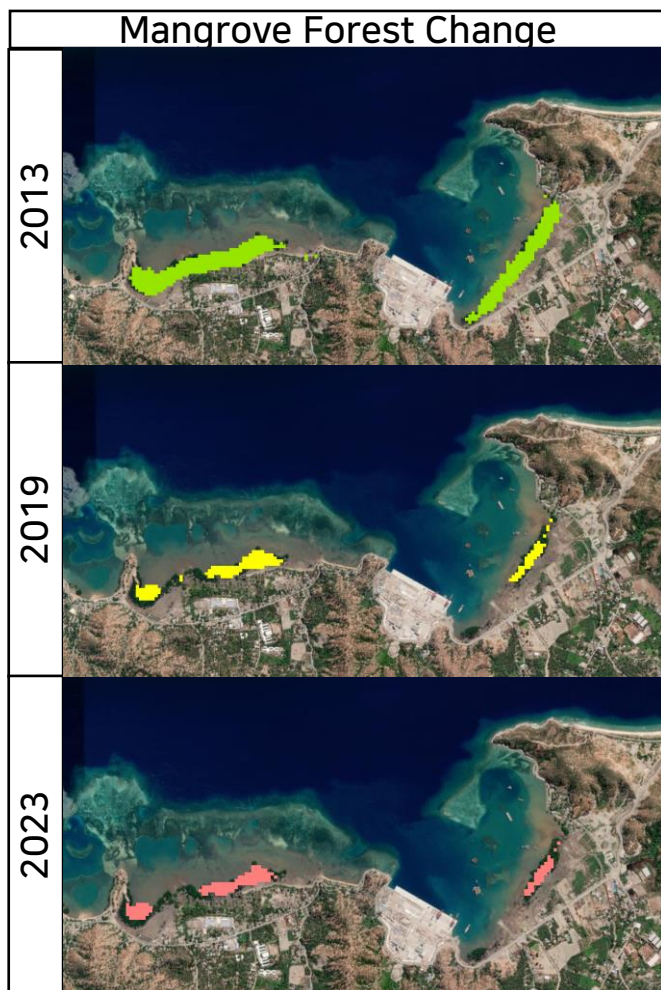
Timor-Leste Mangrove Distribution Map



## Mangrove classification – case study in Timor-Leste

### Construction of Spatial Information for the Selection of Mangrove Forest Areas

- The feasibility is confirmed by calculating the rate of devastation through mapping the mangrove distribution over different periods
- Contributing to preliminary site selection by generating regional statistical data and identifying priority areas for afforestation



Total 45.05% reduction

Year	Area
2013	6,378 ha
2019	4,175 ha
2023	3,505 ha

### Changes in mangrove area at regional level

Municipality	Mangrove Area Change(2013-2023)			
	2013(ha)	2019 (ha)	2023 (ha)	Area Change (%)
Aileu	0.00	0.00	0.00	0.00
Ainaro	554.67	398.25	352.89	-36.38
Baucau	148.59	56.16	50.40	-66.08
Bobonaro	34.02	15.84	11.88	-65.08
Covalima	1363.86	957.96	767.16	-43.75
Dili	234.27	175.59	143.82	-38.61
Ermera	0.00	0.00	0.00	0.00
Lautem	431.28	167.94	95.31	-77.90
Liquica	89.64	39.69	29.25	-67.37
Manatuto	881.82	574.47	547.29	-37.94
Manufahi	1379.70	890.91	834.57	-39.51
Viqueque	1260.36	898.29	672.12	-46.67
Total	6378.21	4175.10	3504.69	-45.05

## Mangrove classification – case study in Timor-Leste

### Validation of classification results of AI model

- The classification performance of the improved model is validated by evaluating accuracy based on ground truth data\*
- Accuracy assessment is conducted by comparing mangrove, forest classified from the constructed model
- Provide more objective information by incorporating data obtained through field trips

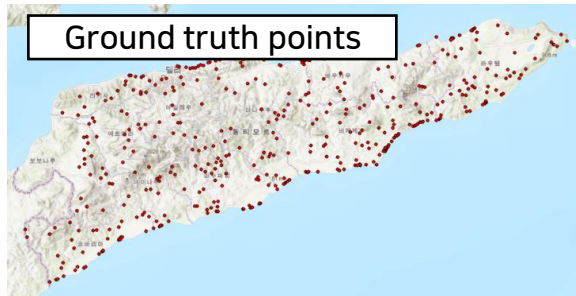
\* Ground truth data based on high-resolution satellite image (provided Google Earth Pro)

#### Make Ground truth data

##### Google earth pro



##### Ground truth points



#### Accuracy assessment

2013		Reference		Total	User's accuracy
		Mangrove	Forest		
Prediction	Mangrove	87	4	91	0.956
	Forest	43	292	335	0.872
Total		130	296	426	
Producer's accuracy		0.669	<b>0.986</b>		
Accuracy		Overall accuracy: 0.890 Kappa coefficient: 0.716			

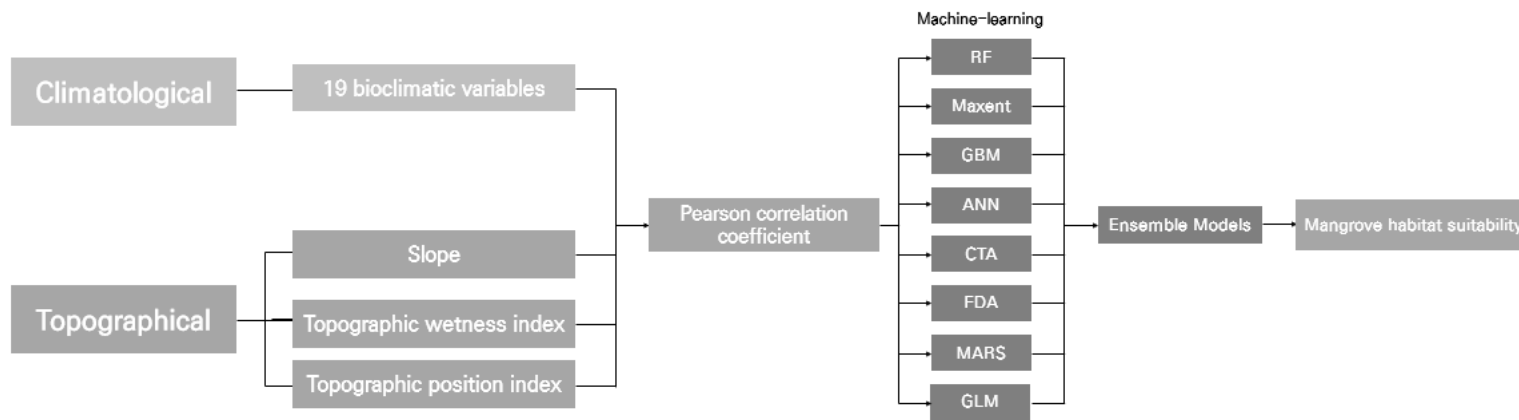
2019		Reference		Total	User's accuracy
		Mangrove	Forest		
Prediction	Mangrove	77	3	80	0.963
	Forest	53	293	346	0.847
Total		125	296	426	
Producer's accuracy		0.592	<b>0.990</b>		
Accuracy		Overall accuracy: 0.869 Kappa coefficient: 0.653			

2023		Reference		Total	User's accuracy
		Mangrove	Forest		
Prediction	Mangrove	95	12	107	0.888
	Forest	30	288	318	0.906
Total		125	300	425	
Producer's accuracy		0.760	<b>0.960</b>		
Accuracy		Overall accuracy: <b>0.901</b> Kappa coefficient: 0.751			

## Mangrove classification – case study in Timor-Leste

Analysis of mangrove suitability area in Timor-Leste using Machine Learning

- Using a machine learning ensemble approach, we investigate suitable regions for mangrove habitats that are applicable to the climate in Timor-Leste
- We used the 1970-2000 average climate data provided by Worldclim
- Mangrove presence points were extracted from ESA WorldCover v100 (2020)
- To incorporate climate data, biologically meaningful bioclimatic variables derived from monthly temperature and rainfall values were used
- To remove multicollinearity, Variables with over 0.8 correlation coefficients were excluded from the analysis
- Following this, the mangrove research presence data and corresponding machine learning model were employed, and an ensemble approach was used to assess the suitability for mangrove survival

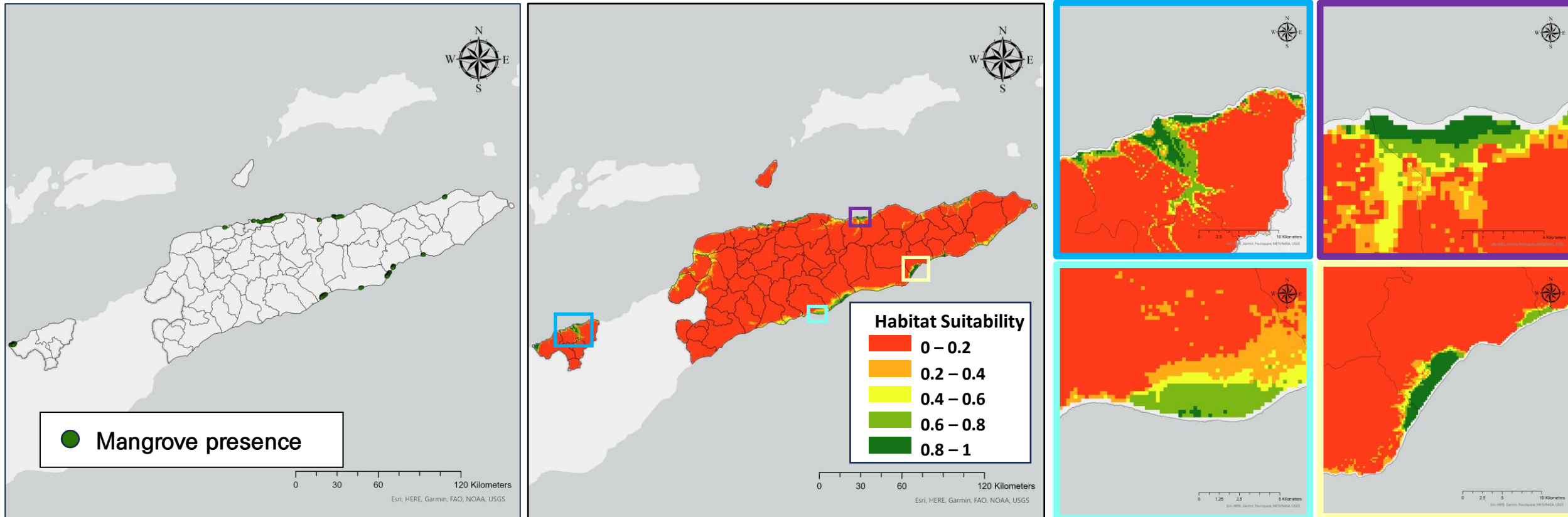


Variable	Variable Name	Description
<b>Climate Factor</b>	BIO3	Isothermality
	BIO5	Max Temperatruue of Warmest Month
	BIO6	Min Temperature of Coldest Month
	BIO7	Temperature Annual Range
	BIO12	Annual Precipitation
	BIO16	Precipitation of Wettest Quarter
	BIO17	Precipitation of Warmest Quarter
<b>Topographica I Factor</b>	Slope	Slope
	TWI	Topographic Wetness Index
	TPI	Topographic Position Index

