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GLOBAL CHANGE RESEARCH

FINAL REPORT

Plausible alternative futures of Island mangroves in the Asia-Pacific: Scenario-based analysis and quantification of mangrove ecosystem services in coastal hazard mitigation and climate change adaptation

CRRP2018-03MY-HASHIMOTO

2023

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1. Summary

Mangrove ecosystem services are pivotal to building nature-based resistance to climate change and hydro-meteorological hazards in coastal areas. However, a dearth of reliable quantitative information on the future extent and availability of such services hinders effective policy planning. To address the future uncertainties in mangrove ecosystem services, this project took a scenario approach for quantifying the mangrove ecosystem services in six selected island locations in Asia-Pacific, namely (1) Andaman Islands and estuarine island mangroves from Odisha (India) (2) Ishigaki Island (Japan) (3) Oriental Mindoro islands (The Philippines) (4) Tamsui River Estuary, Taiwan and (5) Ba River Delta of Fiji. We simulated and developed the future land use of the respective study areas (for 2050), considering various social, environmental, economic and policy drivers and agents of change, and estimated the plausible alternative spatial and temporal extent of mangroves. Furthermore, we simulated key mangrove ecosystem services, wherever applicable, including the contribution of the mangrove ecosystem service (1) Coastal vulnerability reduction (2) Carbon storage (Blue carbon) (3) Sediment retention, (4) Nutrient retention and (5) Habitat Quality. The maps and data generated from this project are very useful for policy planning and serve as the key input to spatial decision-making in the respective study areas.

2. Objectives

The main objectives of this project are as follows:

- The primary objective of this project was to develop spatially explicit, exploratory, land-cover scenarios for island mangroves (for 2050) from the representative study sites, considering the locally relevant drivers and pressures, both from the anthropogenic and environmental origin (e.g. sea level rise etc.).
- Secondly, the study assessed, based on the developed scenarios, likely changes in vital mangrove ecosystem services pertaining to climate change adaptation and disaster risk reduction. Particularly, the project investigated the future availability of mangrove ecosystem services specifically to ‘carbon sequestration/blue carbon’, ‘coastal vulnerability reduction’ and ‘sediment retention’ using appropriate bio-physical quantification tools.
- Lastly, the project conducted a scenario analysis to evaluate the critical synergies and trade-offs in vital mangrove ecosystem services, thereby, will make crucial inputs in developing spatially explicit policy guidelines for optimum landscape planning. This remains particularly imperative to categorize the ‘limit of development’ quantitatively and spatially without compromising vital ecosystem services.

3. Outputs, Outcomes and Impacts

<table>
<tr><th>Outputs</th><th>Outcomes</th><th>Impacts</th></tr>
<tr><td>• Maps of historical land use and land cover changes in the selected study areas.</td><td>- Understanding of historically and locally important drivers of mangrove loss.
- Understanding of the trend and dynamics of land cover changes and other important spatial drivers (e.g., urbanization etc.)</td><td rowspan="3">- Understanding of historically and locally important drivers of mangrove loss.
- Understanding of the trend and dynamics of land cover changes and other important spatial drivers (e.g., urbanization etc.)
- Land use scenarios under plausible alternative pathways are developed using state of the art land change modelling.
- Assessing the future state of mangroves, likely fragmentation, and future state of mangroves.
- Detailed and thorough understanding of mangrove extinction risks
- Detailed understanding of the likely changes in mangrove ecosystem services related to coastal vulnerability, carbon sequestration, nutrient retention etc.</td></tr>
<tr><td>• Develop spatially explicit land cover scenarios through participatory approaches.
• Future land use scenario maps are developed for the year 2050.</td><td>- -Land use scenarios under plausible alternative pathways are developed using state of the art land change modelling.
- -Assessing the future state of mangroves, likely fragmentation, and future state of mangroves.
- Detailed and thorough understanding of mangrove extinction risks</td></tr>
<tr><td>• Current and future ecosystem services maps are generated using InVEST Ecosystem services simulation models.</td><td>- Detailed understanding of the likely changes in mangrove ecosystem services related to coastal vulnerability, carbon sequestration, nutrient retention etc.</td></tr>
</table>

4. Key facts/figures

- Historical land use and land cover maps, viz-a-viz. spatial extent of mangroves were mapped in all the study areas.
- Land use scenarios and future extent of mangrove cover were simulated.
- Likely changes in ecosystem services with respect to landuse changes were mapped.
- Four doctoral students and one master student were supported from this project.
- Over 10 peer-reviewed articles and seven book chapters were published.
- The project proponents collaborated with IUCN and UNESCO and hosted the joint workshops for public outreach of the results.
- The project also had several research disseminations round tables with local stakeholders.

5. Publications

Peer-reviewed articles

1. Tajima, Y., Hashimoto, S., Dasgupta, R., & Takahashi, Y. (2023). Spatial characterization of cultural ecosystem services in the Ishigaki Island of Japan: A comparison between residents and tourists. ***Ecosystem Services***, 60, 101520.
2. Dhyani, S., Shukla, J., Kadaverugu, R., Dasgupta, R., Panda, M., Kundu, S. K., ... & Hashimoto, S. (2023). Participatory Stakeholder Assessment for Drivers of Mangrove Loss to Prioritize Evidence-Based Conservation and Restoration in Bhitarkanika and Mahanadi Delta, India. ***Sustainability***, *15*(2), 963.
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11. Raganas, A.F.M., A.S.Hadsall, N. M. Pampolina, S. Hotes and D.B. Magcale-Macandog. 2020. Regeneration capacity and threats to mangrove areas in the southern coast of Orinetal Mindoro, Philippines: Implications to mangrove ecosystem rehabilitation. ***Biodiversitas*** 21 (8): 3625-3636 (August 2020). DOI: 10.13057/biodiv/d2108xx.

List of Book Chapters

12. Dasgupta, R., Hashimoto, S., & Saito, O. (2022). Envisioning the Future of Mangroves Through Mapping and Modeling of Mangrove Ecosystem Services. In ***Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region*** (pp. 1-12). Springer, Singapore.

13. Takahashi, Y., Hashimoto, S., & Wanhui, H. (2022). Ecosystem Services and Their Future Scenarios Centering on Mangrove Ecosystem in Ishigaki Island, Japan. In ***Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region***, 51-75.
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15. Nath, A., Joshi, C., Prabakaran, N., Ghosh, S., & Talukdar, G. (2022). Change Mapping of Aboveground Carbon Stocks and Ecosystem Services in the Mangrove Forest of Andaman Islands: Implications for Conservation and Ecosystem-Based Adaptation. In ***Assessing, Mapping and Modelling of Mangrove Ecosystem Services in the Asia-Pacific Region*** (pp. 143-166). Springer, Singapore.
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List of theses

1. Jess H. Human. Ecological niche analyses and environmental gradients of mangrove ecosystems across Northern Oriental Mindoro, Philippines. PhD Botany, July 2020.
2. Aaron Froilan M. Laganas. Regeneration capacity of mangrove vegetation in the Southern Part of Oriental Mindoro: Its Implications to future ecosystem rehabilitation. MS Botany, May 2019.
3. Divine Erika T. Madrid. Effect of mangrove forest and land use on the carbon sequestration potential of mangrove soils in the first district of Oriental Mindoro. BS Agriculture (Soil Science). July 2020.
4. Farah Carolina A. Bombio. Carbon sequestration potential of mangrove soils in the second district of Oriental Mindoro. BS Agriculture (Soil Science). May 2019

6. Media reports, videos and other digital content

- Nature Based Solutions for Climate Resilience" Future of Indian Mangroves: National Consultative Workshop (https://nidm.gov.in/pdf/workshops/climate-19.pdf)

- Webinar - "Mangroves of Plenty - Ecosystem Services in World Heritage Sites" (https://www.youtube.com/watch?v=K-KOFMcRSu8)

7. Pull quotes

- "This study demonstrated the importance of various ecosystem services and possible future changes that coastal mangrove forests provide in the Asia-Pacific region by using scenario analysis, filling the knowledge gaps of existing studies." **Dr. Shizuka HASHIMOTO, IGES/The University of Tokyo**

- The tools used for this study are very innovative and helped us to realise the potential of scenario based modelling. It can be applied to other study areas too. **Dr. Shalini Dhyani, NEERI, India**

- "One of the important achievements of this project was bring all the stakeholders together, particularly the local policy planners. It is very important that local decision-making is supported by scientific data, especially those generated from future projections" **Dr. Rajarshi Dasgupta, IGES**

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9. Appendices

Appendix 1: Detailed Case report: Andaman Islands, India
Appendix 2: Detailed case report: Bhitarkanika Mangroves, Odisha
Appendix 3: Detailed case report: Tamasi Estuary, Taiwan
Appendix 4: Detailed Case report: Ba River delta, Fiji
Appendix 5: Detailed Case report: Oriental Mindoro, Philippines
Appendix 6: Detailed case report: Ishigaki Island, Japan

Appendix 1: Detailed report from the Andaman Islands of India

Chapter 1. Land Use Land Cover Mapping and Change Analysis

1.1 Introduction

Mangroves are trees or bushes found in the zone between spring line water high and just above the mean sea level (Macnae, 1968). These inter tidal salt water tolerant plant help in protection of coastal communities from natural hazard like Cyclone, tsunamis, Storms etc. (Danielsen et al. 2005; Selvam 2005) by regulating floods and erosion in coastal areas. Mangrove acts as an indicator of climate change as any disturbance in environmental condition has an effect on mangrove. In recent years, intergovernmental agencies, governments, and other regulatory bodies have widely advocated for building nature-based resistance to hydro-meteorological hazards and combating the possible adverse impacts of climate change. Particularly, ecosystem services of mangroves remain at the centre of discussion considering their exceptional ability to survive in the fragile coastal environment, while providing tremendous services such as storm surge control, sediment retention, and sequestration of carbon, etc. Yet, despite such services, mangroves are still among the fastest declining tropical forests, especially in Asia-Pacific, owing to the large-scale alternation of their natural habitats.

Remote Sensing and GIS technique is used extensively for mapping and monitoring the mangrove (Quader et al. 2017; Sumiko et al. 2017). The mangrove forest is a highly productive ecosystem which requires a cost-effective mapping technique for monitoring the changes in their habitats (Green et al., 1998). Remote sensing plays an important role in the study of mangrove forests from past many years due to inaccessible environmental conditions on the mangrove ecosystem (Blasco et al. 2001). Mangroves can be easily identified on the satellite image because of their conspicuous signature. In recent years mangrove mapping by remote sensing is not only limited to the mapping of extent of mangrove but also about more complex topics such as mangrove species mapping, and ecosystem services etc.

The Andaman and Nicobar Islands are the largest archipelago system in the Bay of Bengal, consisting of 306 islands and 206 rocks and rocky outcrops (Jayaraj and Andrews, 2005). The Andaman and the Nicobar Islands has a considerable forest cover with 7179 sq.km area notified under Forest land (ANI Website, 1927). This includes 68.83% Dense Forest, 8.29% Moderately Dense Forest, and 4.62% Open Forest (ISFR, 2019). The islands are rich in biodiversity with 614.25 sq.km area covered by mangroves, which contributes to 12.39% of India's mangrove cover (ISFR, 2019). The present study concentrate on mangroves of Andaman Island, India. Andaman Island has recorded the drastic changes in mangrove in the last few decades due to high intensity natural disaster like tsunami, and abrupt changes in coastal geomorphology mediated by plate tectonics.

1.2 Literature Review

The interface between land and sea, the coast is an unique geologic, ecological and biological domain of vital importance to an astounding array of terrestrial and aquatic life forms including mankind (Beatley et al. 2002). The coastal ecosystem is highly fragile because of the multivariate dynamically active and pulsatory tectonic and geomorphic processes**.** Coastal zones of India are constantly undergoing changes due to natural forces as well as human development activities. Mangroves are salt tolerant trees and shrubs which dominate the intertidal coasts of tropics and subtropics (Tomlinson 1994). These are well adapted communities which are highly complex dynamic, thriving saline habitats with their special characters such as salt excreting leaves, exposed breathing root systems, and production of viviparous propagules (Robertson et al. 1992). Mangroves in the Indian coastal zones are consistently influenced by coastal environmental change including sea level rise and hydrological variations. The response of mangroves to such impacts tends to be gradual and, particularly in undisturbed systems, is manifested typically as a change in their extent, structure and species composition and hence their distinct zonation. As mangroves are sensitive to even minor transitions in coastal conditions (e.g., altered drainage patterns, saltwater intrusion, accretion or erosion in response to sea level variations), changes in the zonation of these ecosystems are often indicative of broader scale changes and associated impacts in the coastal regions. Especially, these changes can cause cascading impacts on fragile ecosystems in the islands like Andaman and Nicobar archipelago. The mangroves of Andaman Islands provide many fold ecological benefits and deliver multifarious ecological functions to the islands. The direct beneficiaries are the fishers, farmers, labours, pharmaceutical industry, tourism sector, etc. apart from the indirect benefits of the mangroves to the researchers, shoreline protection, conservation of biodiversity, neutralization of greenhouse gasses.

The recent decade had seen a particular increase in the number of studies pertain to mangrove cover change in Andaman Islands using remote sensing and GIS. Few recent works include the assessment of Land Use Land Cover change in South Andaman using Remote Sensing and GIS (Yuvraj and Dharanirajan, 2014), Assessment and monitoring of deforestation and land-use changes (1976–2014) in Andaman and Nicobar Islands, India using remote sensing and GIS (Sudhakar Reddy et al. 2016), Long term dynamics of Mangrove Forest in Andaman (S. Chakraborty et al, 2020). Most of these recent work highlighted the effect of 2004 Tsunami on Mangrove ecosystem in the Island (Sachithanandam et al, 2014; A.K. Das et al, 2014; Majumdar et al, 2019; Ramakrishnan et al, 2020). Also a few studies valuated the mangrove ecosystem services (Chand et.al., 2015), the cultural services including tourism and fishery benefits (Anneboina et.al., 2017). Forest carbon sequestration potential (Bhatt and Kathiresan, 2012) also draw their conclusions from use of RS/GIS technology.

Only two papers (complete text requested from authors) draw on concept of social metabolism and transitions and presents various scenarios of consumption and the consequences these will have on future material and energy demand, land use and time use for the local population in the islands (Singh and Haas, 2006). These above-mentioned studies have provided relevant background context to discuss the integrated scenario building for the islands' sustainable future, both ecologically and socially, with special reference to role of disaster response and resilience post aftermath. (Complete list of papers referend to are placed as bibliography in annexure I)

1.3 Study Area

The Andaman and the Nicobar Islands are a group of islands constituting an archipelago of 572 islands over an area of 8249 sq.km in the Bay of Bengal with its extreme points being between 6-14º N latitude and between 92-94º E longitude. The islands are characterized by its topography which varies from the low range hilly mountains to narrow valleys at the foothills within an altitudinal range of 0-365m from the Mean Sea Level (Chand et al., 2013). This gives rise to an undulating terrain, which ranges from the wetlands, the coastal plains to the steep slopes. The islands depict an equatorial warm humid tropical type experiencing an average of 234.2 mm, 417.1 mm, 1526.0 mm and 712.6 mm rainfall in the winter, pre-monsoon, south-west monsoon and the post-monsoon seasons respectively (Rainfall Statistics of India, 2017). The temperature in the islands vary from between 29-32ºC on the maximum and with 22-24ºC on the minimum with an average relative humidity ranging between 68% to 86% (Chand et al., 2013).

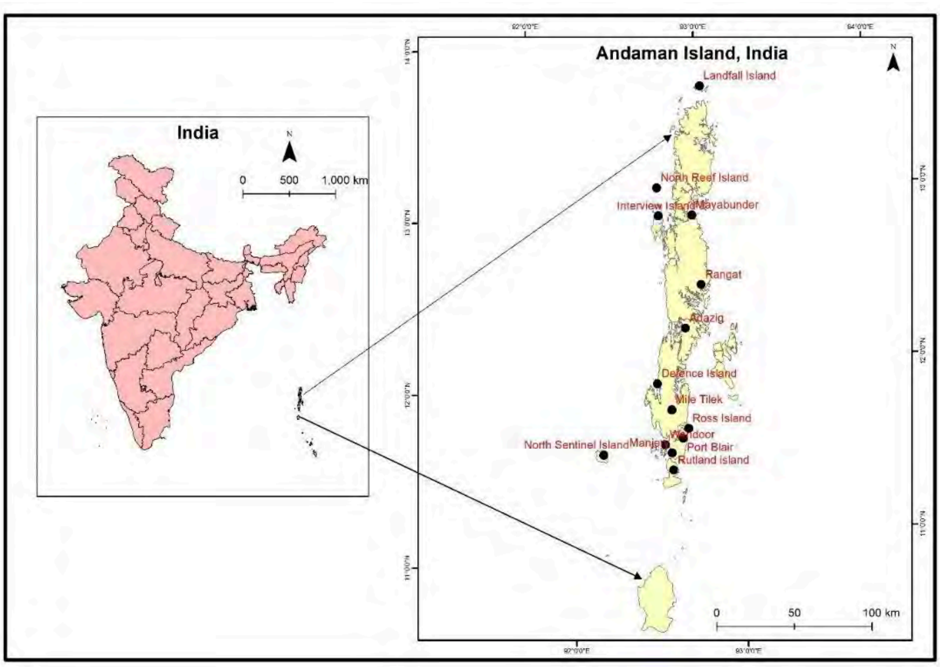


Figure 1: Study Area Map - Andaman and Nicobar Island

1.4 Objectives

- To prepare the LULC database of Andaman Island for the past two decades using satellite images of three different periods (2005, 2010, 2019).
- To analyze the socio-economic and physical drivers for LULC change and study the impact of these drivers on LULC
- To project the future LULC scenario by using spatially-explicit, exploratory, land-cover scenarios for island mangroves (for 2050)

1.5 Data Used

Multi- temporal remote sensing satellite data has been used for the present study. The cloud free satellite data of LANDSAT TM 5 (2005), LANDSAT TM5 (2010) and LANDSAT 8 (2019) is used to map the changes in spatial extant of Mangrove in the island. The data is downloaded from United States Geological Survey (USGS) Earth Explorer Programme website (https://earthexplorer.usgs.gov/). In Andaman's the cloud free data is available for a very limited period. The details of the cloud free satellite data available for study area is given below:

Table 1: Details of dataset used

Date of Pass	Satellite	Sensor	Path/Row	Resolution
19/02/2019	LANDSAT 8	OLI/TIRS	134/51, 134/52, 134/53	30 meters
02/11/2019	LANDSAT 8	OLI/TRS	134/51, 134/52, 134/53	30 meters
26/02/2010	LANDSAT 5	TM	134/51, 134/52, 134/53	30 meter
12/02/2005	LANDSAT 5	TM	134/51, 134/52, 134/53	30 meter

1.6 Methodology

The Land Use Land Cover map of Andaman is prepared for three time period (2005, 2010 and 2019) to understand the spatial extent of Mangrove and its relationship with other Land Cover type. Land use and land cover are not equivalent although they may overlap. Landcover is the physical state of the earth's surface and immediate subsurface. In other words, Landcover describes the physical state of the land surface: as cropland, mountain or forests. Moser (1996) noted that the term – Landcover originally referred to the type of vegetation that covered land surface, but has broadened subsequently to include human structures, such as buildings or pavement, and other aspects of the physical environment, such as soils, biodiversity, surfaces and ground water.

Landuse involves both the manner in which the biophysical attributes of the land are manipulated and the intent underlying that manipulation – the purpose for which the land is used (Turner et al, 1995). Meyer (1996) stated that Landuse is the way in which, and the purpose for which human beings employ the land and its resources. Briefly, Landuse denotes the human employment of land. Skole (1994) expanded further and stated that Landuse itself is the human employment of a Landcover type, the means by which human activity appropriates the results of net primary productivity as determined by a complex of socio-economic factors. Finally, FAO (1995) described Landuse as a function or purpose for which the land is used by local human population and can be defined as the human activities which are directly related to land, making use of its resources or having an impact on them.

In the present study the Land Use Land Cover of Andaman is classified into following six classes at 1:50,000 scale. These six classes are Built-up, Cropland, Forest, Mangrove, Mangrove degraded and Waterbody. The satellite image was classified on the basis of visual interpretation key which take into consideration the elements of visual interpretation like tone, texture, colour, shape, location, association etc. (Nayak et al, 2001). The interpretation key for mapping various LULC classes using satellite data is given below.

Table 2: Interpretation key for mapping LULC

LULC Classes	Tone	Shape	Texture	Pattern	Association
Built-up	Light Cyan	Regular	Smooth	contiguous	Presence of airport, seaport, jetty
Cropland	Light pink to dark pink	Regular	Moderate rough	Non contiguous	Mainly in association with settlement in the island
Forest	Red	Varying	Rough	contiguous	
Mangrove	Bright red	Irregular	Smooth	Non contiguous	In the inter tidal area/along the creeks & low lying flats
Mangrove Degraded	Greenish, Pale red	Irregular	Smooth	Non contiguous	In the inter tidal area/along the creeks &

					low lying flats
Waterbody	Blue to black	Irregular	Smooth	Scattered	Easily identified on satellite imagery

- ***1.6.1 Generation of Land Use Land Cover Map***

This module deals with the procedure for interpretation of satellite data to generate LULC map. Vector LULC map for 2019 at the scale of 1:50,000 was prepared by interpreting two time period of LANDSAT 8 satellite data. Since our mapping scale was 1:50,000, our minimum mappable unit (MMU) is 3mm by 3mm. The LULC map for the year 2019 is the master map for preparing LULC of 2010 and 2005. A copy of this map was overlaid on the preceding year's (2010) satellite data of LANDSAT 5 TM and changes were mapped. The two were registered having uniform projection parameters. The map's LULC class polygons fell over the same LULC class onto the satellite data. However, the area of the polygons of a LULC class varied. Depending upon the variability, the LULC polygon on the map was edited to generate a new set of polygons. Similarly 2010 LULC map was overlaid over the satellite image of LANDSAT 5 TM (2005) and polygon was modified in accordance with the satellite data to generate the LULC map of 2005. The general methodology adopted to map the changes from 2019 to 2010 and from 2010 to 2005 is given below.

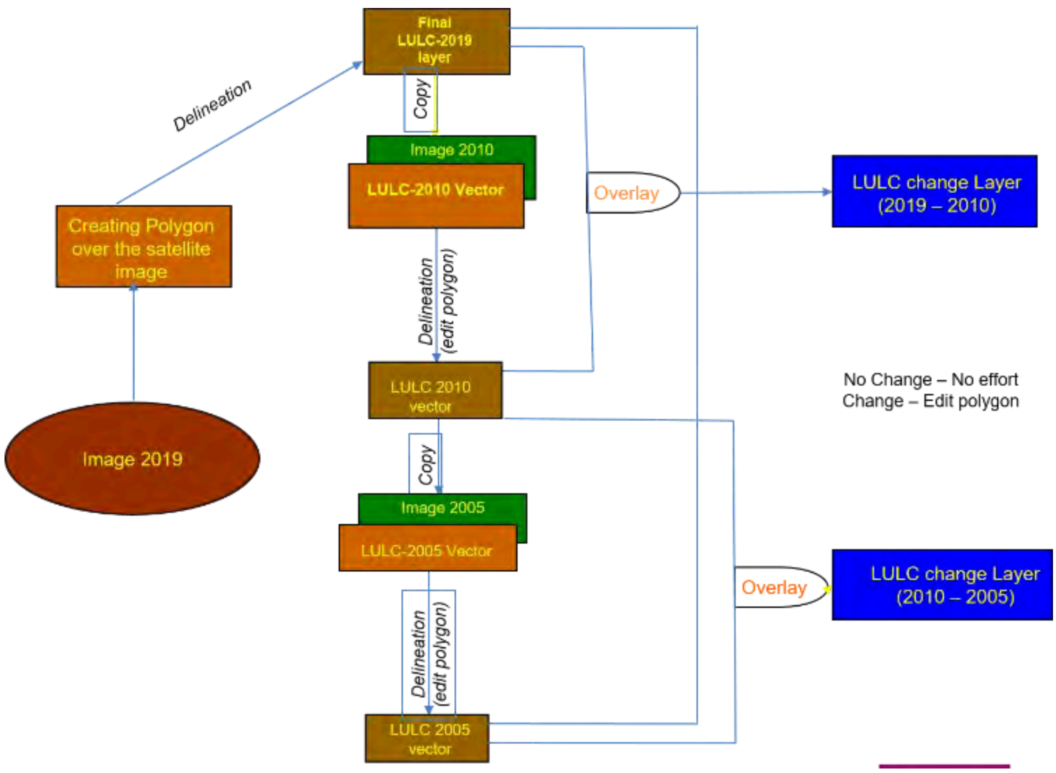


Figure 2: Methodology flowchart

- **1.6.2 Accuracy Assessment**

The increased usage of remote sensing data and techniques has made geospatial analysis faster and more powerful, but the increased complexity also creates increased possibilities for error. In the analysis of Land Use / Land Cover change; it is necessary to conceptualize the meaning of change to detect it in real world situations. Land Use / Land Cover change at the gross level, means (quantitative) changes in the areal extent (increase or decrease) of a given type of Land Use or Land Cover, respectively. It is important to note that the detection and measurement of change depends on the spatial scale; the higher the spatial level of detail, the larger the changes in the areal extent of Land Use and Land Cover, which can be detected and recorded. In the past, accuracy assessment was not a priority in image classification studies. Because of the increased chances for error presented by digital imagery, however, accuracy assessment has become more important than ever (Congalton 1991). A common tool to assess accuracy is the error/confusion matrix. Error matrices compare pixels or polygons in a classified image against ground reference data or high resolution (Spatial and Spectral) satellite imagery like google earth (Jensen 2005). These matrices can measure accuracy in several ways. The overall accuracy of the classified image compares how each of the pixels is classified versus the actual land cover conditions obtained from their corresponding ground truth data. Producer's accuracy measures errors of omission, which is a measure of how well real-world land cover types can be classified. User's accuracy measures errors of commission, which represents the likelihood of a classified pixel matching the land cover type of its corresponding real-world location (Campbell 2007, Congalton 1991, Jensen 2005). Error/confusion matrices have been used in many land classification studies and they were an essential component of this research.

1.7 Result and Discussion

The mangrove forest of Andaman has shown the significant change after the December, 2004 tsunami. The earthquake which struck Andaman and consequent tsunami has completely change the geomorphic setting of the island (Ray and Acharyya, 2007). The mangrove of the South Andaman has degraded to various degree depending on their response to seawater inundation as the landmass of South Andaman was subsided and the landmass of North Andaman was uplifted after the tsunami and earthquake. The island has shown a tilt towards the east (Meltzner et al. 2006) and that is the reason the mangrove in the west cost of the island shows more degradation than east cost in north and middle Andaman. The primary and secondary after effect of an earthquake like destruction of manmade structure, flooding, landslide were evident immediately following the earthquake, while its effects on mangrove and forest were gradual and continues even till date. To clearly understand the impact of the Tsunami on mangrove of Andaman Island the three-time period (2005, 2010, and 2019) LULC map of Andaman is prepared with complete statistics.

Table 3: Area statistics of LULC for 2005, 2010 and 2019

LULC Classes	2005		2010		2019	
	Area (km^2)	**% of TGA**	**Area (km^2)**	**% of TGA**	**Area (km^2)**	**% of TGA**
Built-up	39.89	0.62	51.86	0.80	80.18	1.25
Crop Land	316.33	4.93	315.01	4.91	303.07	4.72
Forest	5221.20	81.47	5216.35	81.40	5211.32	81.32
Mangrove	686.21	10.70	593.69	9.26	631.62	9.85
Degraded Mangrove	39.93	0.62	137.78	2.15	92.04	1.43
Waterbody	104.44	1.62	93.31	1.45	89.77	1.40
Total	**6408**	100	**6408**	100	**6408**	100

TGA = Total Geographical Area of Andaman Island

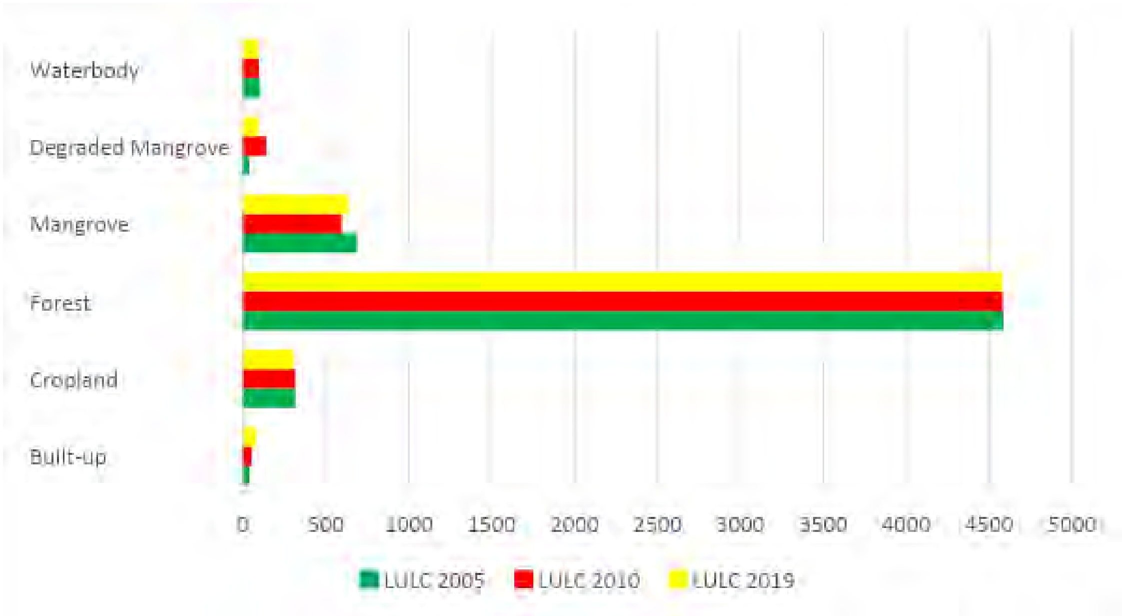


Figure 3: Graphical representation of area statistics of LULC

Forest is the most dominant class in the Island. The total area of forest is around 81pecent of the total geographical area of the island. The forest shows marginal decrease from 2005 to 2019 as most the forest area is protected by the forest and environment laws. As anticipated built-up has shown the gradual increase from 2005 to 2019 mainly in the expanse of cropland. The mangrove forest has shown significant decrease from 2005 to 2010 mainly because of the 2004 Tsunami causing major geomorphic changes in the island. The area extent of mangrove show significant decrease of 92 Km^2 from 2005 to 2010 than increase by 37 Km^2 from 2010 to 2019. The signs of mangrove degradation was evident in the 2005 February images used in the study. The total area under Mangrove in 2005 is around 10.70 percent of the total geographical area of the island, which decreased to 9.26 percent in 2010 and then marginally increased to 9.85 percent in 2019. The degraded mangrove in the island started just after the Tsunami in a gradual manner showing major increases in degraded mangrove from 2005 to 2010 and slight decrease in 2019. The decrease in degraded mangrove in 2019 is due to restoration of mangrove in some areas causing increase in the extent of the mangrove. In north Andaman due to uplift of land the tidal water could not flow into the mudflat causing large scale degradation of the mangrove. Similarly, in southern Andaman due to subsidence of the land the large-scale permanent inundation of mangrove area by the seawater has caused significant damage to the mangrove. The waterbody has marginally decreased from 2005 to 2019.

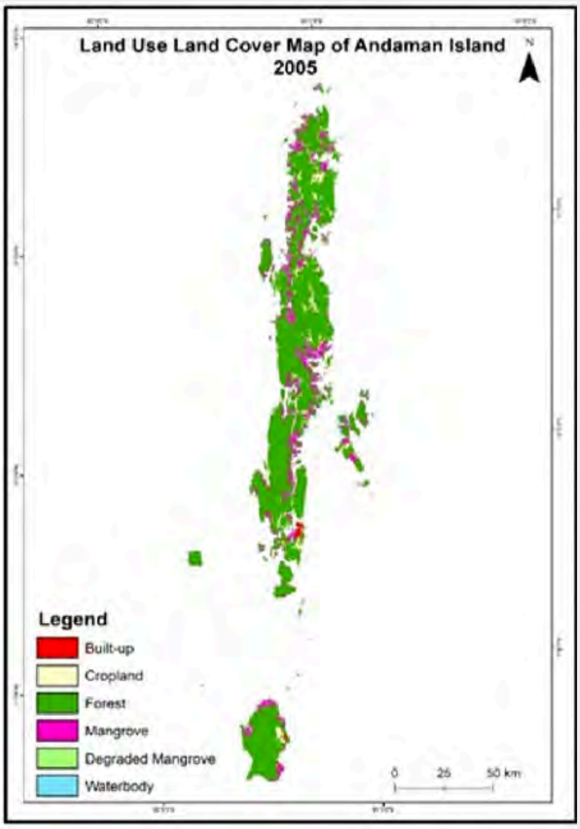


Figure 4: LULC map for 2005

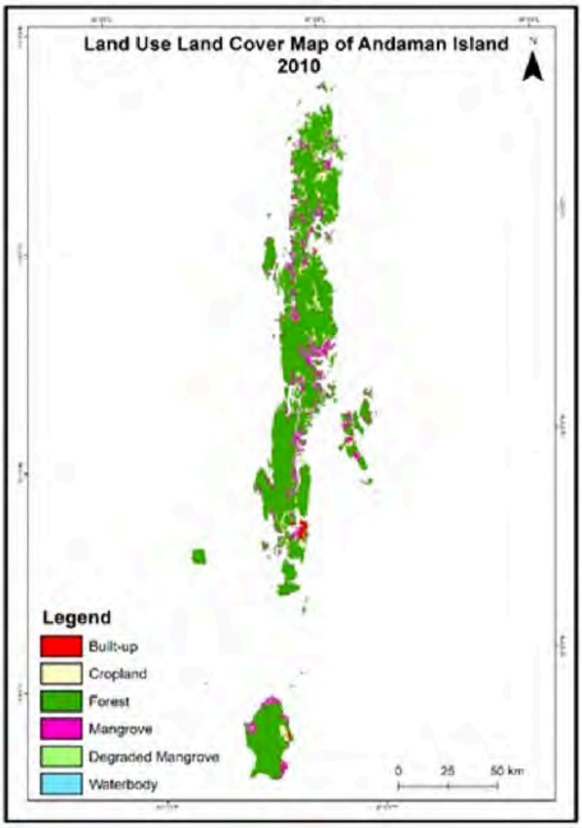


Figure 5: LULC map for 2010

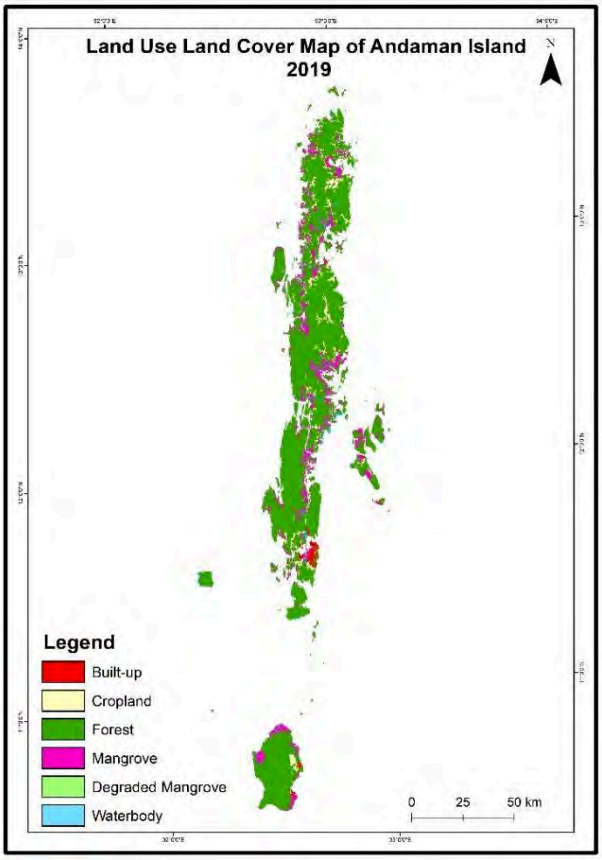


Figure 6: LULC map for 2019

One of the prime aim of LULC classification was to understand the change in areal extent of mangrove and its dynamics with other LULC classes. Land transformation from one LULC class to another is one of the most important aspects of LULC dynamics. To understand the land transformation the change matrix was analysed for three time period.

Table 4: LULC Change matrix

		2010						
		Built-up	Cropland	Degraded Mangrove	Forest	Mangrove	Waterbody	Grand Total
2005	Built-up	**39.90**						39.90
	Cropland	8.11	**303.65**	2.00		2.42	0.14	316.33
	Degraded Mangrove	0.06	2.51	**14.16**	9.76	13.09	0.35	39.93
	Forest	3.53	21.82	32.18	**5130.79**	29.65	3.23	5221.21
	Mangrove	1.14	2.54	88.52	50.37	**535.45**	8.19	686.21
	Waterbody		0.71	0.93	8.39	13.09	**80.74**	103.85
	Grand Total	51.87	315.02	137.79	5199.31	593.76	92.66	6408.00

		2019						
		Built-up	Cropland	Degraded Mangrove	Forest	Mangrove	Waterbody	Grand Total
2010	Built-up	**51.87**						51.87
	Cropland	22.31	**288.18**	0.36		4.30	0.00	315.15
	Degraded Mangrove	0.09	1.61	**41.79**	26.28	66.64	1.41	137.81
	Forest	4.77	23.58	8.88	**5140.89**	28.60	9.65	5216.37
	Mangrove	2.71	1.59	38.91	23.06	**523.97**	3.95	594.18
	Waterbody	1.43	2.50	2.11	4.02	7.84	**74.77**	92.66
	Grand Total	80.18	303.07	92.05	4577.23	631.63	89.77	6408.00

		2019						
		Built-up	Cropland	Degraded Mangrove	Forest	Mangrove	Waterbody	**Grand Total**
2005	Built-up	**39.90**						39.90
	Cropland	27.82	**283.23**	0.41		4.96	0.04	316.46
	Degraded Mangrove	0.06	2.24	**7.78**	12.87	16.48	0.49	39.93
	Forest	7.76	32.44	19.38	**5100.96**	48.97	11.72	5221.23
	Mangrove	3.77	2.58	61.59	64.94	**545.81**	8.03	686.72
	Waterbody	1.43	3.13	2.89	11.58	15.33	**69.51**	103.85
	Grand Total	80.18	303.07	92.05	4577.23	631.68	89.78	6408.00

The largest amount of transformation is seen from mangrove to degraded mangrove (61 km^2) from 2005 to 2019 because of gradual degradation of mangrove after post-tsunami environmental condition. However, the degraded mangrove is transform into mangrove (16.48 km^2) also in this period. The transformation of degraded mangrove into mangrove shows regeneration of mangrove mostly in north Andaman Island. The large area of mangrove (64 km^2) is also transformed into Forest and around 48 km^2 of forest is transformed back into mangrove during this time. A small area of mangrove (3.77 km^2) is also transformed into built-up mainly in and around capital city of Port Blair. The small area of mangrove and degraded mangrove (around 4.82 km^2) is also transformed into cropland as evident from the matrix. In northern Andaman Mangrove and Degraded Mangrove is transformed into Forest due to upliftmnent of landmass whereas in South Andaman forest is transformed into Mangrove due to inundation of seawater into landmass due to subsidence. However, degradation and regeneration of mangrove is slow process and it is still continuous in most part of the Andaman Island. To clearly understand the places where major change happened in Mangrove change map was generated which is shown below. The 27 km^2 of Cropland is acquired by Built-up.

