Vietnam blue carbon opportunity assessment

Erin Swails
Vo Quoc Tuan
Pham Thu Thuy

WORKING PAPER 47

Working Paper 47

Vietnam blue carbon opportunity assessment

Erin Swails
CIFOR-ICRAF

Vo Quoc Tuan
Can Tho University

Pham Thu Thuy
Flinders University

CIFOR-ICRAF

Working Paper 47

DOI: 10.17528/cifor-icraf/009370

Swails E, Tuan VQ, Pham TT. 2025. *Vietnam blue carbon opportunity assessment*. Working Paper 47. Bogor, Indonesia: CIFOR; Nairobi, Kenya: ICRAF.

CIFOR
Jl. CIFOR, Situ Gede
Bogor Barat 16115
Indonesia
T +62 (251) 8622622
F +62 (251) 8622100
E cifor@cifor-icraf.org

ICRAF
United Nations Avenue, Gigiri
PO Box 30677, Nairobi, 00100
Kenya
T +254 (20) 7224000
F +254 (20) 7224001
E worldagroforestry@cifor-icraf.org

cifor-icraf.org

Contents

List of figures and tables

Figures

Tables

1 Introduction

The term “blue carbon” refers to the carbon stored in the vegetation and soils of marine ecosystems, particularly mangroves, salt marshes and seagrass meadows. These ecosystems are global hotspots for greenhouse gas (GHG) sequestration, contributing more than 50% of total carbon storage in ocean sediments (Duarte et al. 2005; Mcleod et al. 2011; Krause-Jensen et al. 2016). Nonetheless, blue carbon ecosystems around the world are facing increasing pressures from human activities and climate change (Waycott et al. 2009; Goldberg et al. 2020; Campbell et al. 2022). Degradation and conversion to other uses release carbon stored in biomass and soil back into the atmosphere, transforming these ecosystems from a net GHG sink into a source of GHG emissions. Protection and restoration of mangroves, salt marshes and seagrass meadows are recognized as effective ways to reduce anthropogenic GHG emissions (Macreadie et al. 2021). Additionally, these ecosystems provide essential services such as fish, timber, coastal protection and pollution control.

Voluntary carbon projects can mobilize foreign direct investment for climate change mitigation and sustainable development that is not provided through regulation. In so doing, it offers financing that complements government efforts to mitigate climate change. A carbon credit is a certified and transferable instrument representing the removal or avoided emission of 1 ton of CO_2 or equivalent GHG (CO_2e). Carbon credits are created by climate change mitigation activities that remove or reduce GHG emissions. Once certified by carbon standards, carbon credits can be traded and ultimately retired to “offset” emissions. The voluntary carbon market is where private individuals, corporations and other actors issue, buy and sell carbon credits outside of mandatory GHG reduction schemes. Global interest in blue carbon credits is growing (IFC 2023).

Voluntary carbon credits, including blue carbon credits, must comply with strict criteria to ensure their integrity and quality. For this reason, carbon standards are central to the operation of the voluntary carbon market. Standards are GHG crediting programmes managed by organizations that provide and administer the rules and requirements for voluntary projects and programmes, certify and issue carbon credits, and facilitate their trade.

Key elements of high-quality carbon credits include conservatively quantifying GHG emissions reductions or removals; credible baselines; accounting for leakage; following robust measurement, reporting and verification protocols; and assuring that the climate benefits are additional and permanent. To this end, carbon standards define methodologies. These are standardized tools for carbon project design that ensure all projects developed under the standard are of similar high quality wherever they are implemented.

The main voluntary carbon market standards with methodologies applicable to blue carbon projects are the Verified Carbon Standard (VCS) and Plan Vivo. Together, these two standards account for all voluntary market blue carbon projects registered or in the pipeline. To date, the VCS has the most projects at 56 (55 mangrove, 1 seagrass) and Plan Vivo has 12, all mangrove.