# Mangrove classification – case study in Timor-Leste

Analysis of mangrove suitability area in Timor-Leste using Machine Learning

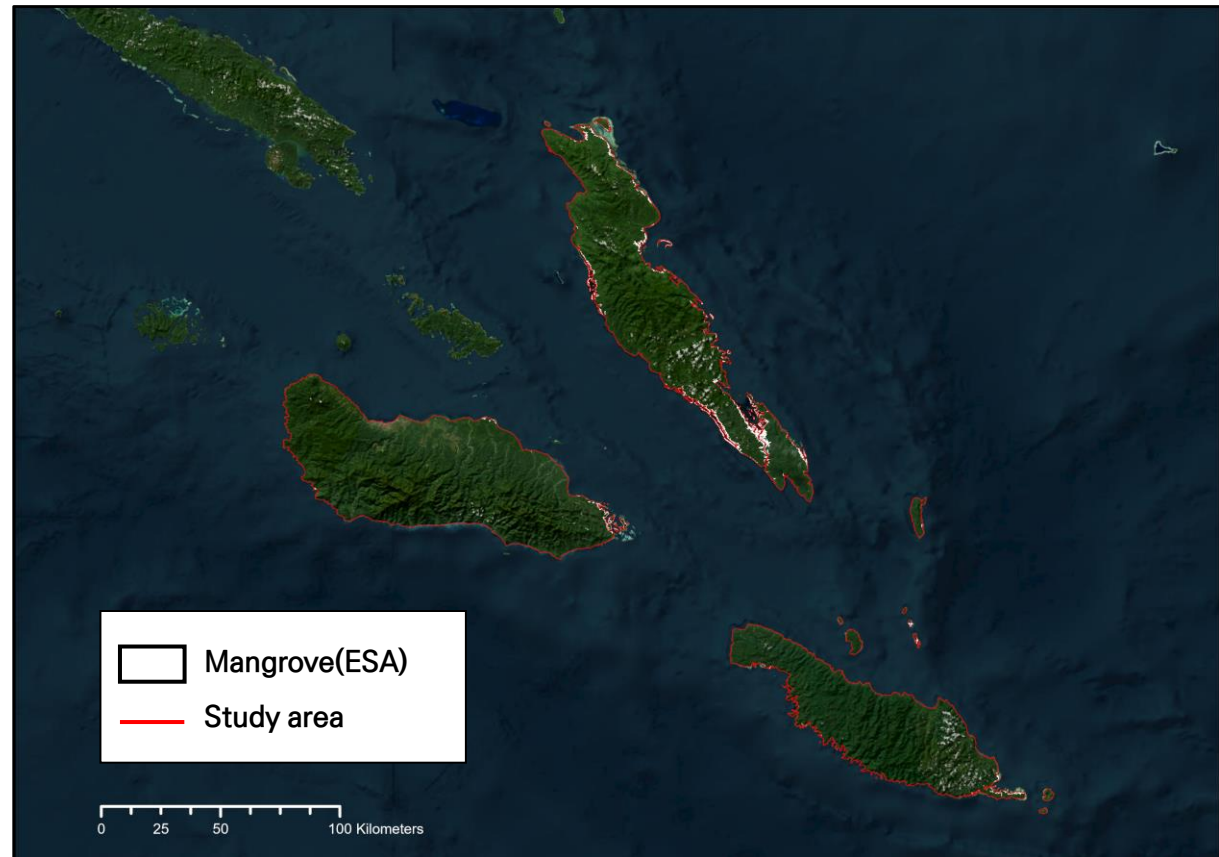
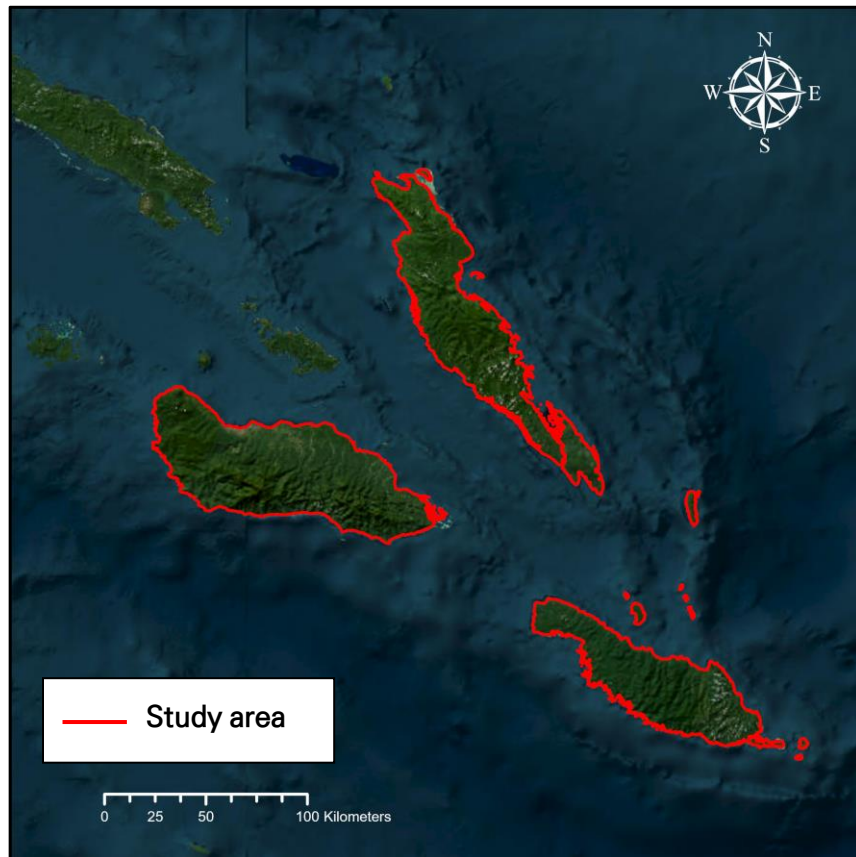
- The AUC(Area Under the Curve) of the ensemble machine learning model was above 0.9, indicating high accuracy
- The growth characteristics of mangroves resulted in elevated habitat suitability along the coastline
- Learned ensemble model can subsequently reflect climate change scenarios to identify future suitable mangrove habitat area



## Study area

### Study area

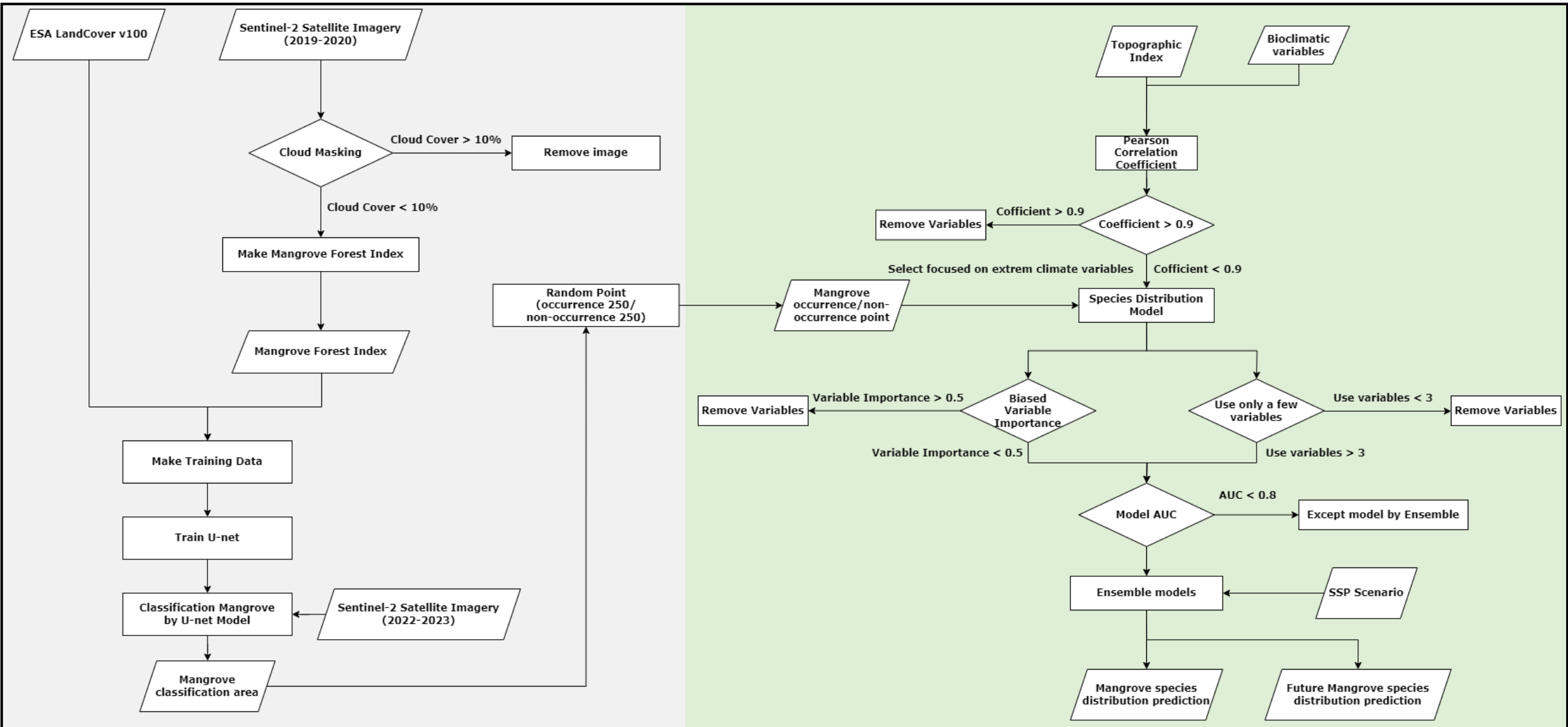
- The areas of Malaita, Guadalcanal, and Makira-Ulawa are being analyzed as the study area
- We aimed to conduct the analysis targeting the entire Solomon Islands region
- However, due to time constraints, we conducted mangrove classification focusing on three specific islands