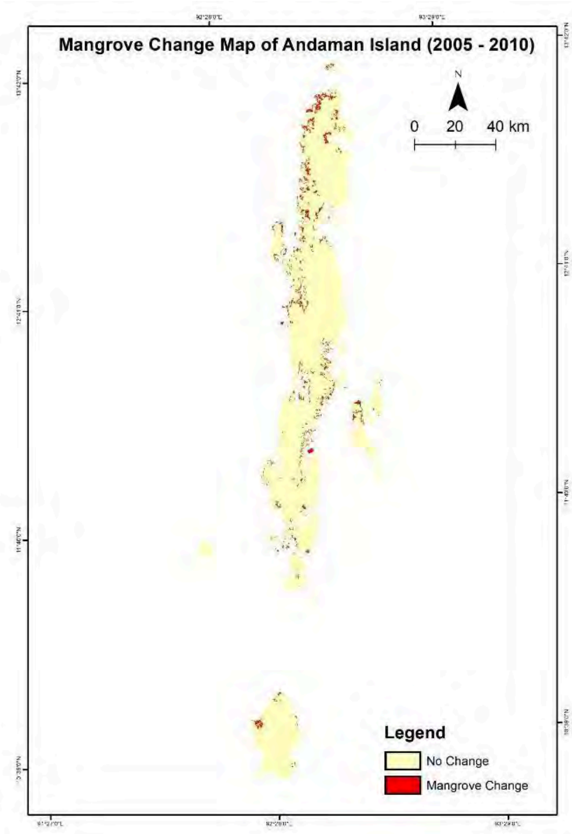


Figure 7: Mangrove change map- 2005-2010

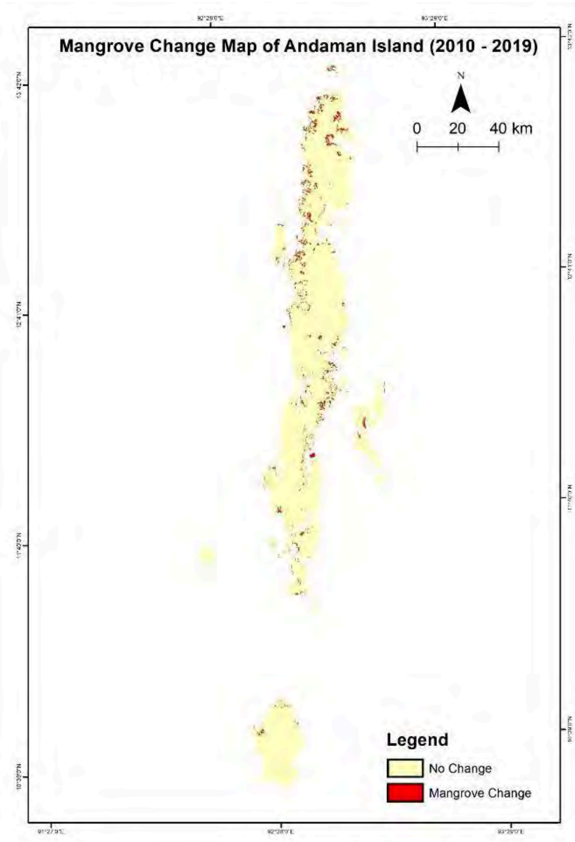


Figure 8: Mangrove change map- 2010-2019

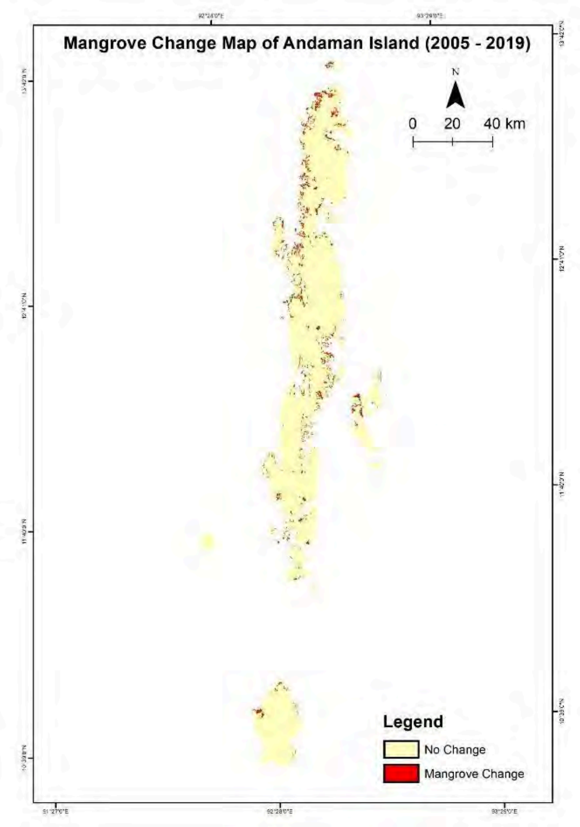
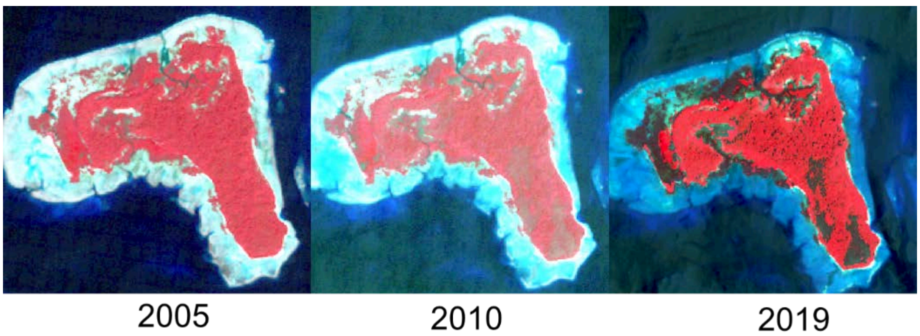
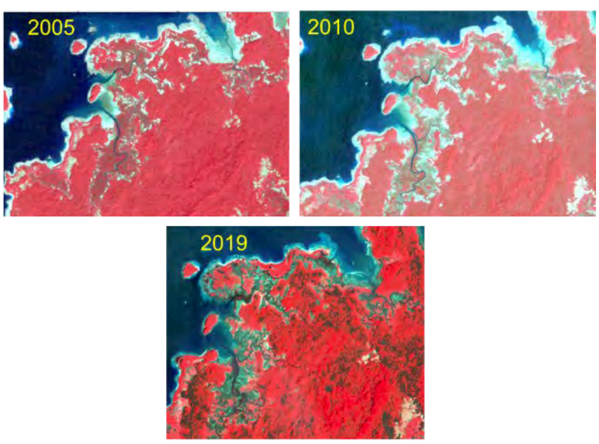


Figure 9: Mangrove change map- 2005-2019





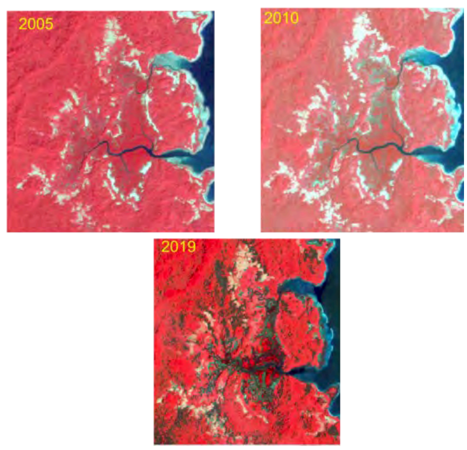


Figure 10: Satellite images of different mangrove locations (2005, 2010, 2019)

1.8 Accuracy Assessment

Accuracy assessment of LULC of Andaman Island for years 2019 was performed where the accuracy has been calculated through the preparation of error matrix. Standard methodology was adopted for accuracy assessment based on error/confusion matrix (Congalton, 1991, Lillesand et al., 2004). The LULC of Andaman Island has six classes for which 50 random points were generated for each class. Ground truthing were conducted at these location on ground. Since, in Andaman Island many areas were inaccessible the ground truth was conducted using high-resolution satellite image of google earth along with the field experience of the project team in the mangroves of Andaman accumulated over the past one decade. The overall accuracy, producer's accuracy and user's accuracy is computed using the matrix. Overall accuracy is computed by dividing the total number of correctly classified pixels (i.e. sum of the elements along the major diagonal) by the total number of reference pixel. User's accuracy is computed by dividing the number of correctly classified pixel in each category by the total number of pixels that were classified in that category (the row total), also known as commission error (Lillesand et al., 2004). A commission error occurs when an area is included in an incorrect category (Congalton, 1991). Producer's accuracy results from dividing the number of correctly classified pixels in each category (on the major diagonal) by the number of training set pixels used for that category (the column total). This indicates how well a training set pixels of the given cover type are classified. It is also a measure of omission error (Lillesand et al., 2004). An omission error occurs when an area is excluded from the category to which it belongs (Congalton, 1991).

Table 5: Accuracy Assessment- Referenced data and Classified data

Referenced Data								
Classified Data	LULC Classes	Built-up	Cropland	Forest	Mangrove	Degraded Mangrove	Waterbody	Row Total
	Built-up	48	2	0	0	0	0	50
	Cropland	5	45	0	0	0	0	50
	Forest	0	0	46	4	0	0	50
	Mangrove	0	0	6	42	2	0	50
	Degraded Mangrove	0	0	3	4	43	0	50
	Waterbody	0	0	0	0	0	50	50
	Column Total	53	47	55	50	45	50	300

Overall Accuracy = (48+45+46+42+43+50)/300*100 = 91%

The overall accuracy is 91% for the year 2019 in the island. The producers and users accuracy was also computed which is given in table below.

Table 6: Accuracy Assessment - Producer's and user's accuracy statistics

LULC Classes	Producer’s Accuracy (%)	User’s Accuracy (%)
Built-up	90	96
Cropland	95	90
Forest	83	92
Mangrove	84	84
Degraded Mangrove	95	86
Waterbody	100	100

Accuracy assessment for the year 2010 and 2005 were done only for change detection, since, 2019 LULC vector data is put over the satellite image of 2010 and only changes were mapped. Similarly, 2010 LULC data was overlaid on satellite images of 2005 and again only changes were mapped. The overall accuracy for 2010 LULC map was 86% and for the year 2005 is 84%.

Chapter 2. Land Use Land Cover modelling and Future Scenarios

2.1 Introduction

Change is a continuous process. Resources, ecosystem, biophysical environment, and land use / cover on the surface of the earth undergo changes over time and space. Human needs dictate the change and variability in the land use/cover. Along with diverse influences of aerosols, these spatially heterogeneous land use effects may be as important in altering the weather as changes in climate patterns associated with greenhouse gases (Pielke, 2005). The importance of land use / cover change and variability is of much concern today as between one-third to one-half of our planet’s land surfaces have been transformed by human development (NASA, 2005). Therefore, land use/ cover changes are of critical values due to their great influence in global warming, biodiversity loss and impact on human lives (Geoghegan et al, 2001).

Models of land use change are tools to support the analysis of the causes and consequences of land use change in order to better understand the functioning of the land use system and to support land use planning and policy. Models also support the exploration of future land use changes under different scenario conditions. Models are generally considered as abstractions, approximations of reality which is achieved through simplification of complex real world relations to the point that they are understandable and analytically manageable (Briassoulis, 2000). Land use change is the result of a complex web of interactions between bio-physical and socio-economic forces over space and time. Coping with this complexity for practical purposes, it is important to simplify complex relationships to manageable and understandable dimensions.

Models generally provide decision support in various decision and policy-making contexts. More specifically, models can be used to describe the spatial and temporal relationships between drivers and the resulting patterns of land use and their changes. Models of land use change can also be used as explanatory vehicles of observed relationships of observed relationships. Very frequently models are used to predict or forecast future configurations of land use patterns under various scenarios of bio-physical and socio-economic change. Models of land use change can play an instrumental role in impact assessment of past or future activities in the environmental and / or socio-economic spheres.

Currently available models for land use change can broadly be categorized into descriptive and prospective models. Descriptive models aim at simulating the functioning of the land use system and the spatially explicit simulation of near future land use pattern. The prescriptive models aim at the calculation of optimized land use configurations that best match a set of goals and objectives. The descriptive land use change models represent a wide variety of modelling techniques and theoretical backgrounds. Reviews that characterize and classify land use models are provided by Lambin (1997) and Kaimowtiz and Angelsen (1998) for deforestation, Miller et al (1999) for integrated urban models, Lambin et al (2000a) for agricultural intensification and by Bockstael and Irwin (2000) for land use models based on economic theory. Agarwal et al (2001) have reviewed a selection of 19 models based on their spatial, temporal and human-choice complexity. Briassoulis (2000) has given an extended review of all types of land use models. Verburg et al (2004) have focused the discussion on a number of features of land use systems that need to be taken into account by modellers.Pontius et al. 2006 opined that it is difficult to compare the performance of the numerous models because LULC models can be fundamentally different in a variety of ways. For example, some models, such as IDRISI's GEOMOD, simulate change between two land categories (Silva and Clarke 2002; Pontius et al. 2001) while others, such as IDRISI's CA_MARKOV, can simulate change among several categories (Li and Reynolds 1997; Wagner 1997; Wu and Webster 1998; Pontius and Malanson 2005). Still others simulate change in real variables as opposed to categorical variables (Veldkamp and Fresco 1996). Most models are for raster data, while some are for vector data. Even if all researchers were to use the same model, comparison among model performance would still be difficult because researchers usually focus on one specific study region. Therefore, it is difficult to separate the quality of the model from the complexity of the landscape and of the data. For example, if a model performs poorly, it is difficult to know whether the conceptual foundation of the model is weak, or the phenomenon of land change at the study site is particularly complex or the data is particularly detailed. Alternatively, if a model performs well, it is difficult to know whether the conceptual foundation of the model is strong, or the phenomenon of land change at the study site is particularly simple, or the data is very simplified. Perhaps most importantly, there is not yet an agreed upon method to measure the performance of LULC models, so two modellers who use the same model on the same landscape with the same data might evaluate one simulation run differently depending on the criteria used for evaluation.

- ***2.1.1 Drivers of Land Use Land Cover change***

Understanding the factors that drive land-use change, and developing better methods for projecting future changes, have become very important in the context of climate change, since land use is both affected by climate and itself is a significant contributor to greenhouse gas emissions (Elliott et al, 2010). It is thus, necessary to assess the driving forces behind Land use/ land cover change (LULC) if past patterns are to be explained and used in forecasting future patterns. Driving forces on LULCC can include almost any factor that influences human activity, including local culture (food preference, etc.), economics (demand for specific products, financial incentives), environmental conditions (soil quality, terrain, moisture availability), land policy and development programs (agricultural programs, road building, zoning), and feedbacks between these factors, including past human activity on the land (land degradation, irrigation and roads). Investigation of these drivers of LULCC requires a full range of methods from the natural and social sciences (Ellis, 2010).

2.2 Methodology

In present study we have considered a total of ten driver variables. The driver variable are both static and dynamic in nature. The drivers were mainly selected on the basis of data availability and the knowledge of study area. Moreover, a participatory survey was conducted on various stakeholders to understand the significant drivers of Land use land Cover change in the island. Out of ten driver's, three are topographic drivers (elevation, slope and aspect), three are proximity drivers (distance to built-up, distance to cropland and distance to drainage), one is socio-economic driver (population density) three are other drivers (roads, ports & Jetty and tourist places). Most of the proximity driver variable are derived from temporal Land use land Cover map. The Euclidean distance is calculated from specific landscape feature to get proximity drivers. The shapefile of roads are downloaded from open street map. Than distance to roads is calculated using Euclidean distance. Since, in Andaman Island our main focus is the mangroves and most of the mangroves are along the sea as well as creeks. Along these creeks and sea shores, new waterways are planned which require construction of new ports and jetties. Therefore, the distance from port and jetties are taken as driver variable. The population density plays an important role in urban sprawl. The population data is taken from census of India website for the census year 2001 and 2011. In Andaman Island tourist places are important driver variable as all the development projects are planned keeping tourism at the centre. Therefore, distance from tourist places is taken as the driver variable.

In the present study we have used Land Change Modeller (LCM) in TerrSet software to predict future Land Use Land Cover for Andaman Island. The original idea behind the design of TerrSet software was to manage the biodiversity and to analyse and predict the future Land Use Land Cover (Shivamurthy and Kumar, 2013; Gibson et al., 2018). The LCM mainly focuses on factors which influence future LULC change, how much land cover change took place between earlier and later LULC, and then calculates a relative amount of transitions (clark Lab, 2021). The LCM was widely tested and used software to predict LULC change (Mas et al., 2012). The LCM module of TerrSet software provides changes in each LULC category as losses and gains. The end result of LCM is two simulated maps, i.e., soft projection and hard projection. The hard projection provides a simulated map for the prediction year, in which each pixel is allocated to a specific land use category. Whereas, the soft projection provides a projected map which shows the vulnerability in which each pixel is allocated a value from 0 to 1. The values closer to zero indicates less vulnerability to change and the values near 1 shows high susceptibility to change (Ayele, et al., 2019).

2.3. Result and Discussion

The present study focuses on the changes for the years 2004, 2010, and 2019 to analysed and predict future years of the Andaman Island. The future land use scenarios were based on past trends, historical land use information, and anticipated future changes. The LCM uses the change analysis tab, the transition potentials tab, and the change prediction tab. The change analysis tab determines the change rates, along with the transition potential maps to simulate the future scenario. The LCM module have three different approaches to produce maps of transition potential based on the individual sub-models and associated explanatory variables: multi-layer perceptron (MLP) neural network, logistic regression, and a similarity-weighted instance-based machine learning tool.

In our study area, we have first predicted the Land Use Land Cover map of year 2019 to calibrate and validate our model. For predicting Land Use Land Cover of 2019, the Land Use Land Cover map of 2005 and 2010 is used. Land Cover Land Use change analysis is done between 2005 and 2010 to understand the major changes and to identify the major land use transition. All these transitions are explained above in result and discussion section of Land Use Land Cover map generation chapter. The predicted 2019 LULC map was compared with actual 2019 LULC map prepared through visual interpretation. The independent driver variable use to run model were elevation, slope, distance to drainage, population density, distance to roads, ports & jetty and tourist places. Initially 11 independent drivers were created for the study, however, on the basis of Cramer's V, which is used to test the significance of each driver variable with respect to Land Use Classes (DasGupta et al. 2018) the driver variable was narrowed down to seven. The value of Cramer's V range from 0 to 1 with higher value indicate higher potential explanatory power of driver variable.

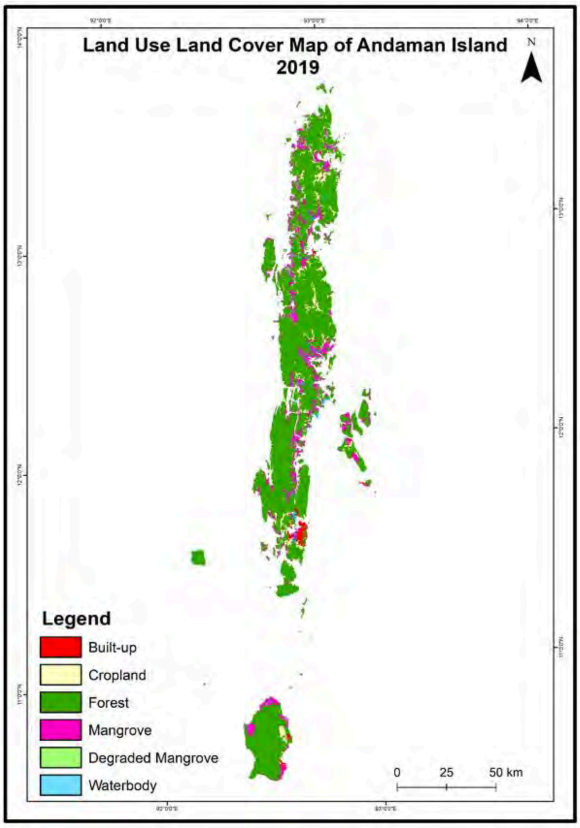
The driver variable with Cramer's value higher than 0.15 have satisfactory explanatory power and value greater than 0.4 is considered good (Hashimoto et al., 2018). The table below explains the explanatory power of each driving force represented by Cramer's Value.

Table 7: Cramer's value of driver variables

Driver Variables	Cramer's value
Elevation	0.4066
Slope	0.4126
Distance to Drainage	0.4082
Population Density	0.3349
Distance to Roads	0.4673
Distance to Port and Jetty	0.5028
Tourist Places	0.6512

These driver variables are added to the models as a static or dynamic variable (Eastman 2016). The static variable value do not change with time while that of dynamic variable keep on changing with time and hence, the value of dynamic variable keep on changing throughout the projection.

The present study, we have used multi-layer perceptron (MLP) neural network to produce Transition probability maps. Then CA – Markhov was used to simulate the future LULC scenario. The actual LULC map of 2019 and predicted LULC map of 2019 are represented as Figure 11 and 12. For predicting LULC of 2019, we have taken business as usual scenario with only constrain that protected area should not change. The protected area boundary is put as constrain in the model.



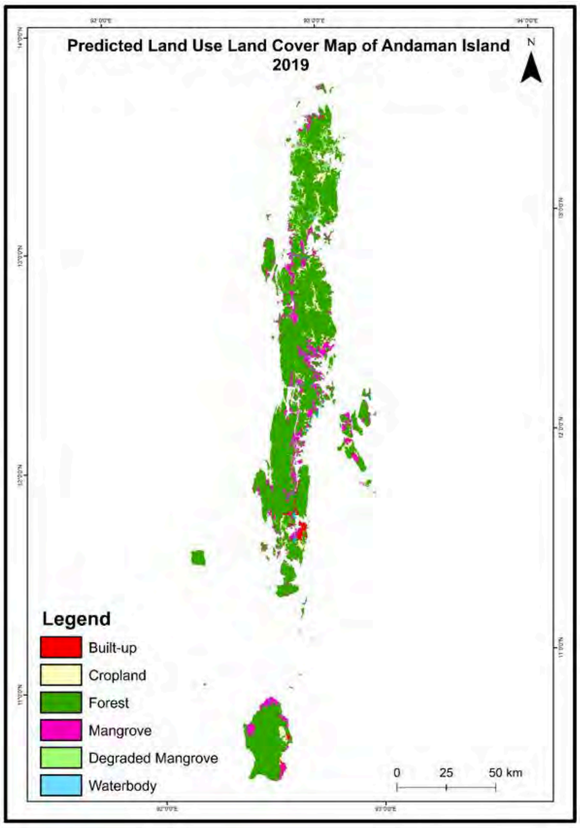


Figure 11: LULC for 2019

Figure 12: Predicted LULC for 2019

To know the quality of the predicted map, accuracy assessment of predicted LULC of Andaman Island for years 2019 was performed through the preparation of error matrix. Standard methodology was adopted for accuracy assessment which is based on error/confusion matrix (Congalton, 1991, Lillesand et al., 2004). The table below shows the overall accuracy, user's accuracy, producer's accuracy and kappa coefficient of predicted LULC map. The actual 2019 LULC map was taken as reference data for accuracy assessment.

Table 8: Accuracy Assessment for predicted LULC- Classified and referenced data

		Referenced Data						
Classified Data	LULC Classes	Built-up	Cropland	Forest	Mangrove	Degraded Mangrove	Waterbody	Row Total
	Built-up	24	2	0	2	2	0	30
	Cropland	2	26	0	1	1	0	30
	Forest	0	0	26	2	2	0	30
	Mangrove	0	1	2	24	2	1	30
	Degraded Mangrove	0	2	2	2	23	1	30
	Waterbody	0	0	1	2	2	25	30
	Column Total	26	31	31	33	32	27	180

Overall Accuracy = (22+26+26+24+23+25)/180*100 = 81%

The overall accuracy is 81% and kappa is 0.81 for the predicted Land Use Land Cover map of year 2019 in the island. The producers and users accuracy of the predicted map was also computed which is given in table below.

Table 9: Accuracy Assessment for predicted LULC- Producer's and User's accuracy.

LULC Classes	Producer's Accuracy (%)	User's Accuracy (%)
Built-up	90.5	80.0
Cropland	83.8	86.6
Forest	83.8	86.6
Mangrove	72.7	80.0
Degraded Mangrove	71.8	76.6
Waterbody	92.5	83.3

- ***2.3.1 Land Use Land Cover Prediction for 2050***

On the successful validation of the model based on actual Land Use Land Cover map of 2019, the LULC map of the future is predicted for 2050. The LULC map of 2010 and 2019 were used to predict the 2050 LULC. The two scenarios were generated; one business as usual and other with proposed infrastructure development as input in the model. The LCM modle of TerrSet software allows the user to input the proposed infrastructure changes map under the planed infrastructure changes sub tab. Again we have used protected area boundary as constrain, so that minimum change happens inside the protected area. The independent driver variable use to run the model are elevation, slope, distance to drainage, population density, distance to roads, ports & jetty and tourist places**.** These independent variables are selected on the basis of Cramer's Value. To make future scenarios for 2050 we have again used multi-layer perceptron (MLP) neural network to produce Transition probability maps. Than CA – Markhov was used to simulate the 2050 LULC scenarios. The first LULC scenario, business as usual for 2050 with complete statistics is shown as Figure 13, 14 and Table 9.

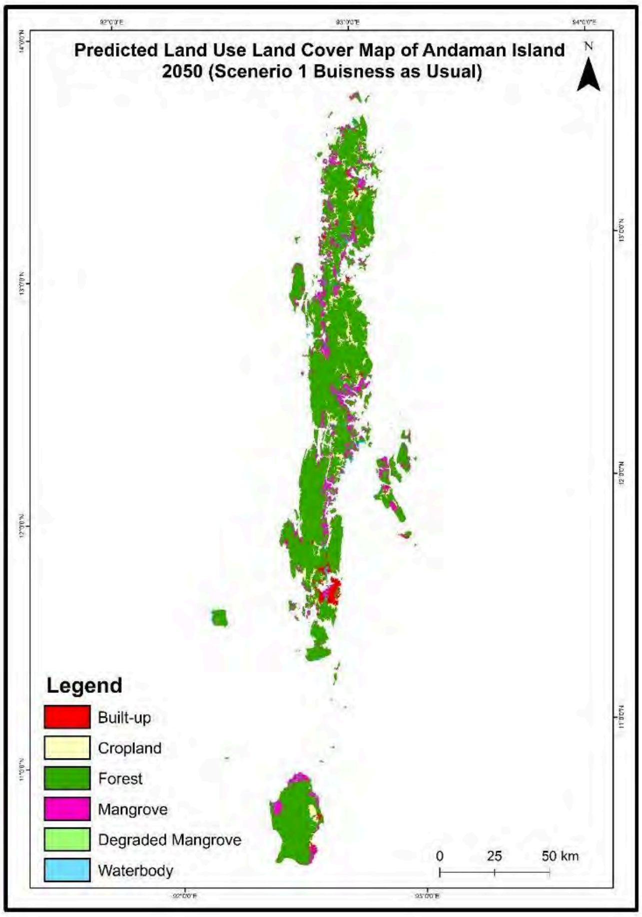


Figure 13: Precited LULC 2050, Scenario 1- Business as usual

Table 10: Area statistics of predicted LULC for 2050, scenario 1

LULC Classes	2005		2010		2019		2050	
	Area (km^2)	% of TGA	Area (km^2)	% of TGA	Area (km^2)	% of TGA	Area (km^2)	% of TGA
Built-up	39.89	0.62	51.86	0.80	80.18	1.25	124.87	1,94
Crop Land	316.33	4.93	315.01	4.91	303.07	4.72	345.58	5.39
Forest	5221.20	81.47	5216.35	81.40	5211.32	81.32	5179.01	80.28
Mangrove	686.21	10.70	593.69	9.26	631.62	9.85	625.96	9.76
Degraded Mangrove	39.93	0.62	137.78	2.15	92.04	1.43	45.68	0.71
Waterbody	104.44	1.62	93.31	1.45	89.77	1.40	86.89	1.35
Total	**6408**	100	**6408**	100	**6408**	100	**6408**	

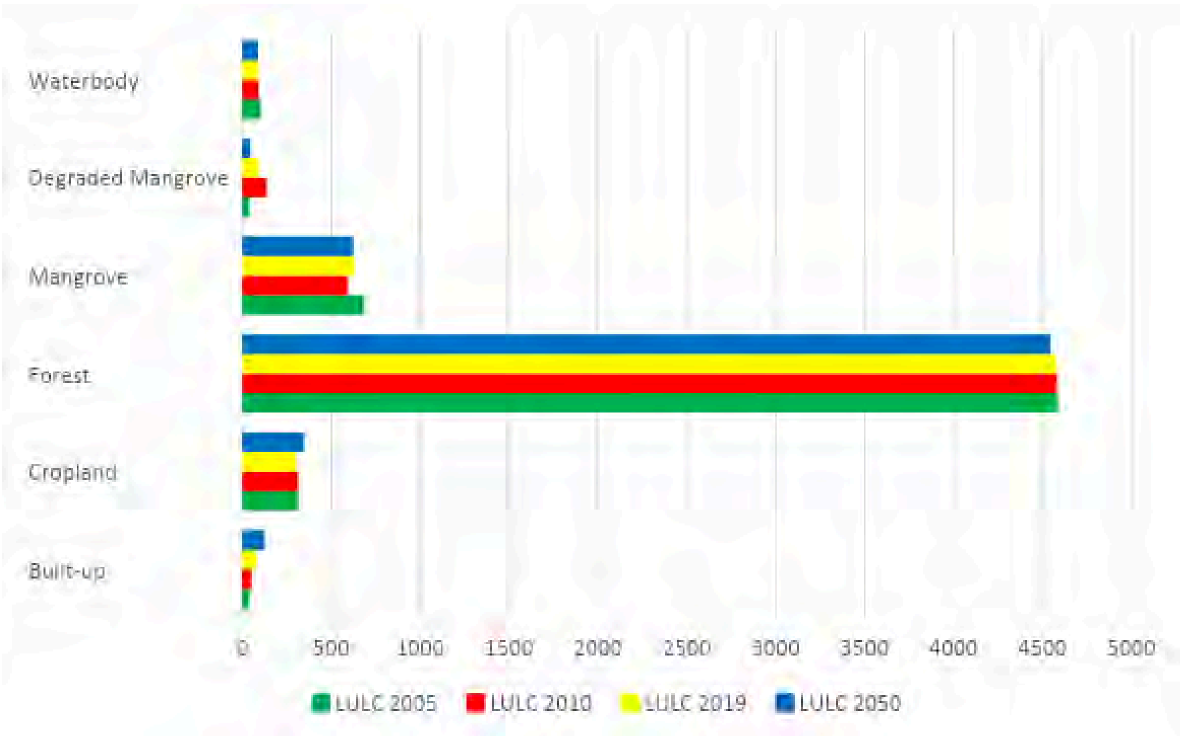


Figure 14: Graphical representation of area statistics of predicted LULC 2050

As evident from the change statistics, forest is the dominant class in the study area and will slightly decrease in 2050 in business as usual scenario because most of the forest is protected area in the island. The built up will increase substantially in 2050 covering 1.95 percent of the total geographic area of the island. The built up will increase on the expense of mainly cropland and near the cost on the expense of mangrove and degraded mangrove. The other major Land Use class which will increase substantially is cropland. The cropland will expand on the expense of mangrove and degraded mangrove. In some places outside the protected area, the forest has also changed into cropland. The mangrove in 2050 will increase from 2019. The main region of increase is the regeneration of degraded mangrove mostly in north and middle Andaman. As explained earlier the 2004 Tsunami is responsible for widespread destruction of mangrove due to sudden geomorphic change in the island. The changes in mangrove that started slowly in 2005 keeps on happening till 2010 (as evident from LULC map of 2010). After 2010 slowly the regeneration of degraded mangrove started and that is the reason the 2019 LULC map is showing slight increase in the mangrove. Along with the mangrove regeneration in the in the degraded mangrove area, mangrove colonization in the uplifted seafloor may also be a reason for the increase in mangrove in 2050. This regeneration of degraded mangrove is happening mostly in north and middle Andaman. However, the degraded mangrove in western Andaman is also showing some restoration but in small patches. The mangrove which are adjacent to cities, town and major tourist attraction is showing reduction due to rapid pace of urbanization. In the case of mangrove and degraded mangrove the elevation, slope, population, distance to port, jetties and tourist places are prominent drives as seen from Cramer's V value. During the development of this model various constraint was put in various Land Use Land Cover Class like protected area boundary, so that the forest under protected area should not change. Even built up was restrain from growing after certain limit.

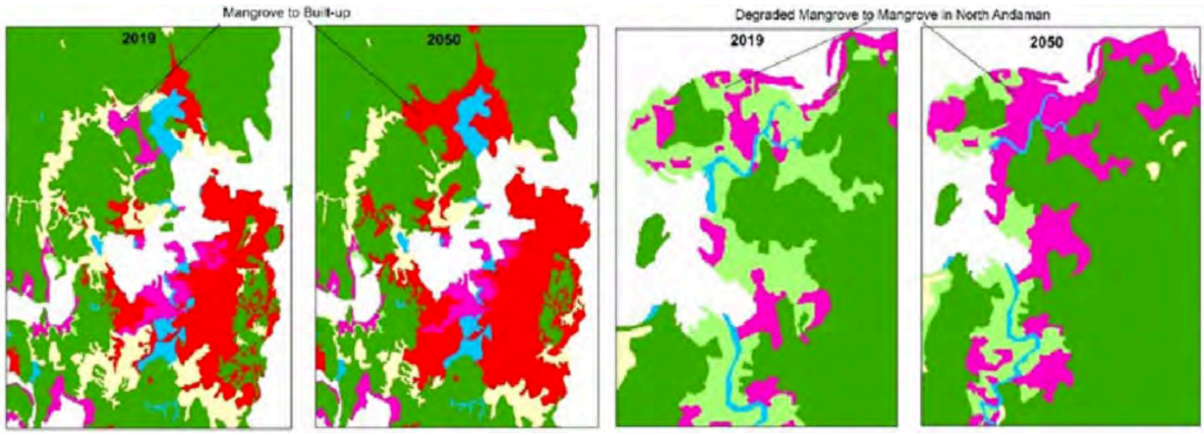


Figure 15: Locations where major changes have occurred in North Andaman in the LULC

The other scenario was developed keeping in mind the proposed infrastructure development in the island. In this case, no constraint was put on expansion of built up. Though, protected area boundary is used but with minimum constrain. This scenario drives fast infrastructure changes in the island causing better connectivity. The biggest proposed infrastructure development in the island is the construction of new railway line which is proposed between Port Blair and Diglipur (www.railnews.in). The other smaller infrastructure development which is likely to happen is the construction of new roads, port and jetty. These infrastructure development will no doubt boost the business of local people residing in the island. Due to these development especially new railway line the tourism and other local business will flourish. However, these developmental activity will have some impact on the ecosystem. The Land Use Land Cover scenario for 2050 with infrastructure development on the focus is represented in Fig. No. 16.

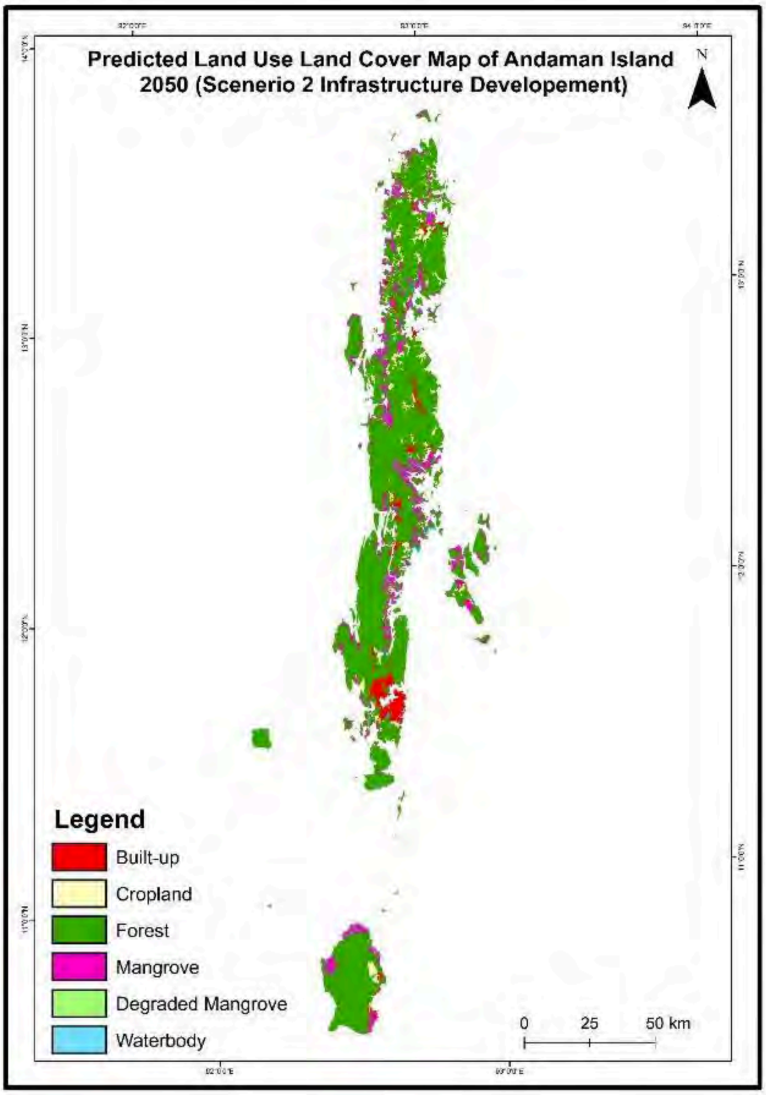


Figure 16: Precited LULC 2050, Scenario 2- Infrastructure development

Table 11: Area statistics of predicted LULC for 2050, scenario 2

LULC Classes	2005		2010		2019		2050	
	Area (km^2)	**% of TGA**	**Area (km^2)**	**% of TGA**	**Area (km^2)**	**% of TGA**	**Area (km^2)**	**% of TGA**
Built-up	39.89	0.62	51.86	0.80	80.18	1.25	165.43	2.58
Crop Land	316.33	4.93	315.01	4.91	303.07	4.72	338.85	5.28
Forest	5221.20	81.47	5216.35	81.40	5211.32	81.32	5165.10	80.60
Mangrove	686.21	10.70	593.69	9.26	631.62	9.85	617.67	9.63
Degraded Mangrove	39.93	0.62	137.78	2.15	92.04	1.43	40.05	0.62
Waterbody	104.44	1.62	93.31	1.45	89.77	1.40	80.90	1.26
Total	**6408**	100	**6408**	100	**6408**	100	**6408**	100

The results (table 10) clearly shows that if these proposed infrastructure development take place in the island there will be reduction in aerial extent of all Land Use Land Cover class except Built-up which will increase substantially. However, very little change is seen in the aerial extent of mangrove from the business as usual scenario because these infrastructure development are proposed in stretches or in and around major tourist attraction. The proposed railway line is still in primary phase and only route is demarcated. It is not clear where all the stations will be built which required substantial amount of land. Since, the proposed railway line is along the cost it will have effect on mangrove mostly in western cost of Andaman Island.

2.4 Conclusion

The analysis of results for future scenario of Andaman Island should be done very cautiously because this study was done with lot of limitations. Firstly, in our future scenario of Land Use Land Cover for 2050 we have not consider the natural disaster like 2004 Tsunami. The whole Andaman Island is very prone for natural disasters and these disaster can suddenly change the geomorphology of the island causing sudden change in Land Use land cover as happened after December, 2004 Tsunami. Secondly, we have considered forest as one single Land Use Land Cover class and more intense classification may show changes in tree species and composition with in forest class. Similarly, mangrove is considered as single Land Use Land Cover class in our classification and past studies has revealed that there are significant changes in tree species composition with in the mangrove class. Our first Scenario business as usual are based on assumption that the changes that are happening today will continue in the future and there will be no drastic change till 2050. The Second scenario is based on proposed infrastructure development projects in the island. Still, 2050 is long time ahead and government policy can change with time and new big infrastructure development project can come in island, which can drastically change the Land Use Land Cover of the Island (eg. the proposed development in the Little Andaman Island).

Chapter 3. Ecosystem services of mangroves

3.1 Introduction

Mangroves are exceedingly productive ecosystems located at the inference between sea and land that plays a vital role in the biogeochemical cycles of the coast environment (Jennerjahn and Ittekkot 2002, Feller et al. 2003). Mangroves are globally recognized for their ecological, social, economic, and cultural significance. Mangroves offer myriad of ecosystems services including habitat for number of coastal fauna; source of fishes, crabs, oysters and non-timber forest products; act as barrier against coastal erosion, cyclones, storms, and tsunamis; and high carbon storage vegetation (Alongi 2008; Spalding et al. 2014). The ecosystem services provided by mangroves have an estimated economic value of more than US$ 900,000 per sq. km annually (UNEP-WCMC 2006) is indicative of their importance. The recent past has witnessed an exponential increase in research on mangroves and its associated ecosystem (Lee et al. 2014). However, mangroves are disappearing globally at an alarming annual rate of 0.16-0.39%, primarily due to anthropogenic pressures (Hamilton and Casey 2016) and nearly 46 % of mangroves were lost globally in the past few decades (Romanach et al. 2018).

The increase in greenhouse gas emission and their links with the economic loss induced by climate change have led to a growing interest in minimizing the atmospheric carbon levels (Parry et al. 2007). Vegetation across the globe can play a crucial role in mitigating the climate change effects as they naturally sequester carbon for their growth and development. Mangroves are especially recognized as an important element in the global measures to mitigate climate change. Recent studies have highlighted that the carbon sequestration potential of mangroves per unit area is the highest among any forest ecosystem in the world (Alongi 2008; Donato et al. 2011; McLeod et al. 2011). Therefore, the function of carbon storage and sequestration adds additional cause in favour of the mangrove conservation. This appeal is even more significant since climate change is intensifying (Parry et al. 2007), and international agreements are being signed to reduce and offset greenhouse gas emissions.

