Long-term Changes in Mangrove Distribution and Its Response to Anthropogenic Impacts

Thuong V. Tran[1], *, Ruth Reef[1], Xuan Zhu[1]

[1] School of Earth, Atmosphere and Environment, Monash University, Clayton, VIC 3800, Australia

Introduction

Mangroves, essential ecosystems found in tropical and subtropical coastal regions across five continents, are under threat due to land use and land cover changes (Romañach et al. 2018, FAO 2020). Over the past three decades, 831 thousand hectares were lost worldwide, and 16% of mangrove species are facing extinction (FAO 2020). Understanding the dynamics of mangrove distributions is critical to providing an accurate reporting for proposing appropriate mangrove ecosystem management strategies and serving as a reference for wider worldwide accounting (Van et al., 2015; Phan and Stive, 2022; Pham et al., 2022). In order to comprehensively understand these dynamics, remote sensing technology offers valuable insights compared to the traditional approach (Bunting et al., 2022; Chen et al., 2017; Giri et al., 2011). In previous studies, time-series Normalised Difference Vegetation Index (NDVI) trend and spatial regression were used to examine long-term changes in mangrove cover while separating changes in land use and land cover (LULC) categories (Betty et al. 2020; Chambers 2020). Therefore, we analysed the patterns of mangrove distribution trends in relation to land use and land cover change from 1988 to 2023 on the relatively protected Vietnamese Southern Coastline (VSC). Our research contributes to the preservation of mangroves and informs conservation efforts, policy-making, and future research.

Materials and Methods

The study area is the coastal region in southern Vietnam, located between 8.34°N to 10.42°N latitude and 104.28°E to 107.04°E longitude (Fig.1). The VSC is within the tropical monsoon region and encompasses low-lying terrain and nutrient-rich alluvial deposits from the Mekong and Dong Nai rivers. As a result, the VSC maintains the largest and richest mangrove ecosystems in Vietnam (Manh et al., 2014; Tinh et al., 2022)

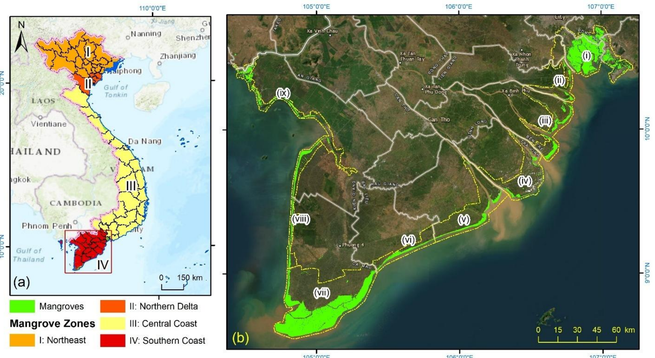

Fig 1. (a) Map showing the location of the study area and the four mangrove zones within Vietnam. (b) Total mangrove distribution (highlighted in light green) within the VSC region during the 1996–2023 period. This map is adapted from data provided by the Global Mangrove Watch (Giri et al., 2011), published VSC mangrove products (Tran et al., 2024), and supplemented with local insights.

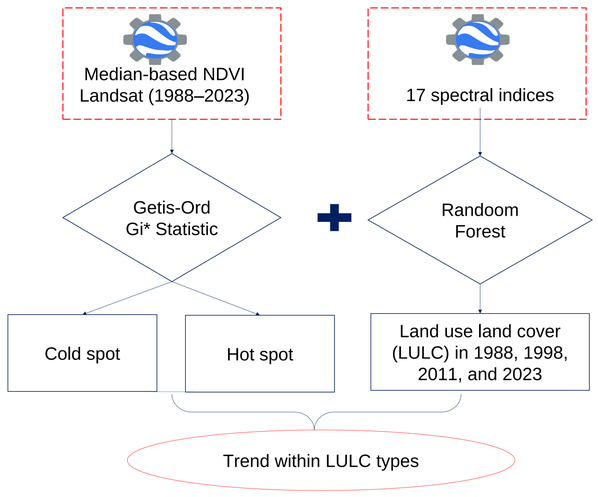

Fig 2. The flowchart of mangrove cover trend examination in relation to LULCC.