# Flow chart

Mangrove classification by AI model

Mangrove suitability analysis by Machine Learning

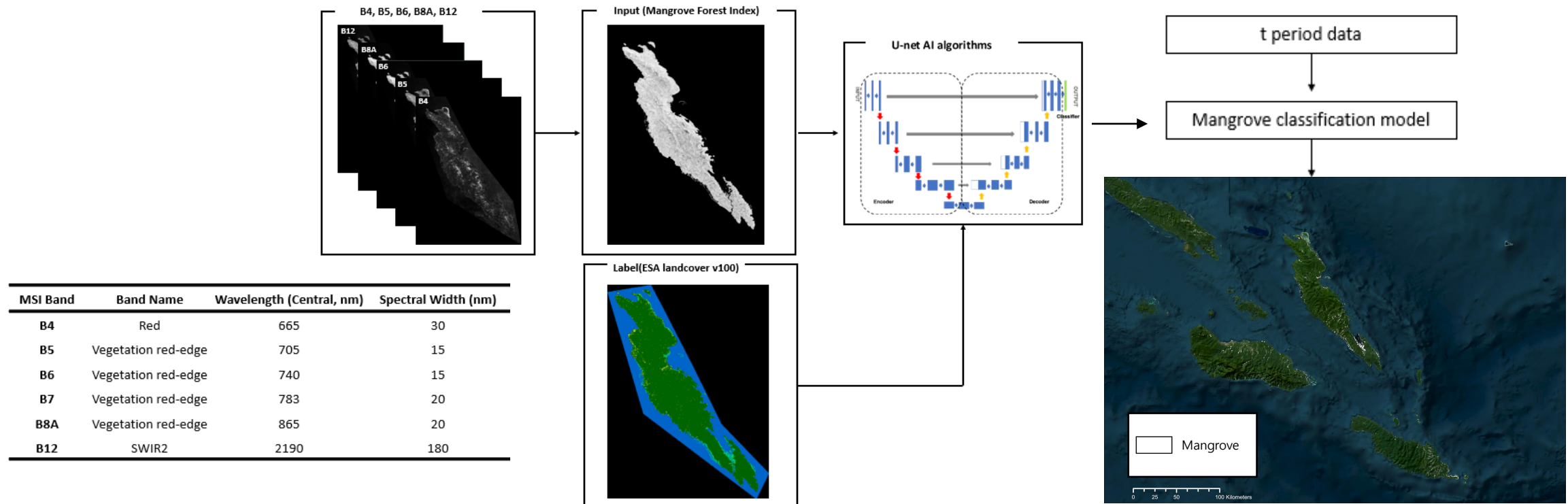


# Mangrove classification using AI model

Satellite image pre-processing, input materialization of Malatia, Guadalcanal, Makira-Ulawa and AI Model build

- Using Sentinel-2A satellite images with spatial resolution of 10m
- Using MFI\*, derived from Sentinel-2A satellite, as training data for AI model
- Training AI algorithms after generating training data using MFI

\*MFI: Mangrove Forest Index



## Mangrove classification using AI model

Satellite image pre-processing, input materialization of Malatia, Guadalcanal, Makira-Ulawa, and AI Model build

- Mangrove classification model utilized the U-Net algorithm, which is currently trending in fields
- U-net algorithm is suitable for mangrove detection in the Solomon Islands, as it can accurately detect with relatively few labeled data
- Mangrove classification model trained using mangrove index input data representative of 2019-2020 dry season (May 01 – October 31)
- However, among the classification results, we further classified the data within the mangrove area of ESA landcover v100 to proceed with a classification of higher precision than ESA WorldCover v100



## Mangrove classification using AI model



〈 Classification Mangrove result by AI model〉

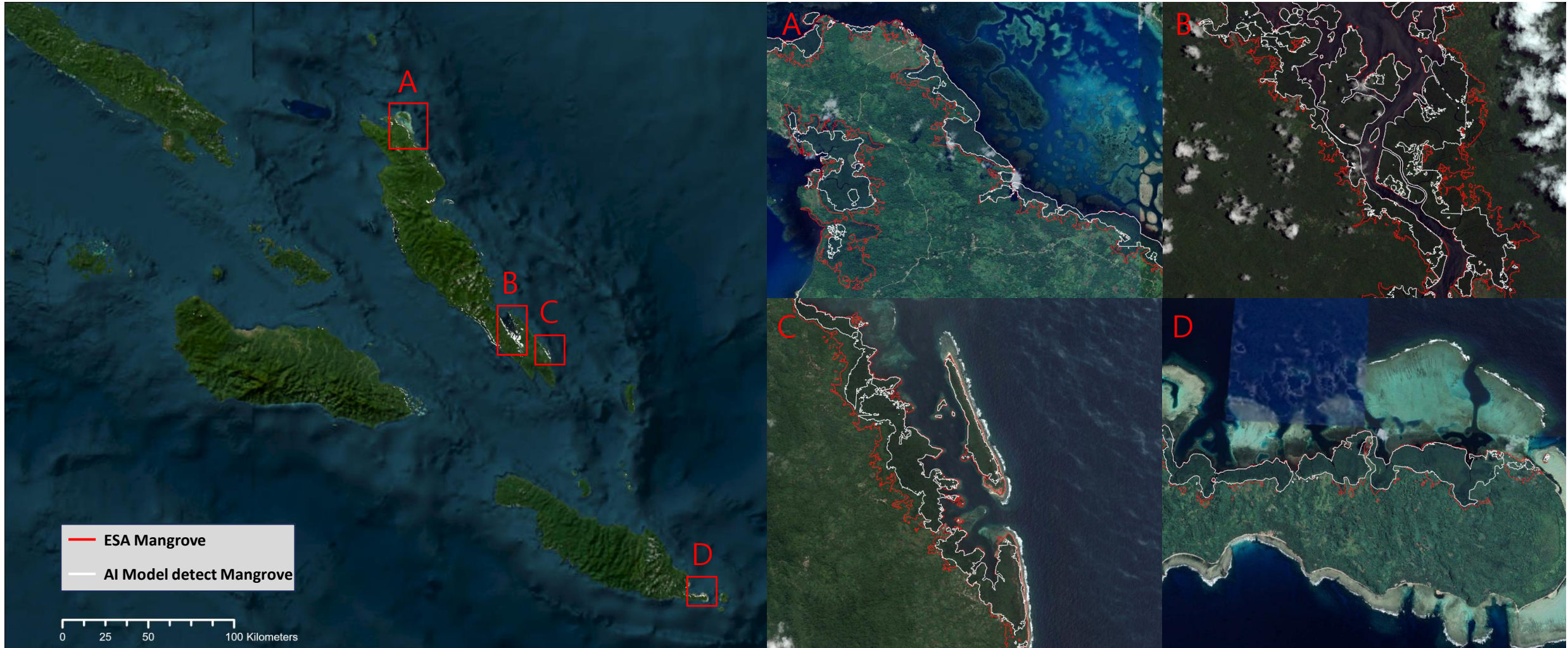
## Mangrove classification using AI model



〈 AI Model Classification Mangrove result in ESA Mangrove area 〉

# Mangrove classification using AI model

Mangrove detection result and high-resolution satellite image (Google Earth Pro)



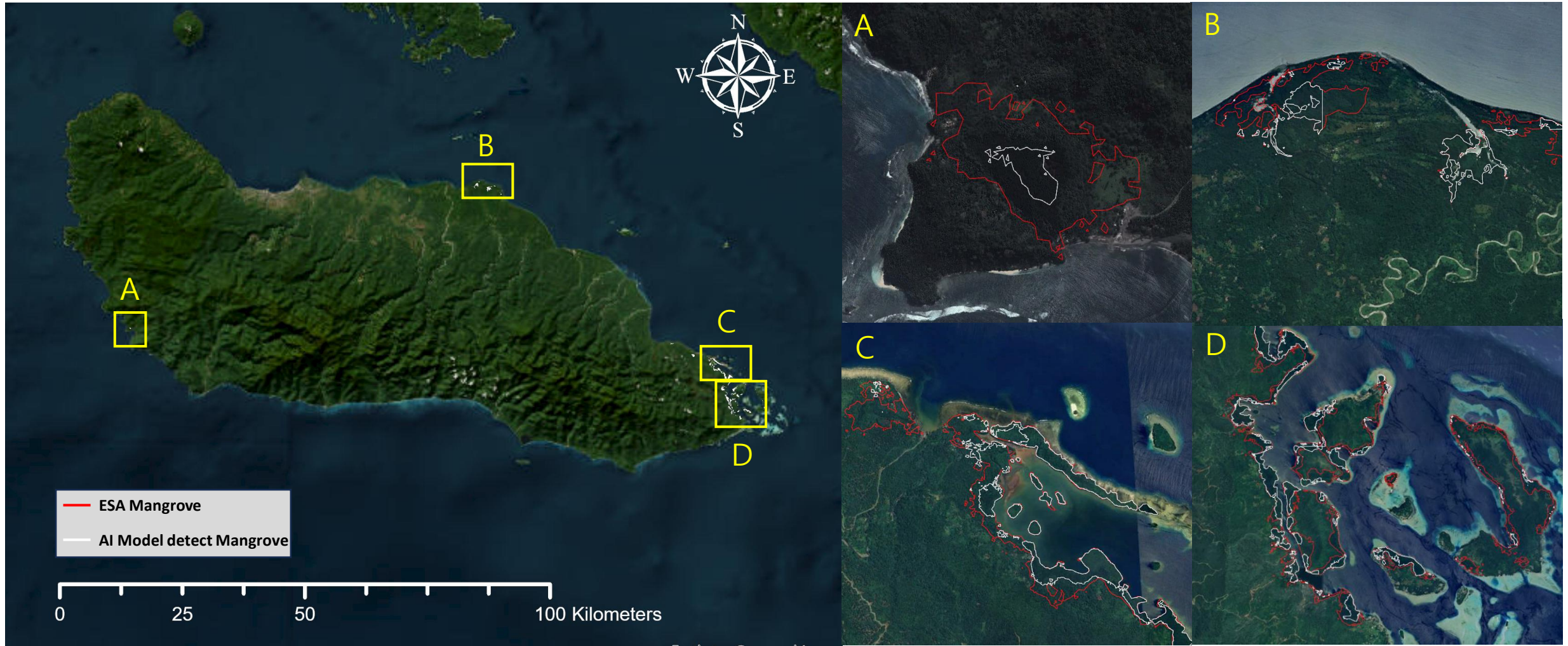
# Mangrove classification using AI model

Mangrove detection result and high-resolution satellite image (Google Earth Pro, Malatia)