Mangrove forests contribute to a mere 0.7% of tropical forested area globally, but provide disproportionate amount of ecosystem services. Despite their myriad of ecosystem services, mangroves are highly threatened due to sea-level rise and increasing pressures from human population growth across its distributional ranges. The increased scientific knowledge on mangroves in the recent decades has contributed to the policy level changes towards mangrove conservation in few countries (Dahdouh-Guebas et al. 2021). However, though mangrove carbon stocks were recently estimated at global/regional and local scales (Alongi and Dixon 2000, Hutchison et al. 2014, Harishma et al. 2020), but to date, these have not been cited within the framework of the management of larger coastal or island landscapes.

In South Asia, India has the second-largest mangrove area of 4975 sq. km. along its vast stretch of coastline (8118 km), which supports rich coastal biodiversity and the livelihood of several million people. The mangrove cover is widespread on the east coast of India because of its distinctive geomorphological settings (Ragavan et al. 2016). In the eastern part, mangroves in the Andaman Islands–that account for 12.3% (614 sq. km.) of the total mangrove cover in India (FSI 2019)–are recognized as the best due to their high species richness and luxuriant growth (Dagar et al. 1991). The canopy heights of mangrove forest in Andaman Islands often exceeds 20 to 30 m and is expected to rival the biomass of the tropical evergreen forests. However, as many other Island ecosystems, the mangroves in Andaman Islands are also vulnerable to disturbances and have experienced increased frequency of natural disasters (e.g., storms, cyclones, earthquakes, Tsunami) and anthropogenic land-use change in the recent past (Yuvaraj et al. 2014).

Several studies in the recent past have highlighted the mangrove species diversity, density, biomass, and the impact of disturbances on the mangroves of Andaman (Mall et al. 1991; Bharthi et al. 2014, Kiruba-Sankar et al. 2017). Yet, carbon storage and other ecosystem services provided by the mangrove forest in these Islands are poorly documented (Chand et al. 2013). In general, the inventory of carbon stocks in mangrove forests of India is scanty (Pandey and Pandey 2013, Sahu et al. 2016, Suresh et al. 2017) and a very few studies have attempted to determine the monetary value of the ecosystem services provided by mangroves. It is noteworthy that the increased frequency of natural disasters and developmental pressures in Andaman Islands can adversely affect the future of its mangrove forests and the associated ecosystem services. Therefore, understanding the vegetation dynamics and land-use changes in mangroves are vital for quantifying carbon stocks, carbon sequestration, and mapping vulnerability of ecosystem services. These are important to develop and implement local and national policies linked to climate change mitigation and mangrove conservation (Harrison et al. 2014). The remoteness of Andaman Islands and the scarcity of ground data can be a major impediment to assess the ecosystem services and carbon stocks. The advancement in ecosystem service modeling that integrates relevant ecological processes into the classification of spatial and temporal distinction can negate the above mentioned impediments (Nelson and Daily 2010). Therefore, in the present study we evaluated the monetary values of carbon stock and its spatial variation in the mangrove ecosystems of Andaman Islands, India using remotely sensed data and GIS applications. The study also highlights the mangrove cover change and systematically reviews the variation in above-ground biomass of mangrove ecosystems in Southeast Asia.

3.2 Methodology

We used the global dataset of above ground biomass (AGB) for the mangrove ecosystem that was prepared based on the in situ field measurements and remotely sensed data by Simard et al. (2019) in our study. They used the GLAS lidar altimetry dataset collected globally from 2003 to 2009 to measure mangrove stands. Subsequently, derived spatially explicit AGB from space-borne remote sensing data and in situ measurements considering local-scale environmental and geophysical conditions (Simard et al. 2019). The resolution of the dataset is 30 m × 30 m. For the present study, we have extracted the values of AGB from each pixel from the datasets as mentioned above and model (fourth-order polynomial: $AGB_{MANGROVE} = -13.21 + 14.22_{DEM} - 1.5180_{DEM} + 0.2779_{DEM} - 0.0072_{DEM}$) with the SRTM elevation dataset for the three different time period (2005, 2010 and 2019) for the Andaman Islands. Initially, we have created a scatter plot with AGB of mangrove and elevation data and successively fit the models in increasing order and test the significance of regression coefficients at each step of model fitting. The total above biomass estimates for the Andaman Islands was generated by summing all corresponding pixels.

The carbon stock was calculated by multiplying the biomass values with the conversion factor 0.5 (IPCC 2006) based on the assumption that the biomass is made up of 50% Carbon. The monetary values for carbon stock for three different time period were calculated following Ricke et al. (2018). The total annual carbon stock was converted to tonnes of carbon, and the social cost of carbon (US$86) was applied (Ricke et al. 2018). The social cost of carbon was used to represent the economic cost associated with climate damage (or benefit) resulting from the emission of an additional tonne (t) of carbon dioxide.

3.3 Result and Discussion

The spatial variation in the mangrove above-ground biomass for three different time periods shown in figure no. 17. As per the distribution of mangrove in 2019, the mean AGB stored in mangrove vegetation of Andaman Islands was $172.82_{Mean} \pm 119.65_{SD}$ t (or Mg) ha^{-1}, and the average vegetation carbon stock of mangroves was found to be $86.41_{Mean} \pm 59.82_{SD}$ t C ha^{-1}. The total carbon estimated for three different time periods are as follows: 4937467.11 t (2019), 4765890.90 t (2010), and 5751127.95 t (2005). Regarding the value of carbon storage, we estimated that US$ 424.62 million (2019) are stored in the AGB of the Andaman mangroves. The negative rate of change (2005-2019) in the monetary terms estimated was US$ 0.0832 million yr^{-1}.

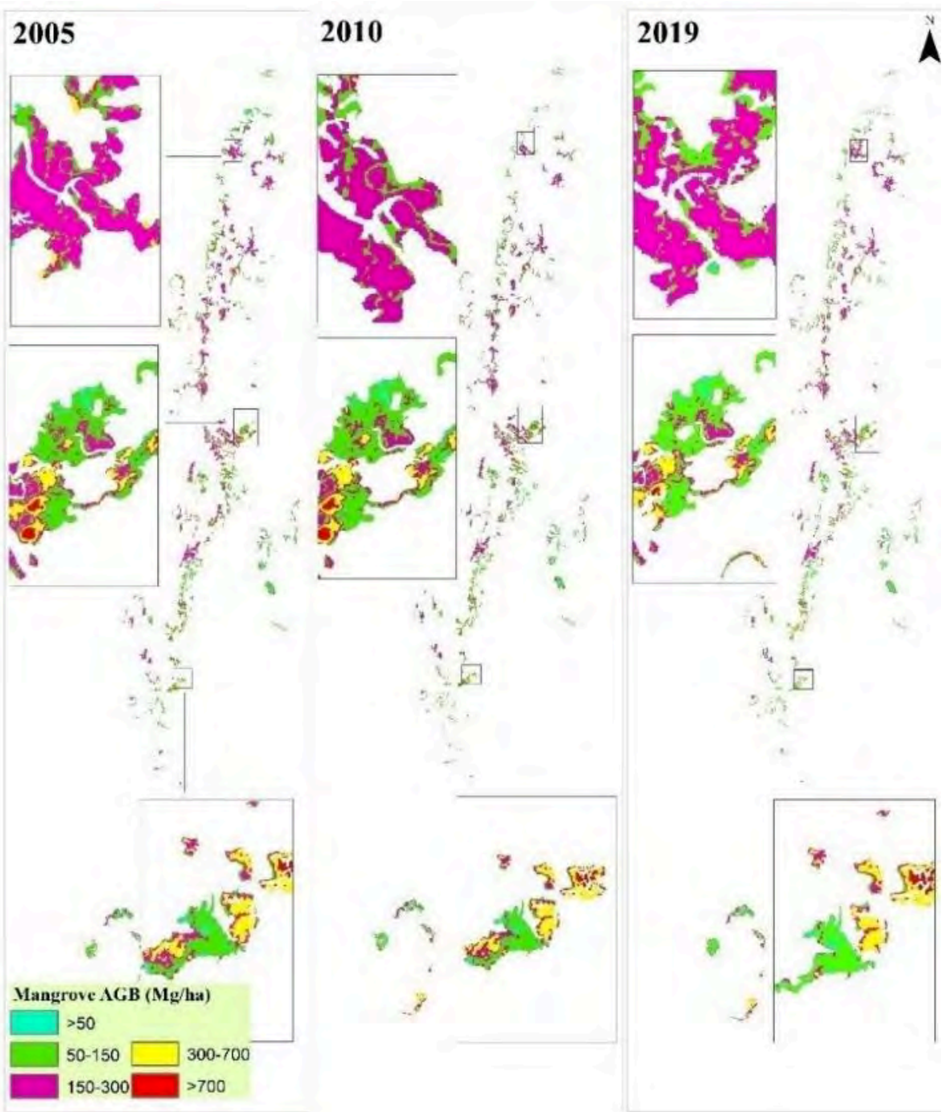


Figure 17: Spatial variation of above ground biomass in the mangrove ecosystem of Andaman Islands (time periods: 2005, 2010 and 2019), India.

The loss of mangrove vegetation after tsunami has significantly impacted the ecosystem services, as shown in the rate of change in carbon valuation in the last 14 years. Besides, the substantial loss of mangrove vegetation has already indicated its effect on marine species, where the fishermen have reported a significant reduction in fish catch especially the crabs and shrimps (Ramakrishnan et al. 2020). Mangroves are ten folds' superior to manmade defence systems in dealing with climate-associated disasters (Chand et al. 2013). Previous studies reported that the economic evaluation of Andaman Mangroves was worked out to be more than INR. 125 million per year (Chand et al. 2013). The value of goods and services harvested per household per year was more than INR 61,000. Similarly, they have also revealed that the value of mangroves per hectare in the Islands was more than INR 0.2 million (Chand et al. 2013). The monetary evaluation of ecosystem services is dynamic in nature, and studies have taken into account different approaches. Besides, assigning a monetary value to an ecosystem service heavily depends on the precision of scientific measurements. We thus position ourselves cautiously with respect to the market mechanisms and the possibility of offsetting emissions. Based on our results, it is highly recommended that areas with high mangrove carbon stock prioritize conservation. Since developing countries generally lack financial resources to sustain long-term environmental management actions. Thus, strict protection of existing mangroves against encroachment and cutting and expansion by regenerating potential intertidal areas through the plantation of suitable species, including vulnerable and threatened species, seems to be crucial management options. Our modeling method delivers a simple measure for AGB carbon stock, and, with better dataset, might be in the same way established for other stocks and fluxes, and for other ecosystem services of mangroves. Beyond carbon stock, mangroves provide a host of other ecosystem services, including coastal safety, water purification, fisheries, timber, and biodiversity (e.g., Sathirathai and Barbier 2001,Gunawardena and Rowan 2005). Thus, increased investments to secure individual ecosystem services are therefore likely to profit several other economic and social benefits. Likewise, enhancements in understanding the value and drivers of other ecosystem services can further strengthen efforts to manage, and restore mangrove ecosystem. The mapping of patterns of various ecosystem services has the great potential in strategizing conservation efforts.

3.4 Conclusion

The Kyoto Protocol-1997 was mounted on the principle that carbon dioxide from the air can be sequestered in biomass and soil and applied to mitigate climate change. More specifically, blue carbon sinks that include coastal habitats like salt marshes, seagrass, and mangrove forests are ranked in order of carbon sinks. Since these habitats are the most carbon-rich forests in the tropic (Duarte et al. 2005). Thus, the mangrove ecosystem presently being radical as a vital component of the climate change strategies such as blue carbon and REDD+. Reducing emissions from deforestation and forest degradation creates a monetary value for the carbon stocked in the ecosystem by offering incentives for developing countries to decrease emissions from forested lands and capitalize on low-carbon paths to sustainable development. REDD+ goes further than merely deforestation and forest degradation and comprises the role of conservation, sustainable management of different forest ecosystems, and enhancement of carbon stocks. The social cost of carbon (SCC) represents the economic cost linked with climate damage (or benefit) resultant from the emission of an additional ton of CO_2 (Ricks et al. 2018). Our estimated monetary value (US$ 424.62 million) in terms of ecosystem service is very low than the actual figure since we have not incorporated major carbon stock for below-ground biomass and soil carbon in the forested mangrove areas. Mangroves accumulate carbon in tree biomass, but then again, a considerable amount of this carbon is lost by way of various anthropogenic activity *viz*., clear-cutting and human use, disintegration, and dissemination to adjacent ecosystems. However, over the long run, carbon is mainly stored below-ground as soil carbon and, in time, under the right conditions, as peat. Therefore, in the future, studies should also consider soil carbon and below-ground carbon stock for the Andaman Islands for a better estimate of valuation.

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Appendix 2: Detailed report from the Mahanadi delta mangroves in Odisha, India

Introduction

The study is aimed to understand the present condition of the mangroves in eastern Odisha, India. The locations of Bhitarkanika and Paradip mangroves are shown in Fig. 1. In the last decade, these mangroves have been facing tremendous pressure from multiple drivers including socio-cultural and economic aspects of the residents, and also from the inevitable climate change. In this technical report, the plausible future scenarios of the mangroves in particular have been predicted based on the Story-and-simulation approach. A participatory survey has been conducted in the region to capture the dependence and understanding about the mangroves. Based on this, scenarios were generated and the ecosystem services of the mangroves in particular have been quantified using the InVEST model. The details will be discussed in the following sections of the report.

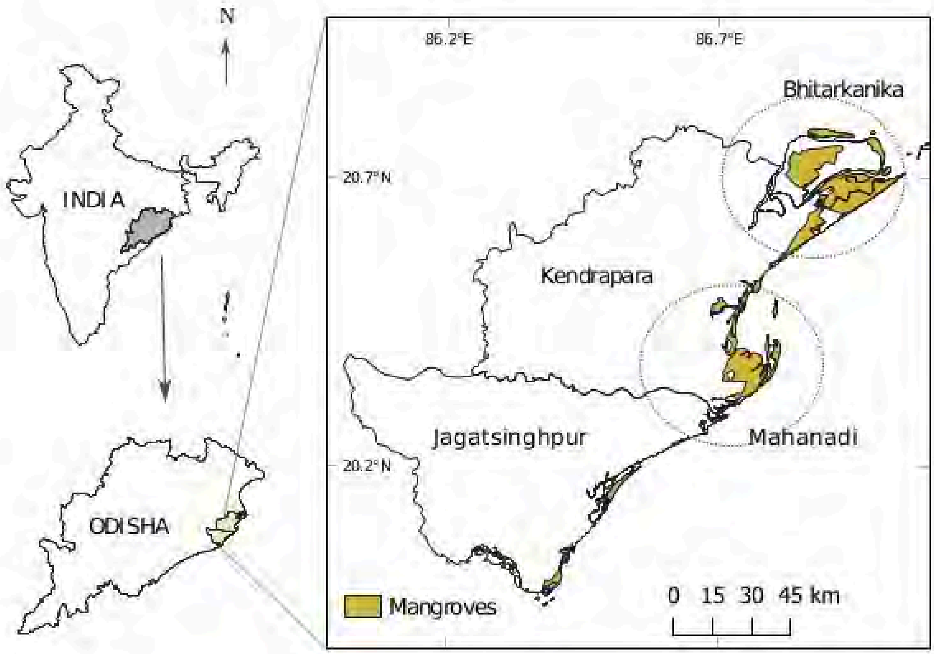


Figure 1: Mangroves patches of Bhitarkanika and Mahanadi

There are around 400 villages within the designated boundary of BNP, out of which 81 are close to mangrove forests (Census of India 2011). About 1,50,000 people live in the adjoining villages of BNP are directly or indirectly dependent on the mangroves for their subsistence demands, that makes the BNP as one of the most complex socio-ecological systems. The people in these remotely located villages are deprived of modern facilities and hence they utilize mangrove resources (e.g. food, fodder, timber, medicine, *etc.*) (Nayak 2004; Mishra et al. 2005). The local people in the region mostly practice agriculture and aquaculture for their livelihood. Hence, the present study captures the scientific knowledge available on ES, and thereby summarize its multiple benefits, drivers of loss, existential threats and opportunities for conservation and restoration planning of BNP mangroves. The glimpses of BNP wildlife is shown in Fig.2.

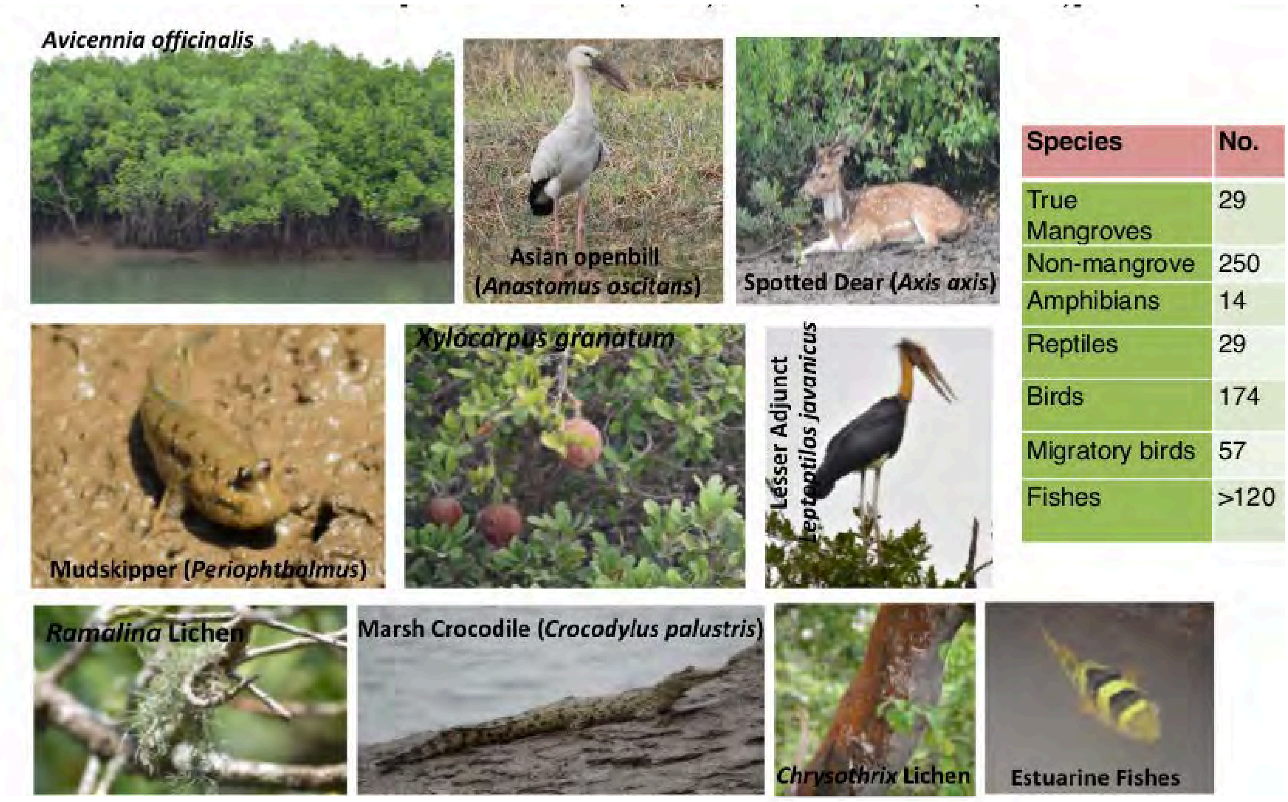


Figure 2 Glimpses of flora and fauna found at Bhitarkanika mangroves

The study area includes five *tehsils* (local level administrative units, equivalent to counties) that are along the coasts and have mangroves. Two *tehsils* viz. Rajnagar and Mahakalapada are from Kendrapara District, while Kujang, Ersama, and Balikuda are from Jagatsinghpur District (shown in Fig. 3). Table 1 shows the area of these *tehsils*.

Table 1 Geographical area of *tehsils* in the study area

Tehsil	Area
Rajnagar	598.4 km2
Mahakalapada	543.2 km2
Kujang	304.7 km2
Ersama	392.2 km2
Balikuda	315.0 km2

Figure 3 *Tehsils* marked in the study area

a) Participatory survey for identifying the drivers of change

The questionnaire based participatory survey has been planned for identifying the drives of change that affects the mangrove habitats of Bhitarkanika. The format of the questionnaire is appended in the Annexure. A list of potential stakeholders consisting of 45 participants is also been prepared. The idea is to obtain the drivers of change from the local stakeholders and to incorporate these drivers in the InVEST model for scenario assessment.

Participatory survey — summary on drivers affecting the mangroves of eastern Odisha, India

Participatory survey was conducted on multiple stakeholders of the region to find out the major concerns of the locals on mangrove degradation. It emerged from the discussion that the stakeholders are highly certain that population growth has severe impact on the mangrove degradation. Many respondents on the discussion have agreed to the major extent that local people are directly or indirectly dependent on the mangrove forest produce and the pressure has been building recently due to the population growth resulting from rural-urban migration. Changes in land use, expansion of built-up area and large construction activities are directly impacting the local hydrology significantly. The effect of industries along the coasts, ports, jetties, are not be ignored when it comes to polluting the surrounding. This will result in water quantity and quality in the estuaries and mudflats, which directly impacts the mangrove habitat quality and also disturbs the balance in ecosystem. The ill-effects of tourism include plastic pollution, pressures the solid and hazardous waste management systems in the localities, and imparts pressure on local resources. Clearing of mangroves for aquaculture and agricultural farms has also been observed by several stakeholders. Majority of the participants believe with high certainty that expansion of aquaculture and agriculture is the major cause for degradation of mangrove habitats. Along with that, most of the participants believe with very high certainty that deforestation and habitat fragmentation are also some of the significant concerns for the mangrove habitat degradation.

Socio-economic and demographic factors of the local people residing in the fringes of the mangrove patches also play an indirect but vital role in exerting pressure on the mangroves. The participants believe with high certainty that local socio-economic factors are an important driver. For instance, tourism, firewood collection, fishing, poaching, and extraction of medicinal plants, etc have been identified as some of the major issues which are directly related to the socio-economic conditions of the people in the region. Further, it emerged from the discussion that there are mixed responses on the role of governmental agencies and implementing authorities in mangrove conservation. Quite a lot of participant believe that the protective measures taken by the government are actually helping in checking the degradation of mangrove habitats. However, there are a few voices expressing the dissatisfaction on slack in policy implementation and reported few instances of violation of coastal protection rules. Remarkably, majority of the participants believe that through the implementation of technology using remote sensing and GIS based surveying the mangroves, will benefit in ecosystem monitoring, management, and resource conservation. Also, certain coastal conservation structural measures are believed to be helpful in reducing the impact of storm surges and cyclones on the mangroves. However, the frequency and intestate of these natural disasters have been increasing in the last decades due to climate change. Most of the participants believe with high certainty that tsunamis, tropical cyclones, and sea level rise are affecting the mangrove habitats. The summary of the drivers is provided in Table 2.

Table 2 Summary of the drives emerged from the participatory survey on mangrove habitats

Major drivers	
Economic development	Increase in built-up, aquaculture, agriculture, pollution, tourism
Conservation measures	Avoiding deforestation and habitat fragmentation
Socio-economic factors	Poor education, lack of awareness, alternative resources, less forest dependency
Use of technology	For monitoring, and coastal protection

Various ecosystem services of the BNP as mentioned below have been reviewed from the existing literature. The review prepared has been communicated for possible publication in the Journal of Coastal Conservation.

1. Provisioning services
2. Regulating services
3. Sediment trapping
4. Mitigation of coastal salinity
5. Carbon sink / blue carbon sequestration
6. Pollinating services
7. Cultural ecosystem services

An array of natural and anthropogenic drivers are also identified in the study area from the existing literature and they are mainly: human settlements, exploitation of forest resources, aquaculture, agriculture and other economic activities.

Land use and land cover Scenario generation

Three scenarios were generated in this study after summarizing the stakeholder perception about the future landscape of the region. The maximum area of 10750 ha (5% of total study area) land which is allowed to change due to land use changes according to the scenarios.

Scenario-1 would be a case where economic development is given utmost importance. Expansion of built-up area, agricultural farms, and aquaculture would be given emphasis without concerning much about the protection of coastal blue carbon ecosystems like mangroves. Conversion of mangroves at the fringes of the intact habitats are possible. Land occupied with other vegetation and water bodies are also seen to be converted into built-up areas. This scenario is particularly favorable for development of economic activities but with a least concern to the mangrove habitats. The conversion of land use according to this scenario is achieved in the InVEST model with a sequential runs of proximity based land use scenario generator model. The steps followed are shown in Table 2.

Scenario-2 would be a case where economic development is though given priority, the conservation of mangroves is also taken care of. In this scenario, economic development is encouraged in terms of expansion of built-up area but encroachment of existing mangrove patches are not allowed to be converted into agriculture or aquaculture farms. The land occupied with agriculture or with other vegetation types is allowed for the expansion of built-up (Table 3).

Scenario-3 would be a more optimistic case where mangrove forest cover will increase along the fringes by conversion of aquaculture, agriculture, and other vegetated areas. This scenario will reflect the improved socio-environmental awareness, and the protective role of mangroves in mitigating climate related hazards is well appreciated by the people.

Table 3 Description of the scenarios and the land use change dynamics envisaged to be converted in the future

No.	Scenario	Description	Focus land use	Convertible land use	Replacement lands
1	Economic development, without protecting mangroves	Expansion in built-up, aquaculture and agriculture	Built-up	mangroves, other veg, water	Built-up
			Aqua, mangroves	mangroves, other veg, water	Aqua
			mangroves	mangroves, other veg	Agriculture
2	Economic development with concern to mangroves protection	Expansion on built-up area, but prohibiting future expansion of agriculture and aquaculture near mangroves	Built-up	agriculture, other vegetation	Built-up
3	Improved Socio-economic factors and concern on climate change	Encouraging people to explore alternative sources of income, making them less dependent on mangroves, conversion of adjacent aqua and agricultural farms to mangroves. Increase in mangrove patches will not only protect the regions form climate extremes, but also fosters marine biodiversity and yield. Existing built-up is not disturbed.	Mangroves	Aquaculture, agriculture, other veg, water bodies	Mangroves

b) **Quantification of ecosystem services according to the future scenarios**

Land cover classification

Land use land cover classification of the study area was done using Google Earth Engine (GEE) and QGIS. GEE has a catalogue of satellite data with analyzing capabilities for spatial datasets while QGIS is well-known GIS software to create, manipulate, and analyse satellite images and other spatial data. Classification of land use in the study was done using the Sentinel-2, Multi-spectral Imagery and Sentinel-1, Synthetic Aperture Radar imagery with 10m spatial resolution. Training points are taken from the image to classify it into 6 different classes representative of Mangroves, built-up, Agriculture, Aquaculture, Water bodies, and other vegetation. Random Forest technique was used in supervised classification approach to get the initial output. The land use classification has an accuracy of around 85% using confusion matrix.

Present and future land use according to the scenarios

Results on scenario analysis indicate that under Scenario-1 the expansion of agriculture, aquaculture cover, and built-up is quite predominant. Some of the land covered with water bodies, other vegetation, and mangroves will be utilized for the economic development (increase in agricultural production, aquacultural yield, and urbanization). In this scenario the mangrove cover has diminished from 9.1 to 2.5%. Similar changes are reflected in the land use pattern for the Scenario-2, in which the mangrove cover is remained unaffected at 9.1%. In contrast, the mangrove cover is increased (from 9.1 to 14.1%) in the Scenario-3. The summary of land use changes is represented in Fig. 4 and Fig. 5 and the percentage change values are presented in Table 4.

Table 4 Summary of land use percentages in the present and future scenarios

Land use (code)	**Present (%)**	**Scenario-1 (%)**	**Scenario-2 (%)**	**Scenario-3**
others	4.7	4.7	4.7	4.7
Water body (0)	8.1	3.5	8.1	7.1
Aquaculture (1)	2.8	7.8	2.8	2.7
Other vegetation (3)	11.5	7.5	10.9	10.2
Built-up (4)	4.5	9.5	9.5	4.5
Agriculture (5)	59.4	64.4	54.9	56.7
Mangroves (6)	9.1	2.5	9.1	14.1

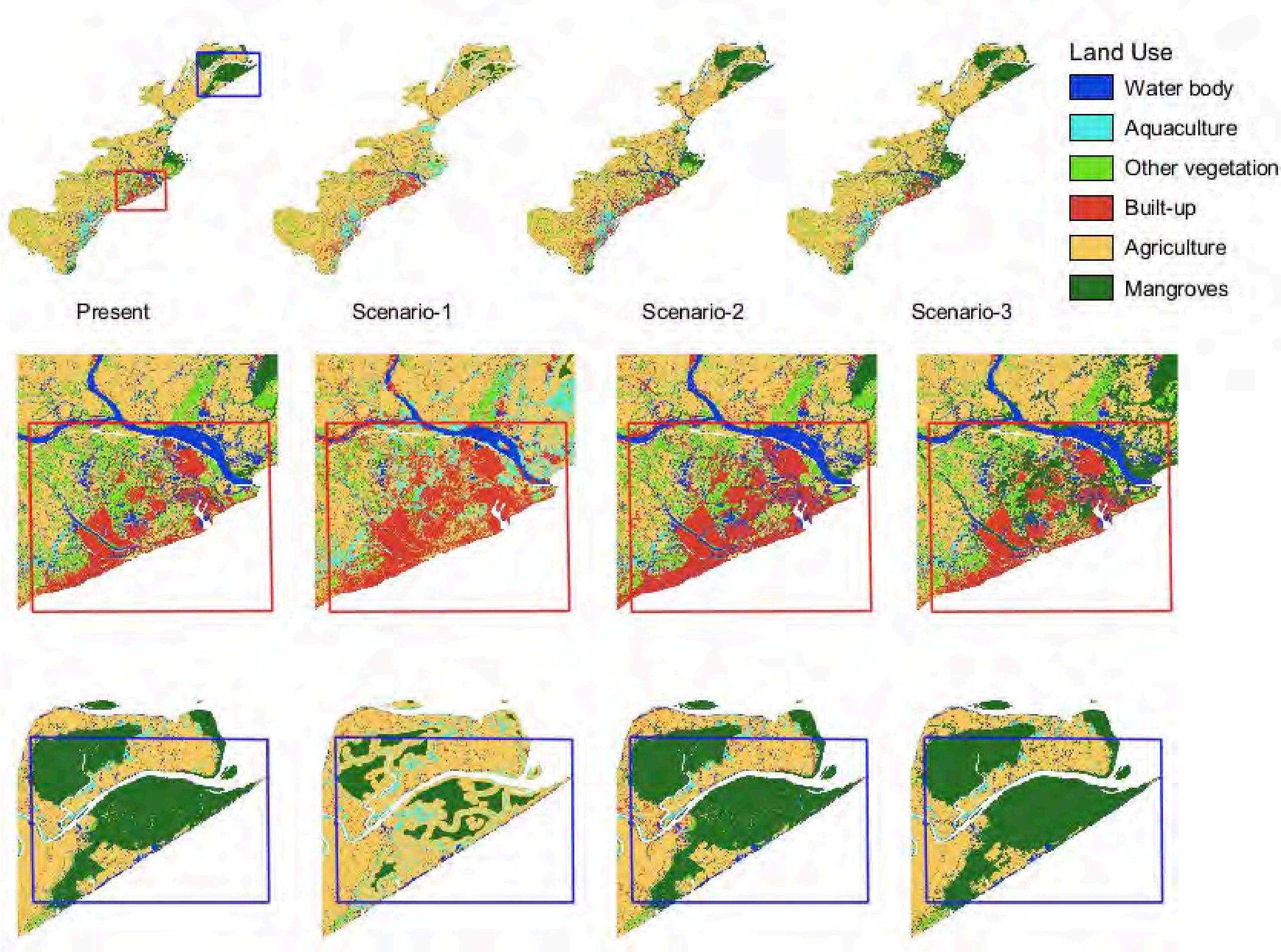


Figure 4 Land use and land cover in the present year (2020) and future scenarios 1-3. The inset boxes cover the mangroves of Bhitarkanika (blue) and Paradip (red) areas in Odisha state

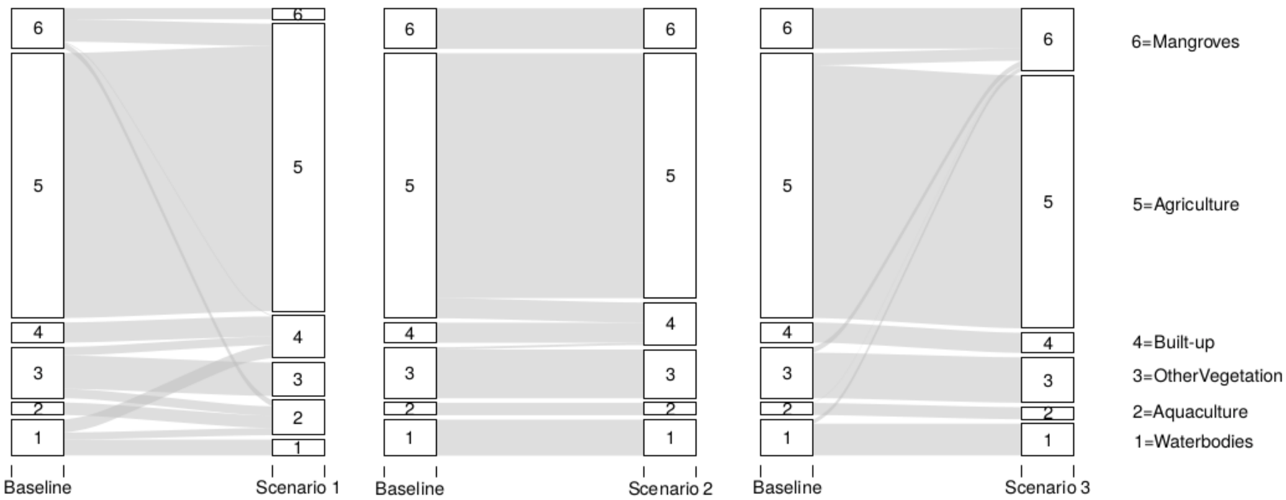


Figure 5 Land use and land cover change Sankey plot for three future scenarios in comparison with the baseline or present land use of 2020

InVEST model

The InVEST model has been setup on the study area for quantifying the blue carbon sequestration, sediment retention and export, and nutrient export in the study area. Input data required for the InVEST model are shown in Tables 5 to 9 and the corresponding spatial pattern of the variables is shown in Fig. 6 to 10.

In the present study, mangroves are alone considered as a source of blue carbon. If the mangroves are converted into aquaculture, then the disturbance is treated as ‘medium impact’, whereas if the mangroves are converted to any other farm, the disturbance is treated as ‘high impact’. Studies show that mangrove sediment carbon pool is still conserved in aquaculture to some extent as the soil is relatively undisturbed when compared to mangroves, which is unlikely with other forms of land use conversion.

Table 5 Parameters used in the blue carbon model

Parameter / data layer related to mangroves	Value and units
Biomass half-life	15 years
Low impact disturbance	50% reduction in biomass carbon, 30% reduction in soil carbon
Medium impact disturbance	50% reduction in biomass carbon, 50% reduction in soil carbon
High impact disturbance	100% reduction in biomass, 66% reduction in soil carbon
Yearly accumulation of carbon	1.789 Mg C/ha/y in biomass, 3.35 Mg C/ha/y in sediments (soil carbon)
Soil carbon half-life	7.5 years

The standing blue carbon in biomass, soil, and litter pools from the mangroves of the study area are assigned with values 100, 134, and 0.59 MgC/ha, respectively. The carbon stored in other ecosystems and land uses are not considered in this study, as they do not represent the coastal blue carbon.

Table 6 Land cover and management practices factors used in the RUSLE (revised universal soil loss equation) soil loss model

Land use code	C factor	P factor
1	0	1
2	0	1
3	0.03	0.8
4	0	1
5	0.4	0.5
6	0.004	1

Table 7 Other parameters used in the sediment delivery model

Parameter / data layer	Value and Unit
Threshold flow accumulation	1000
Borselli k parameter	1
Borselli IC_0	0.5
Max SDR value	0.8

Table 8 Parameters used in the nutrient delivery model

Land use land cover	N load (kg/ha)	Retention efficiency, N and P (%)	Critical length for N and P (m)	P load (kg/ha)
1	0	0	0	0
2	0	0	0	0
3	1.4	0.8	30	1.4
4	2.1	0.26	30	2.1
5	21.27	0.48	30	9.42
6	0	0.9	15	0

*The proportion of nutrients transported from sub-surface flow are not considered in this study.

Table 9 Other parameters used in the nutrient delivery model

Parameter / data layer	Value and Unit
Threshold flow accumulation	1000
Borselli k parameter	2
Subsurface critical length (N and P)	30
Subsurface maximum retention efficiency (N and P)	0.8

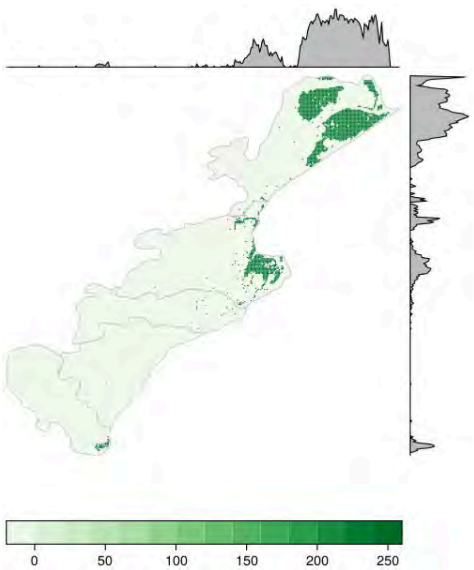


Figure 6 Standing blue carbon stock (tC/ha) in the present condition of year 2020

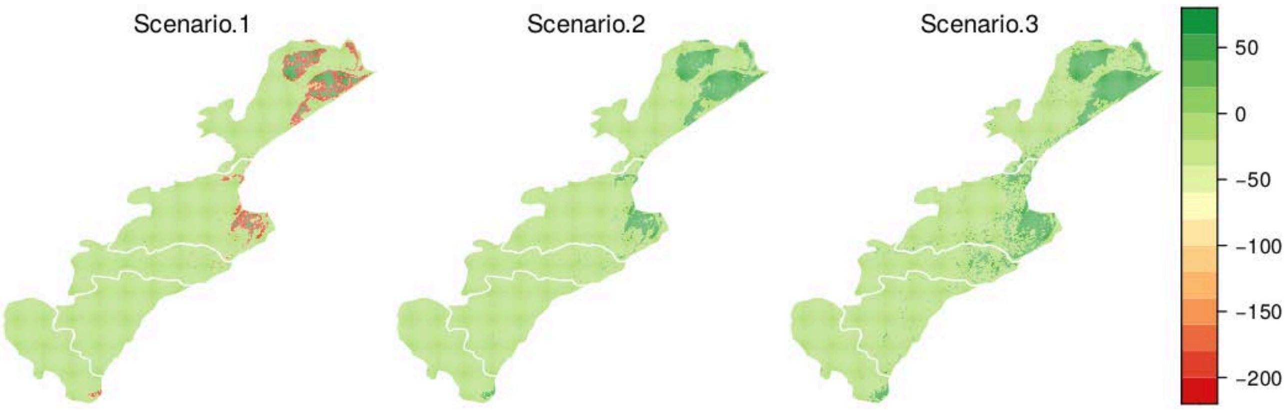


Figure 7 blue carbon in other scenarios (tC/ha)

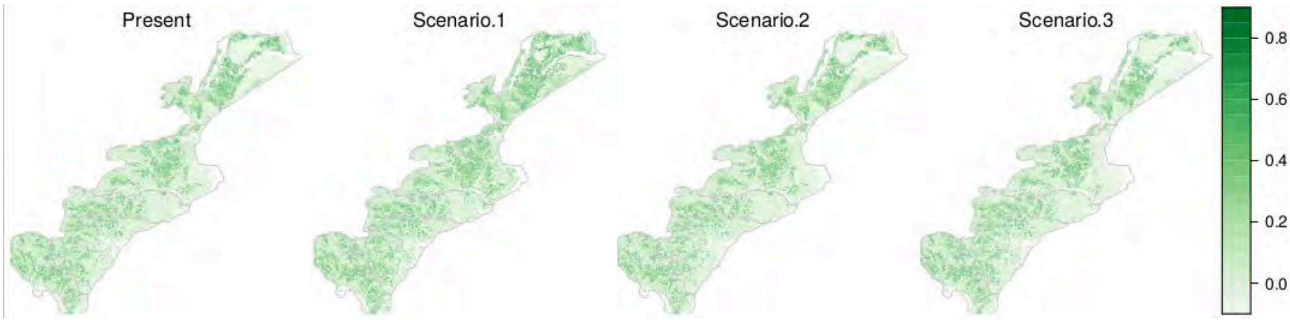


Figure 8 Nitrogen (kg/ha/y)

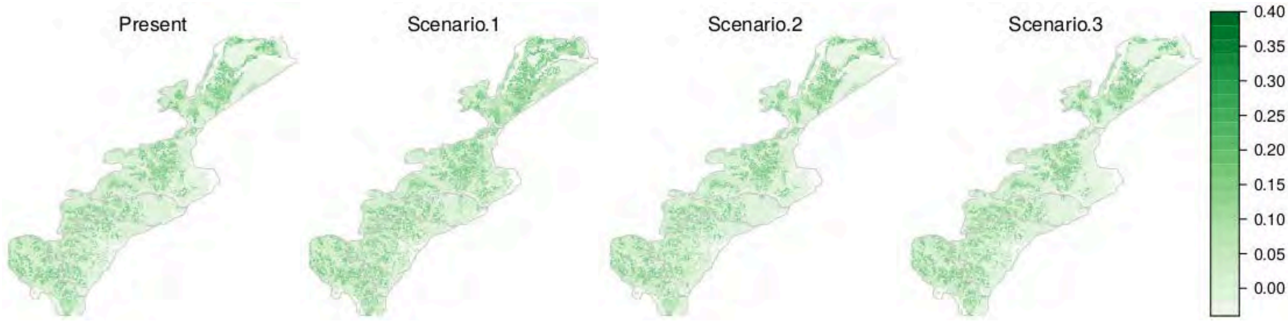


Figure 9 Phosphorus (kg/ha/y)

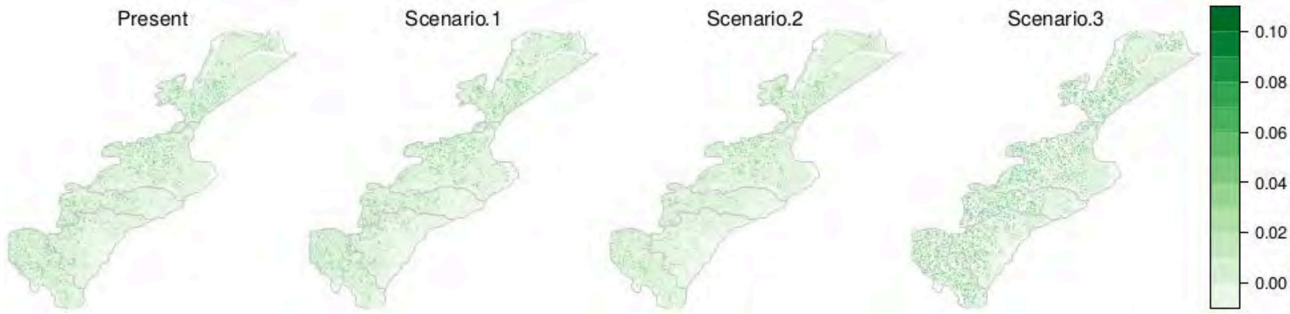


Figure 10 Sediment export (t/ha/y)

The model results on the standing blue carbon, net carbon sequestration in each scenario when compared against the present condition, sediment and nutrient export are summarized in Table 10. The bar diagrams depicting these changes are shown in Fig. 11a-. Results indicate that there is a net emission of blue carbon in Scenario-1 owing to the loss of mangroves due to rapid economic development. The loss of mangrove blue carbon is reflected to be highest in Rajnagar tehsil. Sediment export appears to be increased in *tehsils* for the Scenario-3, further studies are required to actually assess the sediment release and retention dynamics. The nutrient export is observed to be higher in Scenario-2 in owing to the loss of both vegetation cover and mangroves.