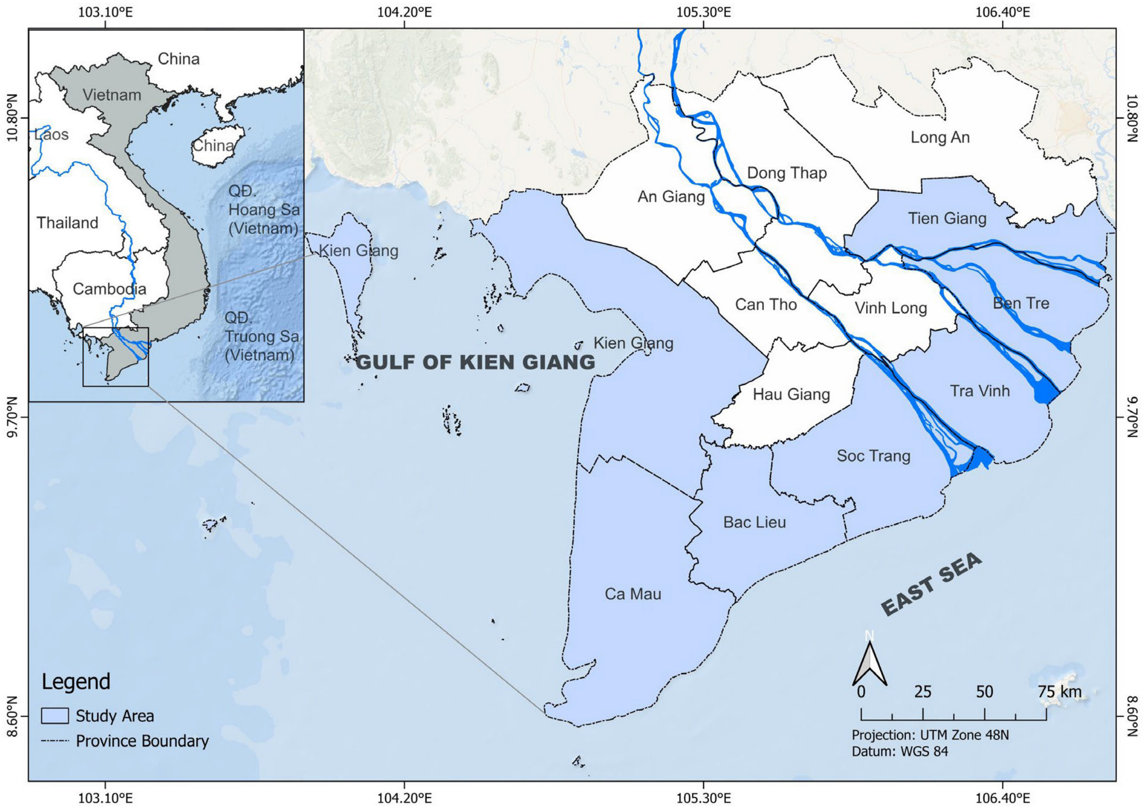

Figure 1. Blue carbon opportunity assessment area

Note: The figure comprises the focus provinces of Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre and Tien Giang in Vietnam. The Mekong River is indicated in dark blue.

We assessed blue carbon opportunities in Vietnam focusing on the seven coastal provinces of the Mekong Delta (Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre and Tien Giang) (Figure 1) under the project "Enabling a high quality – high integrity blue carbon market in Vietnam." This project seeks to develop and build innovative financing mechanisms, transformative partnerships and inclusive decision-making processes for more equitable access to blue carbon market benefits for Indigenous Peoples, local communities, women and youth in Vietnam. The assessment aims to support the Government of Vietnam in evaluating the potential of blue carbon opportunities, leading to the design of appropriate policies.

2 Methods

2.1 Status of blue carbon ecosystems in Vietnam at national level

We reviewed data and scientific literature on mangroves, salt marshes and seagrass meadows in Vietnam to assess four key indicators. These indicators comprised the spatial extent of blue carbon ecosystems; total carbon storage in live vegetation and soil; rates and drivers of degradation; and gross GHG emissions from ecosystem conversion. We then compared the relative sizes of blue carbon opportunities among ecosystems in terms of potential future net GHG impacts.