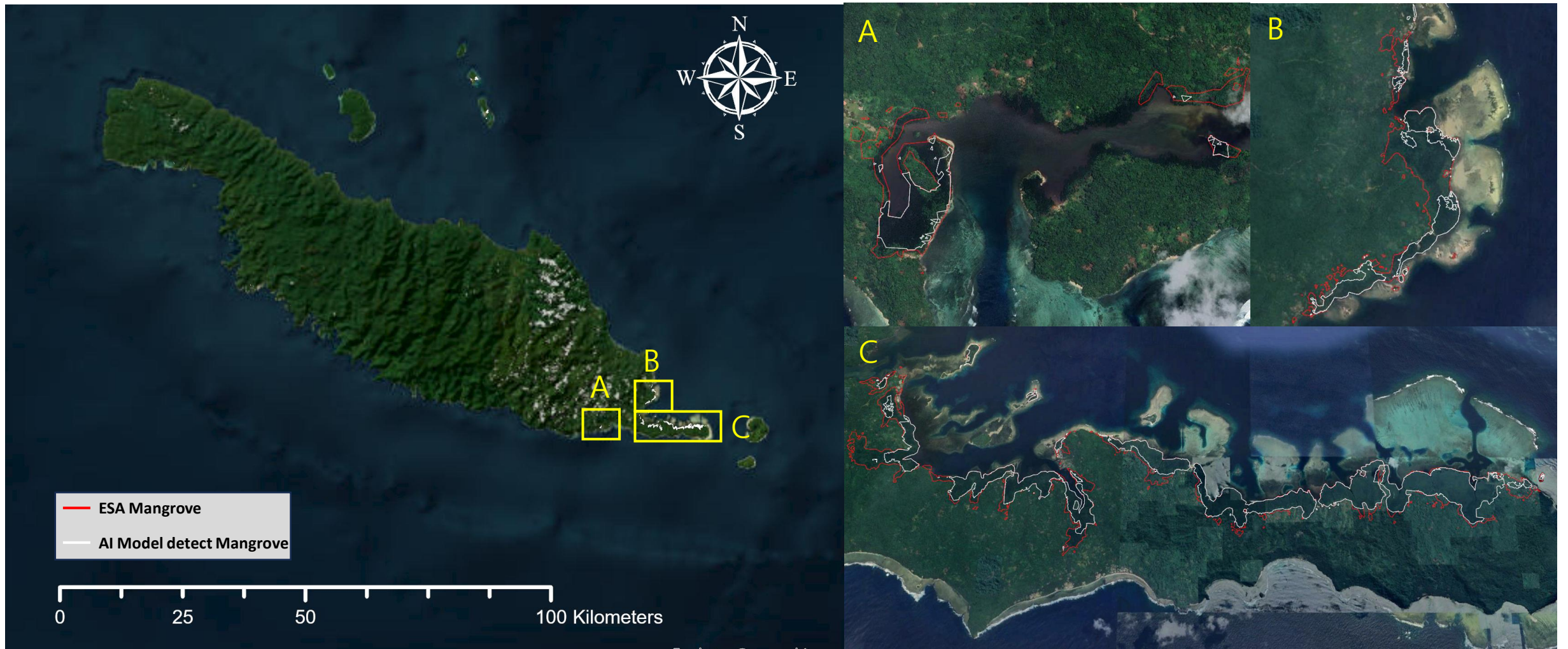
# Mangrove classification using AI model

Mangrove detection result and high-resolution satellite image (Google Earth Pro, Guadalcanal)



# Mangrove classification using AI model

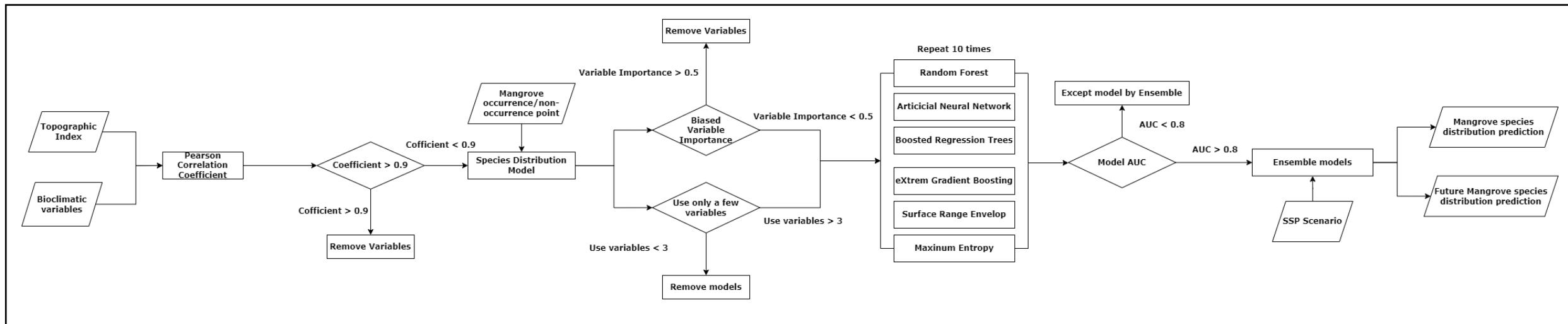
Mangrove detection result and high-resolution satellite image (Google Earth Pro, Makira-Ulawa)



## Mangrove suitability model

Analysis of mangrove suitability area in Malatia, Guadalcanal, Makira-Ulawa using Machine Learning

- Using a machine learning ensemble approach, we investigate suitable regions for mangrove habitats that are applicable to the climate in Solomon Island
- We used the 1970-2000 average climate data provided by Worldclim
- Mangrove presence points were extracted from Mangrove classification model output
- To incorporate climate data, biologically meaningful bioclimatic variables derived from monthly temperature and rainfall values were used
- To remove multicollinearity, Variables with over 0.9 correlation coefficients were excluded from the analysis
- The mangrove research presence data and corresponding machine learning model were employed, and an ensemble approach was used to assess the suitability for mangrove survival



⟨Machine Learning build flow chart⟩

## Mangrove suitability model

Input Variables, variable importance and response curve

- To remove multicollinearity, Variables with over 0.9 correlation coefficients were excluded from the analysis
- Selecting the variables with correlation coefficient above 0.9, prioritizing extreme values
- If Digital Elevation Model(DEM) is included, contribution is consistently high, exceeding 0.7 across all models
- Therefore, in this study, DEM was excluded from the analysis
- Slope, BIO15, and BIO5 make substantial contributions to the model

Variable	Variable Name	Description	Source	Variable Importance
Climate Factor	BIO4	Isothermality	Worldclim	0.01082
	BIO5	Max Temperatrue of Warmest Month	Worldclim	0.14061
	BIO7	Temperature Annual Range	Worldclim	0.05314
	BIO13	Precipitation of Wettest Month	Worldclim	0.00213
	BIO14	Precipitation of Driest Month	Worldclim	0.01039
	BIO15	Precipitation Seasonality	Worldclim	0.19258
Topographical Factor	Slope	Slope	USGS	0.19872
	Soil_group	Topographic Wetness Index	Soilgrids	0.01646
	Soil_organic	Topographic Position Index	Soilgrids	0.00451
Socio-economic Factor	LC	Land Cover	ESA	0.00001
	road	Distance from road	OpenStreetMap	0.0062

< Ensemble model variable table using machine learning >

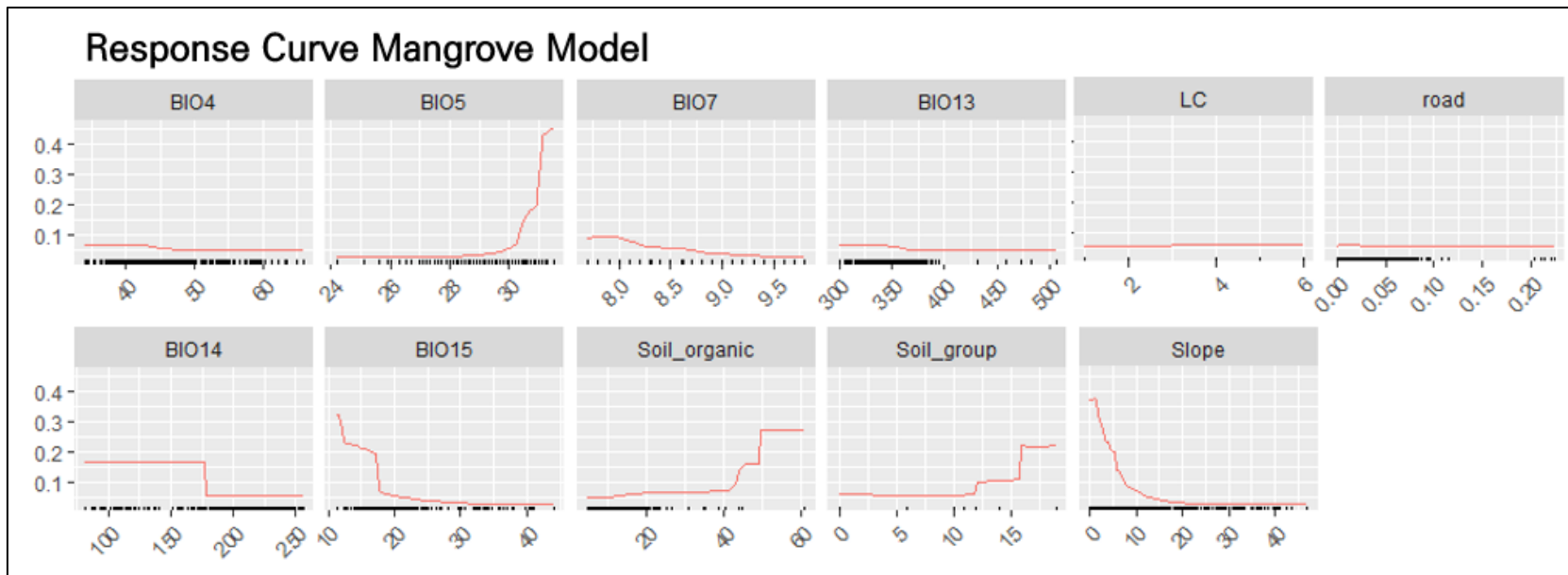


< Ensemble model variable importance box plot in this study >

## Mangrove suitability model

Input Variables, variable importance and response curve

- BIO5 (Max Temperature of Warmest Month) showed very high responsiveness at a threshold of 31°C
- Slope exceeds 10°, responsiveness decreases significantly
- BIO14 (Precipitation of Driest Month) exceeds 175mm, responsiveness decreases significantly
- Similarity in soil organic content across soil groups results in similar response curves