The primary dataset utilised in this study is the median normalised difference vegetation index (NDVI)-based time-series derived from Landsat imagery, obtained through the Google Earth Engine from 1988 to 2023. Afterwards, emerging hot spot analysis (ESRI, 2023) was applied to examine the significant trend and spatial patterns of mangrove cover. Notably, an assessment of mangrove trends in relation to changes in land use and land cover was performed to quantify the influence of human activities on mangrove dynamics (Fig.2).

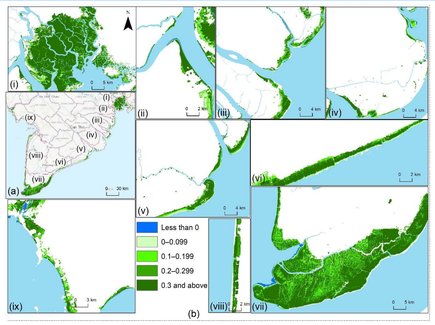

Fig 3. Mangrove density-derived from NDVI value during the 1988-2023 period.

Table 1. NDVI density categories and their area (ha).

NDVI value	Legend	Mangrove density	Area (%)
- 1 – + 0.99		No or almost no mangroves	19,542 (8.3)
+ 0.1 – + 0.19		Low density mangroves	28,651 (12.2)
+ 0.2 – + 0.29		Medium density mangroves	55,180 (23.6)
> + 0.3		High density mangroves	130,712 (55.8)

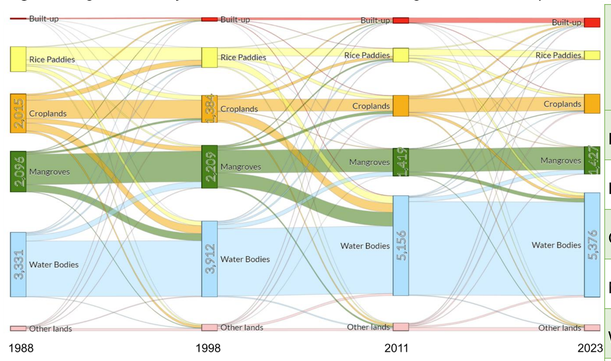

Fig 4. A Shankey diagram depicting the temporal change in area (km^2) of the five LULC types between the years 1988, 1998, 2011, and 2023.

Table 2. Proportion of LULC categories in the entire period.

LULC Categories	% Change in LULC			
	1988-1998	1998-2011	2011-2023	1988-2023
Built-up	190.89	64.03	71.39	717.78
Rice Paddies	-20.44	-30.66	-36.42	-64.92
Croplands	-31.31	-22.1	-8.96	-51.28
Mangroves	5.29	-35.48	0.65	-31.84
Water Bodies	17.29	31.83	4.41	61.58
Other lands	41.86	18.12	-18.52	36.54