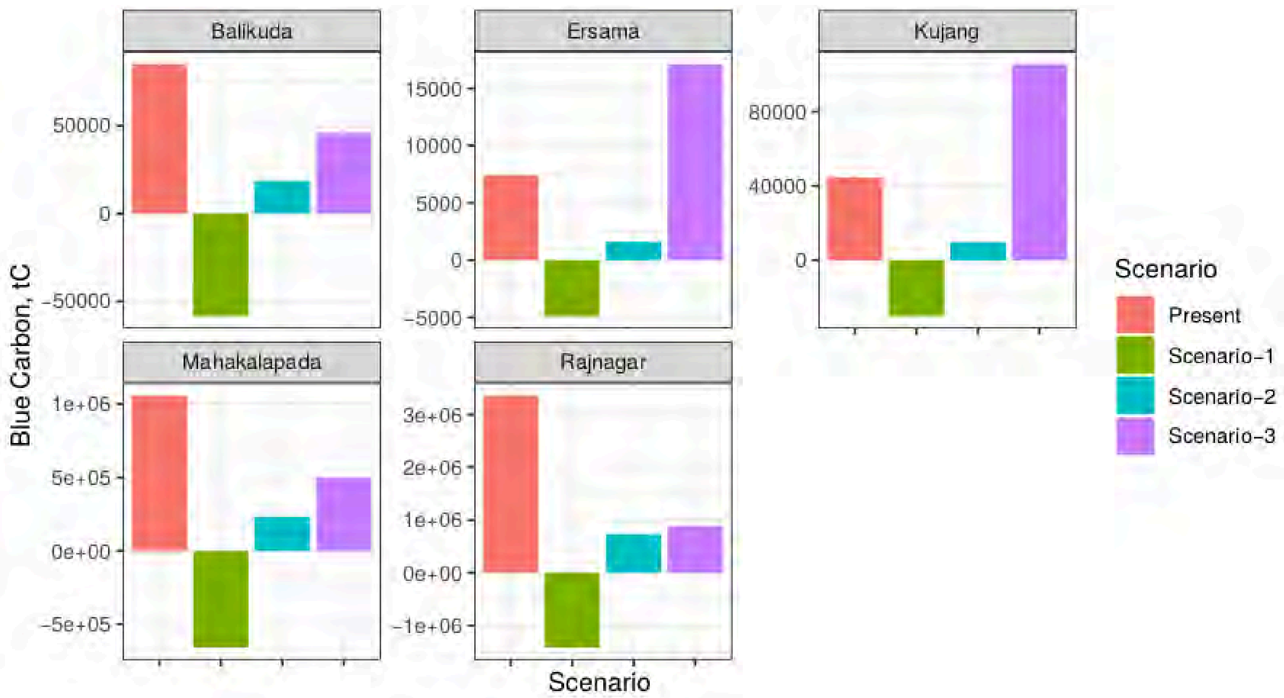


Figure 11a Comparative bar diagram of Blue carbon (tC)

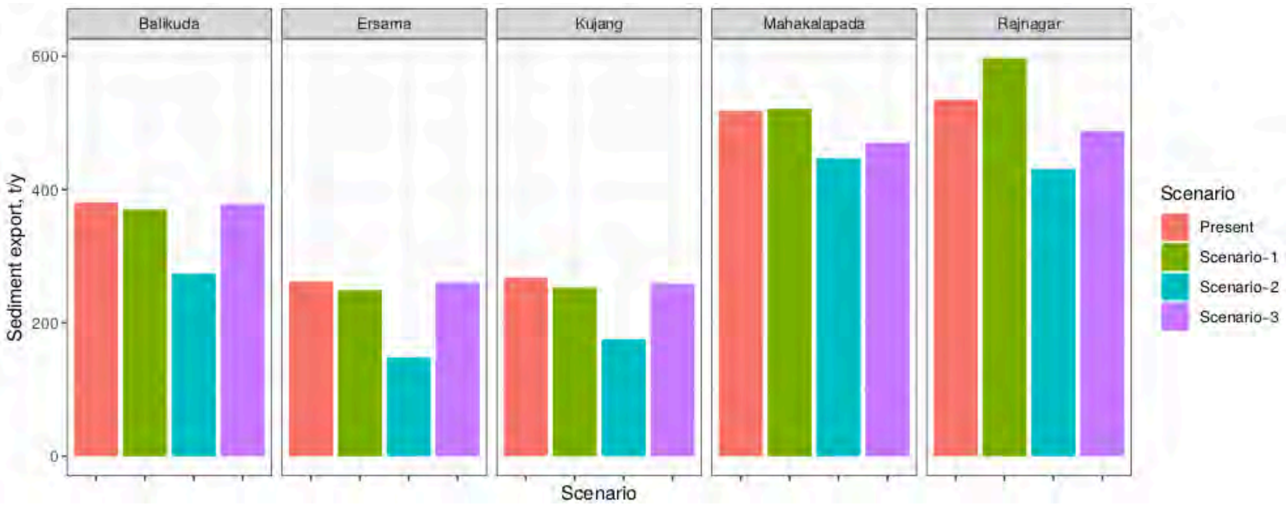


Figure 11b Comparative bar diagram of Sediment Export (t/y)

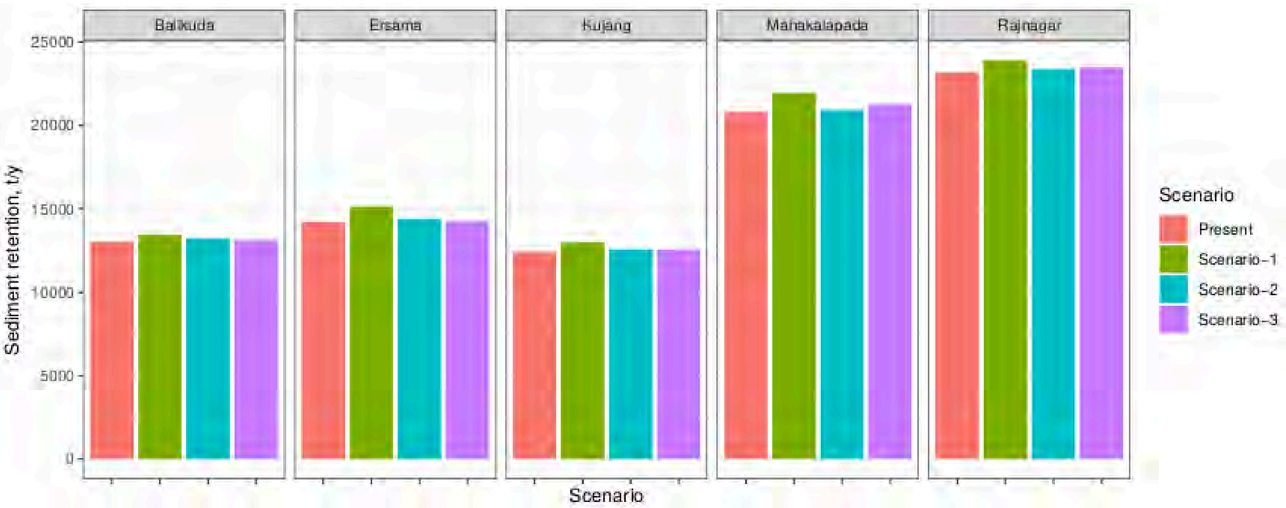


Figure 11c Comparative bar diagram of Sediment Retention (t/y)

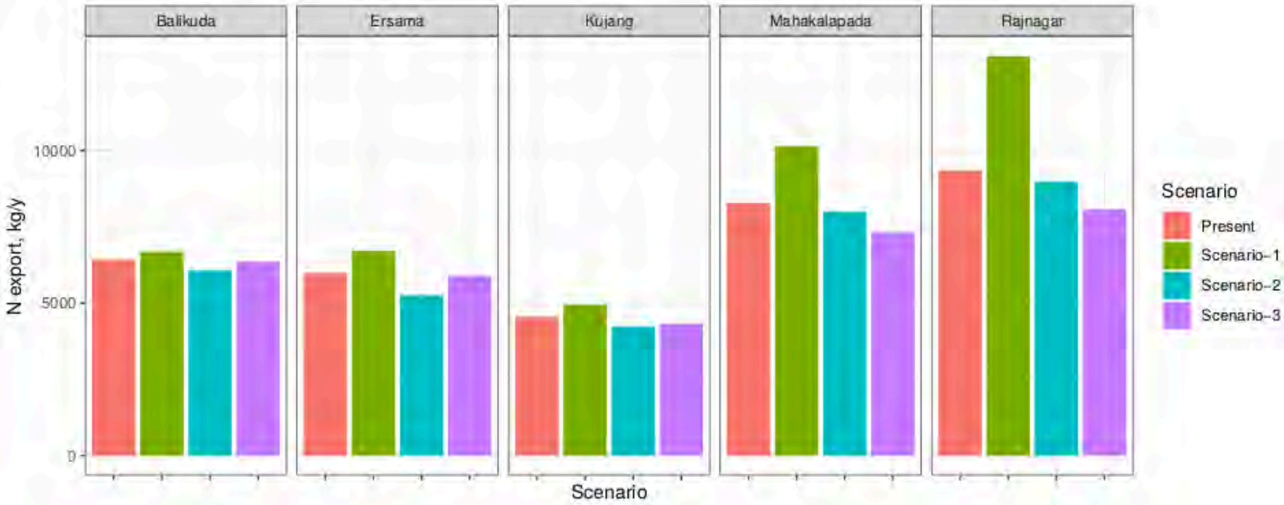


Figure 11d Comparative bar diagram of Nitrogen Export (kg/y)

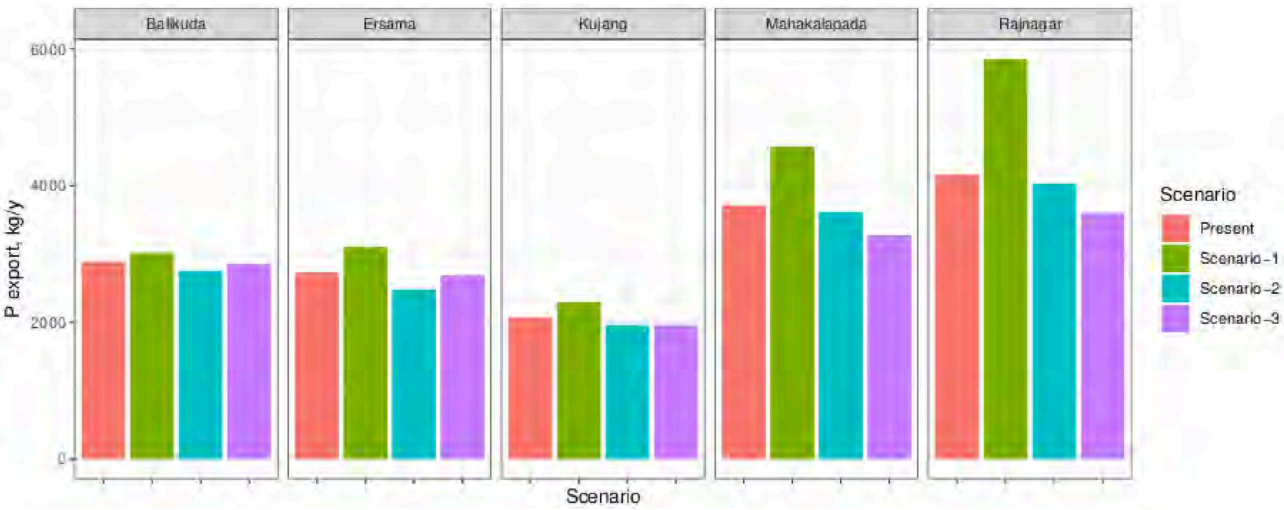


Figure 11e Comparative bar diagram of Phosphorus Export (kg/y)

Table 10 Values of Blue carbon (standing C in the present, net sequestration in each scenario in comparison with the present condition), sediment export, sediment retention, nutrient (N) export, and nutrient (P) export. These values are summarized according to *tehsil* boundaries in the study area

Tehsil	Scenario	Blue_Carbon (tC)	Sediment_exp (t/y)	Sediment_ret (t/y)	Nutrient_N_exp (kg/y)	Nutrient_P_exp (kg/y)
Balikuda	Present	85160	381	13040	6426	2884
Ersama	Present	7403	262	14203	5987	2729
Kujang	Present	44541	268	12432	4546	2072
Mahakalapada	Present	1057280	518	20803	8281	3710
Rajnagar	Present	3359815	535	23178	9346	4162
Balikuda	Scenario-1	-58381	371	13463	6685	3015
Ersama	Scenario-1	-4877	249	15116	6709	3103
Kujang	Scenario-1	-30007	253	13006	4946	2295
Mahakalapada	Scenario-1	-658474	521	21934	10147	4570
Rajnagar	Scenario-1	-1416180	596	23893	13093	5848
Balikuda	Scenario-2	18655	274	13224	6076	2755
Ersama	Scenario-2	1622	148	14381	5259	2481
Kujang	Scenario-2	9757	176	12577	4229	1960
Mahakalapada	Scenario-2	231611	447	20932	8003	3611
Rajnagar	Scenario-2	736011	431	23376	8979	4025
Balikuda	Scenario-3	45693	378	13137	6357	2853
Ersama	Scenario-3	17142	261	14232	5898	2687
Kujang	Scenario-3	105636	259	12563	4319	1962
Mahakalapada	Scenario-3	498742	471	21273	7314	3274
Rajnagar	Scenario-3	882782	488	23472	8079	3597

Appendix 3: APN Mangrove Complete Technical Report on the Taiwan site

Abstract

Tamsui River Estuary mangrove forest is located adjacent to the Taipei Metropolitan area, where the river meets the ocean. The Greater Taipei area is Taiwan's largest metropolitan area with a population of over 7 million. Following successive designations of several mangrove forest reserves in the 1980s, the mangrove area of Tamsui River Estuary mangrove forest now exceeds 108 ha, making it Taiwan's one of the most important sites for environmental education and research. Mangroves are generally considered to perform critical ecological functions, such as water purification and tidal impact reduction. However, only a few studies have assessed the ecosystem services of mangroves at the Tamsui River Estuary. This study highlighted the mangroves and their relationship to the fringes of Taipei City to assess the ecosystem services provided by the catchment area.

1. Introduction

The capacity of a mangrove forest to provide ecosystem services is proportional to its area. The larger and more complete patches of mangrove forest can provide a higher level of ecosystem services (Alemu et al., 2021). Several studies have shown that urban expansion and concomitant changes in land use often lead to a decrease in mangrove coverage (Lugo et al., 2014). This is partly due to the increasing demand for developable land resulting from high rates of urbanization. The construction of housing, roads, and public facilities corresponds to increasing rates of mangrove deforestation (Al et al., 2020). In rural areas outside cities, mangroves are deforested into aquaculture and agricultural lands to meet the increasing food demands of a growing urban population (Richards and Friess, 2016). In addition, a massive increase in urban population and industrial activities leads to pollution caused by wastewater and heavy metals, altering the original nutrient profile of mangrove forests and profoundly affecting the animal community and biodiversity (Kruitwagen et al., 2006; Branoff, 2017). Further fragmentation of mangroves also occurs because of coastal developments, such as harbors and roadways (Rogers, 2004). Therefore, the disappearance of mangroves caused by urbanization is a complex challenge.

The content and value of mangrove ecosystem services are geographically variable (Shih et al., 2015). In some rural areas, mangroves can provide fish, firewood, and various plants for humans (Lee and Yeh, 2009), whereas mangroves in urban areas can provide carbon storage, coastal protection, water filtration, and biodiversity for urban dwellers (Everard et al., 2014; Lee et al., 2017). Such services carry tremendous value for cities with high population density, becoming an important countermeasure for climate change mitigation and adaptation and providing opportunities for education, recreation, and cultural development (Duke et al., 2014). Land development occurring because of economic growth and urbanization poses challenges to the survival of urban mangroves, causing problems such as area loss, reduced density, and increased fragmentation (Branoff, 2018). Additionally, large amounts of sewage and waste produced by urban activities indirectly cause changes and losses of mangrove ecosystem services, and in turn, this adversely affects the safety and well-being of urban residents (Gilman et al., 2008; Chen et al., 2018). Furthermore, mangrove forests have survived in some cities because of policy-based conservation, even expanding beyond their original size at some places.

Severe damage to mangroves from urbanization partly stems from underestimating the value of ecosystem services provided by mangroves, viewing them instead as a patch of wasteland (Valentine, 1994). On the other hand, mangroves are included in the existing regional planning of cities as land-use sites. The economic, cultural, and political characteristics of a city influence management strategies and the quantity and quality of mangroves (Branoff, 2018).

This study was performed with a belief that urban mangroves are embedded in the land use of existing cities and are vulnerable to the impact of the development of surrounding urban areas. Therefore, when evaluating their ecosystem service, it is necessary to approach from various aspects using various models, while also paying attention to the impact of changes in surrounding land use on mangroves. This is critical in effectively obtaining overall benefits from mangroves and in establishing an operational and management model consistent with the current situation within the broader spheres of urban planning and conservation policy.

2. Study Area and Methods

2.1. Study area

The mangroves in Taiwan are mainly concentrated in the estuary area of the west coast. On the western coast of Taiwan, a large amount of mud is deposited in the estuary area, forming a series of shoals and wide tidal zones; they are extremely suitable for the growth of mangroves. In recent years, under active conservation efforts by the government, mangrove areas have gradually increased (Wang et al., 2015). This study focused on mangrove habitats at the edge of a city and their interrelationships with urban development. The Tamsui River basin in northern Taiwan was selected as the study area in this chapter (Fig. 1). Fig. 2 shows the concrete region included in this study, and additionally, the main tributary of the Keelung River was included to further study the impact of urban mangroves and surrounding land use on ecosystem services. Regarding Taiwan's urban development, this region has the highest population density and significant urban expansion and is the most threatened region according to future climate change.

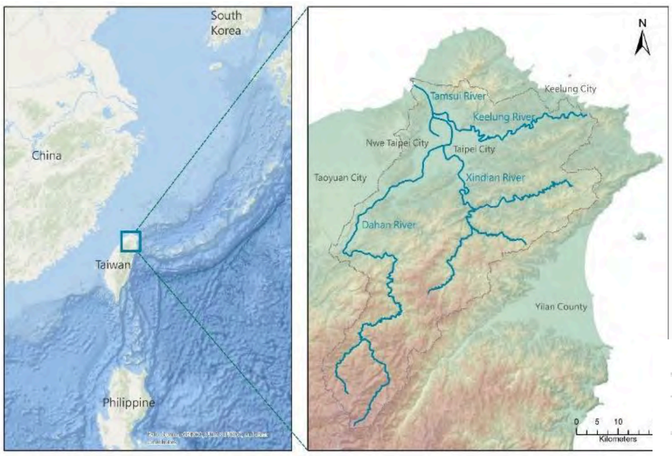


Figure 1 The Tamsui River basin and related sub-catchments

The length of the principal stream of Tamsui River is approximately 158.7 km with a basin area of approximately 2726 km^2, making it the third largest river basin in Taiwan (Fig. 1). The population of the Tamsui River basin area is nearly 8 million (more than 30% of the national population); along with highly developed industries and commerce. In fact, it is the political, economic, and cultural center of Taiwan. In addition, the ecological environment of the Tamsui River is diverse. The main tributary channel of more than 100 km is connected to high altitude mountains, hills, grassy plains, and tidal estuaries. Moreover, it is an important mangrove habitat in Taiwan (Water Resources Agency, 2008). Mangroves in the Tamsui Estuary are mainly distributed in four areas: Wazi Wei, Zhu Wei, Guandu, and Shezidao (Fig. 3). The vegetation mainly includes a single mangrove species *Kandelia obovata*, which is the largest habitat of this species in the Northern Hemisphere (Sheue et al., 2003) and the northernmost boundary of distribution (Lee and Yeh, 2009).

Since 1984, several conservation laws have been enacted, and various protected areas have been created to conserve the precious mangrove ecosystem. In recent years, under active conservation by the Taiwanese government, the mangrove area has been increasing annually. By 2010, the total area reached 107.9 ha (Wang et al., 2015) (Fig. 4). Additionally, the rich mangrove ecosystem has become an important region for environmental education for urban dwellers. The conservation authority has set up a “Mangrove Ecological Education Center” and pedestrian walkways so that citizens can get close to the mangrove ecosystem and understand its presence in the city and the value of ecosystem services provided by it.

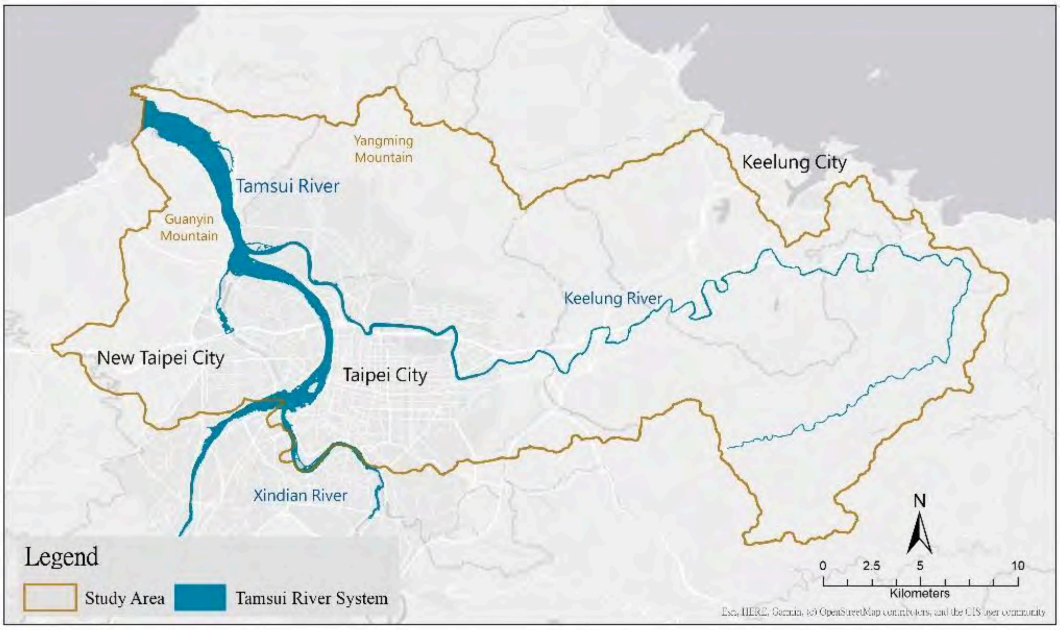


Figure 2 Location of the Study area

Figure 3 Distribution of mangroves in the Tamsui River basin

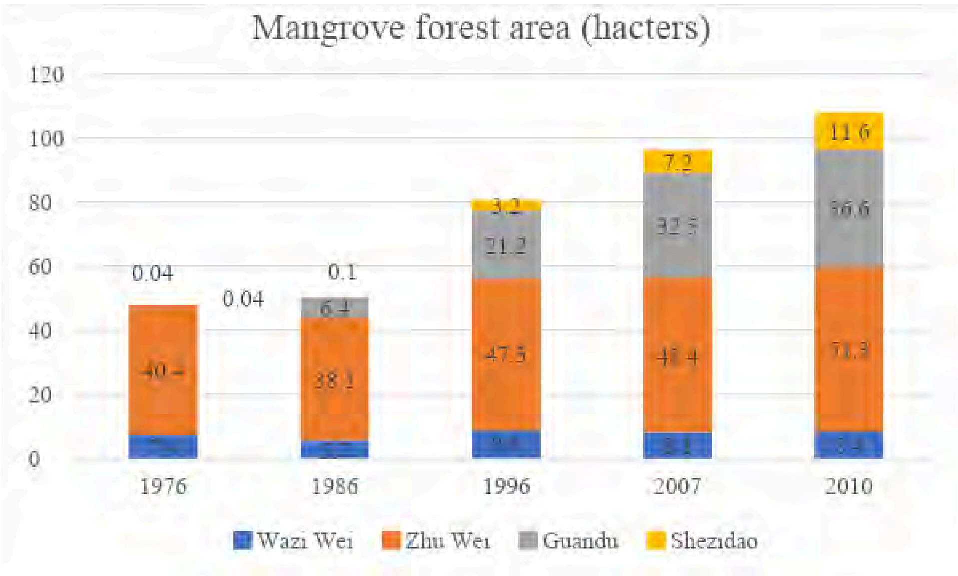


Figure 4 Changes in mangrove area over the years in the Tamsui River basin

Original data source: Wang et al. (2015)

2.2 Methods

Mangrove ecosystem services are increasingly recognized as pivotal to building nature-based resistance to climate change and hydro-meteorological hazards in urban areas. Broadly, the three methods employed in this study were as follows: (1) land change analysis, (2) ecosystem services evaluation, and (3) hotspot/cold spot analysis for ecosystem services.

- 2.2.1 Analysis of changes in land use

Since the 1990s, Taiwan has actively promoted the Land Use Survey Project hoping to use decennial data to understand trends in land-use change and provide a foundation for informed land management and planning. Taiwan's land use survey divided land into nine primary categories: 1. agriculture, 2. forests, 3. transportation, 4. water conservation, 5. construction, 6. public, 7. recreation, 8. mineral salt, and 9. other uses. The land was further subdivided according to 102 classes as per detailed uses (National Land Surveying and Mapping Center 2020). Because mangrove forest information is not recorded in Taiwan's existing land use surveys, we attempted to integrate historical data on mangrove distribution in the Tamsui River with existing land use data. To enable subsequent assessment of ecosystem services, we aimed to reclassify the aforementioned nine land-use categories according to their characteristics as follows: forest, water body, paddy, wasteland, grass, traffic, residential land, other urban, and mangrove. These 10 revised categories were input to GIS to convert the data into 100 m ×100 m land-use units according to the principle of "maximum combined area."

Using the above sorting process, we obtained raster data for the years of 1994 and 2018. Meanwhile, we used the Map Algebra tool in GIS to compare the land use data from different years to further investigate the overall change in land use, aiming to obtain the land use change data of each unit. This was the basis for subsequent analysis.

- 2.2.2 Ecosystem service evaluation

Despite the proximity of the Tamsui River Estuary mangroves to the densely populated Taipei area, their ecosystem service value has been rarely studied. In this study, we integrated the historical distribution of mangroves in the Tamsui River Estuary with existing land use data to evaluate the value of ecosystem services through InVEST 3.8.0. The main assessment items were: 1. carbon storage (ton-C), 2. habitat quality, 3. Nutrient (nitrogen) delivery ratio (NDR) (ton-N/year), and 4. sediment delivery ratio (SDR) (ton/hacter/year). The InVEST model performs the assessment of ecosystem service dynamics and sustainability and predicts changes in service functions through contextual analysis. Previous studies using this tool have confirmed the versatility of sustainable land use (Rompaey et al., 2002; Zhang et al., 2007; Goldstein et al., 2012; Leh et al., 2013; Delphin et al., 2016; Trisurat et al., 2016; Zarandian et al., 2017). Based on the above studies, this study aimed to: 1) measure “carbon storage,” which relatives the function of carbon dioxide to the impact of the study area.; 2) determine “habitat quality” measure for biological habitat space and study the impact of changes in land use patterns (such as increase in built-up land and decrease in green space) on biodiversity in the study area; 3) calculate “nutrients” or the nutritional value of the soil based on the amount of potential nutrient (N) in the freshwater river stream and the way in which they are transported through natural vegetation; 4) calculate “sediment transport” that reflects the effects of disasters (such as typhoons, floods, and landslides). The situation around the Tamsui River basin was analyzed using these four types of regulating services by ecosystem, and in the context of hotspot analysis, the spatial distribution characteristics of ecosystem services were assessed.

- 2.2.3 Hotspot/cold spot analysis for ecosystem services

After obtaining data on the status of ecosystem services in different years, we used GIS Map Algebra to calculate the quantitative changes in ecosystem services in these years. To use statistical methods that can test the spatial aggregation of these changes, we also used the Getis-Ord Gi model to examine the distribution of “hotspots” of ecosystem service change. We treated the difference in ecosystem services between 2018 and 1994 as a random variable “x” and divided the study area into land-use units “i” so that the quantitative change corresponding to *i* can be expressed by “*xi*.” Additionally, we took circular sampling with a fixed radius of 500 m, and other spatial units “j” within this circle were adjacent to the land use units of *i*. To indicate whether there is spatial aggregation in a particular geographic space, the formula uses a weighted matrix to express “*wij*.” If j is inside the circle with center *i* and radius d, *wij* = 1; conversely, if *j* is outside the circle with center *i* and radius d, *wij* = 0. For spatial unit *i*, the degree of aggregation between it and all neighboring spatial units *j* can be expressed using the following formula:

$$Gi^{*} = \frac{\sum_{j=1}^{n} w_{ij}(d)x_{j}}{\sum_{j=1}^{n} x_{j}}$$

After the statistic Gi* has been standardized, the Z-score of each land use unit was obtained and used to estimate its level of significance. After standardizing the spatial distribution of Gi*, we can reveal the hotspots for changes in ecosystem services between 2018 and 1994. Based on the distribution of the hotspot, we also examined the changes in the status of land use to determine the land factors affecting their development.

- 2.2.4 Land use projection for 2050

Based on the existing annual land use data, LCM (Land Change Modeler) of TerrSet is used to simulate land use changes in 2050 based on the existing land use planning and related development scenarios in Taiwan. This includes the production of BaU and Scenario-based future land use maps.

Land use simulating is modeled the land use change between 1994 to 2007, an use 2018 as the material of validation. At the same time, we will also compare the differences in ecosystem services between 2050 and the present, and examine their distribution and strength using GIS spatial analysis, so as to understand the role of mangroves in these ecosystem services.

3 Results and Discussion

3.1 Land use change in 1994 - 2008

The Tamsui River basin is the political and economic center of Taiwan, and changes in its land use reflect trends in population, economic development, and social change in the Taipei Metropolitan area. The total drainage area of the study area was approximately 65,721 ha. According to the land use data from 1994, the study area was divided into the following areas: forest 33,618 ha (51.15%), water bodies 3,233 ha (4.92%), paddy 5,839 ha (8.88%), mangrove 98 ha (4.92%), grass 1,500 ha (2.28%), industry 1,906 ha (2.9%), traffic 2,375 ha (3.61%), residential land 11,163 ha (16.99%), other urban 2,459 ha (3.74%), and wasteland approximately 3530 ha (5.37%). The relevant land use is shown in Fig. 5.

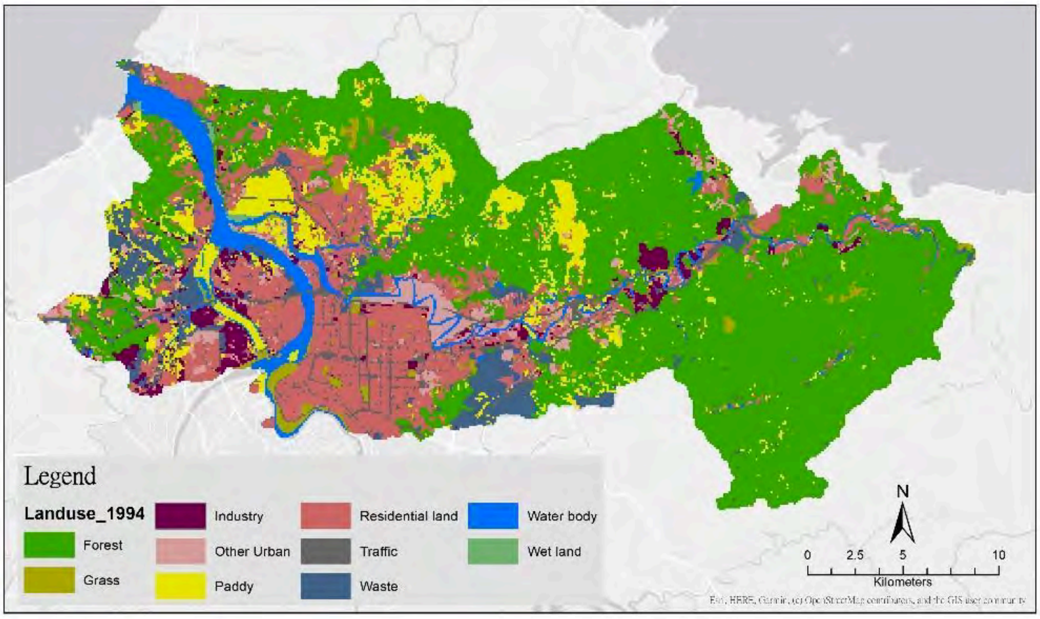


Figure 5 Overview of land use in 1994

According to the land use data from 2018, the study area was divided into the following areas: forestry 37,080 ha (56.42%), water body 2,698 ha (4.11%), paddy 3,496 ha (5.32%), mangrove 104 ha (0.16%), grass 1,997 ha (3.04%), industry 1,696 ha (2.58%), traffic 3,271 ha (4.98%), residential land 14,492 ha (22.05%), other urban 808 ha (1.23%), and waste approximately 79 ha (0.12%). The relevant land use is shown in Fig. 6.

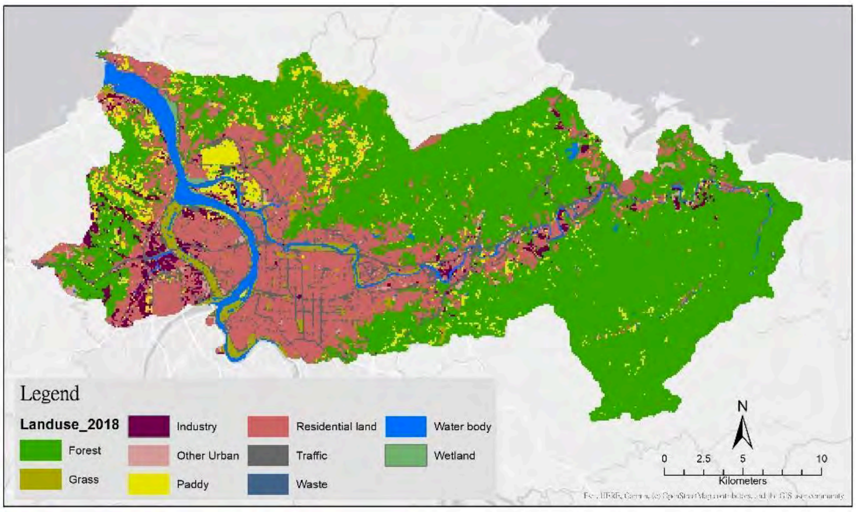


Figure 6 Overview of land use in 2018

When we further analyzed the land-use changes in the basin during the 24-year period from 1994 to 2018, it was observed that forestland increased by 3,462 ha (+10.3%), grassland increased by 497 ha (+33.13%), and water body decreased by 535 ha (−16.55%). Paddy land was heavily reduced by 2,343 ha (−40.13%) due to urban development; similarly, other urban areas saw a steep reduction of 1,651 ha (−67.14%). In contrast, land for traffic and residential land increased by 896 (positive growth rate of 37.73%) and 3,329 ha (positive growth rate of 29.82%), respectively. Finally, the proportion of mangroves increased by approximately 6 ha, with a growth rate of approximately 6.12%, because of the establishment of protected areas and implementation of related conservation measures. Table 1 presents the changes in the relevant land use.

In general, the population of the Tamsui River basin increased from 6.2 million to 7.02 million between 1994 and 2018. The changes in land use during the urbanization process reflect the development trend of the Taipei metropolitan area. Although the residential land and other urban areas increased, total industrial land decreased and gradually migrated to the peripheral area. Under the strong control of the urban plan of the metropolitan area, the core area is based on residential land, whereas nearby paddy lands found in low mountain areas are gradually transformed into forests to aid water and land conservation and disaster prevention in the metropolitan area. In addition, under land use in 1994, there was a large area of undeveloped desert, which was gradually transformed into forests and emergent residential areas under the control of the urban plan. This further facilitated urban development. Since the Tamsui River system has always been prone to flooding, prevention of flooding disaster has become an important agenda for the Taipei City Government over the past 30 years. The Taiwanese government has introduced large-scale dike and diversion measures along the Tamsui River to effectively prevent floods caused by typhoons and heavy rains. We observed that a part of the Keelung River, a branch of the Tamsui River, was cut and reclaimed, and the remaining land generated after the reclamation also became a new residential land with a large number of residents and commercial activities moving in. These developments occurred alongside the development of the urban flood control plan[1] with tower walls and highways along the Tamsui River being built in large numbers, delimiting a clear and visible boundary between residential land and the body of water.