Mangrove areas and change at the national level were taken from an analysis of Landsat data spanning 1995–2019 by Tinh et al. (2022). We assumed carbon stocks in above-ground biomass of 58 Mg C ha^{-1} (MARD 2016). Below-ground biomass carbon (28 ± 6 Mg C ha^{-1}) was computed by applying a root:shoot ratio for wet tropical mangrove forests (0.49, Kennedy et al. 2014). To estimate soil carbon storage, we used a regional stock value for mangroves in Southeast Asia in (258 ± 32 Mg C ha^{-1}, Murdiyarso et al. 2024).

The 1995–2019 annual rate of deforestation (0.3%, Tinh et al. 2022) was projected over 10 years to predict potential future CO_2 emissions from continued mangrove conversion. This assumed total loss of carbon stocks in above-ground biomass in the year of conversion and ongoing CO_2 emissions from soil carbon mineralization. Above-ground biomass carbon losses were multiplied by the molecular ratio of CO_2 to carbon (44/12) to convert to CO_2 equivalents. We calculated an aggregate emission factor for soil CO_2 emissions (20.6 ± 8.9 Mg CO_2 ha^{-1} yr^{-1}, Table 1) based on the relative contributions of aquaculture, agriculture, infrastructure and erosion to mangrove loss (Tinh et al. 2022). Erosion was not considered an anthropogenic disturbance in our analysis. Therefore, we excluded mangrove biomass and soil CO_2 emissions resulting from coastal erosion. We treated unidentified drivers as IPCC "Other Land" category, applying an emission factor of 0.

Additionally, we assessed mangrove coverage across Vietnam to identify the region with the largest opportunity for mangrove protection. To that end, we used 2024 data on mangrove extent developed by the Government of Vietnam.

There are few published measurements of seagrass meadow carbon stocks in Vietnam, except for the Luong and Nga study (2017) in the Thi Nai lagoon in Binh Dinh Province. We took seagrass areas and changes from an analysis of Landsat and Sentinel satellite images of all documented major seagrass beds in Vietnam between 1995–2019 by Trinh and Takeuchi (2019). A meta-analysis of published and unpublished data on seagrass meadows in Vietnam estimates carbon storage in live biomass and

Table 1. Soil CO_2 emission factors for mangrove forest loss at national scale in Vietnam

Land use	Contribution to mangrove loss[a] (%)	Soil CO_2 emission factor (Mg CO_2 ha^{-1} yr^{-1})
Aquaculture	43.9	23.8 ± 1.5[b]
Agriculture	29.1	29.0 ± 6.2[c]
Infrastructure	5.8	29.0 ± 6.2[c]
Erosion	14.9	n.a.
Other	6.2	0

Note: Values are mean ± standard error.
a Tinh et al. 2022
b Murdiyarso et al. 2024
c Kennedy et al. 2014

sediments at 133.2 ± 37.0 Mg C ha^{-1} (Stankovic et al. 2021). We projected the 1995–2019 annual rate of seagrass decline (1.9%, Trinh and Takeuchi 2019) over 10 years to predict potential future CO_2 emissions from continued seagrass meadow loss. This assumed total loss of carbon stocks in above- and below-ground biomass (11 Mg CO_2 ha^{-1}, Mitsch and Gosselink 2000) in the year of conversion and ongoing CO_2 emissions from soil carbon mineralization (0.6 ± 0.3 Mg C ha^{-1} yr^{-1}, n = 4, Macreadie et al. 2014; Marbà et al. 2015; Serrano et al. 2016).

With regards to salt marshes, these ecosystems are found in the intertidal zone of sheltered marine and estuarine environments. They comprise brackish, shallow water and salt-tolerant herbs, grasses and shrubs. They are mainly located at temperate and high latitudes (Mcowen et al. 2017). Salt marshes are reported to occupy parts of the Mekong Delta (Olson and Morton 2018) but have not been well characterized or mapped. The total extent of salt marsh ecosystems in Vietnam is unknown and likely marginal. Therefore, the assessment of opportunities focused on mangrove and seagrass meadow ecosystems.