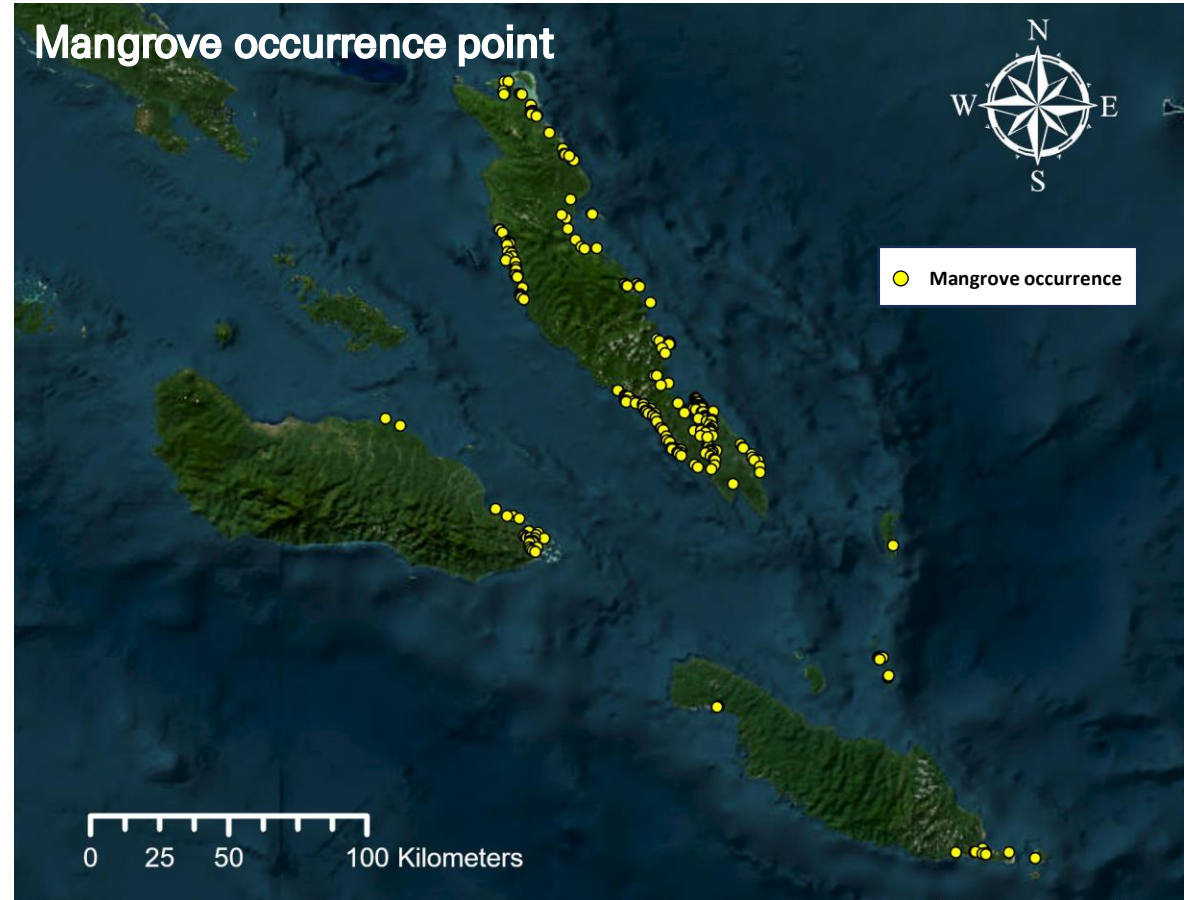
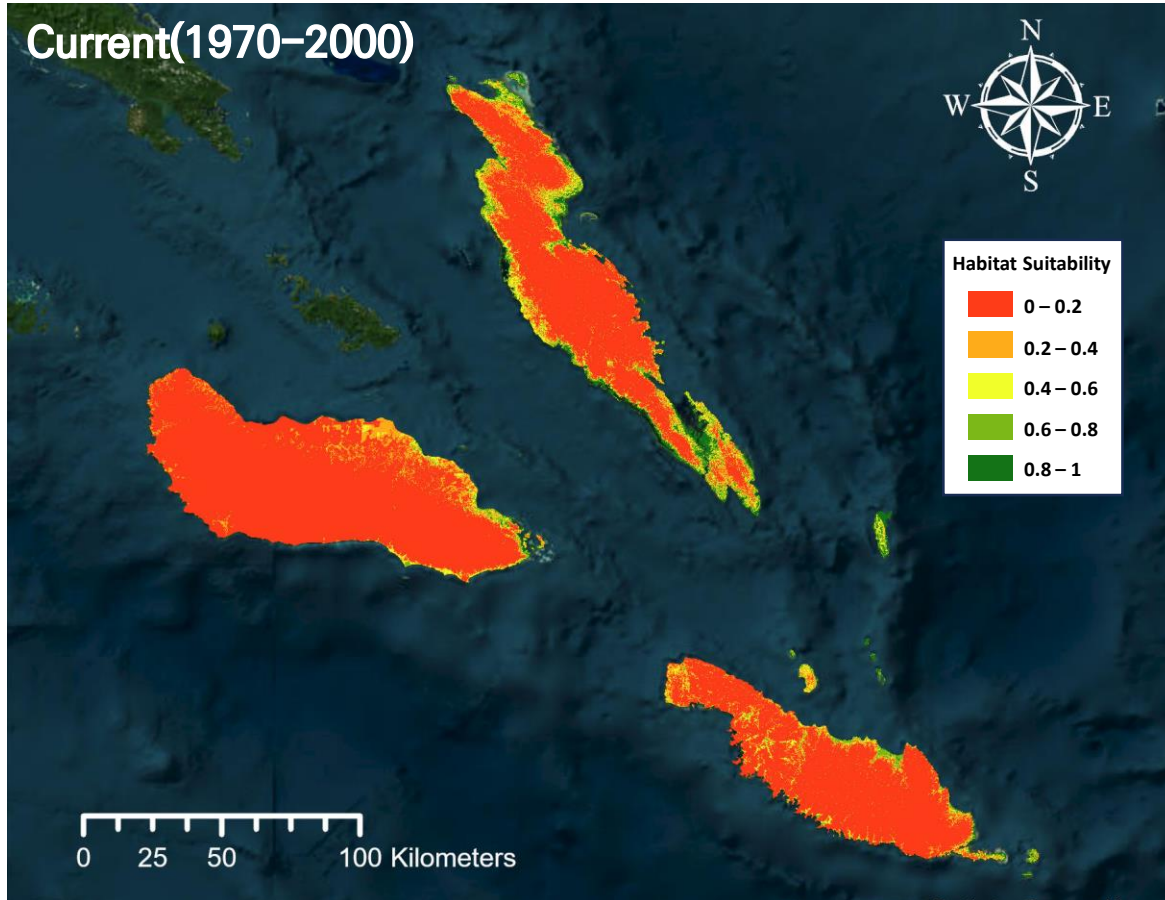


Soil Group Name	Value
Acrisols	0
Andosols	3
Arenosols	4
Cambisols	6
Ferralsols	10
Fluvisols	11
Gleysols	12
Histosol	14
Nitisols	19

## Mangrove suitability model

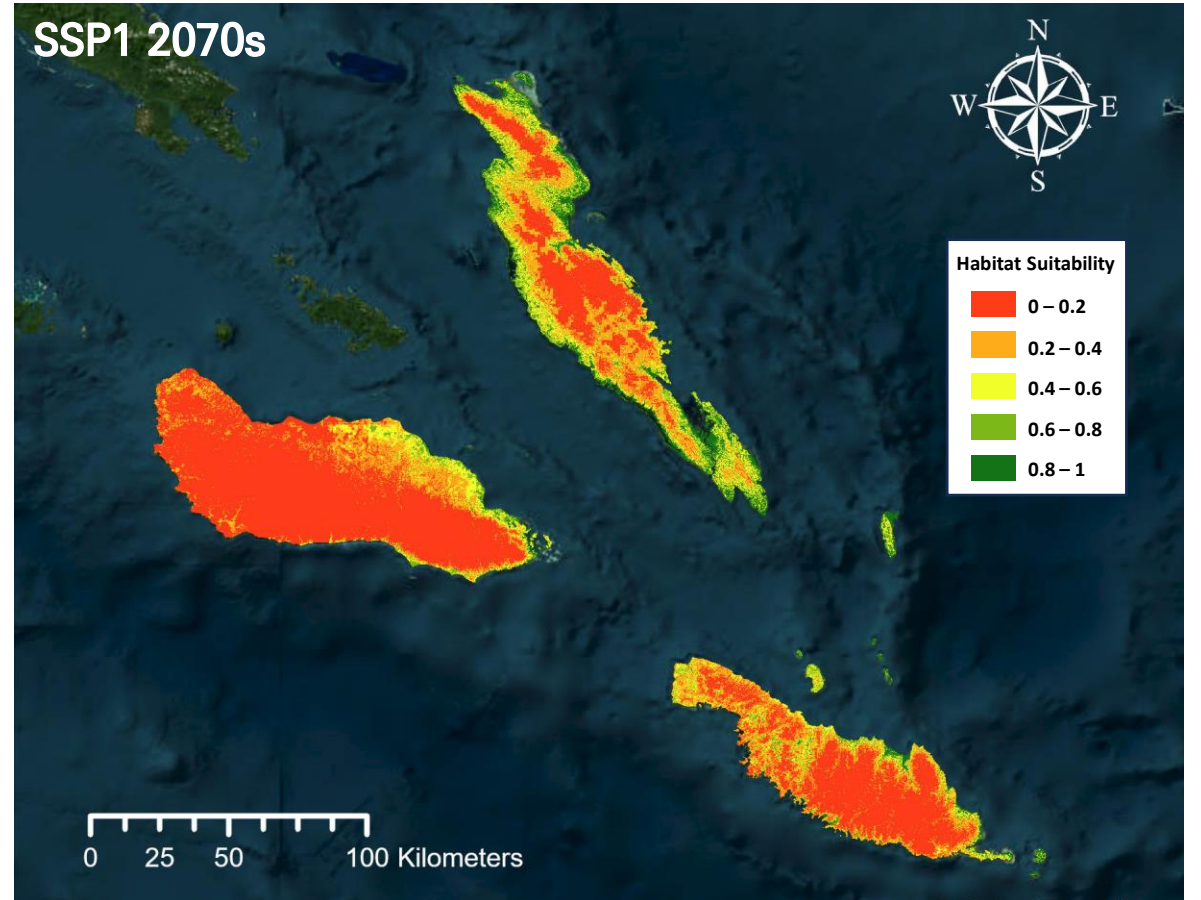
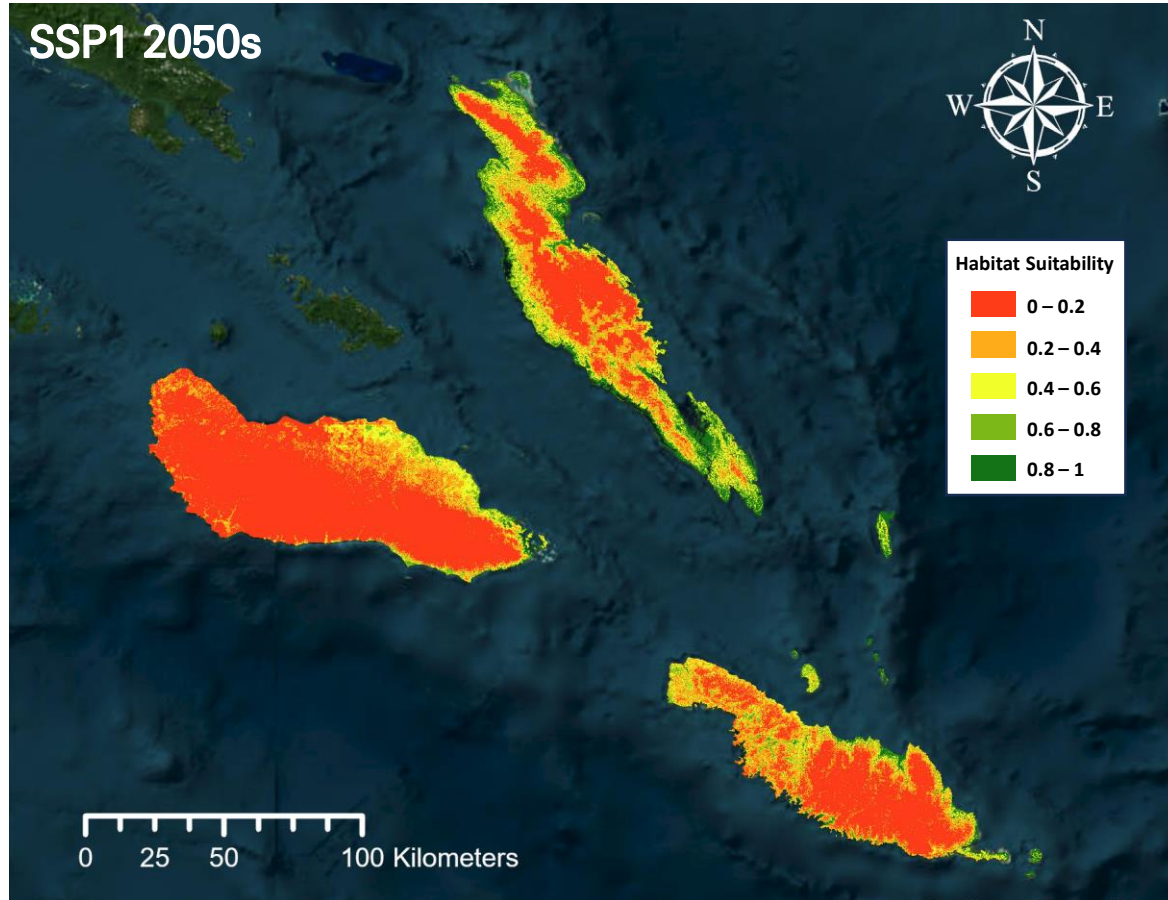
Mangrove distribution probability model output (Current)