Table 1 Land-use changes during 1994–2018 (hectares)

		Year 2018										Total (1994)
		Forest	Grass	Industry	Other Urban	Paddy	Residential land	Traffic	Wasteland	Water Body	Mangrove	
Year 1994	Forest	30521	322	156	222	1078	959	257	18	72	13	33618
	Grass	538	476	9	22	66	225	111		53		1500
	Industry	268	15	702	82	41	631	142	11	14		1906
	Other Urban	388	238	157	86	90	1167	290	4	39		2459
	Paddy	2528	331	234	147	1670	671	147	30	79	2	5839
	Residential land	789	98	170	64	172	9496	337	1	36		11163
	Traffic	117	51	33	36	12	440	1667	1	18		2375
	Wasteland	1868	79	201	130	330	724	138	3	49	8	3530
	Water Body	63	374	33	18	37	179	182	10	2326	11	3233
	Mangrove		13	1	1				1	12	70	98
	Total (2018)	37080	1997	1696	808	3496	14492	3271	79	2698	104	65721

3.2 Land use projection for 2050

Land demand is related to population size. The population in the study area is forecasted to a peak of 7.26 million in 2035 and decrease to 6.61 million in 2050 (Taipei City Government, 2016). Though

[1]Prior to 1980, there was virtually no artificial control of floods of the upper and middle reaches of the Tamsui River. The major erosion and deterioration phenomena caused by the river were driven by natural flows and storm surges. Since 1980, the flood control plan of the Tamsui River basin has been implemented in accordance with the content of the proposal for the flood control plan of Taipei District. The project was completed in 1999. Since then, the erosion and silting processes of the Tamsui River have been overall clearly limited by the twin dikes located on the either riverbank. In 2004, the "Yuanshanzi Flood Diversion Project" was completed in the upper reaches of the Keelung River, bringing a further state of completeness to the Tamsui River flood control system.

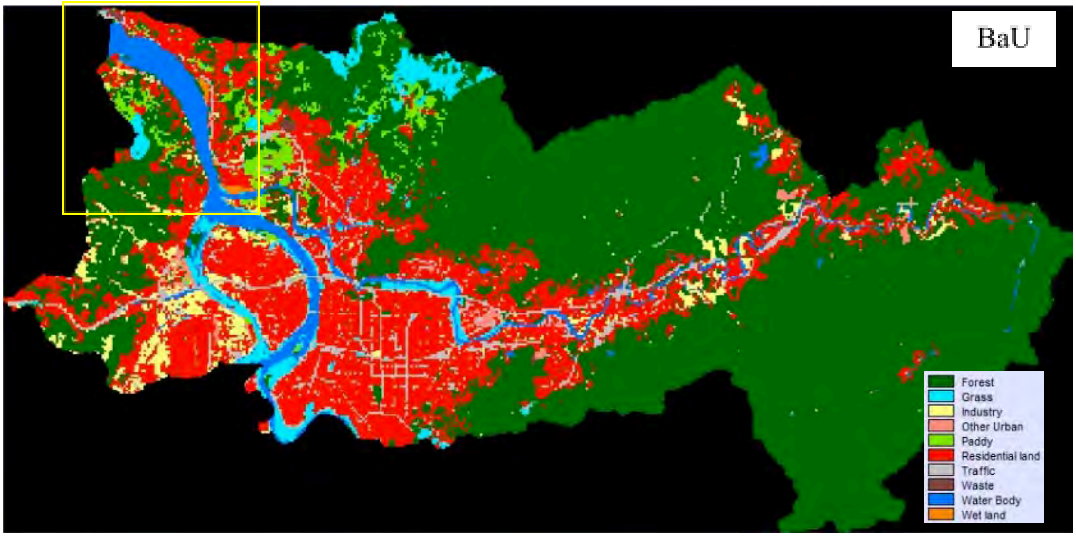
depopulation is expected in the period of 2035 to 2050, urban shrinking is considered will not yet happen in the target projection year of 2050 without manipulate the land demand in TerrSet. As land use translates into human activities, continuous depopulation significantly affects future land demand. Land use simulation modeled the land use change transition from 1994 to 2007 and made a land use projection named business as usual (BaU).

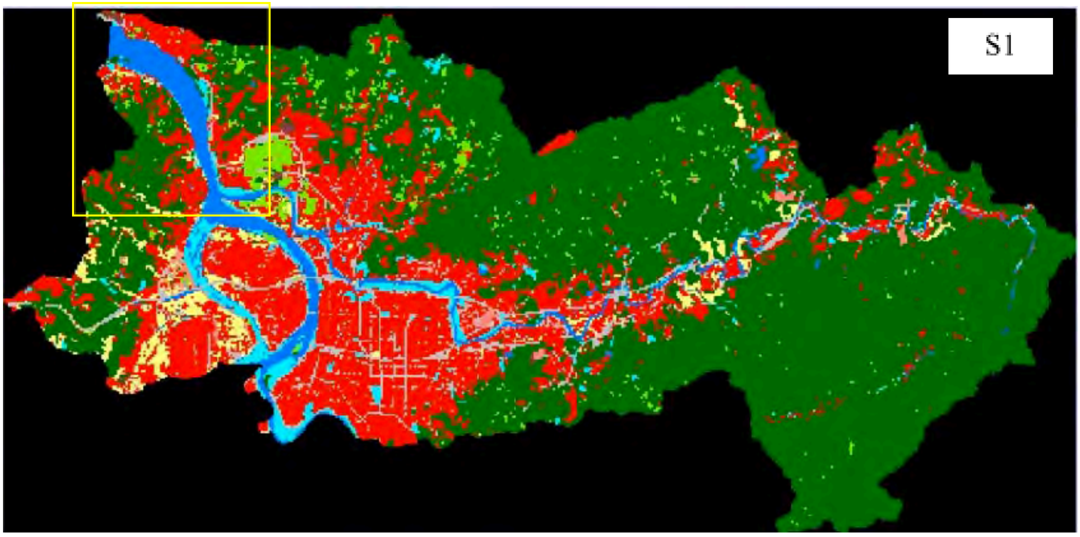
In the period of 1994 to 2007 (Table 2), forestry land increased by 7,162 ha (+23.18%); Water body decreased by 380 ha (+16.36%). Paddy was heavily reduced due to urban development by 1,203 ha (+87.75%); similarly, Industry saw a steep reduction of 927ha (+97.17%). In contrast, Traffic use increased by 1,129 ha, a growth rate of 71.55%; Residential and Other urban increased by 5,138h ha with positive growth rates of 45.52% and 388.38% respectively. Finally, the portion of Wetland Mangrove) increased by approximately 10 ha, with a growth rate of about 11.76%, due to the establishment of protected areas and the implementation of related conservation measures.

Table 2 Land use change in the period of 1994-2007 (hectares)

		Year 2007										Total (1994)
		Forest	Grass	Industry	Other Urban	Paddy	Residential land	Traffic	Wasteland	Water Body	Mangrove	
Year 1994	Forest	30900	542	133	190	692	974	172	11	52		33666
	Grass	544	511	12	22	65	241	87	3	30		1515
	Industry	238	12	954	66	26	485	100	11	12		1904
	Other Urban	427	264	149	198	77	1078	212	12	59		2476
	Paddy	2850	306	234	141	1371	618	88	33	98	1	5740
	Residential land	824	116	171	78	104	9598	290	6	25		11212
	Traffic	144	60	33	30	21	448	1578	3	29		2346
	Wasteland	2040	84	165	166	187	335	71	424	63	2	3537
	Water Body	94	356	30	75	31	189	109	11	2323	7	3225
	Mangrove	1	7		1		1		1	12	85	108
	Total (2007)	38062	2258	1881	967	2574	13967	2707	515	2703	95	65729

Land use (ha)	Forest	Grass	Industry	Other urban	Paddy	Residential land	Traffic	Waste	Water body	Wet land	Tot
2007 lcm	38028	2273	1887	935	2643	13913	2746	526	2678	92	65
BaU	38759	1972	1887	548	1439	15418	2746	182	2678	92	65
S1_grass	38759	2064	1887	548	1439	15418	2746	182	2678	0	65
S2_water	38759	1972	1887	548	1439	15418	2746	182	2764	6	65





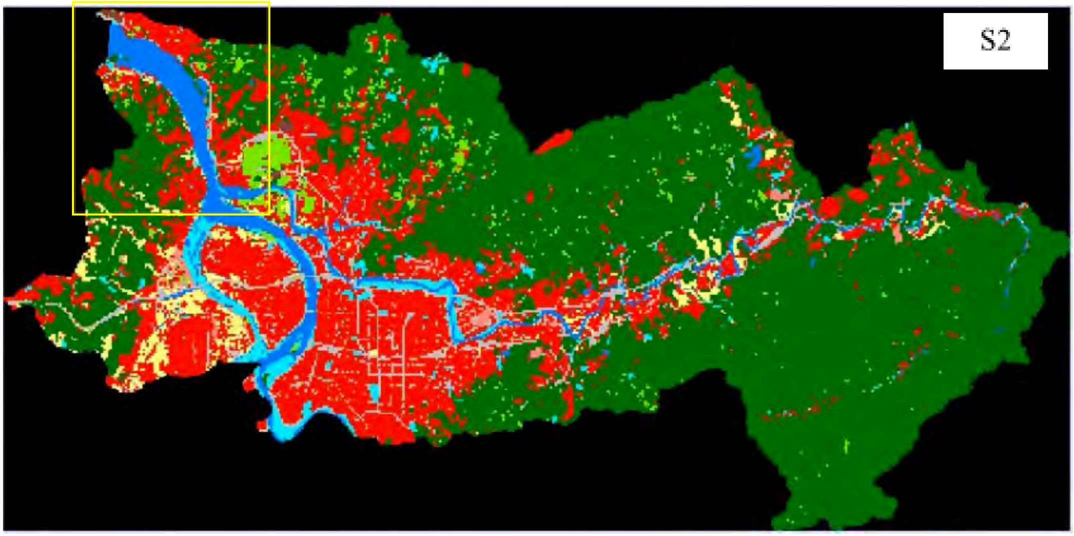


Fig. 7 Land use projection for 2050

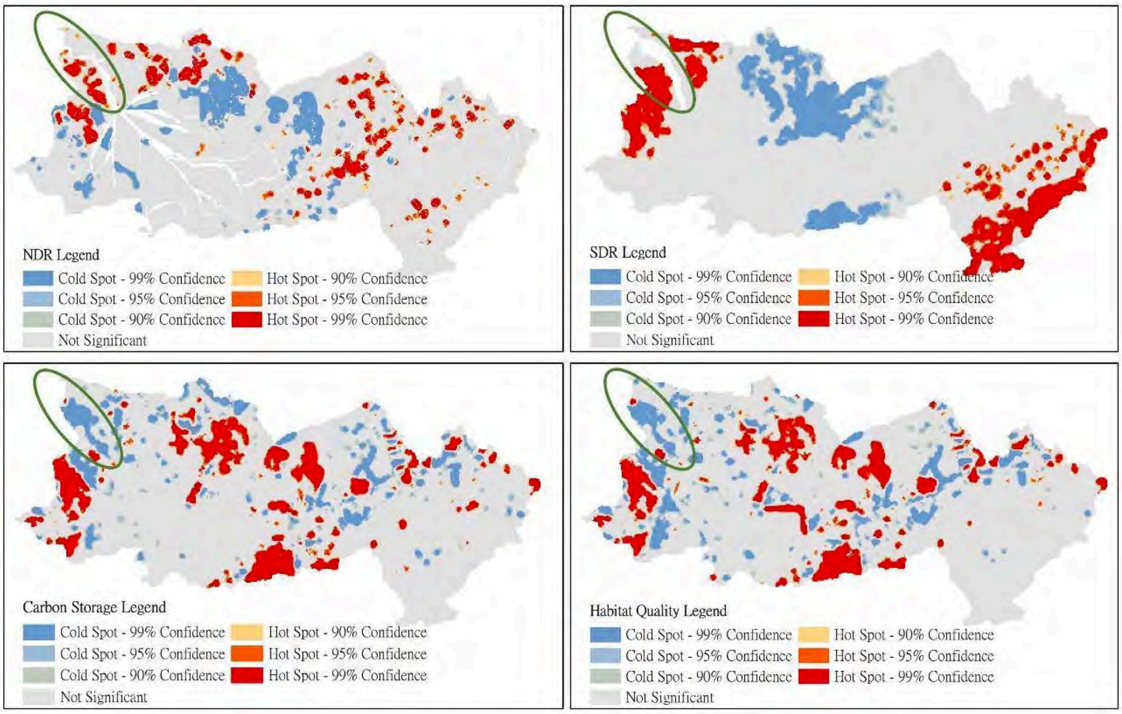
Additionally, to elucidate the ecosystem services performance of mangrove forest, mangrove forest are simulated with two types of land use scenario in 2050. Scenario 1 (S1) is a land use projection that mangrove converted to grass land; scenario 2 (S2) is a land use projection that mangrove converted to water body (Fig. 7). Only grassland and water body conversion scenarios are available due to the limitation of LCM. According to land use change of 1994 to 2007, only transitions such as "wetland to grass" and "wetland to water body" could be utilized in scenario building. Comparing the ESs of historical land uses and future projections helps to quantify the difference. Three future scenarios (BaU, S1 and S2) were projected based on the results of the land use modeling. As the results of BaU, comparing to 2007 land use, forest and residential land increase, grass land, other urban, paddy and waste land decrease. Wet land (mangrove forest) remains 92 ha in 2050 BaU, due to the conservation laws against mangrove development. In S1, 86 ha of wet land was converted to grass land; in S2, 86 ha was converted to water body. These projection results stand that the influence of policy interventions led to land use conversion, which indicates that our scenario settings in this model have palpable effects.

3.3 Ecosystem service hotspots analysis in 1994 and 2008

To further investigate the differences in ecosystem services between 1994 and 2018, we used the Map Algebra feature in GIS software to compare the values of these 2 years and calculated the "Hotspot" based on their differences. This provided an understanding of the distribution trends of the overall variation. Furthermore, we examined the changes in land use in this area by considering the different thermal zones as a category to unravel the impact of changes in urban land use on ecosystem services. Overall, different hotspots for the four ecosystem services including carbon storage, habitat quality, NDR, and SDR are shown in Fig. 8.

In Fig. 8, the main hotspots for carbon storage were found in the Guanyin Mountains on the east side of the Tamsui estuary and in the shallow mountain range around the Tamsui River basin. The primary land use types in the hotspot were forest (73.2%), residential area (12.5%), and paddy (8.1%). Fig. 9 shows the differences in land use between 1994 and 2018 at the hotspots. The most important elements in this land use change within these categories were: inherent forest (1793 ha), paddy land to forest (1704 ha), wasteland to forest (1658 ha), followed by inherent residential land (569 ha) and wasteland to residential land (195 ha).

The increase in the ecosystem service benefits of carbon storage was mainly because of the increase in forests within the study area. Because Taipei City is an important core city of Taiwan, the primary aim of land use control is to maintain the development of the city while maintaining the safety of the catchment area. Therefore, conservation of the environment is recognized as a critically important task within non-urban mountainous areas, and severe restrictions are imposed. Moreover, urbanization processes in Taipei lead to rural residents living in many surrounding areas to migrate to urban areas, abandoning shallow mountain agricultural land and allowing its transformation into forests. This in turn contributed to the increase in carbon storage benefits. Two hotspot blocks were observed inside the mangrove area, and high carbon storage might have contributed directly to the distribution of mangrove forest.



(* Circled area is the mangrove distribution area)

Figure 8 Hotspots of the different ecosystem services between 1994 and 2018

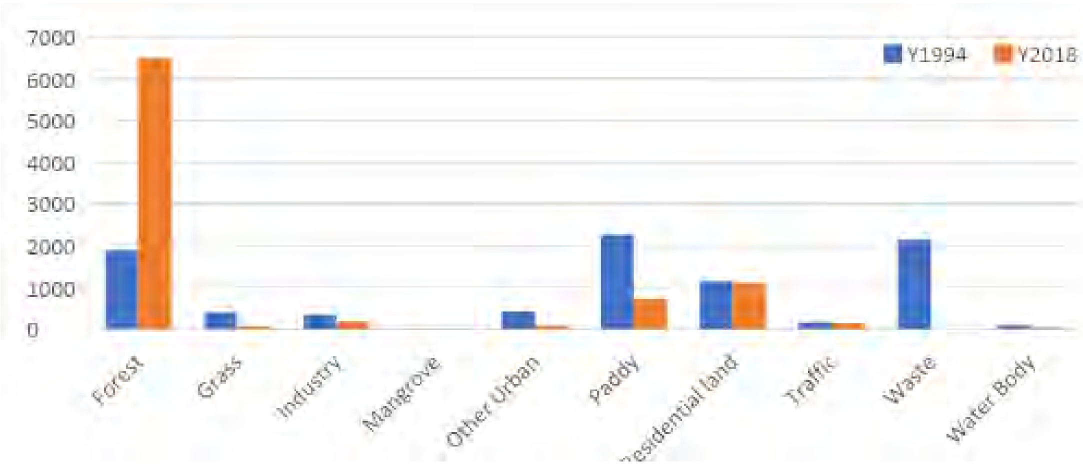


Figure 9 Changes in land use in hotspots with differential carbon storage

The hotspots related to habitat quality occurred mainly in the Guanyin Mountains east of the Tamsui estuary, the shallow mountain ranges around the city, and the Keelung River valley. This included 68.7% of forests, 12.7% of residential areas, and 7.2% of paddy lands. Fig. 10 shows the differences in land use between 1994 and 2018 at the hotspots. The most important elements in this land-use change were wasteland to forest (1603 ha), paddy to forest (1534 ha), inherent forest (1530 ha), inherent residential land (606 ha), residential land to forest (500 ha), and wasteland to residential land (128 ha). Numerous factors influence the habitat quality. In addition to changes in land use, other threats include traffic land and settlements. The change trends of habitat quality and carbon accumulation in this study area were roughly the same, both of which increased gradually. The reason might be that the large areas of land under the control of urban and regional planning are gradually being converted into underutilized grasslands or forests. Interestingly, a hotspot for habitat quality change appeared in the city center. This was mainly caused by the flood control project that began in the 1980s and continues today. It has converted the land it reclaimed from the river into park land, providing a rare boost to habitat quality in the center of the city. Inside the mangrove area, two hotspots were observed because of mangrove forest distribution. This was similar to the results of carbon storage.

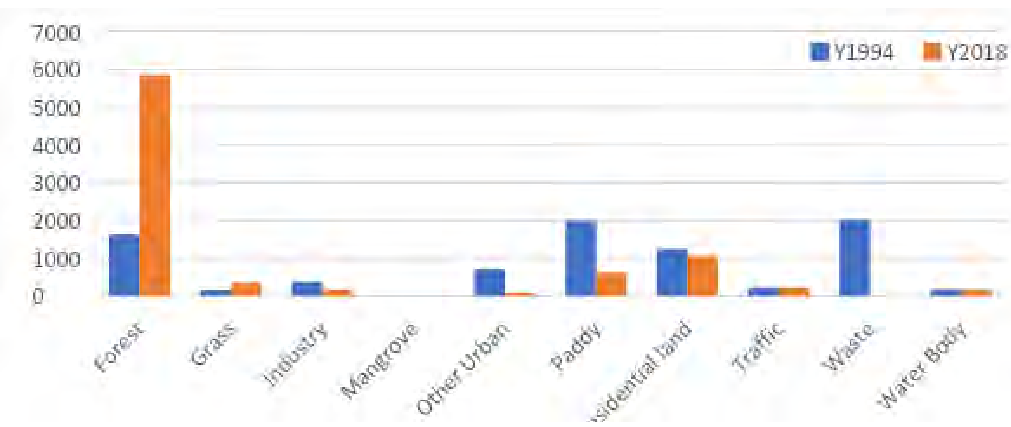


Figure 10 Changes in land use in hotspots with differential habitat quality

The NDR hotspots were Guanyin Mountain on the east side and Yangming Mountain on the west side of Tamsui estuary and the upper and middle valleys of the Keelung River, covering 47.2% of forests, 27.8% of residential land, and 17.8% of paddy land. Fig. 11 shows the differences in land use between 1994 and 2018 at the hotspots. The most important elements in this land use transition were inherent forest (2713 ha), forest to paddy (687 ha), followed by inherent residential area (583 ha) and forest to residential area, with others sporadically distributed. NDR focuses primarily on the amount of potential nutrients (N) in river basins and the way in which they are transported by natural vegetation. For the hotspots of NDR change identified in this study area, we observed that forests still play an important role, and residential and paddy areas play a secondary role. This trend is reflected not only in the forests of shallow mountains but also in the fields of the river valleys and emerging residential areas developed in response to the housing needs of urban immigrants. The reasons for this trend go beyond the aforementioned regulatory effects of urban and regional planning. They also include the overall impacts on ecosystem services resulting from land-use changes caused by urban development (particularly, demand for housing).

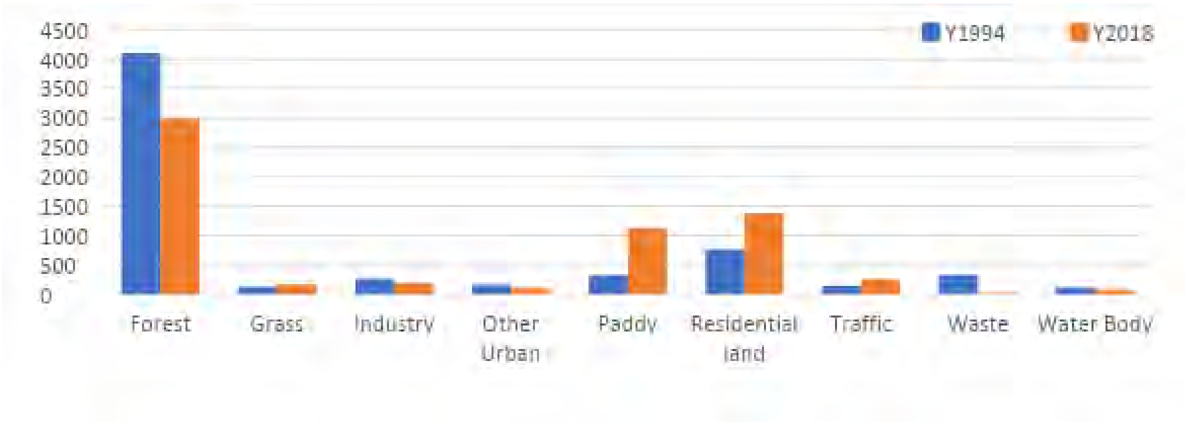


Figure 11 Changes in land use in hotspots with differential NDR

Lastly, in the SDR area, the hotspots appeared mainly in the Guanyin Mountains and Yangming Mountains on the east side of the Tamsui estuary and the shallow mountains in the upper parts of the Keelung River, covering corresponded to approximately 83% forest, 7.6% paddy, and 7.3% residential land. Fig. 12 shows the differences in land use between 1994 and 2018 at the hotspots. The most important elements in land use transition were: inherent forest (7181 ha), wasteland to forest (422 ha), forest to paddy (353 ha), followed by inherent paddy (209 ha) and paddy converted to forest (141 ha). SDR focuses on the measurement of sediment transport in the catchment area and uses it to understand the impact of rainfall, soil, and erosion on sediment retention. By comparing the changes in the land use area, we could observe that the total land and water retention system is guaranteed by the increase in mountain forests, and the distribution of hotspots also showed a similar trend.

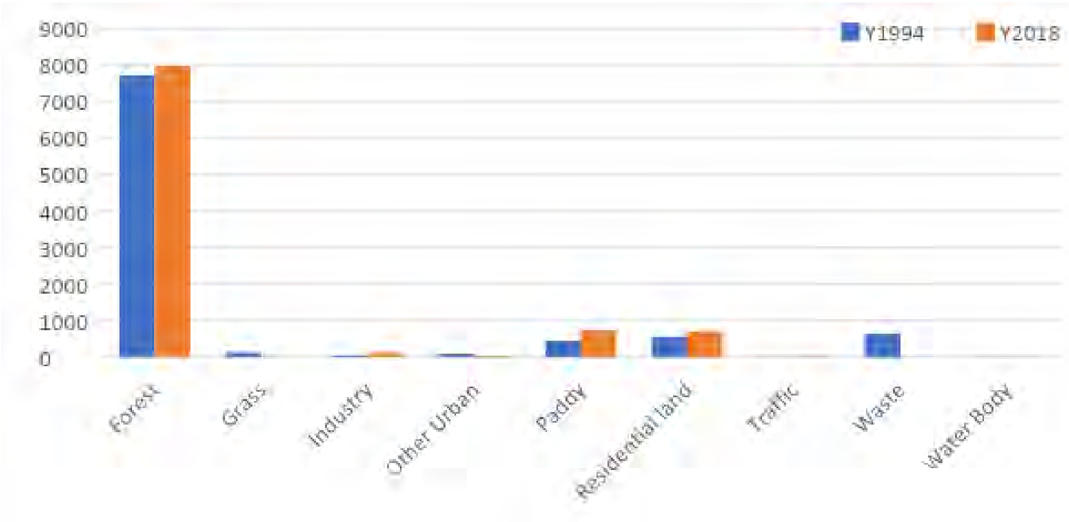


Figure 12 Changes in land use in hotspots with differential SDR

Overall, the ecosystem services in the study area gradually improved over the period included in this study. The hotspots of change have been concentrated mainly in the suburbs of the city and the Keelung River valley, whereas the core area of the city showed virtually no significant change. The reason may be that the land use in the core area is stable and highly intensive, such as residential land and other urban areas. The hotspots in suburban hills on the outskirts of the city were observed because of the control of urban and regional plans and migration of farmers to the city. This leads to underutilization of agricultural land, which is gradually transformed into forests and thus improves ecosystem services. In addition, the city's powerful ability to control land is also present in terms of water management. After the ongoing water management projects from the 1980s to the present, large dikes and large public park spaces have been built in Taipei City along the riverbanks within the dikes. Additionally, urban green spaces created by water management have contributed to ecosystem services.

3.4 Ecosystem service changes from 1994 to 2050

After analyzing the data on land-use changes and land use projection in the study area, we used InVEST to assess the ecosystem services within the area. The following results were obtained from InVEST, revealing changes in the study area over the past 24 years and future 32 years. Figure 13 provides a detailed spatial distribution of ecosystem services. Fig. 14 presents the average ES value of each raster cell in the historical land uses (1997, 2006 and 2018) and three kinds of future scenarios (BaU, S1 and S2) .

Overall, the ecosystem services in the study area, such as carbon storage and habitat quality, exhibited a slight increase indicating that the overall environmental quality gradually improved; Nitrogen retention and sediment delivery ratio tended to decrease toward 2050. Among the ecosystem services, a clear change in carbon storage strongly correlated with the amount of forest land. The forests surrounding the Tamsui River basin have a high carbon storage capacity, and the increase in forest area affect the amount of carbon in the ecosystem. This is mainly because the urban plan attaches great importance to the conservation of catchment areas, which has caused many wasteland and paddy land to be converted into forests. Carbon storage in 2050 BaU is forecasted to get higher service than 2018; moreover, comparing with 2050 S1 and 2050 S2, BaU land use with mangrove convention policy earns the highest carbon storage potential.

The habitat quality range is determined by the degree of threat to the habitat. The value takes between 0 and 1, and the closer to the value of the habitat is to 1, the better habitat quality is. This study defined agricultural, residential, and transportation lands as habitats that threaten the survival of organisms and assessed land use based on the presence of threat sources as high- or low-quality occupants. Generally speaking, habitat quality increased incrementally as the distance increased from the city center toward the outer forest. In other words, damage and disturbance from land use were less intensive and habitat quality was higher when we move further away from the urban area. 2050 BaU land use is evaluated in a higher score of habitat quality than past land uses, however, mangrove convention policy do not present a difference in our scenario analysis.

The nutrient delivery ratio (NDR) assesses the correlation between land use and delivery of nutrients (Nitrogen) particularly focusing on the transformation of agricultural land, which has heavily altered the natural nutrient cycle. In addition, the impact of rainwater flows can carry urban pollutants into streams, rivers, and oceans. However, ecosystems can retain or degrade pollutants before they flow downstream through purification services. The high value of nitrogen retention in 1994 is due to the distribution concentrated within agricultural land, wetlands, and grasslands on both sides of the riverbank. All NDR in three scenarios all have lower value than historical land use. NDR is a dis-service index, meaning the nutrient delivery ration is forecasted to be improved in 2050. Although scenarios presents no change between each other, contribution of mangrove convention policy couldn’t be proved in this study.

Sediment transport is calculated by the annual ratio between the soil and rock loss of each grid, and the calculation will also be influenced by the grid’s digital elevation model. In the sediment delivery ratio (SDR) model, we calculated the annual soil loss of each grid and sediment transport rate to estimate the actual ratio of river soil loss. It was clearly observed that the area ratio of paddy and desert lands in 1994 was relatively high compared with that in 2018. SDR in 2050, no meter in which scenarios, provides low service than historical land uses. SDR is also a dis-service index of ecosystem service. Low value stands for an improved environment.

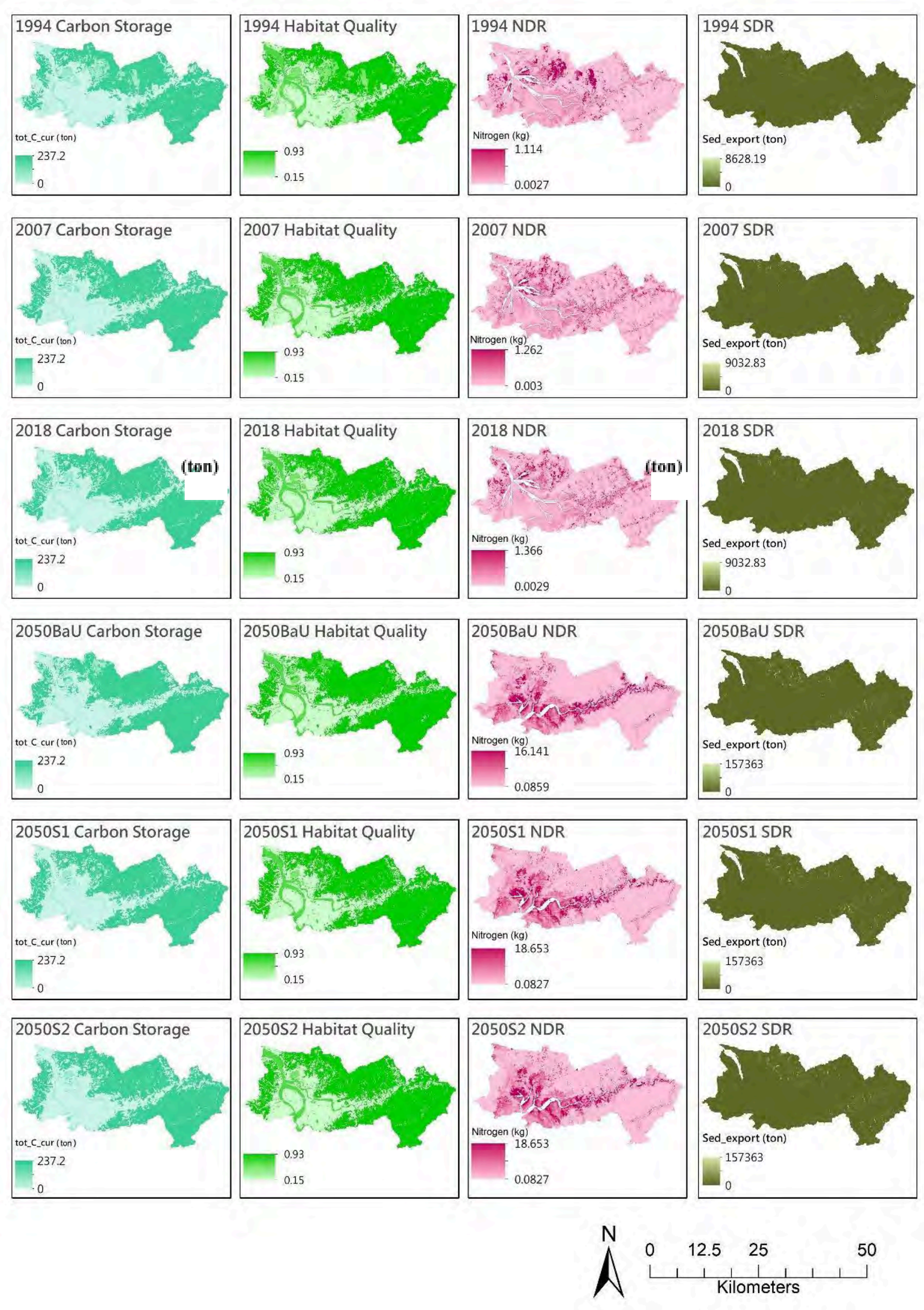


Fig. 13 Ecosystem Services Evaluation Mapping

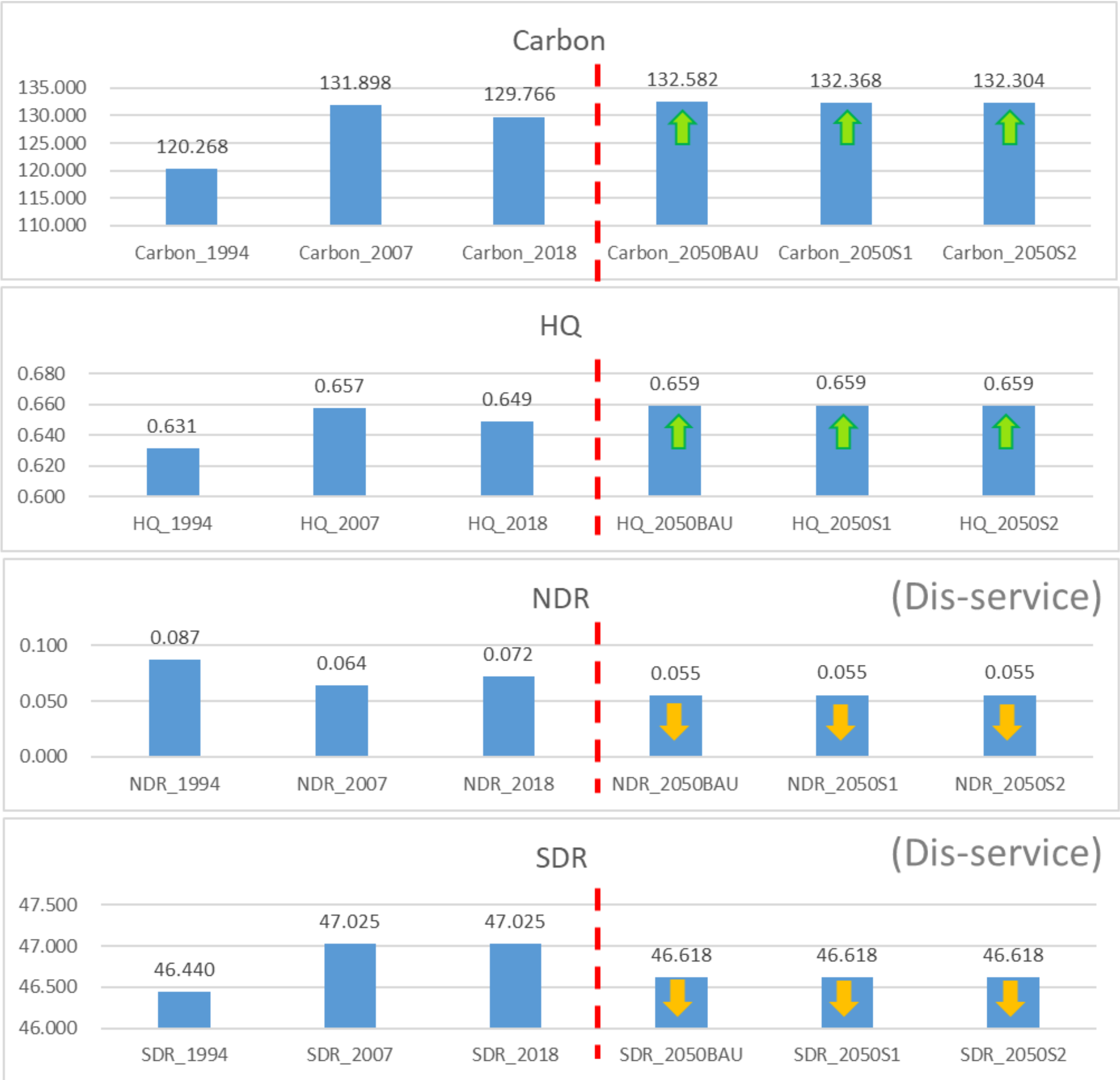


Figure 14 Historical Changes and comparison of Ecosystem services

3.5 Policy recommendation and research limitation

Mangrove forests in the Tamsui River Estuary are deeply affected by urbanization processes in the Taipei Metropolitan area. The Tamsui River basin is the political and economic center of Taiwan. To keep the capital city free from the threat of natural disasters, the Taiwanese government used high-intensity urban and regional planning to preserve land, water, and overall environmental quality in the upper and middle parts of the catchment. However, these measures haven't been observed to improve ecosystem services in catchment areas. In this study, we examined the interactive relationship between mangroves and changes in urban land use within the watershed. We analyzed the overall changes in ecosystem services from the perspective of land uses. In response of highly increasing population, many new residential areas have been created around the core of the city. A deterioration in ecosystem services could be seen across these four ecosystem services from 1994 to 2018. Modeling the transitions of land use change in 1994 to 2006, a BaU land use of 2050 are projected to be relatively stable in 2050, due to a land use of increasing forest land and decreasing agricultural land. According to the projection of 2050 land use and the evaluation of ESs, land use do have a improving impact on ecosystem services.

In contrast, scenario analysis is utilized to clarify the performance of mangrove forest. Our research made a hypothecate that urban mangroves influence ecosystem service in Tamsui river catchment deeply. However, except the carbon storage, other 3 kinds of ESs, including habitat quality, NDR and SDR do not present visible differences between the BaU, S1 and S2. We consider this result is due to two reasons. One is the mangrove area (92 ha) is only 0.14% to the whole river basin (65721 ha), which reduce the impact of mangrove conversion; the other reason is that the residential land and forest in our scenario setting are kept with the same amount to the BaU. Beside, only 4 ecosystem services are chosen in this study, other service such as flood protection performance or cultural services were not yet evaluated. Follow-up studies should attempt to integrate more kinds of ecosystem services. Such research can productively improve the understanding of the potential impacts various land development policies will have on mangroves and the surrounding urban environment. Current ecosystem assessment methods calculate the impact factor primarily from land use. In case of mangrove forests in the Tamsui River estuary, the opportunities for environmental education and cultural services provided by mangrove forests have become increasingly important, indicating the need for a broader perspective than that which forms judgment from land use alone.

5. Conclusion

Mangrove forests in the Tamsui River Estuary are deeply affected by urbanization processes in the Taipei Metropolitan area. The Tamsui River basin is the political and economic center of Taiwan. To keep the capital city free from the threat of natural disasters, the Taiwanese government used high-intensity urban and regional planning to preserve land, water, and overall environmental quality in the upper and middle parts of the catchment. Such measures have been observed to improve ecosystem services in catchment areas. In this study, we examined the interactive relationship between mangroves and changes in urban land use within the watershed. We analyzed the overall changes in ecosystem services from the perspective of multiple types of ecosystem services. In particular, ecosystem services such as carbon storage, habitat quality, NDR, and SDR are quantitatively assessed in this study. An improvement in environmental quality could be seen across these four ecosystem services. In response to an increasing population, many new residential areas have been created around the core of the city; however, because the overall core residential area and land use are stable, they do not have a significant impact on ecosystem services. In contrast, the surrounding hills have gradually become a focal point for improving ecosystem services due to the control of urban planning which could be provide by the future scenario analysis in this study.

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Appendix 4: Detailed report from Ba River Delta, Fiji

1. Detailed description of study site

Fiji contains over 65,000 ha. of mangrove cover (Cameron, Maharaj, et al., 2021), one of the highest of the Pacific Island nations. These mangrove ecosystems provide a variety of ecosystem services to the people of Fiji, e.g., through coastal protection and provisioning of habitat and nurseries for fish. This study focuses on the Ba watershed of Fiji, which contains the second largest contiguous mangrove ecosystem in the country (Cameron, Kennedy, et al., 2021) (Figure 1). Two distinct *Rhizophora spp.*-dominated mangrove assemblages can be found in this watershed, with taller vegetation species being mainly located around the river and coastal margins, and scrub or dwarf mangroves being found mainly in interior regions (Figure 2-3 show some examples of the local mangrove habitats). The watershed is also home to several local communities, with Votua Village being one of the main population centers (Figure 3 shows the location and photographs of Votua Village).

The Ba watershed's natural ecosystems play a vital role in the lives of the communities that inhabit the watershed, from the headwaters to the delta (river mouth). A previous study which conducted a social survey in Ba watershed reported that nearly half (45%) of respondents visited the mangrove area daily to get fish and other resources used in their daily lives (Avtar et al., 2021). They also sell a variety of products that are reliant on the mangrove ecosystems, including firewood, fish, mud crabs, mud lobster, and shrimp (Avtar et al., 2021). These communities are considered the traditional owners or the first to use or occupy the watershed. Ba river connects the ecosystem from the headwaters, forest, sugar cane plain areas and down to the mangrove deltas. Communities are also connected and somehow related, and the watershed is something that links them together. Some of the current land use and development practices, however, may pose threats to the vital ecosystems in this watershed, including the large mangrove habitat.