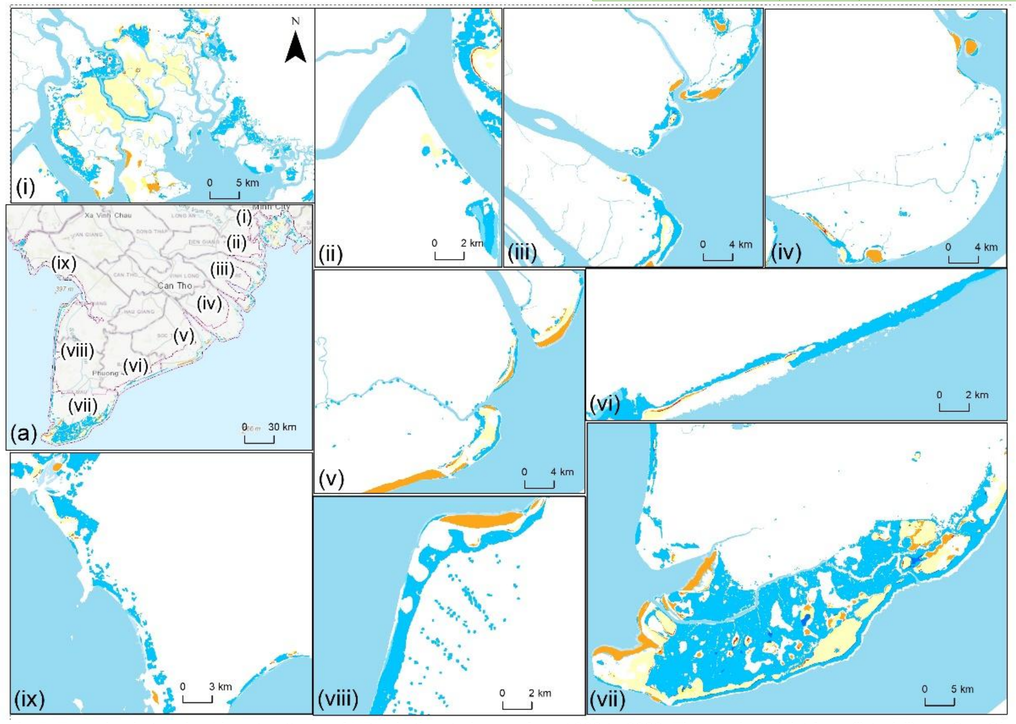

Fig 5. Emerging hot and cold spot patterns of NDVI in the study area from 1988 to 2023. The numbered list from (i) to (vii) are Can Gio area, Long An and Tien Giang, Ben Tre, Tra Vinh, Soc Trang and Bac Lieu, Ca Mau, Ca Mau west and Kien Giang, respectively.

Table 3. Change in mangrove area (ha) *(p<0.05)* based on NDVI hot spot analysis during the 1988 – 2023 period.

Pattern	Legend		Area		Net change	Definition
	Hot spot	Cold spot	Hot spot	Cold spot		
No pattern			8,646 (5.4%)		0	Does not fall into any of the hot/cold spot patterns defined.
Sporadic			469 (0.3%)	- 133 (0.1%)	336 (0.2%)	Some of the time step intervals are hot/cold.
Oscillating			13,005 (8.1%)	- 97,395 (60,6%)	-84,390 (52.5%)	Some of the time step intervals are cold/hot, some are hot/cold.
New pattern			182 (0.1%)	- 1,269 (0.8%)	-1,087 (0.7%)	The most recent time step interval is hot/cold for the first time
Intensifying			375 (0.2%)	- 3,325 (2.1%)	-2,950 (1.9%)	At least 90% of the time step intervals are hot/cold, and becoming hotter/colder over time
Historical			1,531 (1.0%)	- 263 (0.2%)	1,268 (0.8%)	At least 90% of the time step intervals are hot/cold, but the most recent time step interval is not.
Diminishing			29,357 (18.3%)	- 4,835 (3.0%)	24,522 (15.3%)	At least 90% of the time step intervals are hot/cold, and becoming less hot/cold over time

Fig 6. (a) Map displaying the number of regions in the VSC, with (vii) marking the Ca Mau Peninsula; (b) Location of the islet where natural mangrove regeneration occurred between 2017 and 2023 using composite RGB imagery, obtained from Google Earth Engine; (c) Field photo taken by T.V.T in 2023.

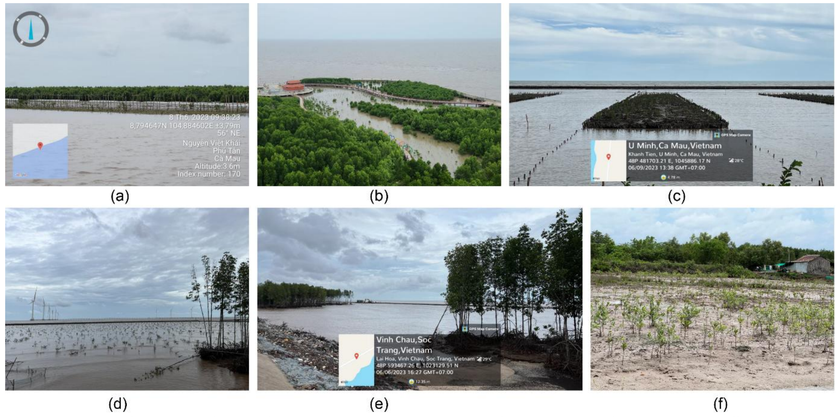

Fig 7. Examples of activities in mangrove restoration include: (a) Groins were installed to trap sediments, creating favourable conditions for mangrove growth on the islet (referenced in Figure 6); (b) planting mangroves in a tourism area; (c) preparation of land for mangrove plantation; (d) planting mangroves following the completion of wind farm construction; (e) a dyke designed to protect mangroves from wave action; and (f) planting mangroves in shrimp farming areas. All field photos were taken by T.V.T in 2023.

Highlights and Key Findings

+ **Advanced Methods:** Emerging hotspot analysis and machine learning revealed mangrove trends and land use impacts.