2.2 GHG emissions and removals by mangroves and seagrass in Mekong Delta coastal provinces

2.2.1 Spatiotemporal change in mangrove area

We used object-based image analysis (OBIA) to assess recent historical changes in the extent of mangroves (2016–2024) in the seven provinces. Many investigations use this approach for land-use and land-cover classification as it has more advantages than pixel-based classification (Son et al. 2014; Giri 2016; Baker et al. 2018; Zweifel et al. 2019).

Briefly, OBIA involves two steps: segmentation and classification. First, we used the multiresolution segmentation algorithm (Baatz and Schäpe 2000) to create a meaningful object based on our collected coordinates and our prior knowledge of mangrove forests in the region. Second, we used the Normalized Difference Vegetation Index and the distance to the coast to identify mangrove objects.

Based on our prior knowledge of patch sizes of mangrove forests in the region, segmentation parameters chosen were: scale = 40, shape = 0.01 and compactness = 0.5; while weights for layers were: NIR = 5 and other bands = 1. As these were deemed sufficient for collectively delineating mangrove patches in the region, they were applied for the segmentation process in this analysis. The final classification output was used to generate detailed spatial maps of mangrove extent. These maps were analysed to understand the distribution and changes in mangrove cover over time.

The classification results were validated using an independent validation dataset. The accuracy assessment for mangrove extent mapping from 2016 to 2024 is based on a different number of groundtruth points in each year, divided into mangrove and non-mangrove points. For instance, in 2016, the assessment used 452 mangrove points and 197 non-mangrove points for validation, while in 2024, it used 588 mangrove points and 298 non-mangrove points.

Accuracy metrics, including overall accuracy and Kappa Index, were computed to assess the performance of the classifier (Table 2). The overall accuracy of the classification ranged from 88.4% in 2016 to 93.8% in 2024. The Kappa Index, which measures the agreement between predicted and actual classifications, also fluctuated across the years. It improved from 0.73 in 2016 to 0.87 in 2020, stabilizing at 0.86 in 2024. These values reflect the varying reliability of the classification models, with some years showing stronger agreement between predicted and observed mangrove extents.

Table 2. Groundtruth point sample sizes, overall accuracy and Kappa coefficient values for accuracy assessment of mangrove classification results

	2016	2017	2018	2019	2020	2021	2022	2023	2024
Mangrove points	452.0	442.0	436.0	440.0	463.0	448.0	476.0	549.0	727.0
Non-mangrove points	197.0	313.0	236.0	257.0	207.0	201.0	206.0	205.0	384.0
Overall accuracy (%)	88.4	92.4	87.4	93.5	94.1	89.1	88.4	88.1	93.8
Kappa Index	0.73	0.83	0.72	0.84	0.87	0.76	0.74	0.73	0.86

2.2.2 Estimation of GHG emissions and removals by mangroves

We estimated CO_2 emissions and removals from mangrove conversion and restoration in the Mekong Delta coastal provinces between 2016–2024. As for the national level assessment, we assumed total above-ground biomass loss in deforested mangroves. We calculated soil CO_2 emissions using an aggregated emission factor for southern Vietnam (20.2 ± 8.9 Mg CO_2 ha^{-1} yr^{-1}, Table 3). We assumed that restored mangrove ecosystems accumulate soil carbon at the rate of -6.2 Mg CO_2 ha^{-1} yr^{-1} (Murdiyarso et al. 2024), and above-ground biomass at the rate of 9.9 ± 1.1 Mg ha^{-1} yr^{-1} (Kennedy et al. 2014). Above-ground biomass accumulation was converted to CO_2 equivalent (16.4 ± 1.8 Mg CO_2 ha^{-1} yr_{-1}), assuming a carbon fraction of 0.451 (Kennedy et al. 2014) and multiplying by the molecular ratio of CO_2 to carbon (44/12). Carbon accumulation rate in below-ground biomass (8.0 ± 0.9 Mg CO_2 ha^{-1} yr^{-1}) was computed applying a root:shoot ratio for wet tropical mangrove forests (0.49, Kennedy et al. 2014) to above-ground biomass carbon accretion.