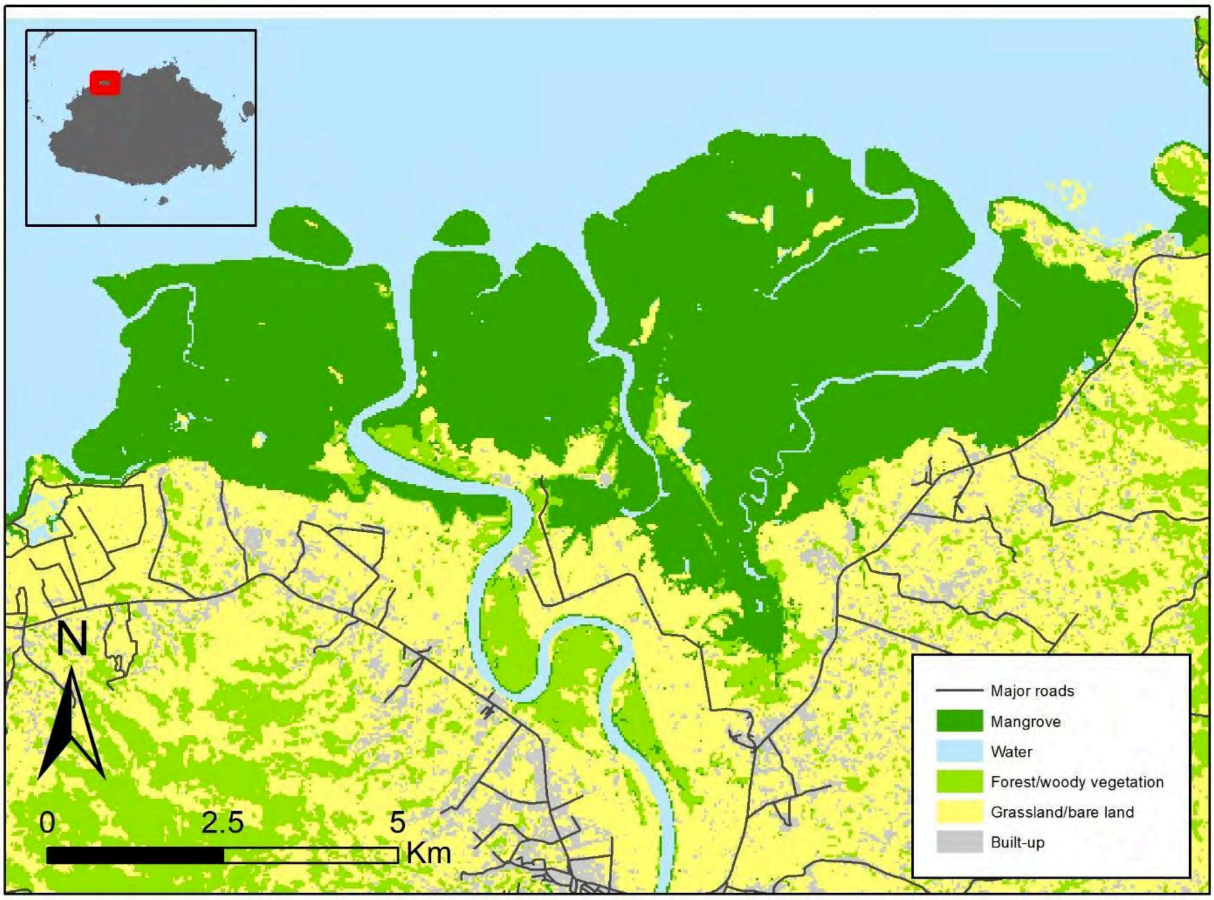

Figure 1. Map of land-use/land/cover and major roads in the Ba watershed, Fiji, as of the year 2020.

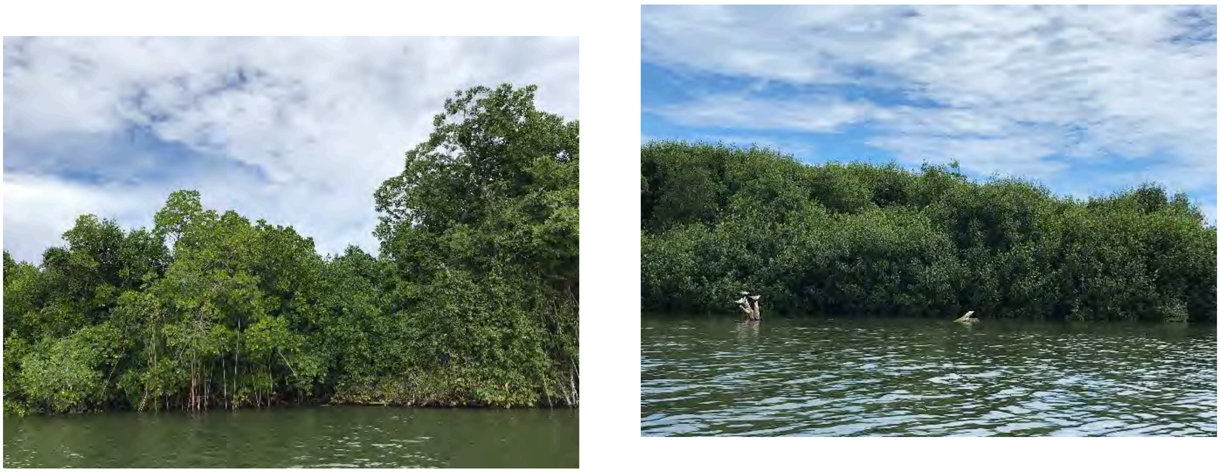

Figure 2. Typical mangrove species in Ba watershed.

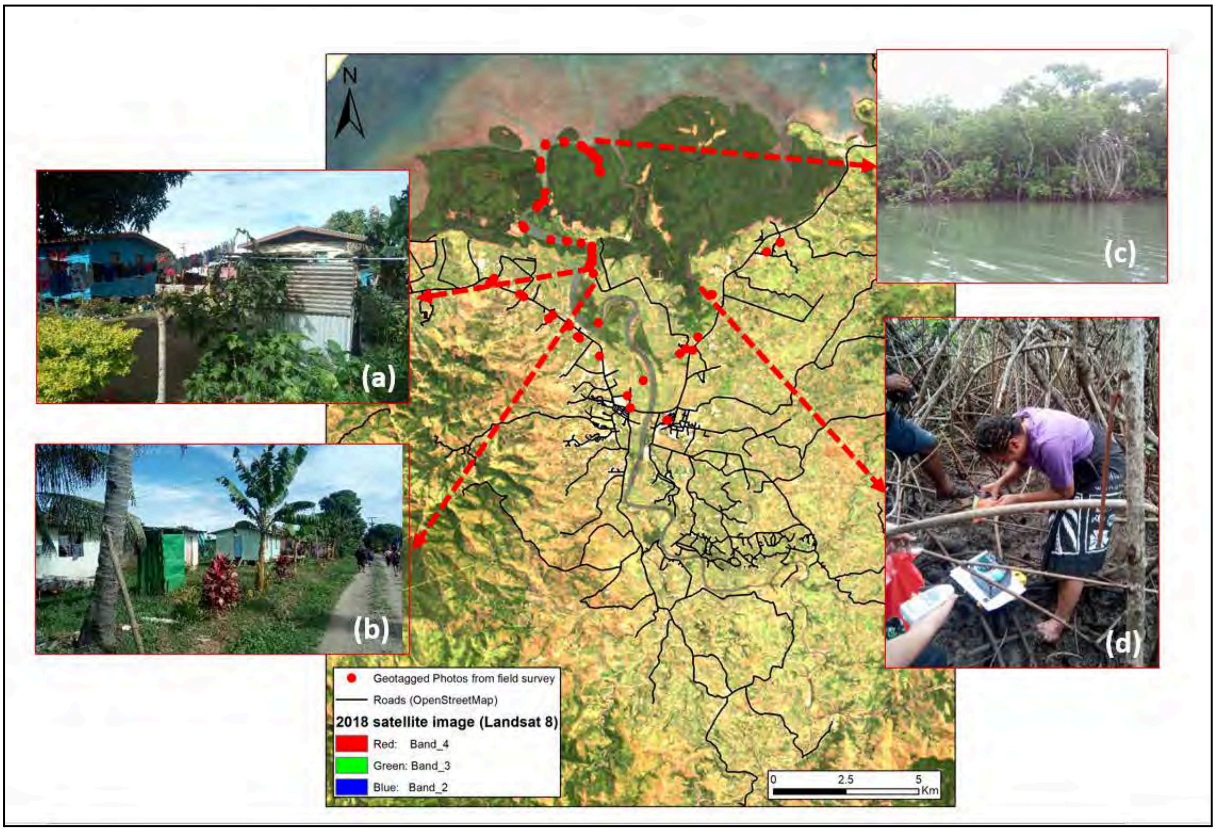

Figure 3. Overview of Ba watershed study site. Landsat satellite data (2018) in background. Red points indicate geotagged photographs taken during the field survey. Photographs of a local community (Votua Village) in the midstream area of the watershed (a-b), and mangroves along the coast (c) and further upstream (d).

2. Drivers of mangrove loss/gain

Insert text here

At the national scale, key direct drivers of mangrove loss include conversion of mangrove habitats to other types of land-use/land-cover (i.e. built-up, agricultural, or bare land) for tourism development, coastal land reclamation, construction of industrial estates, establishment of squatter housing, agricultural expansion, and construction of sugarcane tram lines (Ministry of Economy, 2018). Mangrove ecosystem degradation is also known to occur due disposal of dredging spoil and harvesting of mangrove timber for fuelwood and construction materials (Ministry of Economy, 2018). As these drivers of mangrove change vary to some degree locally, we also assessed the local drivers in Ba watershed through literature review and stakeholder consultations.

2.1. Literature review of studies on Ba watershed

We identified a few studies focusing on drivers of mangrove changes in Ba watershed. The most detailed one, by Cameron et al. (2021), identified drivers of mangrove change (gross loss) in the Ba Province, Fiji, from 2001-2018 through remote sensing image analysis and field studies. They found that the main driver, Tropical Cyclones, accounted for 61% of the mangrove losses, with the 2012 Tropical Cyclone Evan event being the cause of much of these losses. A subsequent study found that Tropical Cyclones disproportionately affected the taller mangrove trees in Ba (Cameron, Kennedy, et al., 2021), as they were more easily blown over by the high winds. Tourism development was the second most significant driver of mangrove losses, accounting for 35% of mangrove losses. The third driver identified was dredge disposal, which accounted for the remaining 4% of mangrove losses. Another study in Ba watershed also reported dredging as a driver of mangrove losses (Avtar et al., 2021).

2.2. Stakeholder workshop (on August 07, 2019)

To supplement the literature review and introduce this APN project, we (IGES and WWF) organized a consultation meeting with local community representatives, civil society organizations, and government representatives at Votua Village, Nailaga district.

The objectives of this consultation were to:

i. Inform participants of the project goal, objectives; expected outcomes and synergies between this project and current projects including alignment to national policies and strategies

ii. Collate data and information on current land use patterns in the Ba delta through consultation and community participation

iii. Using information on current land use patterns, potential threats, drivers and impacts to develop models/scenarios to predict future distribution or availability of mangrove ecosystems in Ba delta

At this workshop, we distributed a questionnaire (Figure 4) to attendees to understand their perceptions of the key drivers of mangrove changes in the watershed. We received survey responses from 35 people, including fishermen, forest managers, farmers, government staff, NGO staff, and retirees. The drivers of mangrove loss/degradation identified most commonly were:

- Tropical Cyclones or floods: 16 respondents
- dredging/land reclamation: 11 respondents
- mining of sand/gravel: 8 respondents
- sea level rise/climate change: 7 respondents

These identified drivers were similar to those found in the literature, although tourism development was found in the literature (Cameron, Maharaj, et al., 2021) but not in our stakeholder consultations. This may be due to tourism development mainly occurring in other areas of Ba Province that are not located within the Ba Delta. In other words, the tourism development is likely driving mangrove losses nearby the larger urban areas in the Province. Another driver noted in our stakeholder consultation was sea level rise/climate change. To understand the local sea level rise rate, we obtained annual mean sea level data from nearest tide gauge monitoring station through the "Permanent Service for Mean Sea Level" website https://www.psmsl.org/data/obtaining/stations/1805.php (Station #1805). Based on linear interpolation, we found that the local sea level was rising at a approximately 3.76 mm/year between 1992-2021. This rate is within the range that mangroves can manage through vertical soil accretion (Krauss et al., 2014).

1. Name:
2. Designation:
3. Occupation:
4. Are you a resident of the place? Yes/No, if yes, how long? ....years.

Please list the drivers which you believe can affect (both positively/negatively) future conservation, functioning of mangrove ecosystems. Please use a score between 1 to 5 to identify their impact and uncertainty, where 5 means highest impact and lowest uncertainty.

- **Impacts:** (1) No impact. (2) Very little impact (3) Moderate Impact (4) High Impact (5) Very high Impact
- **Uncertainty** (1): Very Low uncertainty (2) Low uncertainty (3) Moderate uncertainty (4) High uncertainty (5) Very high uncertainty.

Drivers	Impact *	Uncertainty*	Remarks
Example: *Population growth*	*5 (Highest impact)*	*1 (but, it is very certain, no uncertainty)*	*About 2% annual population growth is expected.*
Please start from here, and list as many of the important drivers as possible.			
1.			
2.			
3.			
4.			
5.			
6.			
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Figure 4. Questionnaire related to drivers and impacts of mangrove change in Ba watershed. 35 responses were received.

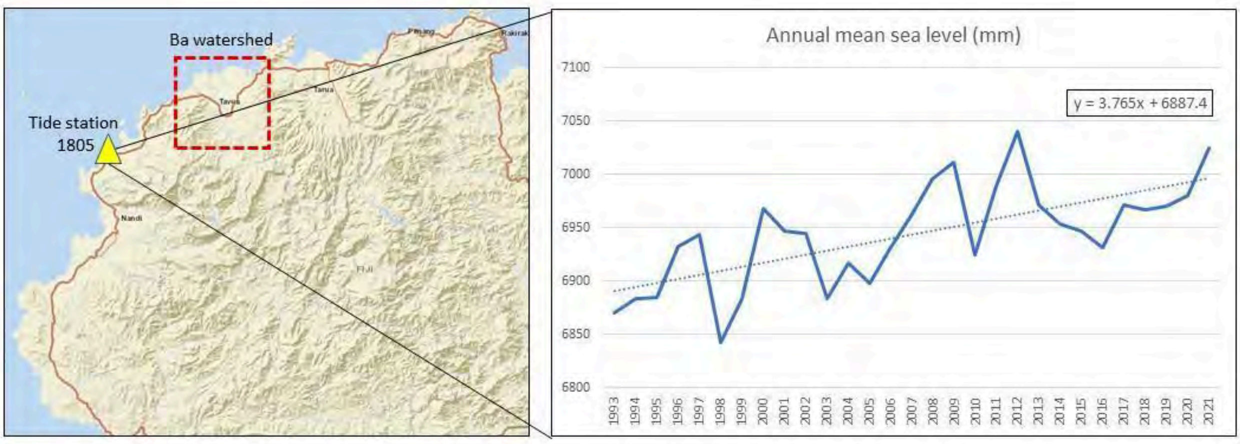

Figure 5. Annual mean sea level (mm), 1992-2021, based on data from nearest sea level monitoring station: https://www.psmsl.org/data/obtaining/stations/1805.php.

3. Methods, drivers, and key considerations for scenario planning

Based on the literature review and questionnaire survey of Ba watershed residents, explained in Section 2, we identified the major drivers of mangrove change to be Tropical Cyclones and dredging of the river. Based on this, future scenarios of mangrove change were developed.

A factor to consider for the scenarios was the types of mangrove restoration activities (and potential funding sources) that could be considered for enhancing mangrove cover in the future. As one example, previous research suggested that restoration activities in Ba could focus on restoring the mangrove areas lost due to Tropical Cyclone damage (e.g. through replanting), and that these activities could potentially receive funding from international partners interested in receiving carbon credits (i.e. under the 'Afforestation, Reforestation, Revegetation' Verified Carbon Standard (VCS) framework (Cameron, Maharaj, et al., 2021). Another factor to consider for the scenarios was the disposal of dredging materials along the river bank, which can degrade or displace mangrove ecosystems.

4. Land-use simulation/scenarios and analysis,

The most recent land-cover map of Ba watershed that could be obtained was for the year 2020, and generated from remote sensing image analysis of Landsat 8 imagery (30 m resolution) by Avtar et al. (2021) (Figure 1). Based on this map, the mangrove area of Ba watershed is currently 4,992 ha. We developed two future scenarios of future mangrove changes, targeting the year 2050, based on the 2020 land-cover map and the identified drivers of mangrove changes.

The first scenario (business-as-usual) assumed no change in mangrove extent in the future, compared to 2020. This scenario is sensible as a business-as-usual case because the trend of historical net changes in mangrove cover of the area is unclear. For example, there are conflicting reports of the historical mangrove changes in Ba in the literature, with Cameron et al. (2021) reporting loss of mangrove cover and Avtar et al., (2021) reporting gains of mangrove cover in Ba. Thus, for this business-as-usual scenario, the extent (and spatial location) of mangroves in 2050 is assumed to be equivalent to that of 2020.

The second scenario (mangrove enhancement scenario) assumed that mangrove areas damaged or destroyed by Tropical Cyclones would be restored by 2050. We identified these areas through visual interpretation of the 2020 land-cover map. In particular, areas in the map classified as other land-cover besides "mangrove" (e.g. "water" or "grassland/bare land") that were totally surrounded by "mangrove" land-cover were noted as being areas that had experienced mangrove cover loss due to Tropical Cyclones. This was because it was highly likely that these areas were previously covered by mangroves (i.e. a continuous mangrove habitat), and it is unlikely that the areas were purposely converted to non-mangrove land-cover (e.g. agricultural land) due to the difficulty in accessing these areas due to the challenging terrain. The total area of mangrove cover in 2050 under this scenario is 5050 ha., which is 58 ha. larger than the mangrove cover in 2020. The implementation of mangrove enhancement/restoration activities under this scenario could potentially be funded by international donors for GHG emission reductions through REDD+ under the VCS (or another alternative carbon trading) reporting framework.

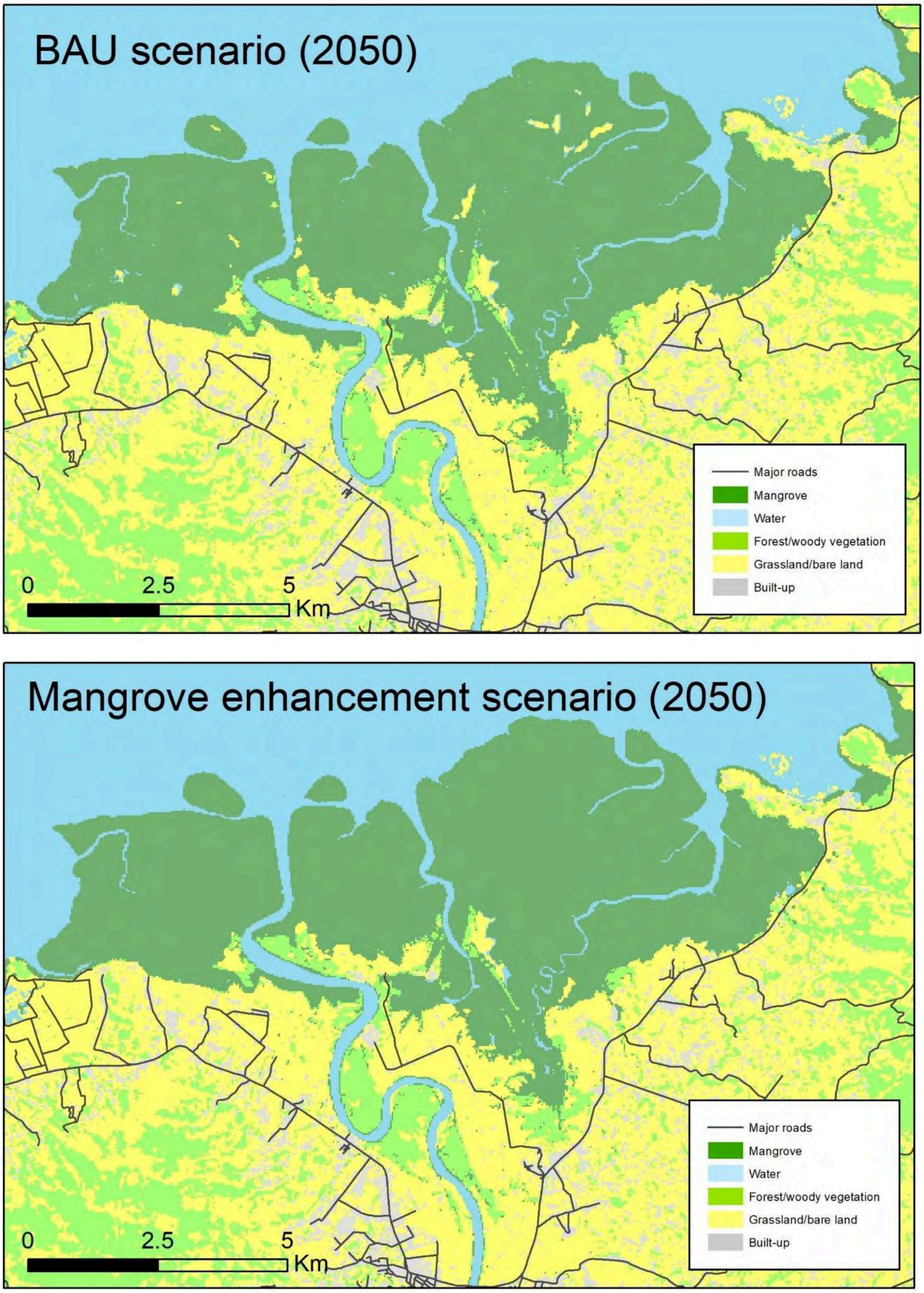

Figure 6. Future scenarios of mangrove cover in Ba watershed: BAU scenario (top), Mangrove enhancement scenario (bottom).

5. **Modeled ecosystem services and their synergies and trade-offs across scenarios**

Next, we assessed the potential future (2050) ecosystem services provided by mangroves, taking into account the two plausible scenarios of future mangrove cover. We focused specifically on the two services provided by the mangroves in Ba watershed:

- Provisioning of goods and services for the local community, and nutrient filtration
- Coastal blue carbon

We chose these ecosystem services for analysis because the local communities mainly benefit from the provisioning services of the local mangrove ecosystems, including their provisioning of food (i.e., fish/shellfish that live in or otherwise rely on mangroves) and firewood for household consumption and sale, and their nutrient filtration services. On the other hand, the global community benefits from the carbon sequestration services provided by the mangrove ecosystems, so it is also important to quantify. This ecosystem services estimation was conducted based on a combination of literature review and geospatial data analysis.

Coastal blue carbon refers to carbon captured by marine ecosystems (including mangroves), and it is thought to represent 55% of all of the carbon captured by living organisms (Lovelock & Duarte, 2019). The mangrove species in Ba watershed vary in terms of the amount of carbon they capture, e.g., due to variations in tree height and root structure. Previous research found that large *Rhizophora spp.* trees (~20 m in height) covered approximately 28.8% of the area, with the remaining mangrove cover being largely composed of much smaller scrub *Rhizophora spp.* mangroves having a canopy height of 2-4 m (Cameron, Kennedy, et al., 2021). Based on this, we have calculated blue carbon under the two future mangrove scenarios based on the assumption of the current/future mangrove areas being composed of 28.8% large trees (20 m in height) and 72.2% scrub mangroves (2-4 m in height).

Table 1: Average carbon stocks of mangrove ecosystems in Ba watershed, based on field measurements (Cameron, Kennedy, et al., 2021).

Biomass (t C ha^{-1})	Large *Rhizophora spp.* (~20 m height)	Scrub *Rhizophora spp.* (2-4 m height)
Live tree biomass	27.5 ± 10.2	4.5 ± 0.3
Dead tree biomass (	29.7 ± 6.0	0
Dead and downed woody debris biomass	145.3 ± 10.7	3.7 ± 0.4
Total above-ground biomass	202.4 ± 27.0	8.2 ± 0.7
Soil carbon	490.3 ± 43.3	451.9 ± 49.5
Total carbon stock	692.7 ± 70.3	460.1 ± 50.2

The total area of mangrove cover in 2050 under this scenario is estimated as 4,992 ha. under scenario 1 (BAU) and 5,050 ha. under scenario 2 (mangrove enhancement). Thus, we multiplied these area estimates by the average carbon stocks of large *Rhizophora spp.* and scrub *Rhizophora spp* in Ba watershed (including live tree biomass, dead tree biomass, dead and downed woody debris biomass, and soil carbon), derived from measurements at 15 field plots (Table 1) (Cameron, Kennedy, et al., 2021):

- Scenario 1 blue carbon = (4,992 x 692.7 x 0.288) + (4,992 x 460.1 x 0.722) = 2,654,195 t C
- Scenario 2 blue carbon = (5,050 x 692.7 x 0.288) + (5,050 x 460.1 x 0.722) = 2,685,033 t C

As seen by comparing Scenario 1 and 2, mangrove enhancement activities can result in an additional 30,838 t C sequestered as blue carbon in Ba watershed.

The goods and services provided by mangroves are also important to the local community of Ba. A social survey of Ba watershed households, conducted in September 2018, found that 45% of surveyed households visited the mangrove ecosystems in Ba daily to obtain seafood and other materials (e.g. firewood) for their household consumption, and approximately 20-30% of households relied on selling seafood or firewood products from the mangrove ecosystems as a source of income (Figure 7). Although we were unable to quantify the contributions of these goods and services (mainly due to COVID, which prevented follow-up workshops in Ba after 2019), we obtained estimates of the economic value of these goods and services from a prior study in Fiji. As shown in Table 2, mangrove forestry products (e.g. firewood) is estimated as having a value of 6 USD/year for each ha of mangrove cover, while fisheries products are estimated as 100 USD/ha/year, and nutrient filtration (mainly human waste treatment) is estimated as having a value of 2,600 USD/ha/year (due to the reduced need for water treatment plants) (Lal, 2003).

By multiplying the area of mangroves under Scenario 1 (4,992 ha) and Scenario 2 (5,050 ha) by these estimated economic values, we found that Scenario 2, which involves enhancing mangrove cover by approximately 58 ha., results in an additional 156,948 USD/year of goods and services for the local community of Ba watershed. This is a relatively significant amount considering the size of the local population of Ba watershed (estimated as a few thousand, although we were unable to get precise village-level population counts).

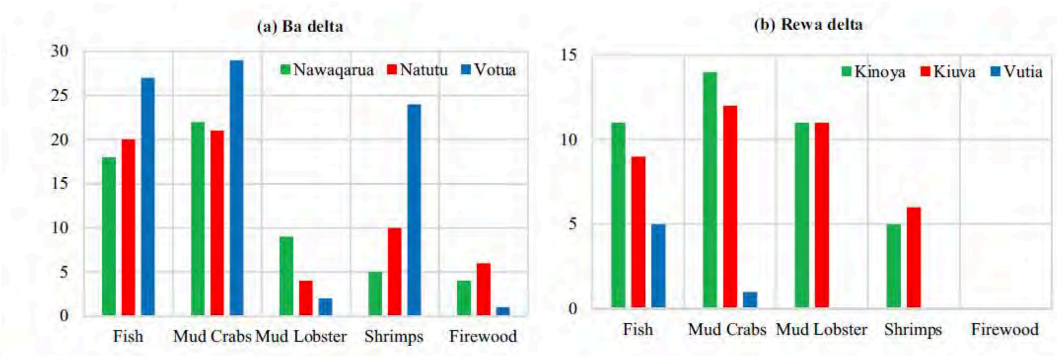

Figure 7. Number of survey respondents (i.e. households) who sold different products from the mangrove ecosystems in the Ba watershed (Avtar et al., 2021). Total number of survey respondents = 113.

Table 2.Economic values of goods and services provided by mangrove ecosystems, based on national-level estimates for Fiiji

	Economic value (USD/ha/year)	Scenario 1: Total economic value for Ba watershed (USD/year)	Scenario 2: Total economic value for Ba watershed (USD/year)
Forestry	6	29,952	30,300
Fisheries	100	499,200	505,000
Nutrient filtration (human waste treatment)	2,600	12,979,200	13,130,000
Sum	2,706	13,508,352	13,665,300

6. Conclusions and policy recommendation

The mangrove ecosystems of Ba watershed are an important cultural and economic resource for the local communities. Nearly half of residents visit the mangroves daily to obtain household supplies, and around 1/3 rely on mangrove ecosystem-related products as a source of income. The historical changes in mangrove cover has mainly been driven by Tropical Cyclone damage and dredging, with some impacts of tourism development of Ba (likely in the larger urban areas outside of the watershed limits). Local communities hoped to reduce the negative impacts of dredging on mangrove habitats, and to restore mangrove areas that were damaged or destroyed by Tropical Cyclones.

Based on the above factors, we generated two future scenarios of mangrove cover in Ba watershed: Scenario 1 (BAU), which does not require any additional efforts by the local communities; and Scenario 2 (Mangrove enhancement), which could require community efforts to restore mangrove habitats that were damaged/destroyed by Tropical Cyclones. By comparing Scenario 2 with Scenario 1, we found that these mangrove enhancement efforts could lead to an additional 38,838 t C sequestered as blue carbon, and an additional 156,948 USD/year of goods and services from the mangrove ecosystems. Thus, these mangrove enhancement efforts represent an important contribution to local community livelihoods and global climate change mitigation efforts. If sufficient external funding is available (e.g. through REDD+ or national climate change funding sources), it would be possible to restore additional mangrove areas beyond those assumed in Scenario 2, e.g. by planting mangrove seedlings in new areas identified as having high potential for survival. If these areas are located along the river banks, they could also bring coastal flood mitigation benefits to the local communities.

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Appendix 5: Detailed Technical Report: Oriental Mindoro Island, The Philippines

Basic information on Oriental Mindoro, Philippines

Oriental Mindoro is a province in the Philippines, located ~130 km south of Metro Manila. It is surrounded to the North by the Verde Island Passage, Semirara Island to the South, Sibuyan Sea and Romblon to the East, and Occidental Mindoro to the West (Figure 1). Furthermore, three geographical zone surfaces of coastal, lake, and riparian areas cover Oriental Mindoro. The coastal areas stretch a total of 342.45 km, while the lake has an area of 8,128 ha, and about 388,460 ha of riparian areas characterized by nutrient rich mountainous and valley landmasses (DENR-PAWB, 2009).

Oriental Mindoro is bounded on the west side by a mountain range that traverses the central part of the island from Northwest to Southeast. Figure 1 shows the general topography of Oriental Mindoro, of which 47% is flat plains and 53% is hilly to mountainous areas. This rugged terrain and uneven coastline led to the creation of a network of streams and rivers in the province. As seen in Figure 1, a large portion of the low-lying areas in Oriental Mindoro are situated near the coastline, making the province vulnerable to coastal and river flooding.

Figure 2 shows the most recent land-use/land-cover of Oriental Mindoro and it's neighboring province, Occidental Mindoro (NAMRIA, 2015). Table 1 shows the area of each land-use/land-cover type in Oriental Mindoro. As seen in the Table, the dominant land-use/land-cover types are brush/shrub, open forest, annual cropland, perennial cropland, and grassland. The built-up/urban area is 16,580 ha. These built-up areas are mainly located in the low-lying coastal areas, where flood hazards exist.

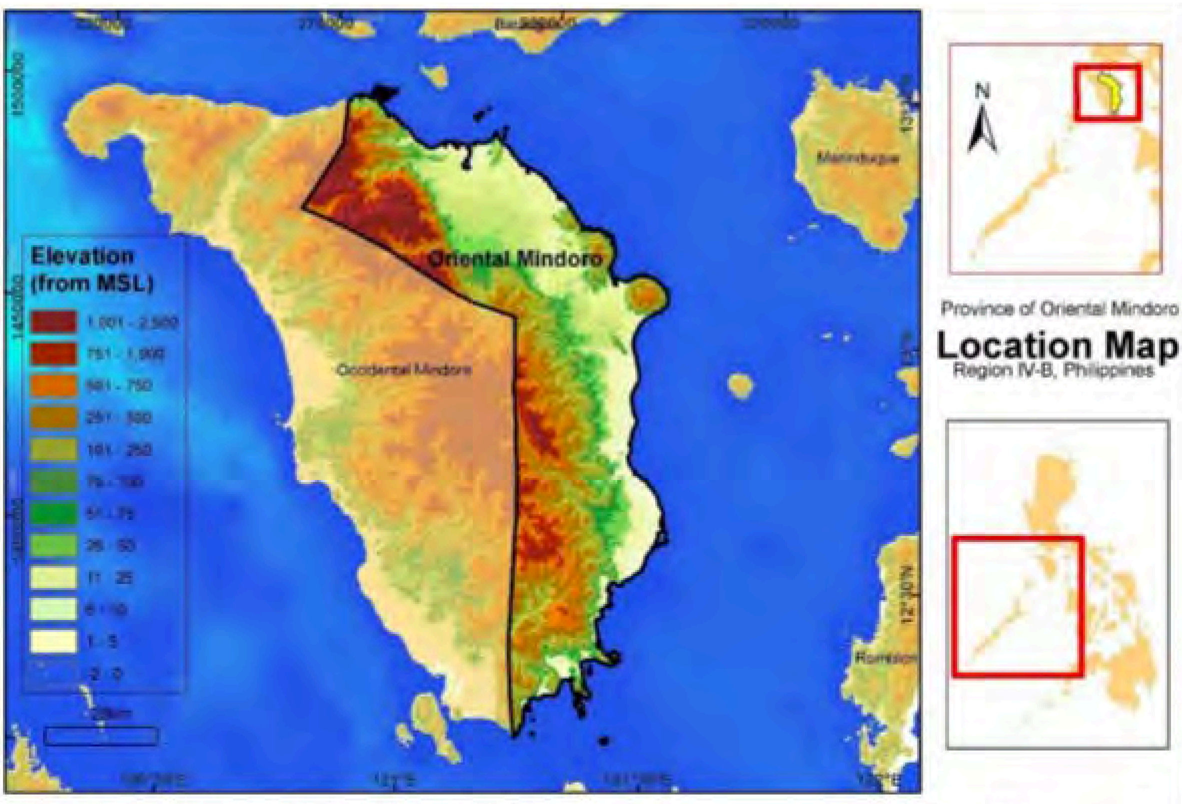


Figure 1. Oriental Mindoro location and topography.

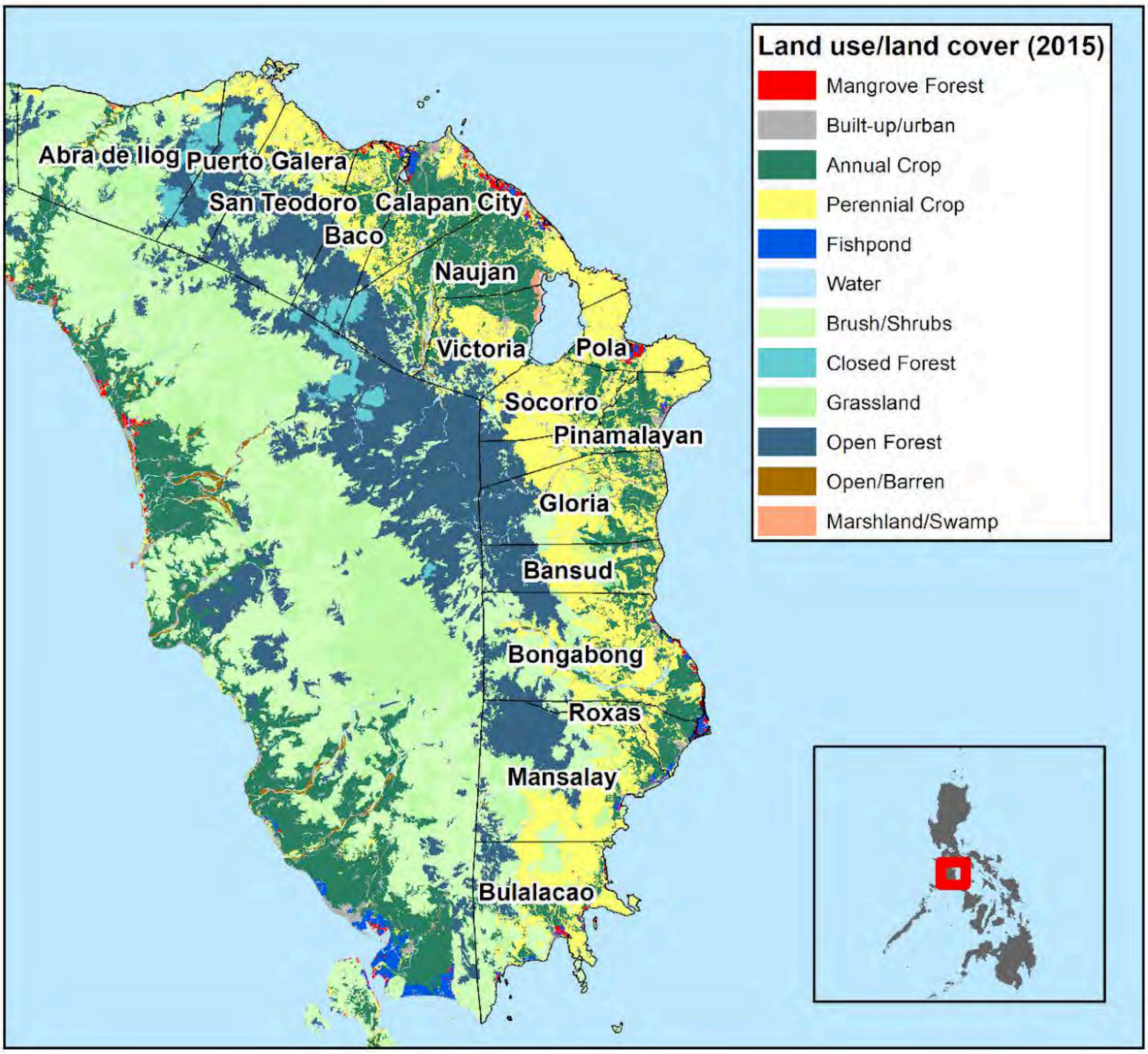


Figure 2. Land-use/land-cover map of Mindoro Island in 2015 (NAMRIA land-cover map). Labels indicate the name of each municipality in Oriental Mindoro.

Table 1. Land-use/land-cover of Oriental Mindoro in 2015.

Land-use/land-cover type	Ha (2015)
Annual Crop	164,100.34
Brush/Shrubs	266,711.08
Built-up	16,580.08
Closed Forest	14,843.03
Fishpond	7,467.28
Grassland	151,031.57
Inland Water	23,516.55
Mangrove Forest	4,813.59
Marshland/Swamp	670.88
Open Forest	188,082.84
Open/Barren	7,460.11
Perennial Crop	147,612.11

Mangrove cover in the province is represented by fringing and riverine forest types (Figure 3), and dominated by Rhizophora and Avicennia species (Alcanices, 2017). The main structure of the riverine - basin mangrove forest type is a riverine mangrove forest which was influenced with incursion of freshwater and tide. The mangrove extends away from the main river, as land depressions form towards the interior and create swampy substrates inhabited by stunted mangroves. Given the rich coastal resources of Oriental Mindoro, 12 out of the 13 coastal LGUs have established marine protected area (MPA) within their municipal waters. Table 2 shows the total area of established MPAs per municipality. Wherein 4,828.00 ha or about 34.69 % of Puerto Galera's municipal water has been established as an MPA. This can be attributed to Puerto Galera being a popular tourist area of the island. Far from the statistics of Puerto Galera, the percent area covered by the MPAs from the corresponding municipal waters of San Teodoro and Gloria are 2.49% and 1.28%, respectively.

Figure 3. The mangrove forest types in sampling areas of Oriental Mindoro include fringing (top left), riverine (top right) and basin (lower left and right) forest types.

Table 2. MPAs established in Oriental Mindoro.