+ **Study Example:** Vietnamese Southern Coastline.

+ **Mangrove Loss Peaks:**
  - 1998–2011: Largest decline of 46.79% (3.6% per year), with 2,249 hectares deforested (2.0%).
  - 2011–2023: Deforestation slowed to 17.49% (1.5% per year).

+ **Restoration Success:** 1988–1998 saw the highest mangrove recovery, adding 1,795 ha (1.4%).

+ **Land Use Drivers**:
  - Shrimp Farming: Replaced 38.91% of mangroves.
  - Agriculture: Accounted for 5.82% of losses.
  - Built-Up Areas: Contributed 3.34% to mangrove decline.

+ **Policy Impact:** Land use policies strongly shaped mangrove distribution and restoration efforts.
  - Unsustainable Trends: Conversion to shrimp farming and impervious surfaces threatens sustainability.
  - Conservation Gains: Enhanced efforts and natural regeneration show promise.

+ **Broader Application:** This analytical approach can assess mangrove and land use changes in other coastal regions worldwide.

References

Betty EL, Bollard B, Murphy S et al., 2020. Using emerging hot spot analysis of stranding records to inform conservation management of a data-poor cetacean species. Biodivers Conserv 29:643–665.
Bunting, P., Rosenqvist, A., Hilarides, L., Lucas, R.M., Thomas, N., 2022. Global Mangrove Watch: Updated 2010 Mangrove Forest Extent (v2. 5). Remote Sens. 14, 1034.
Chambers SN, 2020. The spatiotemporal forming of a state of exception: repurposing hot-spot analysis to map bare-life in Southern Arizona's borderlands. GeoJournal 85:1373–1384.
Chen, B., Xiao, X., Li, X., Pan, et al., 2017. A mangrove forest map of China in 2015: Analysis of time series Landsat 7/8 and Sentinel-1A imagery in Google Earth Engine cloud computing platform. ISPRS J. Photogramm. Remote Sens. 131, 104–120.
ESRI, 2023. How emerging hot spot analysis works [online]. ArcGIS Pro. Available from: https://pro.arcgis.com/en/pro-app/latest/tool-reference/space-time-pattern-mining/learnmoreemerging.htm. [Accessed 25 Jul 2023].
FAO, 2020. The World's Mangroves 1980–2020. Rome: Food and Agriculture Organization of the United Nations, Rome, Italy.
Giri, C., Ochieng, E., Tieszen, L.L., Zhu, Z., Singh, A., Loveland, T., Masek, J., Duke, N., 2011. Status and distribution of mangrove forests of the world using earth observation satellite data. Glob. Ecol. Biogeogr. 20, 154–159.
Kendall, M.G., 1946. The advanced theory of statistics. Advanced theory Stat.
Mann, H.B., 1945. Nonparametric tests against trend. Econom. J. Econom. Soc. 245–259.
Pham T. T., Vien N. N., Vo Q. T., Tang T. K. H., Nguyen T. L., Tran N. M. H., et al., 2022. Opportunities and challenges for mangrove restoration in the Mekong delta: Status, policies and stakeholder (Bogor, Indonesia: CIFOR).
Phan, M.H., Stive, M.J., 2022. Managing mangroves and coastal land cover in the Mekong Delta. Ocean Coast. Manag. 219, 106013.
Romañach, S.S., DeAngelis, D.L., Koh, H.L., Li, Y., Teh, S.Y., Raja Barizan, R.S., Zhai, L., 2018. Conservation and restoration of mangroves: Global status, perspectives, and prognosis. Ocean Coast. Manag. 154, 72–82.
Sen, P.K., 1968. Estimates of the regression coefficient based on Kendall's tau. J. Am. Stat. Assoc. 63, 1379–1389.
Theil, H., 1992. A rank-invariant method of linear and polynomial regression analysis, in: Henri Theil's Contributions to Economics and Econometrics. Springer, pp. 345–381.
Van, T.T., Wilson, N., Thanh-Tung, H., Quisthoudt, K., Quang-Minh, V., Xuan-Tuan, L., Dahdouh-Guebas, F. and Koedam, N.J.A.O., 2015. Changes in mangrove vegetation area and character in a war and land use change affected region of Vietnam (Mu Ca Mau) over six decades. Acta Oecologica, 63, pp.71-81.

thuong.tran@monash.edu
Thuong Tran
0000-0003-1612-6313

SCAN ME