Table 3. Soil CO_2 emission factors for mangrove forest loss in southern Vietnam

Land use	Contribution to mangrove loss[a] (%)	Soil CO_2 emission factor (Mg CO_2 ha^{-1} yr^{-1})
Aquaculture	41.4	23.8 ± 1.5[b]
Agriculture	26.9	29.0 ± 6.2[c]
Infrastructure	8.9	29.0 ± 6.2[c]
Erosion	17.7	n.a.
Other	5.1	0

Note: Values are mean ± standard error.
a Tinh et al. 2022
b Murdiyarso et al. 2024
c Kennedy et al. 2014

2.3 Anthropogenic pressures on mangroves in Mekong Delta coastal provinces

We additionally assessed human pressures on mangroves in the seven provinces using the Human Footprint Index (HFI) dataset (Figure 2). This dataset provides a global measure of human influence on terrestrial ecosystems by combining many factors, such as population density, land use, infrastructure and access points like roads and railways (Sanderson et al. 2022). The index is useful for understanding the extent and intensity of human activities affecting mangroves, which are highly sensitive to human-induced pressures.

We first prepared the HFI dataset by reclassifying the index values (0–50) into low, medium and high categories. This classification aimed to simplify the analysis by grouping similar levels of human pressure, facilitating the interpretation of results. The reclassified HFI layers were overlaid onto mangrove changes from 2016–2024. Through this analysis, we evaluated how varying levels of human pressure corresponded with mangrove loss or gain.