- The AUC of the ensemble model is 0.983, indicating a very high level of performance



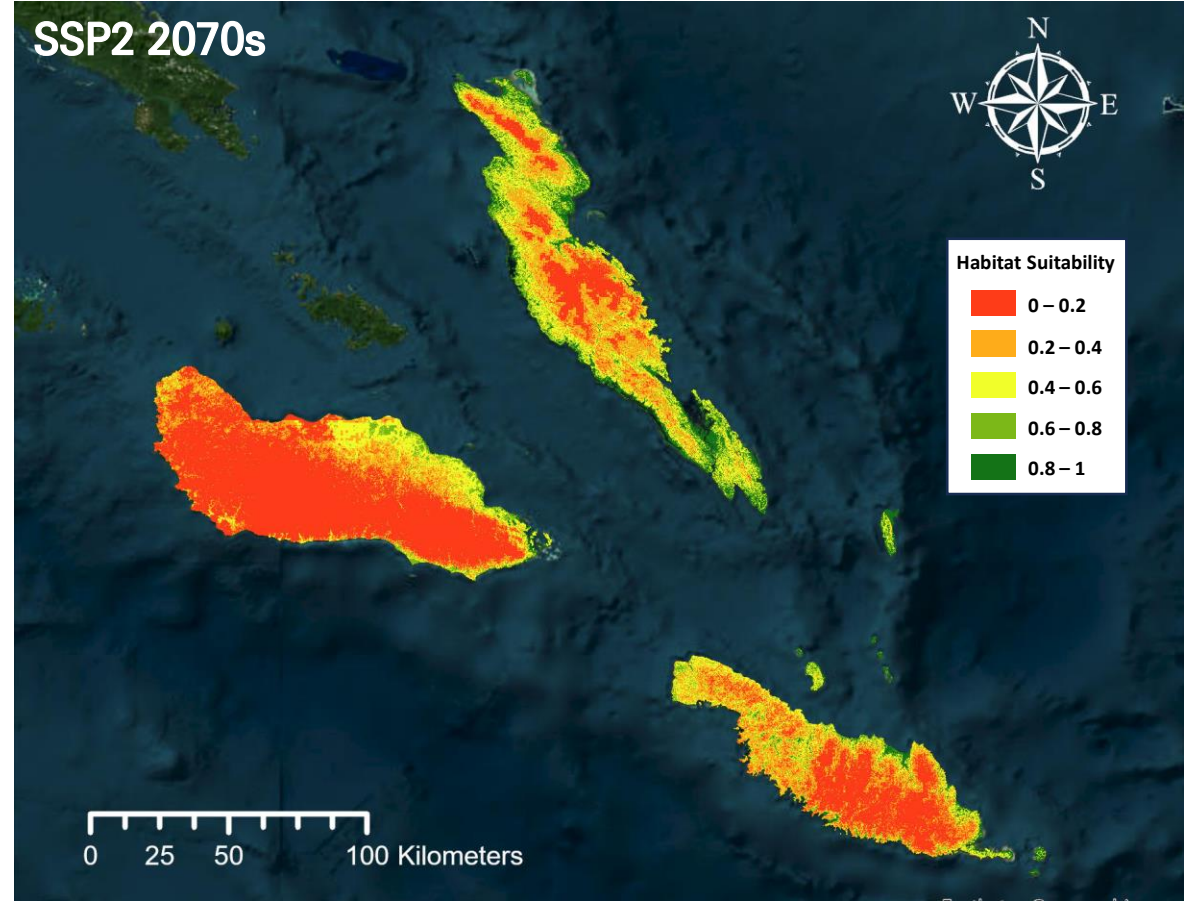
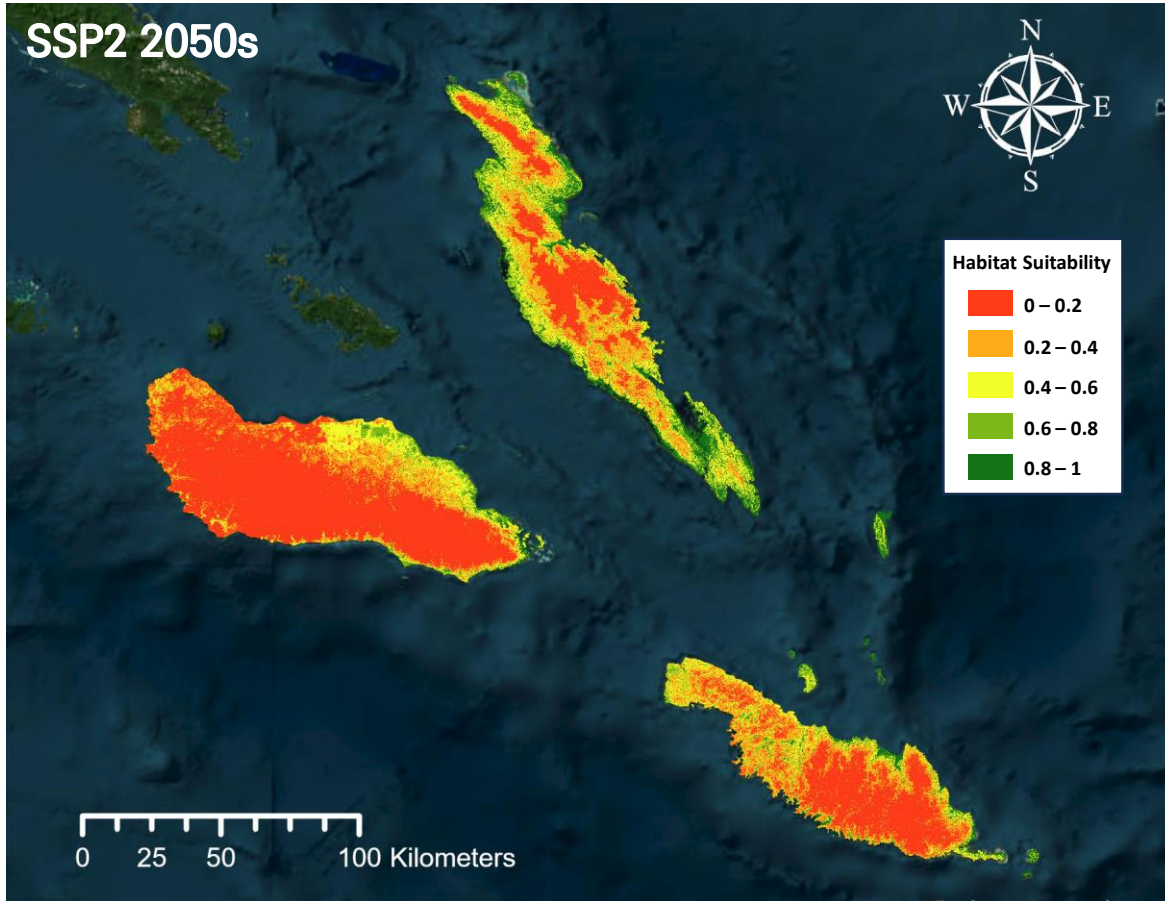
# Mangrove suitability model

Mangrove distribution probability model output (SSP1 – 2.6 Scenario)