LOCATION	BARANGAY	NAME OF MPA	AREA (HA.)	YEAR
Calapan City	Lazareto	HarkaPiloto Fringing Reef Fish Sanctuary	37.44	2003
	Silonay	Silonay Mangrove Conservation Area	41.00	2010
San Teodoro	Ilag	Punta Ilag Fish Sanctuary	23.10	2006
	Tacligan	Tamauyan Reef Fish Sanctuary	89.37	2006
Puerto Galera	San Antonio	Pto. Galera Fish Sanctuary	4,828.00	2006
Naujan	SitioTujod, Herrera	Tujod Fish Sanctuary	30.00	2006
	Masaguing	Masaguing Fish Sanctuary	16.39	2010
Pola	Bacawan	Bacawan Fish Sanctuary	23.44	2006
	Puting Cacao	St. John the Baptist Fish Sanctuary	49.38	2010

	Tagumpay	St. Peter the Rock MPA	25.11	2010
	Calima	Stella Mariz Fish Sanctuary	30.12	2013
	Misong	Song of the Sea Fish Sanctuary	60.61	2013
	Tiguihan	Kingfisher Fishery Reserve	14.66	2013
Pinamalayan	Ranzo	Ranzo Fish Sanctuary	16.39	2006
	SitioSimboryo, Banilad	Banilad-Simboryo MPA	10.41	2010
	Sitio Ginapangan, Banilad	Banilad-Ginapangan MPA	10.28	2010
	SitioBulaklak, Pili	Pili Marine Protected Area	24.00	2010
Gloria	Agsalin	Agsalin Fish Sanctuary	80.13	2003
	Sta. Theresa	Sta. Theresa Fish Reserve	14.00	2013
	Tambong	Tambong Fishery Reserve	80.4	2013
Bansud	Proper Tiguisan	Bansud Fish Sanctuary	45.07	2010
Bongabong	Masaguisi	Masaguisi Fish Sanctuary	21.68	2003
Roxas	Paclasan	Paclasan Seagrass Protected Area	30.00	2010
Mansalay	Palaylay Cove & Balanga Point, B. Del Mundo	Palaypay Cove Fish Sanctuary	82.79	2006
	Sta. Brigida	Allegria Sea Turtle Habitat (Tikling Point)	8.2	2008
Bulalacao	Balatasan	Balatasan Fish Sanctuary	179.00	1993
	Maujao	Maujao Fish Sanctuary	40.00	2009

Field survey of mangroves in Oriental Mindoro

A total of 31 mangrove species were recorded in Oriental Mindoro, based on field investigations as part of this study. Twenty-one species were found in both Northern and Southern halves of the province. Six mangrove species were identified only in the Northern half while five mangrove species were identified only in the Southern half of Oriental Mindoro.

Mangrove Species Composition of Northern Oriental Mindoro

List of mangrove species. The sampling locations covered the northern coastal municipalities in Oriental Mindoro include Puerto Galera, San Teodoro, Baco, Calapan City, Naujan, Pola and Pinamalayan. There were 26 mangrove species recorded in the mangrove areas in the northern 7 municipalities of Oriental Mindoro, Philippines. Twenty-five (25) species are consistently observed in the sampling quadrats while the species *Osbornia octodonta* was found outside the sampling quadrats. Majority of the mangrove species are classified as major species. The habit of these mangrove species is generally from shrub to trees and only the species *Nypa fruticans* has a palm habit.

The 26 mangrove species belong to 13 different plant families (Table 3). The family Rhizophoraceae had the most number of mangrove species with nine. This include *Bruguiera cylindrica, Bruguiera gymnorhiza, Bruguiera parviflora, Bruguiera sexangula, Ceriops decandra, Ceriops tagal, Rhizophora apiculata, Rhizophora mucronata* and *Rhizophora stylosa*. This is followed by family Avicenniaceae with 4 species namely *Avicennia alba, Avicennia marina, Avicennia officinalis* and *Avicennia rumphiana*.

Table 3. List of mangrove species observed in the 7 sampling areas in Northern Oriental Mindoro, Philippines.

FAMILY	SPECIES
Arecaceae	*Nypa fruticans*
Avicenniaceae	*Avicennia alba*
	Avicennia marina
	Avicennia officinalis
	Avicennia rumphiana
Bombacaceae	*Camptostemon philippinense*
Combretaceae	*Lumnitzera littorea*
	Lumnitzera racemosa
Euphorbiaceae	*Excoecaria agallocha*
Lythraceae	*Pemphis acidula*
Meliaceae	*Xylocarpus granatum*
	Xylocarpus moluccensis
Myrsinaceae	*Aegiceras corniculatum*
Myrtaceae	*Osbornia octodonta**
Rhizophoraceae	*Bruguiera cylindrica*
	Bruguiera gymnorhiza
	Bruguiera parviflora
	Bruguiera sexangula
	Ceriops decandra
	Ceriops tagal
	Rhizophora apiculata
	Rhizophora mucronata
	Rhizophora stylosa
Rubiaceae	*Scyphiphora hydrophyllacea*
Sonneratiaceae	*Sonneratia alba*
Sterculiaceae	*Heritiera littoralis*

Legend: * species was observed outside the sampling plots.

Mangrove species composition in southern Oriental Mindoro

The study sites located in the southern part (District II) of the province comprise of six municipalities-Gloria, Bansud, Bongabong, Roxas, Mansalay and Bulalacao. As of 2010, these municipalities cover approximately 661.02 hectares of mangrove forests. A total of 25 species of mangroves were encountered in the mangrove vegetation in all the study sites (Table 4). Among the sampling sites higher number of species was recorded in Roxas with 16 species, followed by Gloria and Bansud with 13 species and Mansalay and Bulalacao with 12 species, respectively. On the other hand, nine species were recorded in Bongabong which has the least number of mangrove species. New records of mangrove species were identified in previously assessed areas such as in Gloria with six and Roxas with eight new species records.

In comparison to the number of species recorded in the previous study (Table 4), there was an increase in species richness in all municipalities. The recorded mangrove species in most of the municipalities have increased in number except in Bongabong with a decreasing number of species. The low number of species record may be attributed to the different locations of the study sites in Bongabong. Moreover, previously assessed mangrove areas in Mansalay and Bulalacao have lower numbers of species compared to the present study sites.

Table 4. Summary of the recorded species across mangrove vegetation in the southern coasts of Oriental Mindoro from previous and current studies.

Municipality	No. of Species Recorded	
	Previous record (2014)	Current record (2019)
Gloria	7	13(6)
Bansud	13	13
Bongabong*	13	9
Roxas	11	16(8)
Mansalay*	5	12
Bulalacao*	8	12
Total No. of Species	**19**	**25**

Note: (*) Newly assessed mangrove areas. Number inside parenthesis in the current record (2019) represents number of new recorded species.

Table 5 shows the list of species observed in the mangrove vegetation in the six municipalities. A total of twenty-five (25) species was recorded with four new species added to the list of known mangrove species. Newly species recorded were mostly mangrove associates encountered from the previously assessed mangrove areas (Table 1). The six new species recorded in Gloria includes *Acanthus ebracteatus, Acrostichum aureum, Aegiceras corniculatum Bruguiera gymnorrhiza, Osbornia octodonta* and *Sonneratia alba.* While the eight new species recorded in Roxas were *Acrostichum speciosum, A. corniculatum, Bruguiera cylindrica, B. gymnorrhiza, Ceriops decandra, Excoecaria agallocha, Nypa fruticans,* and *Scyphiphora hydrophyllacea*. Amongst these species recorded, 4 new species record were *A. aureum, A. speciosum, A. volubilis ans S. hydrophyllacea. Avicennia rumphiana, E. agallocha*, *Rhizophora apiculata, Rhizophora mucronata* and *S. alba* were the most common species in all study sites*. Rhizophora mucronata* was commonly used in the rehabilitation activities, however, it was also observed that there was a newly planted *Avicennia marina* in the riverine zone of Gloria.

Table 5. List of recorded species across mangrove vegetation in the southern coasts of Oriental Mindoro. Check (√) indicate the presence of the species in the study site (s).

Species	Gloria	Bansud	Bongabong	Roxas	Mansalay	Bulalacao
1. *Acanthus ebracteatus* Vahl, Symb. *^{G}	√	√			√	
2. *Acanthus volubilis* Wall. +		√				
3. *Acrostichum aureum* L.*^{G}+	√					
4. *Acrostichum speciosum* Willd.*^{R}+				√		
5. *Aegiceras corniculatum* (L.) Blanco*^{G,R}	√	√		√		√
6. *Aegiceras floridum* Roem. & Schult.					√	
7. *Avicennia marina* (Forssk.) Vierh.^{P}			√	√	√	√
8. *Avicennia rumphiana* Hallier f.^{C}	√	√	√	√		√
9. *Bruguiera cylindrica* (L.) Blume*^{R}		√		√	√	
10. *Bruguiera gymnorrhiza* (L.) Lam.*^{G,R}	√			√		
11. *Bruguiera parviflora* (Roxb.) Wight & Arn. ex Griff.						√
12. *Ceriops decandra* (Griff.) W.Theob.*^{R}	√	√	√	√		
13. *Ceriops tagal* (Perr.) C.B.Rob.		√		√	√	√
14. *Excoecaria agallocha* L.*^{R,C}	√	√		√	√	√
15. *Heritiera littoralis* Aiton		√			√	
16. *Lumnitzera littorea* (Jack) Voigt			√			
17. *Lumnitzera racemosa* Willd.			√	√	√	√
18. *Nypa fruticans* Wurmb*^{R}	√	√		√		
19. *Osbornia octodonta* F.Muell.*^{G}	√	√				√
20. *Rhizophora apiculata* Blume^{C}		√	√	√	√	√
21. *Rhizophora mucronata* Lam.^{C,P}	√		√	√	√	√
22. *Rhizophora stylosa* Griff.	√				√	
23. *Scyphiphora hydrophyllacea* C.F.Gaertn. *^{R}+			√	√		
24. *Sonneratia alba* Sm.*^{G,C}	√	√	√	√	√	√
25. *Xylocarpus granatum* J.Koenig	√			√		√

Note: (*) represents new record species from the previously assessed areas represented by subscript letters (G-Gloria, R-Roxas); (+) are the new species record added to the list of mangrove species found in the region. Common species across sites are represented by letter (C); Species used in the rehabilitation are indicated by letter (P).

7. Drivers of mangrove loss/gain

The specific threats to mangrove ecosystem in each respective municipality in Southern Oriental Mindoro were determined through an interview with the key informants directly involved in the conservation of mangroves. The key informants include representatives from the municipal environment and natural resources office, municipal agriculture office, coastal resources management office and the 'bantay-dagat' who were directly involved in the conservation of mangroves in their respective municipality. The study also selected coastal households living nearby the mangrove stand in each municipality. Their name (optional), age, gender, educational attainment, occupation and years of residency were recorded. The survey questionnaire used was composed of similar set of questions regarding the observed past and present threats to the mangrove ecosystem. The interview was carried out to obtain necessary information on human activities and natural calamities that occurred in the mangrove ecosystem such as urbanization, clearing/cutting, aquaculture, agriculture activities, water pollution, flood, siltation, coastal erosion, sea level rise, strong tidal waves, typhoon/storm surges, increase in temperature and change in precipitation patterns that influenced the mangrove ecosystem. Each threat was classified based on the following observations: Frequent (F), if they observed it oftentimes; Not Frequent (NF), if they observed it once or twice a year. The categories to types of threats were the following: (0- not a threat; 1- less threat, if it has a minimal impact; 2- strongly believed as threat, if it has huge impact). The length of time of the threats observed were also noted. Results were tallied according to the total scores of each type of threat observed and were presented as graph.

Key informant interview with the key respondents in each respective municipality was conducted to determine the perception of the local communities towards various threats to mangrove ecosystem. The selection of the key respondents was based on their direct involvement in the conservation of mangroves in their respective municipality. The key respondents include personnel representatives from the Municipal Environment and Natural Resources Office (MENRO), Coastal Resources Management office (CRMO), Municipal Agriculture Office (MAO) and bantay-dagat (coast guard). Also, the survey included some selected households living in the coastal area to come up with a holistic approach towards getting the information of the current status of the mangrove ecosystems in each respective study site.

Threats to mangrove ecosystem determined in this study include some climatic events and natural phenomenon such as change in precipitation patterns, increase in temperature, siltation, typhoon surges, strong tidal waves, sea level rise, flooding and coastal erosion. Human-induced threats such as cutting of mangroves, used as raw materials for building houses, charcoal making and raw product extraction, water pollution, agriculture, aquaculture and influx of coastal residents near the mangrove ecosystem were also determined in this study.

The threats to mangrove ecosystems frequently observed by the key respondents are presented in Table 6. The Table shows the percentage of the total respondents per municipality that have agreed that they frequently observed such type of threats. Climatic factors such as precipitation change and increase in temperature were frequently observed in all municipalities. Respondents noticed that these climatic events fluctuate seasonally and annually, wherein during the summer months there were times they experience heavy rainfall. On the other hand, sea level rise has been frequently observed in Gloria and Bongabong as evidenced by the remnants of tree stumps and the prevalent erosion of soils along the shore. Some residents, especially in Bansud, Mansalay and Bulalacao still observed cutting of mangrove trees. Water pollution has been frequently observed in Roxas attributed to the huge community residing near the mangrove area. A large fraction of rice farm activities was observed in the backward parts of the mangrove areas in Gloria and Mansalay, while the large fishpond operations were frequently observed from the municipality of Bongabong down to the last municipality in the south (Bulalacao). Other threats such as siltation, typhoon surges, flooding and charcoal making were also observed but not that frequent.

Table 6. Threats observed in mangrove ecosystems in southern municipalities of Oriental Mindoro. Methods, drivers, and key considerations for scenario planning

Threats N=113 respondents	Respondents' responses per site						
	Gloria n=20	Bansud n=20	Bongabong n=14	Roxas n=20	Mansalay n=9	Bulalacao n=30	Length of time observed (years)
Urbanization (Immigration)	5 (25)	17 (85)*	0	20 (100)*	0	30 (100)*	≥30
Aquaculture	2 (10)	0	13 (93)*	15 (75)*	8 (89)*	21 (70)*	≥30
Agriculture	13 (65)*	0	1 (7)	6 (30)	9 (100)*	0	≥30
Water pollution	6 (30)	5 (25)	2 (14)	20 (100)*	4 (44)	4 (13)	10-15
Illegal logging/ cutting of mangrove trees	4 (20)	13 (65)*	2 (14)	3 (15)	7 (78)*	17 (57)*	≥30
Used mangroves as raw materials for tannin extraction, charcoal making, etc.	5 (25)	1 (5)	2 (14)	3 (15)	3 (33)	5 (17)	≥30
Coastal Erosion	6 (30)	2 (10)	4 (29)	4 (20)	2 (22)	0	≥20
Flooding	9 (45)	2 (10)	3 (21)	3 (15)	0	2 (7)	≥20
Sea Level Rise	12 (60)*	5 (25)	9 (64)*	5 (25)	2 (22)	0	≥20
Storm surges/ strong tidal waves	4 (20)	0	2 (14)	4 (20)	3 (33)	0	≥15
Siltation	3 (15)	0	1 (7)	3 (15)	2 (22)	4 (13)	5-20
Increase in temperature	14 (70)*	20 (100)*	13 (93)*	20 (100)*	7 (78)*	24 (80)*	10-15
Change in precipitation patterns	13 (65)*	20 (100)*	13 (93)*	20 (100)*	7 (78)*	20 (67)*	10-15

Note: N: total number of respondents in all study sites; n: total number of respondents per study site. Value inside parenthesis is the percentage of the respondents based on their responses toward observed threats. Asterisk (*) means frequently observed threats and zero (0) means threats not observed at all.

Based on the identified drivers of mangrove change, next we developed three plausible scenarios of future mangrove cover in Oriental Mindoro, targeting the 2030-2050 period.

Scenario 1: Current situation of mangrove area continues in the future

The first scenario (Scenario 1) used was a continuation of the current situation, i.e. no change in mangrove extent in the future as compared to the present. The most recent official mangrove area map of Oriental Mindoro was produced by NAMRIA in 2015. In this map, the extent of mangroves in the province is 4,813.59 ha (Table X). Thus, in the future scenario, the same extent (and spatial location) of mangroves is assumed in Scenario 1.

Scenario 2: Participatory mapping scenario with inputs from local governments

Based on our understanding the drivers of mangrove changes in Oriental Mindoro, we conducted a stakeholder workshop in Calapan City, Oriental Mindoro, to understand local governments' future plans related to mangroves and other coastal land-use, considering these drivers and their local plans. At this workshop, local government officers from all of the municipalities located in Oriental Mindoro sketched their future land-use plans related to mangroves and other coastal land-use types, including, e.g., the areas planned to be restored to mangrove habitats, or the areas planned for urban development. We then digitized the data obtained through this participatory mapping activity using GIS software, to obtain a spatially explicit scenario of the coastal land-use of Oriental Mindoro (Scenario 2).

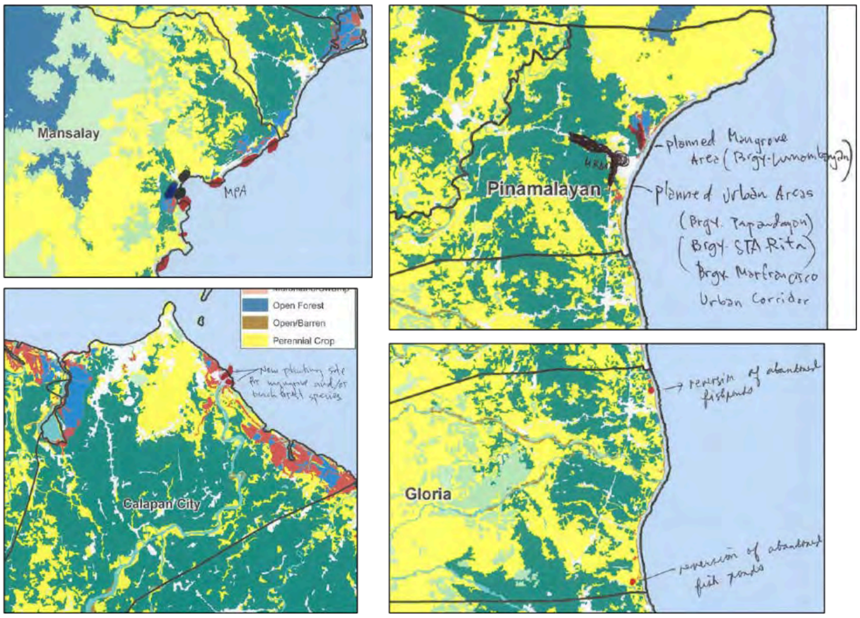
Scenario 3: All coastal ecosystems (including mangroves) lost

We also generated a more extreme scenario in which all coastal ecosystems are lost, with the goal of showing the importance of the existing coastal ecosystems in the Province, e.g. how they provide protection from coastal hazards like storm surge and coastal erosion. The participatory mapping scenario and the coastal ecosystems lost scenarios were

8. Land-use simulation/scenarios and analysis

To estimate how climate change and land-use change will affect a coastal area, planners and policymakers need to have an understanding of how the land-use are likely to change in the future (e.g. over the next 10, 20, or 50 years). Here we took a participatory mapping approach. For this, we organized several stakeholder consultation workshop from each of the local government units and then the likely changes was mapped through a participatory mapping activity. In this method, government officials identified their planned future and likely land use conversions (e.g. based on their land-use plan or their knowledge of planned land development). These maps are then digitized and georeferenced using the formal GIS methods.

Participatory mapping results



-Areas marked in red indicate new mangrove planting sites

-Areas marked in black indicate planned urban development sites.

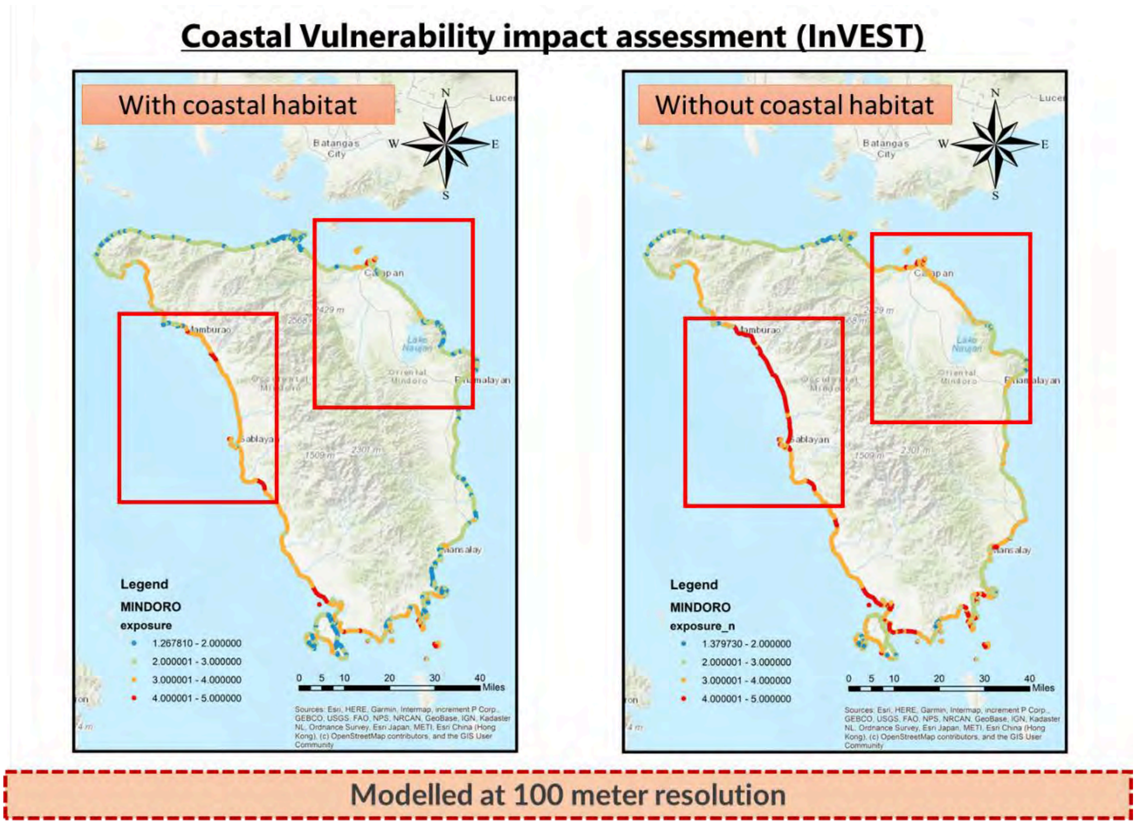
-digitized using QGIS software.

Land-use/land-cover type	Ha (2015)	Ha (2030)	Change (Ha)	Change (%)
Annual Crop	164,100.34	163,713.76	-386.58	-0.24%
Brush/Shrubs	266,711.08	266,696.67	-14.41	-0.01%
Built-up	16,580.08	17,171.06	590.99	3.56%
Closed Forest	14,843.03	14,843.03	0.00	0.00%
Fishpond	7,467.28	7,198.62	-268.67	-3.60%
Grassland	151,031.57	151,031.48	-0.09	0.00%
Inland Water	23,516.55	23,510.84	-5.72	-0.02%
Mangrove Forest	4,813.59	5,169.70	356.11	7.40%
Marshland/Swamp	670.88	670.88	0.00	0.00%
Open Forest	188,082.84	188,082.84	0.00	0.00%
Open/Barren	7,460.11	7,445.06	-15.05	-0.20%
Perennial Crop	147,612.11	147,355.53	-256.58	-0.17%

Modelled ecosystem services and their synergies and trade-offs across scenarios

- **Coastal Vulnerability modelling**

In this step, we took a past to present land-use change simulation approach to determine coastal vulnerability in Mindoro Island of the Philippines, and critically examine the role of natural habitats in reducing the exposure from storm-induced erosion and flooding. Alongside current and future land use maps (2050) of the study area, we used a wide array of geospatial data, including relief, wave/wind exposure, sea-level rise, bathymetry, geomorphology, extent of natural habitats, and population density to quantify the current and future vulnerability of the shoreline. To highlight the protective roles of coastal vegetation, two sets of scenarios were developed which hypothetically characterized the presence and absence of coastal habitats and their contributions in storm surge attenuation. The shoreline vulnerability maps were generated using the InVEST 3.8.7 coastal vulnerability assessment model at a 100-meter spatial resolution. The results, represented through a five-point coastal vulnerability index (CVI), suggested high vulnerability of the south and western coast of the Mindoro islands. In addition, coastal ecosystems such as mangroves and sea grasses were found to significantly reduce the exposure from storm surge inundation. The study highlighted the protective role of coastal habitats and provided an opportunity to visualize and foster ecosystem-centric adaptation approaches in the coastal areas of Mindoro Island. Moreover, the result, in combination with other geospatial data, can be very effectively used to identify new locations for mangrove restoration, which can strongly facilitate Ecosystem-based Adaption for the low-lying island communities.

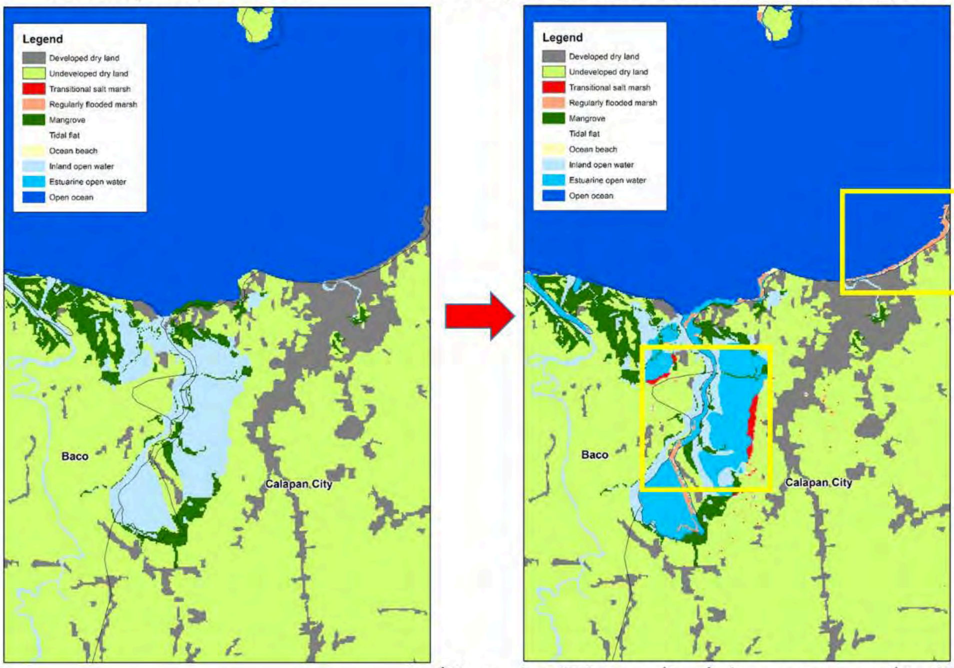


- **Sea Level Impact Assessment**

Climate change is already resulting in global sea-level rise and is expected to cause further rises in sea level in the future as the climate continues to warm. The rates and impacts of sea-level rise vary from location to location, being affected by many factors including local sea-level rise rates, land subsidence/uplift rates, and soil accretion/erosion rates in coastal areas. The latter can be significantly affected by land change. The future extent of mangroves also depends upon the sea encroachment. Here we used the SLAMM (Sea level affecting marshes model) model using different land-use and sea-level. The following outputs were generated using the SLAMM Model.

Sea-level rise impact assessment (SLAMM model)

Current (2015) land cover | Future (2050) land cover considering 8mm/year sea-level-rise*



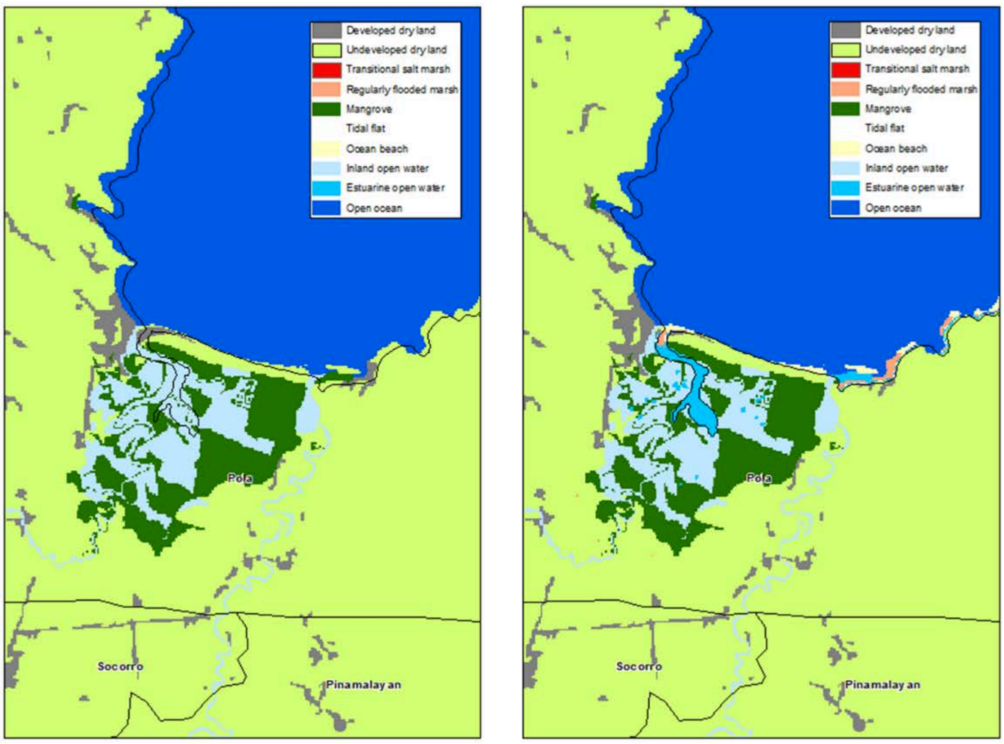
Results for Calapan City/Baco area

-Coastal urban areas may be regularly inundated by 2050.

-Salinity levels of inland water bodies (including Caluangan lake) may increase significantly.

*Assuming 0.5m sea-level-rise as compared to 1990 level. (~8 mm/year)

Current (2015) land cover | Future (2050) land cover considering 8mm/year sea-level-rise*



Results for Pola area

-Coastal urban areas may be regularly inundated by 2050.

-Some mangrove areas may also convert to regularly flooded marshes due to higher/more frequent inundation.

Appendix 6: Detailed Report from Ishigaki Island of Japan.

Introduction

This report summarizes the major activities and key results from the Ishigaki Island site of the APN Mangrove project during the entire project period from 2019 to 2022. In comparison with the field research sites in other countries, the extent of and recent changes in the mangrove ecosystem were fairly limited so modelling future change in mangroves and their ecosystem services was not likely to produce meaningful research outcomes. This reasoning is clearly presented in the body of this report. Therefore, the Ishigaki site team took the landscape approach in which the scope was not limited to mangroves but included all major ecosystem types identified on the island and the observed and potential interactions with mangroves and changes in other ecosystems. Hence, in developing future scenarios, we adopted exploratory scenarios which aim to capture an overall socio-economic trend of the human population on the island and their interactions with nature.

The presentation of methods and results in this report is structured into three large sections, following the logical framework presented in the full proposal document Appendix 6. These are (1) development of spatially explicit land-cover scenarios; (2) ecosystem services assessment; and (3) scenario analysis on synergies and trade-offs in ecosystem services.

Activities and results

1. **Develop spatially explicit land-cover scenarios**

We first mapped and quantified the past trend of the extent of mangrove and other ecosystems on Ishigaki Island using existing vegetation spatial datasets. With that and using land change modelling, we projected the future distribution of these ecosystems in 2050. We then identified observed and potential direct and indirect drivers of ecosystem changes on the Island from field observations, government statistics and other secondary data. On that basis and drawing on existing global, national and regional scenarios and relevant frameworks, we proposed four plausible future scenarios and their key metrics that are likely to affect the future extent of mangrove, other ecosystems and their services. Below subsections summarise the methods used and key results for the respective components.

1.1. **Mangrove extent mapping and quantification**

A comparison of the vegetation map of the Natural Environmental Information GIS datasets between 1981 and 2006 yielded LULC changes between the two-time points (Table 1). Mangrove cover gain between two-time points was 56 hectares and the loss was 25 hectares (Figure 1), which made 25 hectares net increase and 88 hectares turnover. An increase in mangrove cover was most notably seen in Nagura Anparu (Figure 1), which was the consequence of a mass deposition of red soil on the lagoon waterbody derived from upstream farmlands (Nakaza et al. 2011). Mangrove was lost mainly for broadleaf woodland (16 hectares) and open water (10 hectares). The replacement of broadleaf woodland with mangrove (14 hectares) was not probable, which we presumed to contain errors in the identification of boundaries between these two classes.

Table 1. LULC between 1981 and 2006

1981 LULC class	2006 LULC class												
	01	02	03	**04**	05	06	07	08	09	10	11	12	Total
01 Broadleaf	7,110	360	680	**10**	30	50	40	30	520	150	40	90	9,100
02 Coniferous	120	120	60	**0**	0	0	0	0	50	0	0	10	370
03 Grassland	1,280	240	1,620	**10**	30	20	20	20	750	160	40	40	4,230
04 Mangrove	**20**	**0**	**0**	**50**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**10**	**80**
05 Riverside, marsh, saltswamp, sanddunes	160	10	120	**10**	30	20	10	40	140	10	0	20	570
06 Natural bareland	10	0	0	**0**	0	0	0	0	0	0	0	0	10
07 Abandoned land	0	0	10	**0**	20	0	0	10	0	0	0	30	70
08 Paddy	90	10	110	**0**	30	0	20	200	160	10	10	10	640
09 Dryfield	1,060	130	1,390	**0**	40	0	70	80	2,760	250	30	50	5,870
10 Building	60	0	30	**0**	0	0	0	0	60	540	10	0	700
11 Other	40	0	90	**0**	0	0	0	0	40	60	20	10	260
12 Open water	130	10	60	**20**	10	50	0	0	10	50	40	110	470
Total	10,080	890	4,150	**100**	180	140	160	380	4,480	1,240	190	370	22,360

Summary	01	02	03	**04**	05	06	07	08	09	10	11	12	Total
No-change between 1981 and 2006	7,110	120	1,620	**50**	30	0	0	200	2,760	540	20	110	12,550
Gain (a)	2,980	760	2,530	**60**	150	140	160	180	1,720	700	170	260	9,810
Loss (b)	1,990	250	2,610	**30**	540	10	70	440	3,110	160	250	360	9,810
net-change (a-b)	980	520	-70	**30**	-390	130	100	-260	-1,390	540	-80	-110	0
turnover (a+b)	4,970	1,010	5,140	**90**	690	150	230	620	4,830	860	420	620	19,620

Note: The 1981 vector dataset had 34 LULC categories on a 1:50,000 map, while the 2006 dataset had 51 LULC categories on a 1:25,000 map. These datasets were converted into 30 meters raster datasets with 12 LULC classes to assess LULC flow between the two-time points. The hectare numbers rounded off below the tens place.

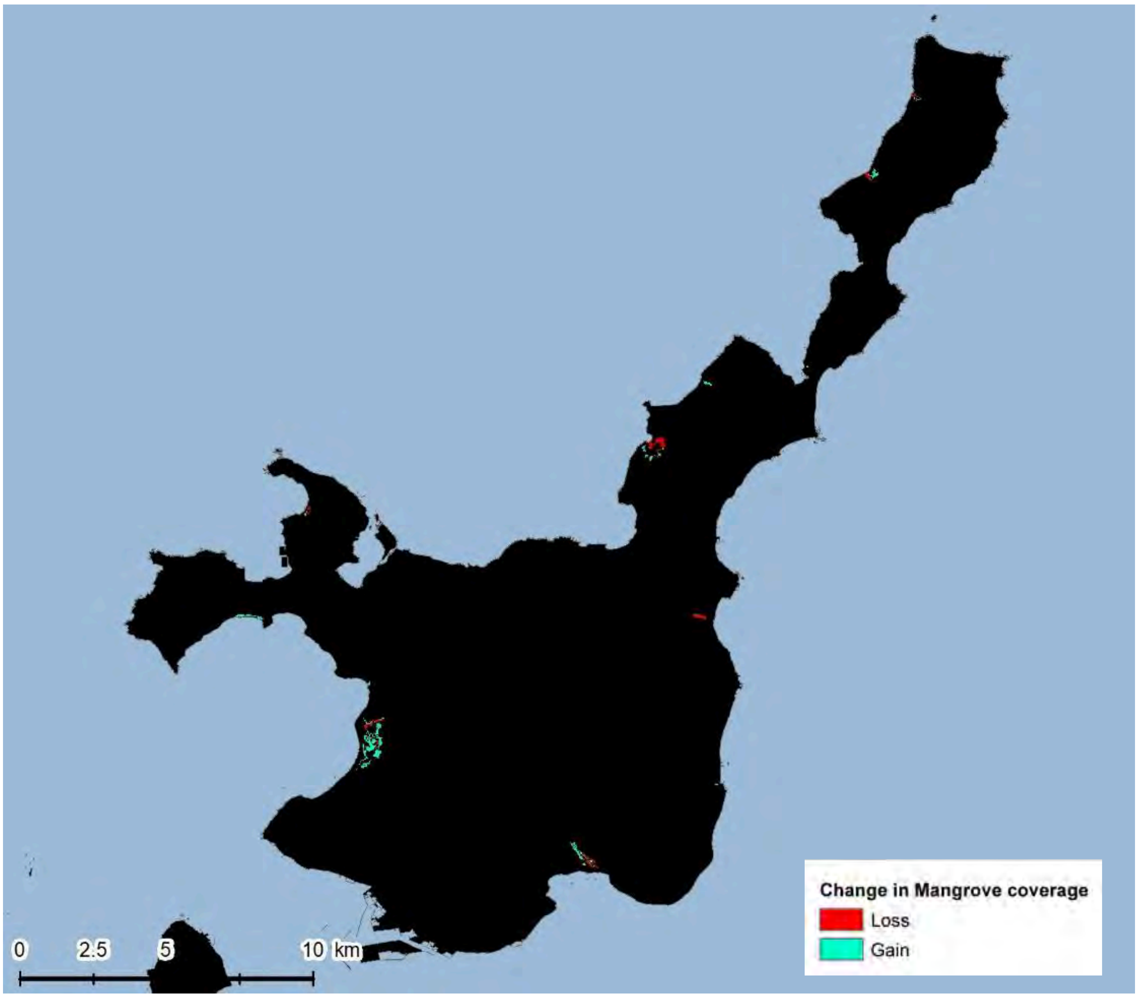


Figure 1. Mangrove cover loss and gain between 1981 and 2006

1.2. Future mangrove extent simulation

We conducted future land change simulation up until 2050 under the business-as-usual (BaU) scenario based on 1981 and 2006 vegetation map. In this course, we applied threshold value of 1% to screen out minor land use transitions: all land transitions whose total area are less than 1% of the total Ishigaki islands were not modelled. Further, we developed four sub-models representing nine land transitions (Table 2). Accuracies of the four transition probability models ranged from the lowest value of 65.1% (Grasslands) to the highest value of 78.3% (ResDev), which leave some areas of improvement. For transition modelling, we included all the major existing land-use zonings, including urban development, agricultural promotion, and nature conservation (e.g., nature reserves and forest reserves). There was a small increase in the mangrove area (see Figure 4, Figure 5) but the increase was very minor considering the threshold used for screening (< 1%). Thus, in the modelling, both transitions from and transitions to mangroves were not modelled.

We performed soft and hard prediction for 2050 with 10 intervals (see Figure 2 for a hard prediction and Figure 3 for Soft prediction), which represent the business-as-usual situation in 2050. The result of hard prediction indicates that there will be a large increase in grassland (589 hectares) and cropland (987 hectares) in exchange of the reduction of broadleaf forest (522 hectares), coniferous forest (740 hectares) and residential land (284 hectares) (Table 3).

The map of soft prediction (Figure 3) indicated that land use is rather stable within the protected areas while the other areas are more vulnerable to land change, showing the effectiveness of zoning regulations such as nature reserves and forest reserves. However, there will be continuous loss of forest area into the future in exchange of the expansion of grassland and cropland outside of the protected areas (Table 3). The shrinkage of the residential area did not look a reasonable result since the recent statistics showed the steady increase in population. The underestimation of future growth in the future projection is presumably due to the year of land-use data used in the land-change modelling process: we used the land-use/cover data for the year 1981 and 2006 for transition potential modelling, which did not capture recent urban growth trend since the opening of the new Ishigaki airport in 2013. Future land demands used in the land-change simulation need to be revisited for revision.