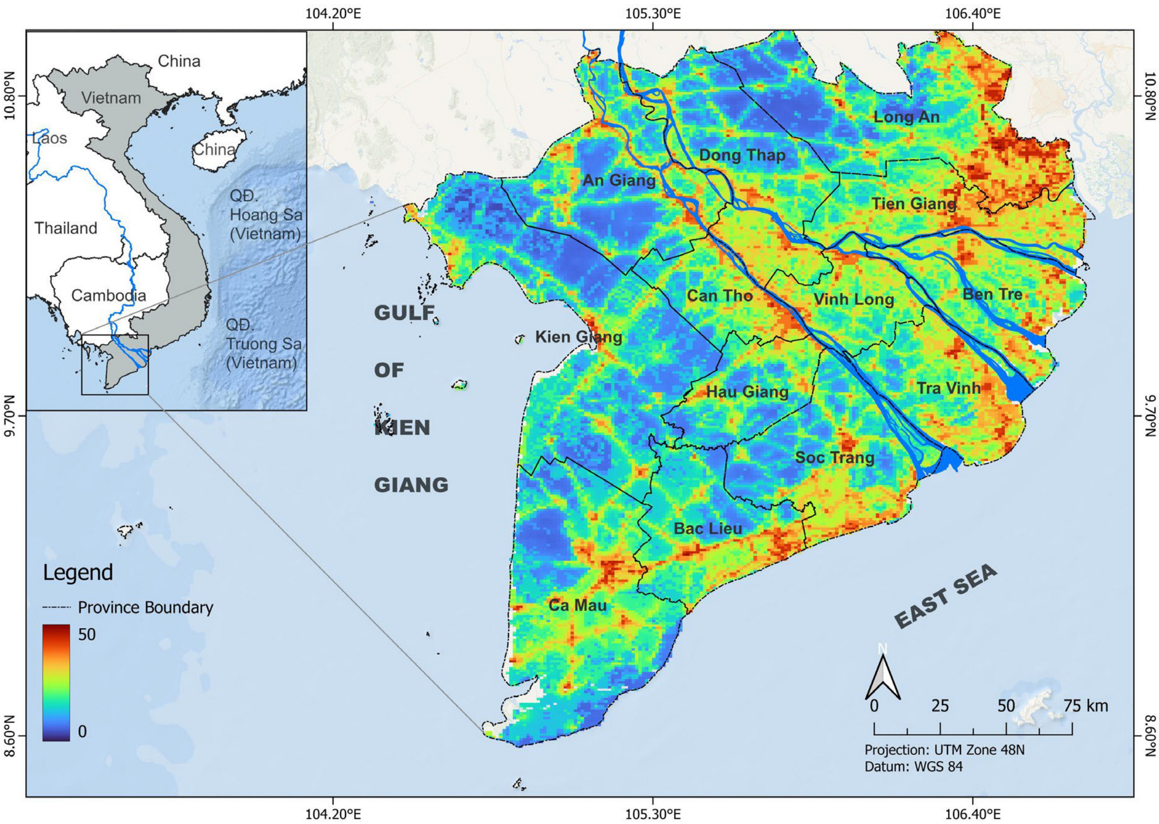

Figure 2. Human Footprint Index in the Mekong Delta of Vietnam in 2020

Source: https://wcshumanfootprint.org/data-access

2.4 Estimation of GHG emissions from seagrass loss

Our assessment of changes in seagrass meadow ecosystems in the Mekong Delta focused on Phu Quoc Island in Kien Giang Province. The seagrass beds at Phu Quoc Island contribute an estimated 66% of total seagrass extent in Vietnam; they are the only major seagrass beds in the Mekong Delta (Trinh and Takeuchi 2019). We calculated CO_2 emissions from seagrass loss at Phu Quoc Island between 2016–2024 based on an annualized rate of conversion between 2010–2019 estimated by Trinh and Takeuchi (2019).

As for the national level assessment, we assumed total loss of carbon stocks in above- and below-ground biomass (11 Mg CO_2 ha^{-1}, Mitsch and Gosselink 2000) in the year of conversion and ongoing CO_2 emissions from soil carbon mineralization (0.6 ± 0.3 Mg C ha^{-1} yr^{-1}, n = 4, Macreadie et al. 2014; Marbà et al. 2015; Serrano et al. 2016).

We estimated CO_2 emissions from seagrass meadow conversion in the Mekong Delta coastal provinces following the methods for the national-level assessment.

2.5 Identification of areas potentially suitable for blue carbon projects

We identified areas potentially suitable for conservation and restoration of mangroves in the Mekong Delta coastal provinces based on historical rates of conversion, extent of areas potentially suitable for restoration, estimated GHG emissions and removals, and existing anthropogenic threats. We considered areas of mangrove loss as potential areas for restoration, while mangroves experiencing medium to high levels of human pressures were considered as potential areas for conservation. We also evaluated the potential suitability of Phu Quoc Island as a seagrass carbon project site.

To evaluate the potential suitability of candidate sites, we considered the criteria of project additionality and baseline.

Additionality: A project is additional if it can be demonstrated that its activity results in GHG reductions or removals in excess of what would be achieved under a "business as usual" scenario without the incentive provided by carbon markets. Additionality is an important characteristic of GHG credits because it indicates they represent a net environmental benefit and a real reduction of GHGs that can be used to offset emissions.

Demonstration of "regulatory surplus" is critical to proving project additionality. Regulatory surplus means that project activities shall not be mandated by any law, statute or other regulatory framework; for UNFCCC non-Annex I countries such as Vietnam; or for any *systematically enforced* law, statute or other regulatory framework.

Baseline: The baseline refers to what would have happened in the absence of the project activity. A viable carbon project activity generates GHG emission reductions or removals compared to the baseline. We assessed the study of opportunities and challenges for mangrove restoration in the Mekong Delta by Thuy et al. (2023) to gain further insights into the potential suitability of candidate project sites.