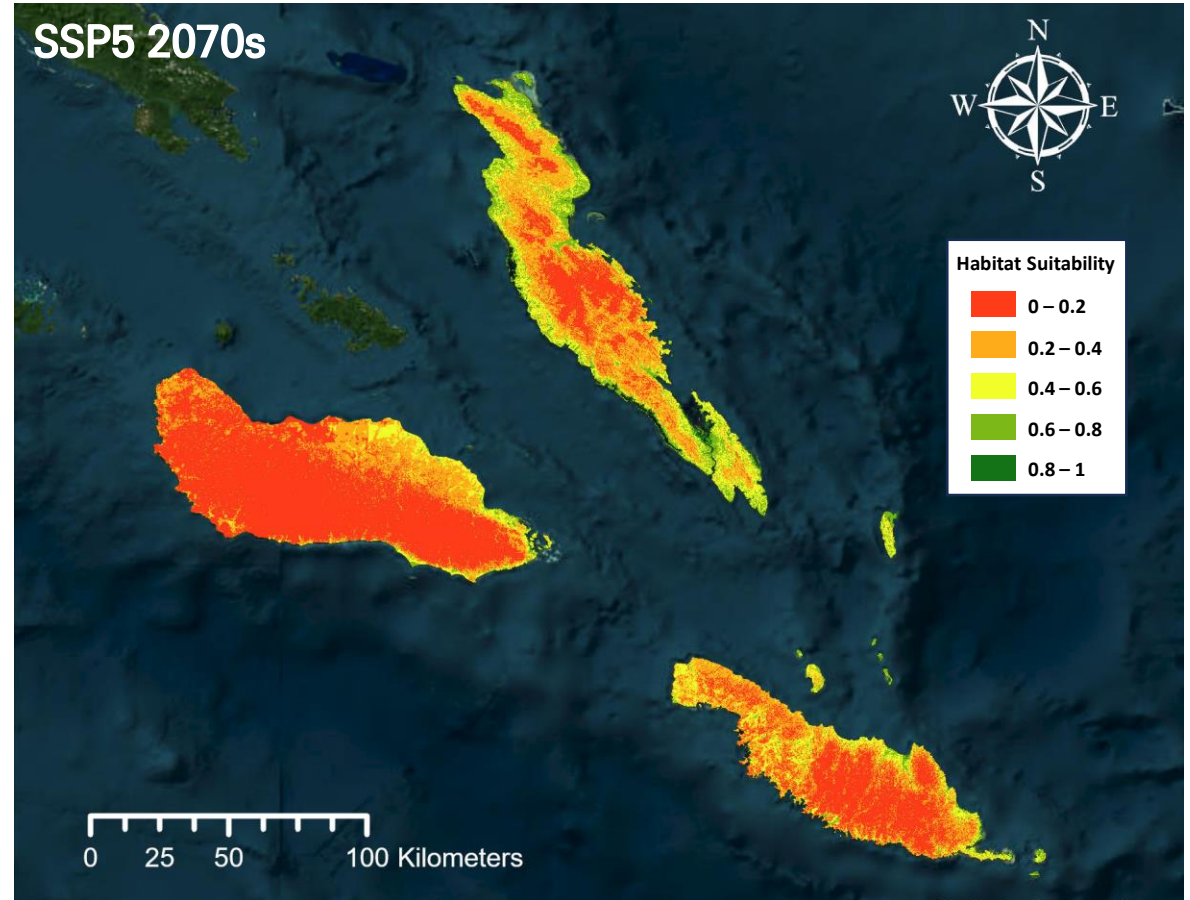
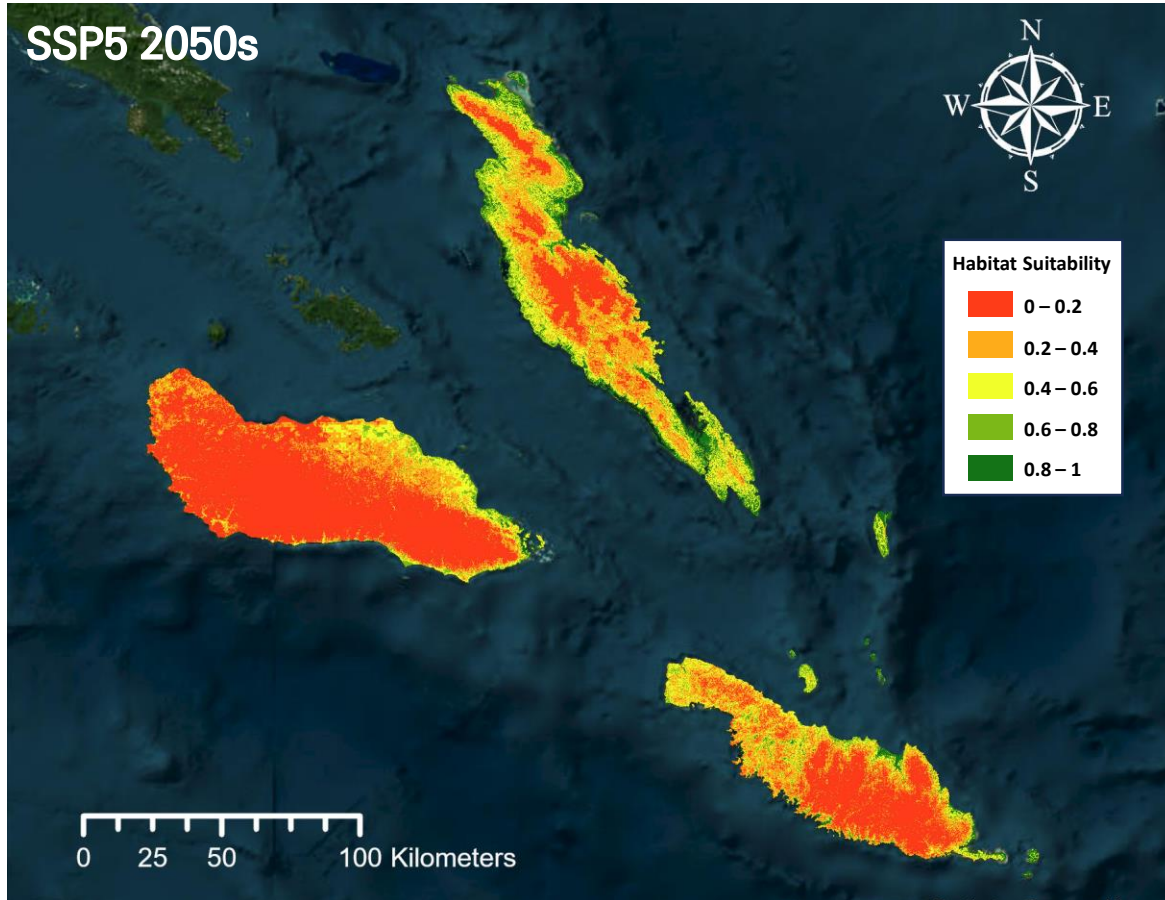
# Mangrove suitability model

Mangrove distribution probability model output (SSP2 – 4.5 Scenario)



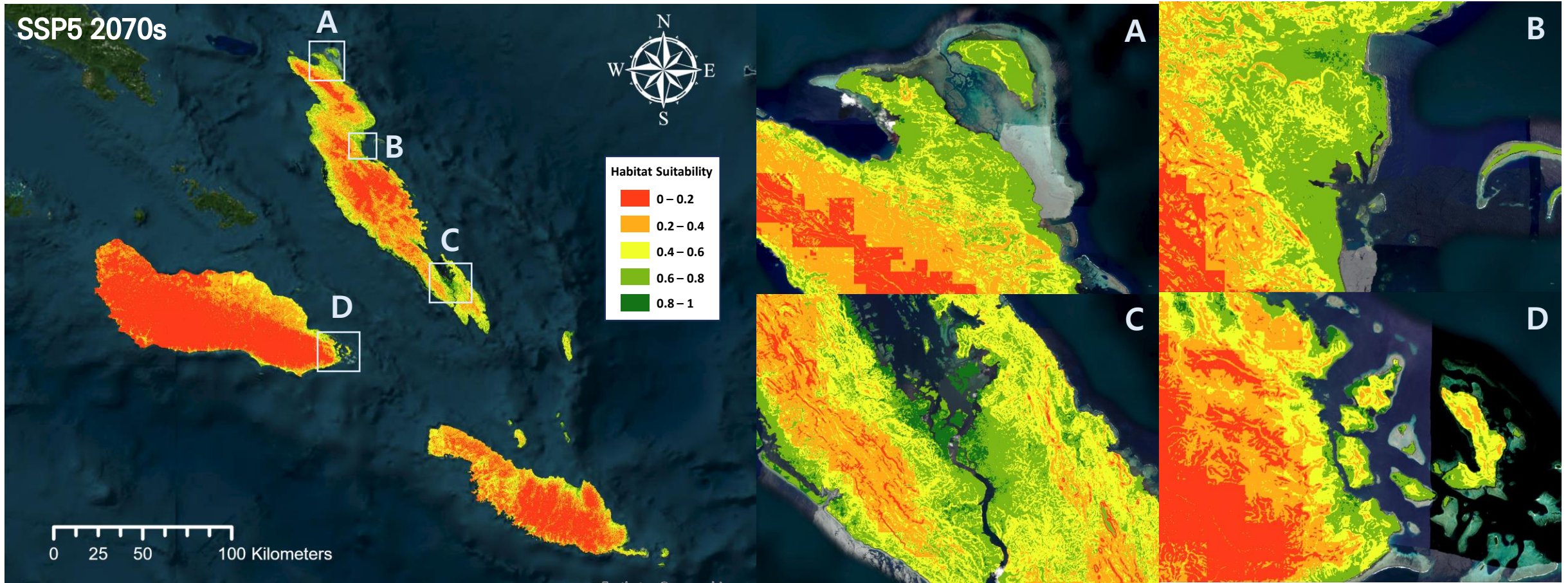
## Mangrove suitability model

Mangrove distribution probability model output (SSP5 – 8.5 Scenario)



# Mangrove suitability model

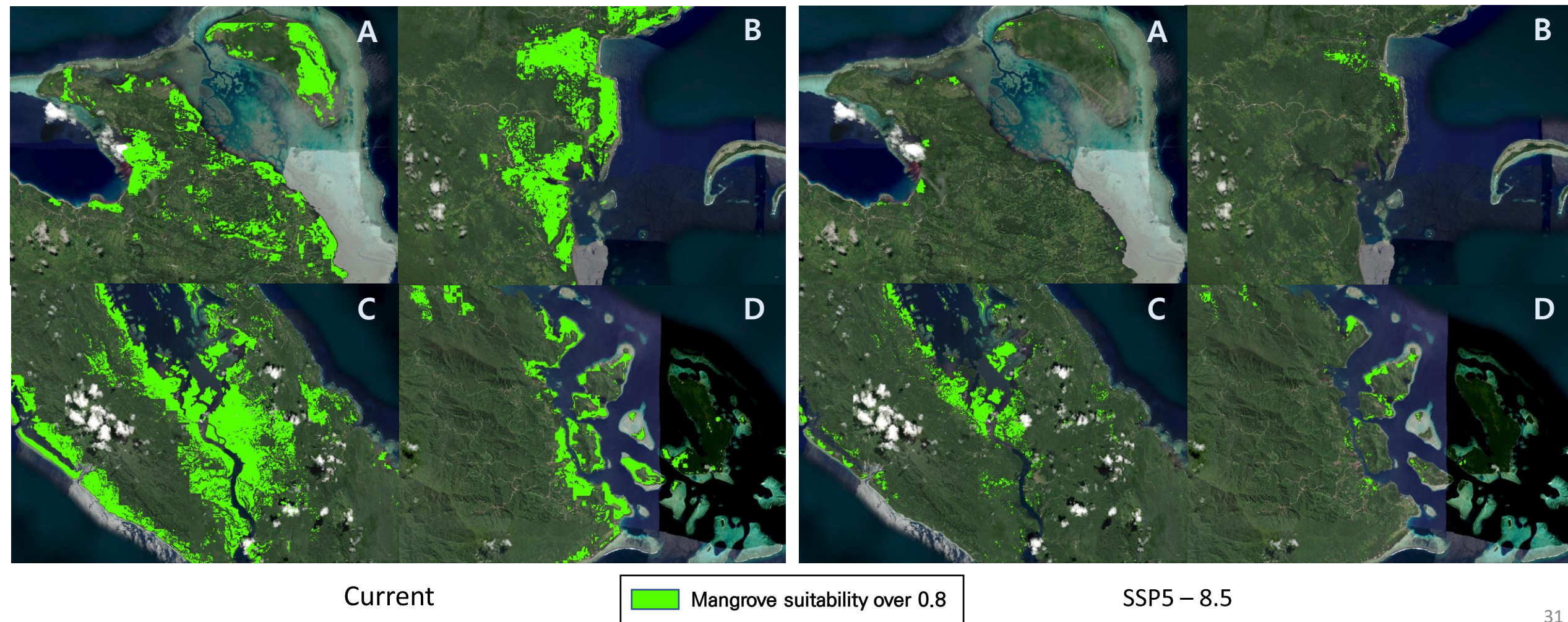
Mangrove distribution probability model output



## Mangrove suitability model

Mangrove distribution probability model output (Current / SSP5 – 8.5)