Table 2. Composition of the four transition sub-models

Model name	From	To
Forestation	Cropland	Broadleaf
	Broadleaf	Coniferous
	Broadleaf	Grass
	Grass	Broadleaf
	Grass	Coniferous
Grasslands	Cropland	Grass
Reclamation	Broadleaf	Cropland
	Grass	Cropland
ResDev	Cropland	Residential

Table 3. Changes in land use by class between 2006 and 2050

Class	2006	2050	net change
Broadleaf	10602	10080	-522
Coniferous	1626.75	886.95	-739.8
Grass	3593.7	4152.6	558.9
Mangroves	104.22	104.22	0
Riverside and coasts	180.63	180.63	0
Barren	142.65	142.65	0

Abandoned	164.34	164.34	0
Paddy	378.54	378.54	0
Cropland	3491.55	4478.85	987.3
Residential	1523.52	1239.12	-284.4
Other	184.59	184.59	0
Open water	365.49	365.49	0

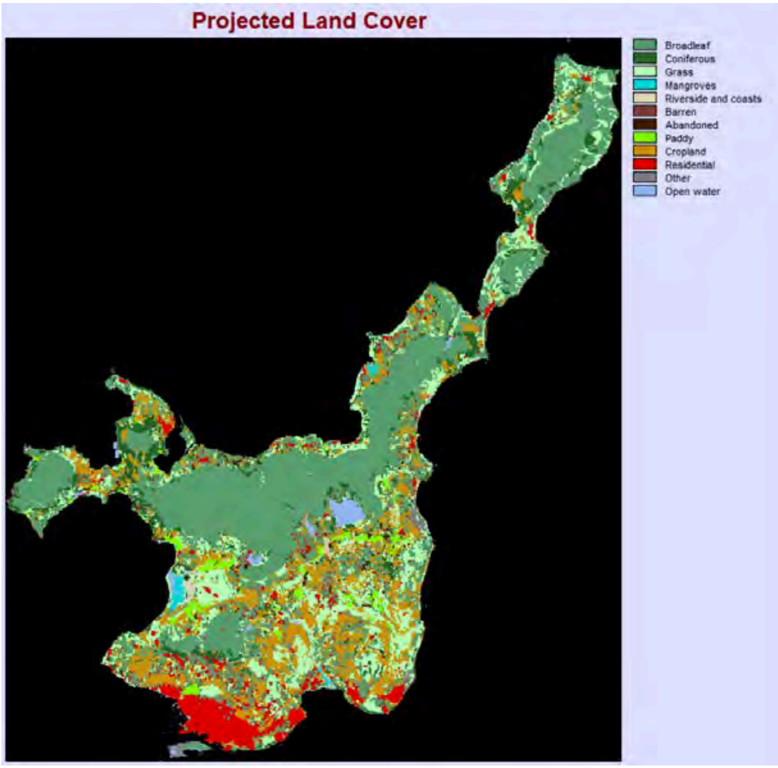


Figure 2. Future projection of land use of Ishigaki for 2050 under the business-as-usual condition.

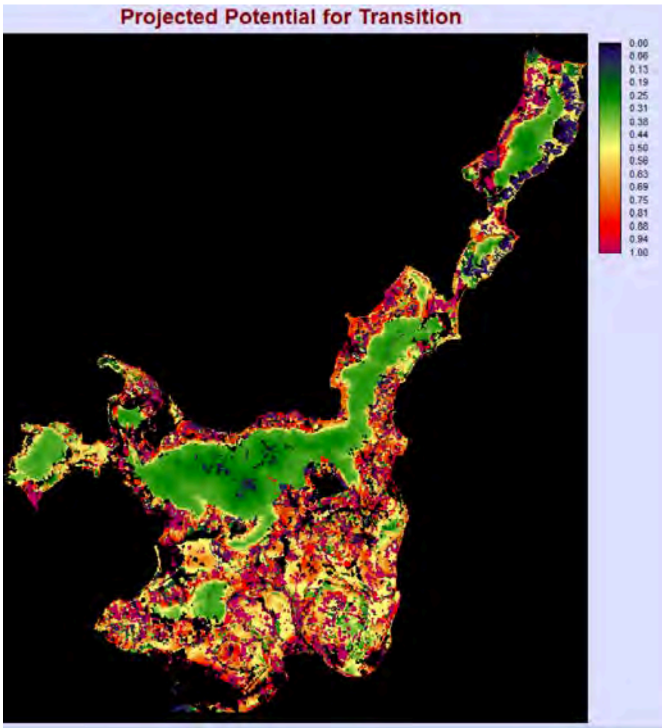


Figure 3. Soft-prediction for 2050 under the business as usual conditions. The closer the mesh value goes to 1 (from black to green, green or red), the more likely land use change is to occur at that location, demonstrating spatially-explicit land-change susceptibilities across the study area.

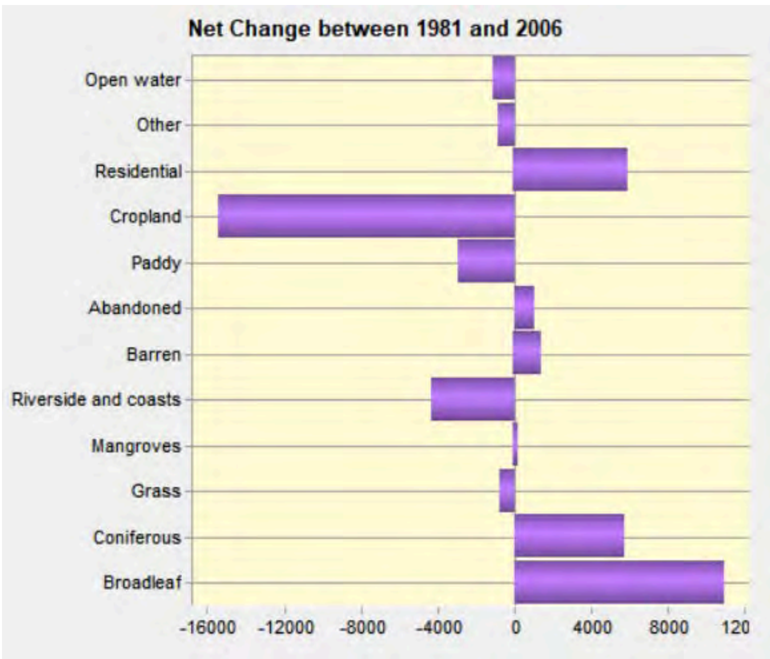


Figure 4. Net change between 1981 and 2006

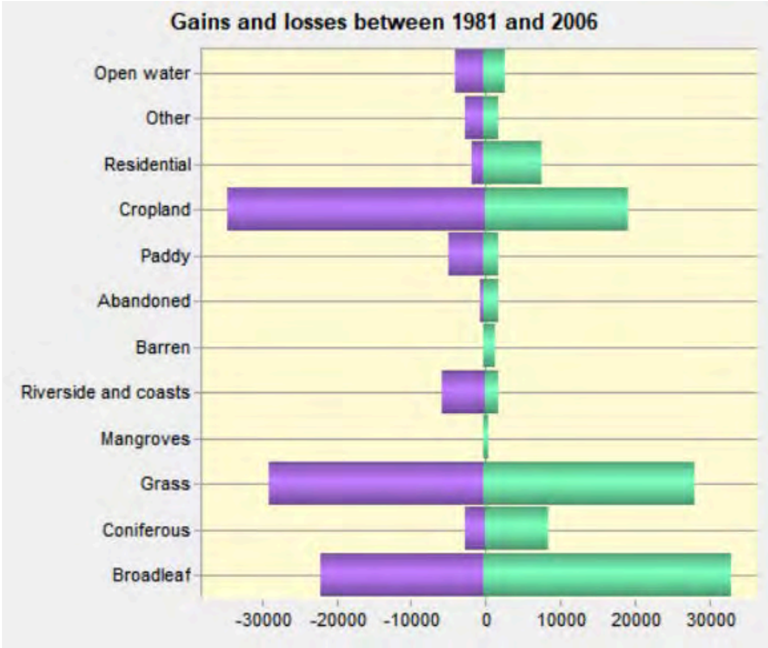


Figure 5. Gains and losses between 1981 and 2006

1.3. Direct drivers

We identified three likely drivers of mangrove cover change, out of the five common drivers of biodiversity loss (IPBES 2019), drawing on the temporal LULC data and field observations. These were anthropogenic land-use change, climate change and pollution, as presented below:

Land-use change: LULC flow from open water, riverside, marsh, salt swamp, and sand dunes to mangrove, and subsequently to broadleaf woodland may indicate dry succession towards more terrestrial type vegetation. Whereas, mangrove loss for open water may indicate natural disturbance that has been eroding mangrove stand frontier. Mangrove cover change in these two directions are not directly attributed to anthropogenic drivers but presumably indirectly to the two direct drivers explained below. Besides, we found the loss of a small patch of mangrove along Miyara River for constructing a new road for improving access to the new Ishigaki Airport from the Ishigaki City centre (Figure 6(a)). The Miyara river mangrove, which locates on unprotected private lands, are more prone to land-use change than the other two major mangroves that are protected as Natural Parks and/or Wildlife Preserve.

Climate change: Climate change is projected to exacerbate extreme climate events that impact mangroves. From field observations, we identified two incidents where extreme climate events affected mangroves. At Fukido river estuary, *Bruguiera gymnorhiza* was dying out due to massive sedimentation caused by a soil erosion in an upstream tributary (Figure 6(c)). Along Nakama river in the adjacent Iriomote Island, strong typhoon wind fell and opened up *B. gymnorhiza* stands (Figure

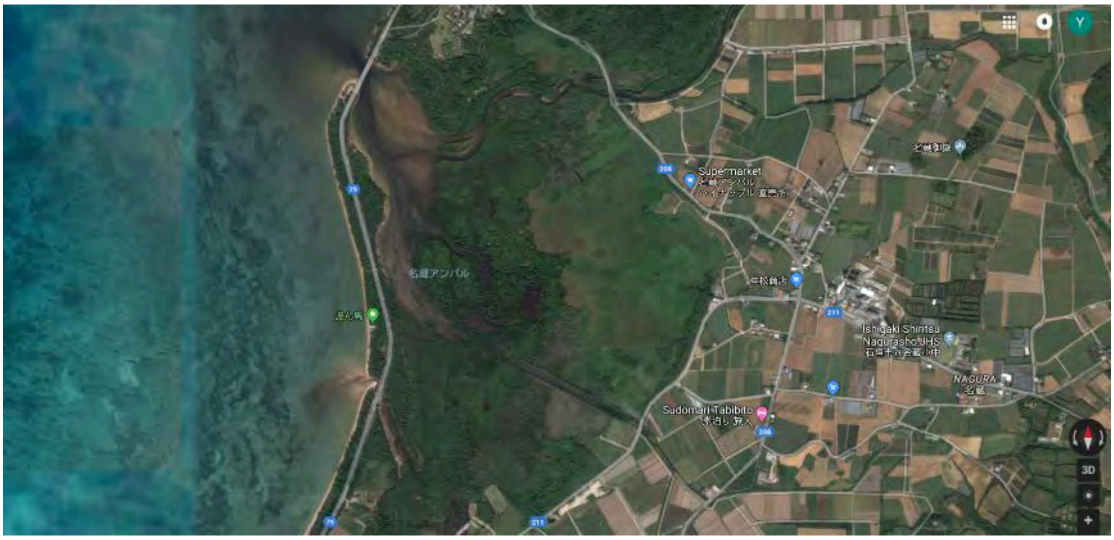
6(d)). These indicate the possible negative impacts of climate change on mangroves in two different ways: increased sedimentation caused by heavier rainfall and stronger river flow velocity accelerates dry succession, while stronger typhoon wind and storm wave directly damage mangrove trees.

(a) Road construction across Miyara river mangrove corridor

(b) Bare red soil during sugarcane intercrop susceptible to soil runoff in heavy rains

(c) *B. gymnorhiza* dying off along Fukido river due to massive sedimentation caused by a soil erosion in upstream catchment

(d) Strong typhoon wind destroyed *B. gymnorhiza* stands along Nakama river in the adjacent Iriomote Island



(e) Aerial photo of Nagura Anparu, indicating red soil deposit in saline swamp (source: Google Map)

Figure 6. Snapshots of the direct drivers of mangrove cover change

Pollution: Red soil runoff from agricultural lands in the upstream catchment (Figure 6(b)) affect downstream mangroves. For example, the Nagura Anparu swamp is undergoing rapid accumulation of red soil deriving from upstream agricultural lands (Nakaza et al. 2011) (Figure 6(d)). The mangrove cover gain and loss map (Figure 1) indicates expanding mangrove cover into previous open water and tidal flat areas in Nagura Anparu. Further sediment deposit is likely to drive its succession to terrestrial-type vegetation such as broadleaf forests. Mangroves along Miyara River, as well as in Nagura Anparu, are likely to be affected by pollution deriving from the upstream catchments, particularly red soil and associated nutrients runoff such as nitrogen and phosphorous (Blanco et al. 2010) runoff from sugarcane and pineapple farms that dominate agricultural lands in Ishigaki Island.

Direct use, i.e., mangrove wood extraction for house construction materials and dye was common in the past (Yoshimi 2011) but is not practiced nowadays. The impact of invasive alien species on mangrove cover was not identified from the information we collected.

1.4. **Indirect drivers**

We extracted the government statistics on demographic and economic trends that potentially act as indirect drivers of land use change. Below we summarized the overall tendencies of population and major industrial sectors on Ishigaki Island, i.e., tourism, agriculture and forestry.

The current population of the Ishigaki Island is 49,704 (as of August 2019) (Ishigaki City 2019). The population of the island has been increasing since 1920 except for a temporal decrease from the late 1960s to 1970s and is projected to increase until 2025 (Ishigaki City 2016). This mainly is attributed to in-migration from other regions. Accordingly, the aggregated building floor area has been in a continuous gradual increase in the past two decades (Figure 7).

Services sector, including tourism, is by far the largest economic sector (396.61 million USD) in the Island, followed by public services (288.38) and construction (114.76) as of 2014 (Ishigaki City 2017). Tourist number and tourism income nearly doubled since 2012 (Figure 7), which started immediately after the opening of the New Ishigaki Airport in 2013 enabled the landing of longer-distance flights from the Japan mainland and abroad. The tourist accommodation capacity gradually increased since 2003 but by far slower than the increase in the tourist number. The growing tourism sector may have various direct and indirect impacts on mangroves. Direct impacts may include the development of tourism infrastructures, such as roads across mangrove areas, and direct use of mangroves for boat or kayak trips. Indirect impacts may include land development, such as a golf course currently planned within the Nagura river watershed (Unimat Precious Co. 2018), that may change the hydrological and sedimentation scheme within the mangrove.

Agriculture is the seventh-largest sector, in which the share of beef cattle production is by far the largest (64.0 million USD[2]) in 2017, followed by industrial crops including sugarcane and Tabaco (14.2), vegetables (6.0), fruits (4.8) and cow milk (4.7) (MAFF 2018). Agricultural stock represented by the total farmland area, including grassland, and beef cattle heads underwent a continued slow decline in the past two decades. Nevertheless, GDP in the agriculture sector has been in overall increase, suggesting improved value-addition in the sector. The direct impact of agriculture development on mangroves, e.g., draining and converting mangroves into farmland, was not observed. Nevertheless, indirect impacts were implied from our observation and secondary data. The literature points out that farmland –particularly sugarcane field- affect mangroves through red soil and nutrient run-off (Blanco et al. 2010).

Forested land has been slowly increasing. The negligibly small economic output of the forestry sector indicates fairly limited use of the forest for timber production. A large share of forest (32.5% in 2017) is protected as forest reserve (Ishigaki City 2021) or as a natural park, and the share has been gradually increasing (Figure 7). In 2007, the Iriomote and Ishigaki National Park was expanded to include forested land on Ishigaki Island (MOE 2020a). The National Park area on Ishigaki Island was further expanded in 2016 which currently covers 7,121 ha (32%) over the total terrestrial surface of Ishigaki Island (MOE 2020b). These area protection measures are likely to prevent the decrease, or possibly drive the increase of forest land in the future.

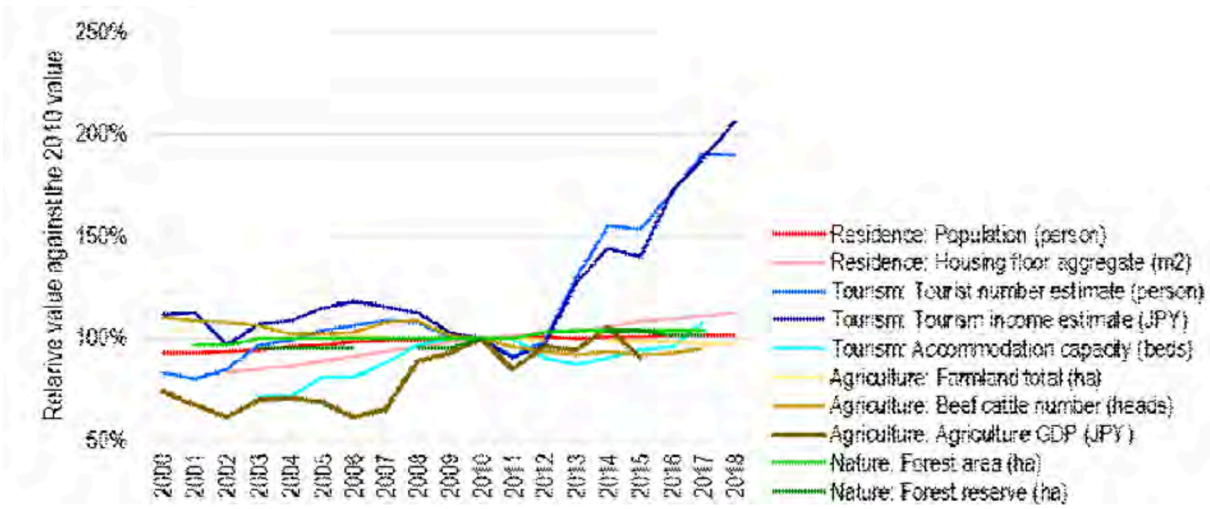


Figure 7. Trends in key variables on population, tourism, agriculture and nature conservation in the past two decades (Ishigaki City 2021)

1.5. Future scenarios

Downscaling of the global-scale scenario framework (the Nature Futures Framework (NFF)) (Pereira

[2] Applied the exchange rate of 1 USD = 110.60 JPY as of 11 August 2021

et al. 2020), Japanese national scenarios (the PANCES scenarios) (Saito et al. 2019) and the local scenarios for the Yaeyama region (PANCES 2021) identified three dimensions that are likely to drive future ecosystem changes. These were agriculture development, tourism development and nature conservation. Mapping existing general and sectoral policies and plans for Ishigaki Island in the three-dimensional space identified four distinct orientations that represent possible combinations of the three factors to different extents. These orientations were interpreted as plausible future scenarios:

- **Nature-sensitive integrated tourism and agriculture scenario** assume maximum synergies between the three foci. It assumes maintaining the total agricultural land area including dry and paddy fields and grassland and expanding conservation agriculture such as red soil run-off prevention measures for sugarcane and pineapples production, and windbreak forests along farmland borders (Okinawa Prefecture 2017). The scenario further assumes the expansion of protected areas and ecosystem restoration efforts into unprotected forested or open areas, e.g., from the current level (32%) to 50%.
- **Nature-centred tourism scenario** prioritises tourism over agriculture in scenario A. It assumes the decline in agricultural land, e.g., by abandonment and nature restoration, where natural ecosystems are rehabilitated and protected to the level equivalent to scenario A (50%). This may result in a wider option for nature tour destinations.
- **Integrated tourism and agriculture scenario** is less sensitive to negative impacts on the environment in scenario A. It assumes an increased number of tourists and associates increase in the development of tourism infrastructure, including accommodations, where possible within protected areas. It maintains total agricultural land area with weak environmental conservation measures. The scenario consequently can reduce nature tour destinations.
- **Resort island scenario** places higher tourist numbers and tourism revenue first. It increases land and sea surfaces converted for tourism infrastructure, including accommodations and other built recreation facilities. Such plans already exist on the Island, such as the development of a new integrated golf resort on current forest and agricultural lands (Unimat Precious Co. 2018), as well as an off-shore floating pier (pontoon) for more convenient marine leisure experiences (Yaeyama Mainichi Shinbun 2021). This scenario assumes less strict law enforcement that allows these developments within protected areas and thereby may result in reduced quality of nature tour destinations. Agricultural lands, including dry fields, paddy fields, and grasslands may be replaced by tourist infrastructure.

Ten key policy outcome metrics across the tourism, agriculture, and nature conservation sectors that can represent the four scenarios are also presented in Table 4. Among these, seven can be directly or indirectly translated into land surface change and thus relatively easily extrapolated into future ecosystem services modelling. Further, we illustrated how these metrics can be used for the assessment of the current and future drivers of change in the island ecosystem services in Figure 8.

Table 4. Four scenarios and the change in the relevant policy metrics assumed under the respective scenarios.

Sector	Metric	Scenario: A. Nature-sensitive integrated tourism and agriculture	B. Nature-centred tourism	C. Integrated tourism and agriculture	D. Resort island	Assumptions	Modellable
Tourism	Tourist number (person)	→	→	↗*	↑	*BaU	Yes
	Nature tour destination (ha)	→	↗*	↘**	↘**	*abandoned agricultural lands rehabilitated and used for nature tourism; ** natural land/sea developed for tourism	No?
	Residential area (ha)	→	→	↗*	↑**	*replace natural land; **replace natural and agricultural land	Yes
	Land development (e.g. golf course) (ha)	→	→	→	↗*	*replace agricultural/abandoned land	Yes
	Coastal development (e.g. pontoon) (ha/km)	→	→	→	↗*	*replace natural coastline/ecosystem	No?
Agriculture	Dry and paddy field (ha)	↘*	↘**	↘*	↓***	*abandoned farmland replaced by grazing land; **forest restored on abandoned farmland; ***replaced by residence or tourism infra	Yes
	Grassland (ha)	↗*	→	↗*	↘**	*grassland replace dry/paddy field; **replaced by residence or tourism infra	Yes
	Conservation agriculture (ha)	↗	→	→	→		Yes
Nature	Protected area (ha)	↗*	↗**	↘***	↘***	*expand protected area to unprotected/rehabilitated natural ecosystems; **abandoned land rehabilitated and protected; ***weak enforcement	Yes
	Restored area (e.g. reforestation) (ha)	↗*	↗**	→	→	*rehabilitate degraded ecosystems; **restore ecosystems on abandoned agricultural lands	No?

Legend	
↑	Increase
↗	Slight increase
→	Unchanged
↘	Slight decrease
↓	Decrease

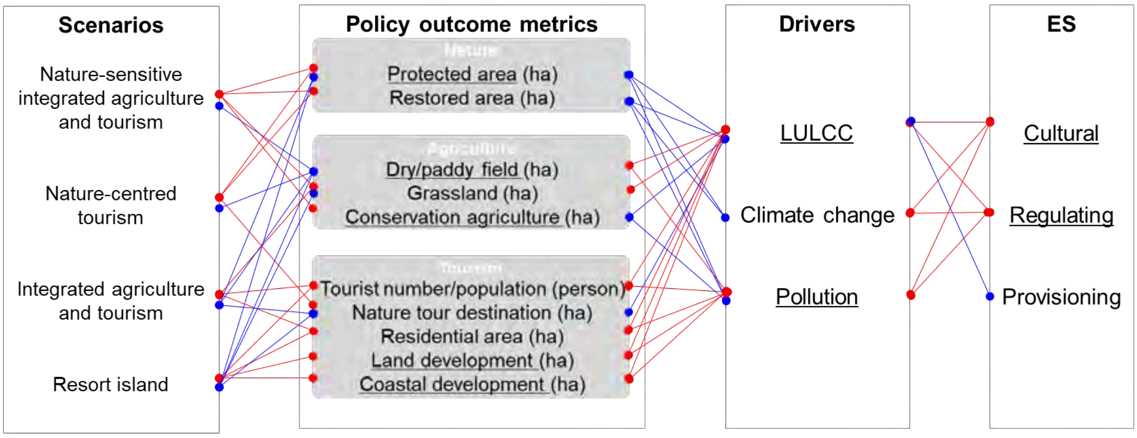


Figure 8. A schematic diagram on the links between scenarios, key policy outcome metrics, drivers and ecosystem services.

Note: Blue nodes and lines between policy metrics and drivers boxes indicate probable positive contributions to addressing the drivers and thereby to increased ecosystem services, while the red nodes and lines indicate possible negative impacts that further deteriorate the drivers and thus reduce ecosystem services. Policy metrics, drivers and ecosystem services that are found or likely to be relevant to mangroves are underscored.

2. Ecosystem services assessment

We had two distinct components in ecosystem services assessment for the Ishigaki site. The first component was a deep qualitative investigation of the present status of cultural ecosystem services (CES) from the residents' and tourists' perspectives. Due to their qualitative nature, CES are usually out of the scope of ecosystem services quantification and future projection, e.g., by InVEST. However, considering the importance of tourism for the Island's economy, better understanding of the present and potential future interplay between tourism development and ecosystem services provision was necessitated. The second component was the quantification and future projection of regulating ecosystem services as stipulated in the project proposal.

2.1. Present cultural ecosystem services

We conducted a questionnaire survey with the residents and visitors that included mapping exercise using public participatory GIS (PPGIS) method. Here, the visitors are those who visited Ishigaki from other parts of Japan and thus do not include international tourists. The survey asked the respondents to indicate in an Ishigaki Island map the places they found important for the provision of different cultural ecosystem services, i.e., for recreation, spiritual, learning, therapeutic, aesthetic and historic/bequest through mail survey (for residents) and face-to-face interviews. We obtained 384 (response rate: 12.8%) and 102 valid responses from residents and visitors respectively. The analysis clarified CES hotspots, which were different between the residents and tourists (Figure 9), and presented the following findings:

- Perception of different CES categories was different between residents and tourists.
- People attribute different type of CES to the areas of different land use/cover types, and the attribution pattern differed between residents and tourists.

A paper that compiled the result of this study was published in Ecosystem Services (https://doi.org/10.1016/j.ecoser.2023.101520).

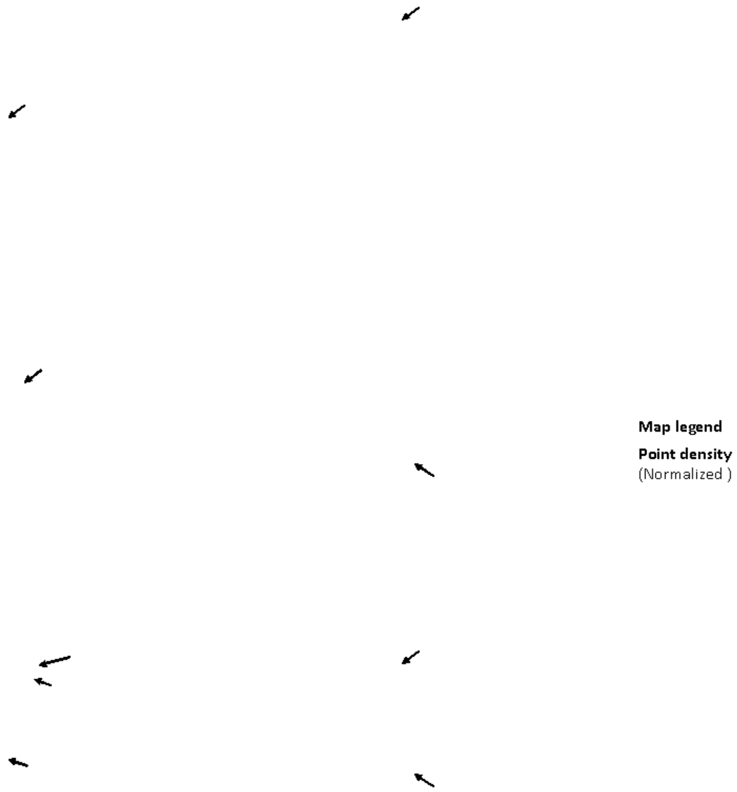


Figure 9. Spatial representation of recreational, spiritual, and educational cultural ecosystem services identified by residents and tourists.

2.2. Scenario-based estimation of future ecosystem services

As the basis for scenario-based projection of future regulating services, we projected the extent of different ecosystems on the Island towards 2050 under different future scenarios. We used different extent of cropland reduction (25 % and 50 %) to represent agricultural development, considering the persistent gradual farmland abandonment across the Island; and forest expansion vs. grassland expansion to represent the extent of area conservation. Upon these orthogonal axes, we projected the future extent of land use and land cover in four quadrants (Figure 10).

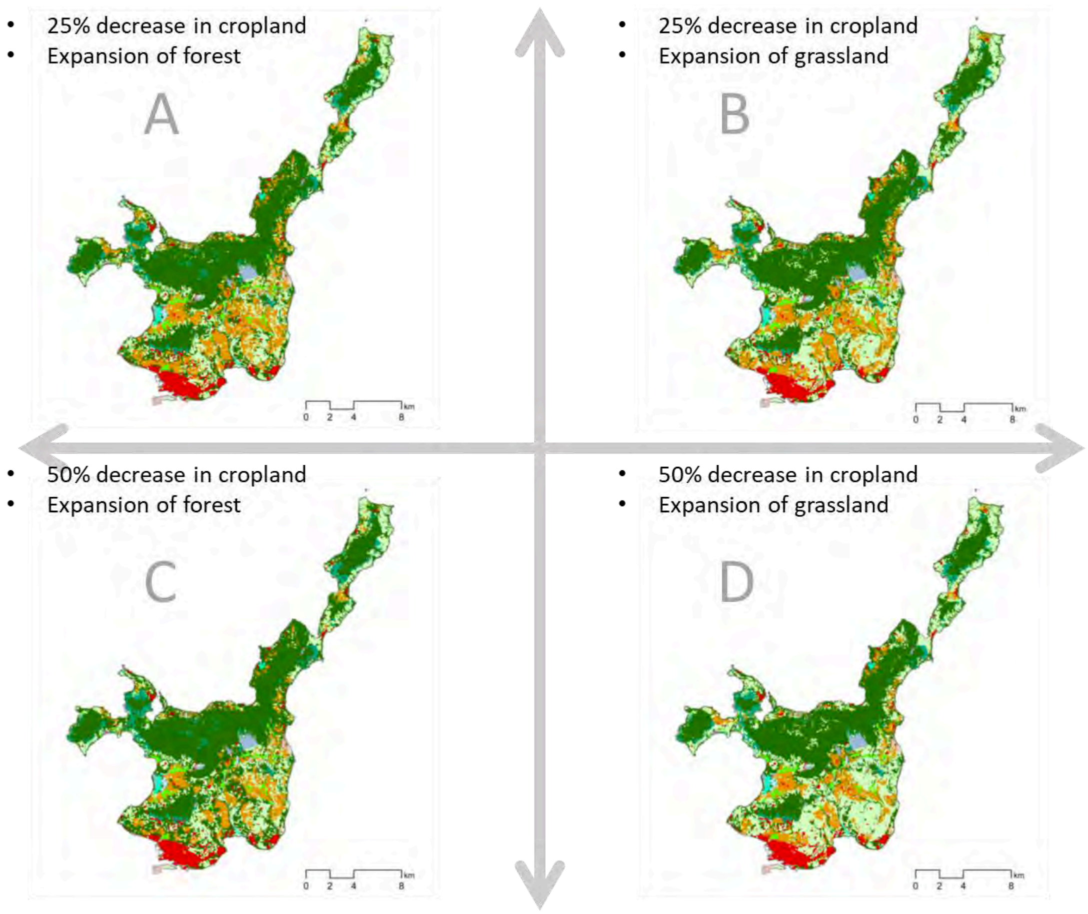


Figure 10. Projected extent of different ecosystem types in 2050 under the four scenarios

Thereafter, using InVEST, we mapped and quantified current and projected regulating ecosystem services at present (2006) and in 2050 under the four different scenarios with respect to nutrient (N and P) export and sediment deposition (Figure 11). All three ecosystem services projected demonstrated a significant declining trend since 1981 under all scenarios, which was presumably due to the large decrease in the cropland, one of the major non-point sources of nutrient and sediment. Overall, towards 2050, scenario D with a high cropland reduction and grassland expansion is projected to increase nutrient export the highest, whereas scenario C with a high cropland reduction and forest expansion will cause the highest sediment retention among the four scenarios (Figure 12).

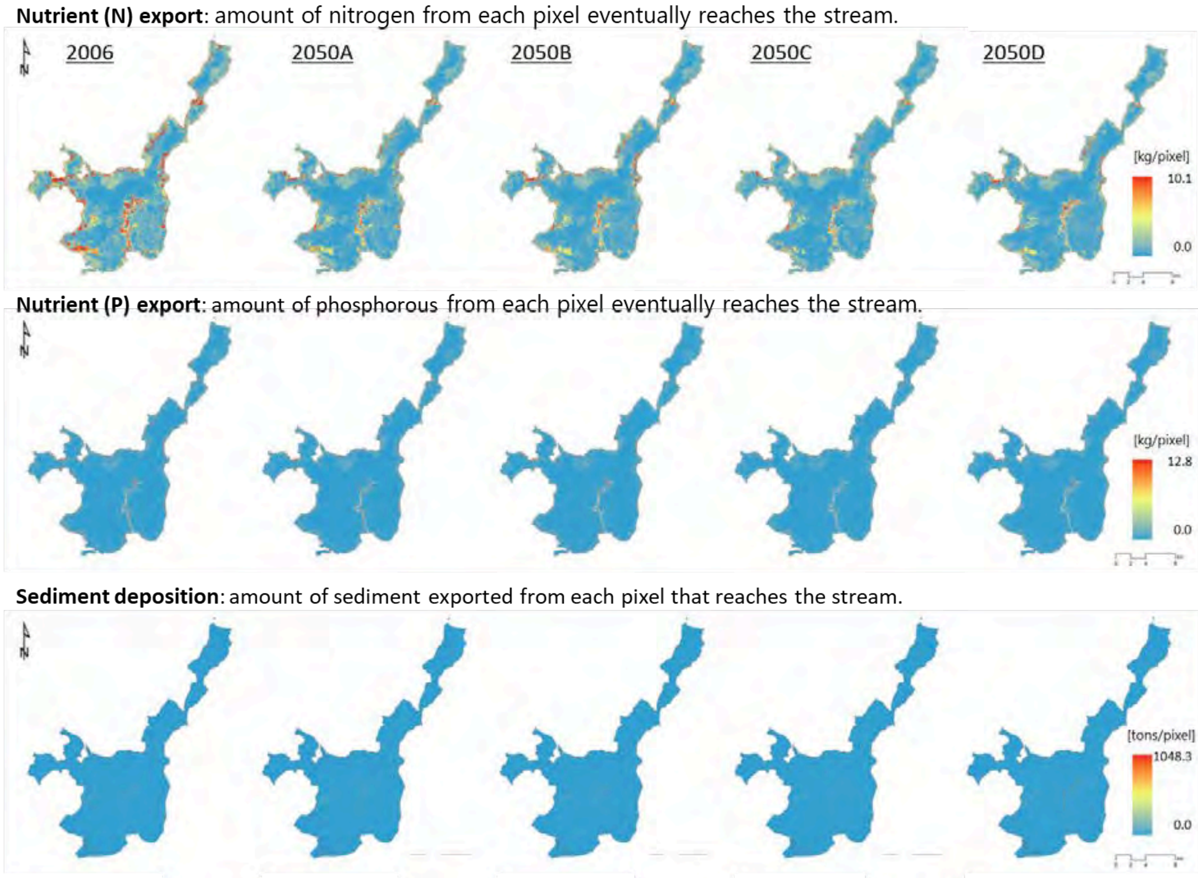


Figure 11. Spatial representation of current (2006) and projected (2050) regulating ecosystem services

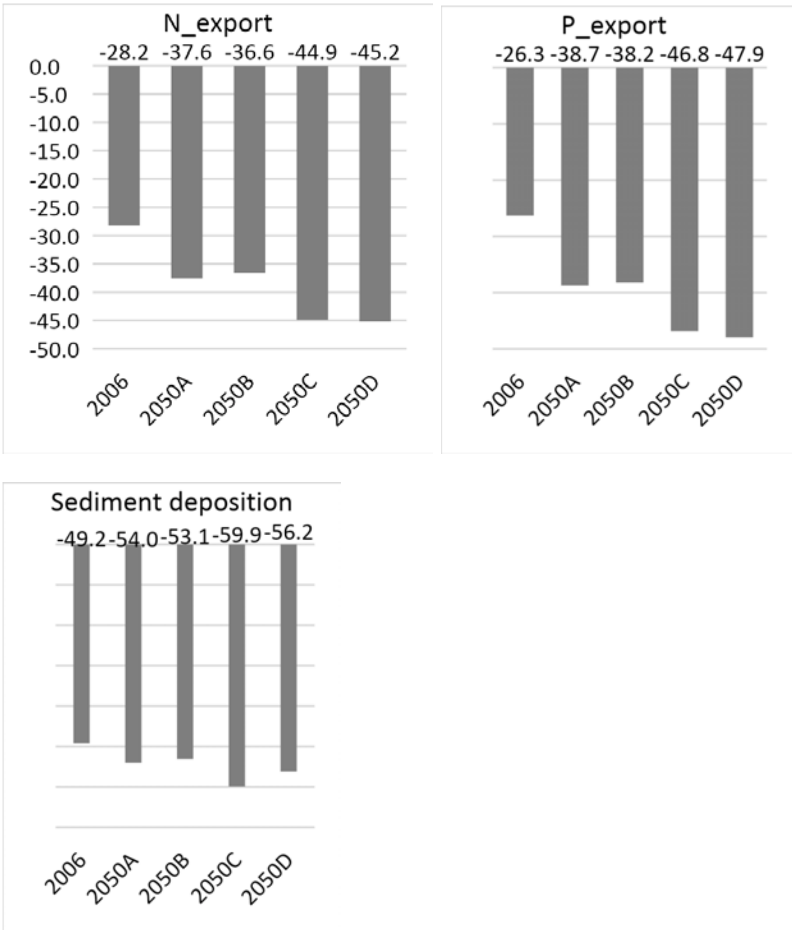


Figure 12. Percent change of nitrogen (N) export, phosphorus (P) export and sediment deposition from 1981

3. Scenario analysis on synergies and trade-offs in ecosystem services

The future projections of ecosystem services imply that changes in the three ecosystem services are closely linked to changes in local land use, especially in the area of cropland (Figure 11). Cropland in Ishigaki Island are known to be a major source of nitrogen, phosphorus, and sediment, and have various impacts on downstream water quality and estuarine ecosystems, including mangroves (Nakaza et al. 2011). Results of our analysis suggest that, under any future scenario, the threat from these pollutants may decrease due to future reductions in cropland. The extent of the reduction in nutrients export and sediment deposition varies from scenario to scenario, but is greater in Scenarios C and D, where the reduction in cropland is greater. The results also suggest that there is no significant difference between scenarios that assume the cropland area (i.e., Scenarios A and B, and Scenarios C and D), regardless of whether the cropland is replaced by grassland or forest. This is due to the fact that the indicators used in in this study are sensitive to increases or decreases in cropland area. If ecosystem services such as carbon sequestration and water yield, which are more sensitive to forest coverage, are used in the assessment, the result could be different; the scenarios with more forest coverage are likely to exhibit larger amount of carbon sequestration capacity but with less water yield due to increased evapotranspiration.

Publications

Takahashi Y, Hashimoto S, Wanhui, H. In Press. Ecosystem services and their future scenarios centring on mangrove ecosystems in Ishigaki Island, Japan. in Dasgupta R, Saito O (eds). *Assessing, Mapping and Modelling Mangrove Ecosystem Services in the Asia-Pacific*. Springer Nature, Singapore.

Tajima Y, Hashimoto S, Dasgupta R, Takahashi Y. (under review). Spatial characterization of cultural ecosystem services in Ishigaki Island of Japan: A comparison between residents and tourists. Ecosystem Services.

Difference between plan and actual implementation and self-evaluation

We accomplished all major benchmarks for the project period, while we were ought to change our approach to scenario development due to COVID-19 pandemic. COVID-19 spread in Japan since February 2020 severely constrained our field work, particularly a scenario workshop that requires attendance of a wide range of stakeholders within and beyond the project site. Instead, we conducted a desktop analysis to interpret existing global- and national-level future scenarios on biodiversity and ecosystem services into Ishigaki's context referring to relevant policy documents as explained in section 1 (1). Policy and planning documents we reviewed, such as the General Plan of Ishigaki City and LBSAP, include future vision statements and sets of policy objectives, often with specific time frames, to accomplish the visions. Development of these visions and policy objectives often goes through a predetermined administrative process mostly led by the municipal government, and sometimes includes multi-stakeholder participation. Thus, our approach to localized scenario development drawing on downscaling of the global and national scenarios as well as on local policy documents can be taken as an alternative to participatory scenario development.

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