2.6 Evaluation of blue carbon standards and methodologies for their application in Vietnam

We additionally reviewed carbon standards and methodologies applicable to blue carbon projects and evaluated their potential for use in a blue carbon market in Vietnam.

We assessed advantages and disadvantages of different standards and methodologies, and summarized enabling conditions for their application. Our analysis was limited to VCS, Plan Vivo and Gold Standard as the leading voluntary carbon market standards with methodologies applicable to blue carbon projects.

3 Results

3.1 Status of mangroves and seagrass meadows in Vietnam

3.1.1 Mangroves

Mangrove forests comprise shrub and tree species that thrive in saline and brackish waters along shores, rivers and estuaries in the tropics and subtropics. They are highly productive ecosystems accounting for 10% to 15% of global coastal sediment carbon storage (Alongi 2014). In 2020, the total area of mangrove forests worldwide was estimated at 145,068 km^2 (Jia et al. 2023).

Among regions, Asia contributes the largest share of global mangrove coverage (39.2%) (Alongi 2014). In Vietnam, the total estimated area of mangrove forests in 2019 was 1,685 km^2, primarily concentrated in southern Vietnam (Tinh et al. 2022). The Mekong Delta contributes approximately 60% of mangrove Vietnam's coverage (Veetil et al. 2019). Table 4 summarizes total mangrove coverage and estimated carbon stocks in Vietnam.

Globally, mangrove ecosystem loss largely results from conversion for aquaculture and agriculture. Up to 80% of these human-driven losses occur in six Southeast Asian nations, reflecting the region's focus on expanding aquaculture for export to support economic development (Goldberg et al. 2020). In Vietnam, aquaculture is the primary driver of mangrove deforestation, followed by agriculture (Veetil et al. 2019; Tinh et al. 2022). The Government of Vietnam has encouraged shrimp exports since the early 1990s and shrimp farming is widespread, particularly in the Mekong Delta coastal provinces (Pham et al. 2023). Urban development and coastal erosion are additional causes of mangrove loss in northern and southern Vietnam, respectively (Tinh et al. 2022).

Between 1995 and 2019, Vietnam lost 7.3% of its mangrove forest (Tinh et al. 2022). In recent years, restoration efforts have reversed the national trend of net mangrove forest loss to forest gain. However, Vietnam continues to lose mangroves due to the expansion of aquaculture, agriculture and infrastructure. Potential CO_2 emissions from mangrove conversion to other uses in Vietnam over the next decade are summarized in Table 5.

Table 4. Total estimated mangrove coverage and carbon (C) storage in above-ground (AGB) and below-ground (BGB) biomass and soil in Vietnam

Total area (km^2)	AGB (Mg C ha^{-1})	BGB (Mg C ha^{-1})	Soil (Mg C ha^{-1})	Total C (Tg C)
1,685[a]	58[b]	28 ± 6[c]	258 ± 32[d]	58 ± 5

Note: Values are mean ± standard error.
a Tinh et al. 2022
b, MARD 2016
c computed from AGB applying a root:shoot ratio of 0.49 (Kennedy et al. 2014)
d Murdiyarso et al. 2024.

Table 5. Estimated annual CO_2 emissions from potential future mangrove loss in Vietnam over 10 years

Year	Cumulative mangrove area loss (ha)	Vegetation carbon loss (Mg CO_2)	Soil carbon loss (Mg CO_2)	Total CO_2 emissions (Mg CO_2)
1	545	300,073	11,227	311,300
2	1,090	300,073	22,454	322,527
3	1,635	300,073	33,681	333,754
4	2,180	300,073	44,908	344,981
5	2,725	300,073	56,135	356,208
6	3,270	300,073	67,362	367,435
7	3,815	300,073	78,589	378,662
8	4,360	300,073	89,816	389,889
9	4,905	300,073	101,043	401,116
10	5,450	300,073	112,270	412,343
Total	**5,450**	**3,000,727**	**617,485**	**3,618,212**

Source: Authors' own calculations.