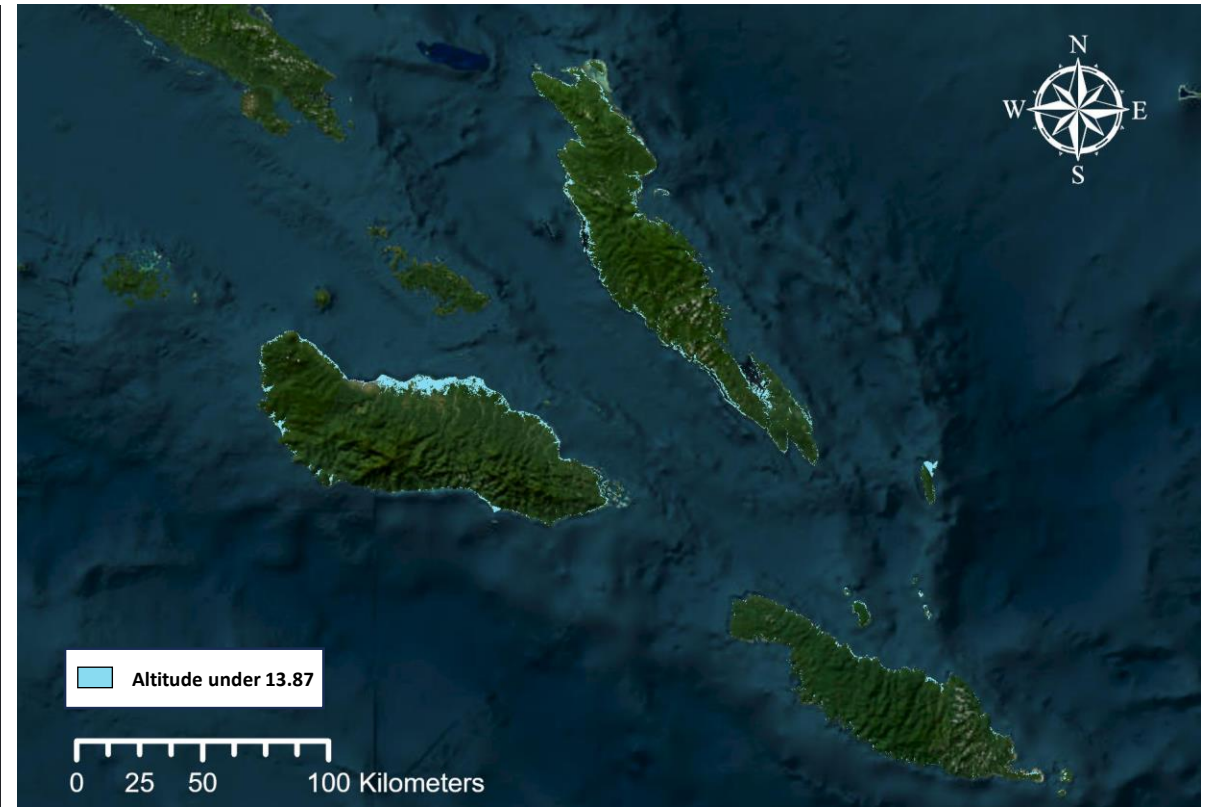
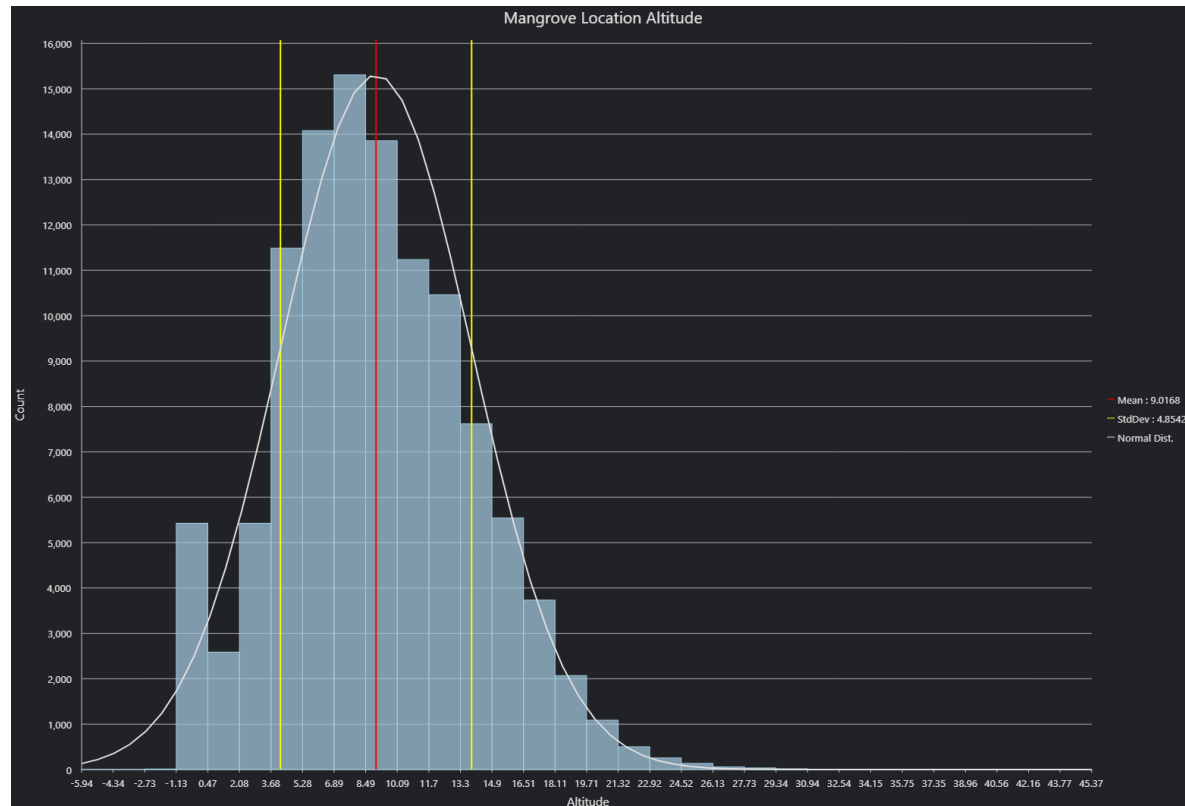
- Most regions with a current suitability index of 0.8 or above exhibit a decrease to less than 0.8 under SSP5 – 8.5 Scenario



## Mangrove distribution probability

### Mangrove distribution probability model output

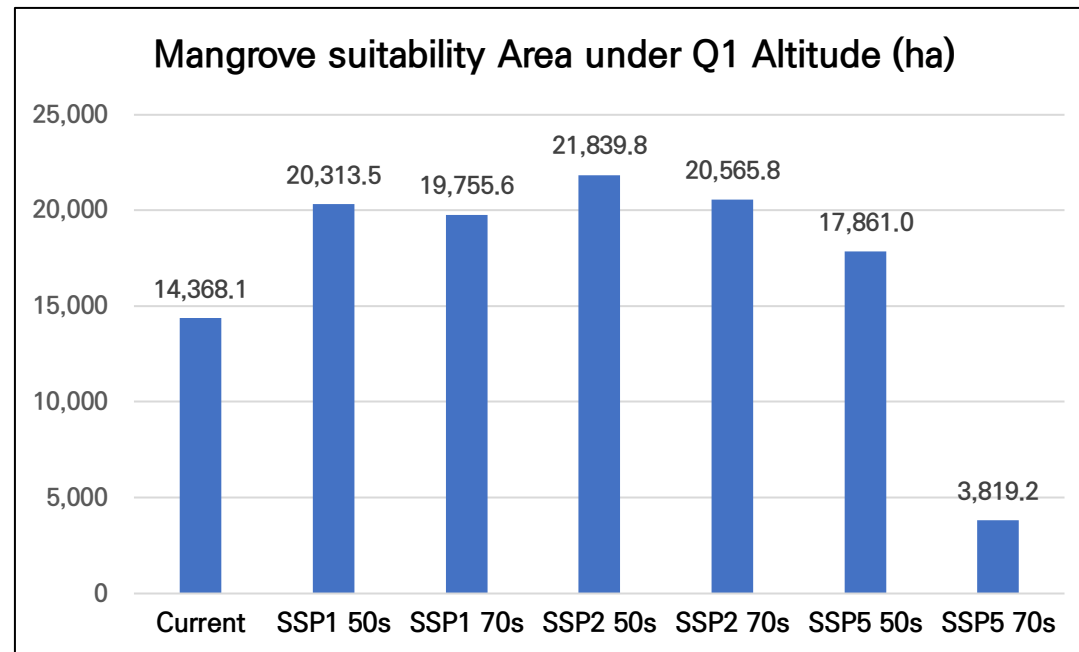
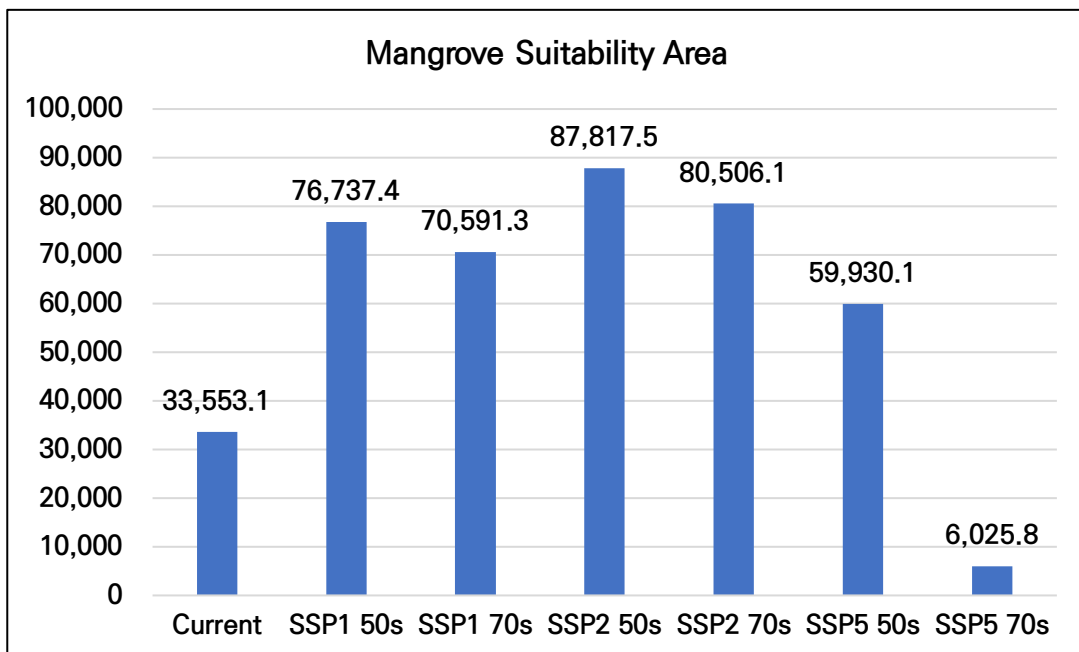
- Mangroves encounter challenges in inhabiting high elevations removed from the coastline
- However, the DEM was omitted from the model training process, leading to inadequate representation of elevation
- Investigated the distribution of mangrove habitats altitude with values below the first quartile of the normal distribution



## Mangrove distribution probability

### Mangrove distribution probability area by SSP Scenario

- The calculation is performed for the area with a suitability score equal to or exceeding 0.9
- Overall, suitability habitat area increased during the 2050s and 2070s compared to the present
- However, under SSP5-8.5 Scenario, suitability habitat area experienced a geometrically significant decrease during the 2060-2080
- The increase in mangrove habitat under the SSP1 and SSP2 scenarios can be explained by the Theory of Ecological Niches, suggesting that the adaptation of species through changes in individual traits led to the species' adaptation
- The decline in mangroves during the 2070s under SSP5 suggests that the species may have reached the limits of adaptability



**Thank you for your attention!**