Table 6 gives an overview of all 28 provinces with mangrove forests in 2024. The Mekong Delta provinces of TP HCM, Tien Giang, Ben Tre, Tra Vinh, Soc Trang, Bac Lieu and Kien Giang together account for 80% of mangrove forest area in Vietnam.

Table 6. Contributions of natural, plantation and mangrove forests to total forest area in 2024 per province in Vietnam

STT	Province	Total forest area 2024	Forest type		Total mangrove area in 2024	Total mangrove area/total forest area 2024 (%)
			Natural forests	Plantation forest		
		Hectares				
1	Quảng Ninh	282,010.00	119,652.70	162,357.30	18,823.08	6.67
2	Hải Phòng	12,004.20	7,923.56	4,080.64	2,557.35	21.30
3	Thái Bình	157,079.00	-	4,155.51	4,155.51	2.65
4	Nam Định	3,077.57	114.16	2,963.41	2,831.15	91.99
5	Ninh Bình	26,947.28	23,125.03	3,822.25	663.74	2.46
6	Thanh Hóa	599,224.92	393,361.33	1,786.57	874.46	0.15
7	Nghệ An	973,011.94	790,396.60	182,615.34	337.62	0.03
8	Hà Tĩnh	313,452.99	217,351.47	96,101.52	685.98	0.22
9	Quảng Bình	548,240.71	469,481.54	78,759.17	19.64	< 0.01
10	Quảng Trị	85.05	55.48	29.57	72.19	85
11	Thừa Thiên Huế	282,893.85	205,581.66	77,312.19	90.30	0.03
12	Đà Nẵng	57,731.39	42,886.72	14,844.67	0.00	0
13	Quảng Nam	630,557.31	461,326.57	169,230.74	50.80	0.01
14	Quảng Ngãi	265,445.76	106,708.51	158,737.65	109.08	0.04
15	Bình Định	350,436.50	214,041.01	136,395.49	92.62	0.03
16	Phú Yên	240,278.00	126,959.84	113,318.16	0.00	0
17	Khánh Hòa	240,157.20	177,822.30	62,334.90	48.23	< 0.01
18	Ninh Thuận	158,086.00	147,419.70	10,666.40	5.10	< 0.01

Continued on next page

Table 6. Continued

STT	Province	Total forest area 2024	Forest type		Total mangrove area in 2024	Total mangrove area/total forest area 2024 (%)
			Natural forests	Plantation forest		
		Hectares				
19	Bình Thuận	342,410.22	296,926.80	45,483.40	12.63	< 0.01
20	Bà Rịa - Vũng Tàu	27,757.70	16,735.84	11,021.86	2,068.23	7.45
21	TP HCM	33,354.42	13,508.43	19,845.99	32,477.25	97.37
22	Tiền Giang	2,259.55	-	2,259.55	901.87	39.91
23	Bến Tre	4,272.09	1,237.53	3,034.56	3,885.23	90.94
24	Trà Vinh	9,705.55	2,935.00	6,770.55	8,862.38	91.31
25	Sóc Trăng	8,307.44	1,722.92	6,584.52	5,935.05	71.44
26	Bạc Liêu	4,327.23	1,848.27	2,378.96	4,307.77	99.55
27	Cà Mau	74,103.71	11,389.03	62,714.68	73,579.03	99.29
28	Kiên Giang	74,082.09	58,014.55	16,067.54	5,295.21	7.15
Total		**5,721,299.67**	**3,908,526.55**	**1,455,673.09**	**168,741.50**	

Sources: Authors' compilation of data based on different government reports.

3.1.2 Seagrass meadows

Seagrasses are aquatic plants that form patchy or extensive underwater meadows. These ecosystems are reported to occur in 191 countries spanning temperate and tropical regions (Short et al. 2007). Quantifying seagrass extent is difficult for several reasons. First, seagrass meadow areas fluctuate naturally in the absence of human disturbances. Second, remote sensing of underwater environments that vary in water clarity and depth is challenging (McKensie et al. 2001). Thus, estimates of global seagrass spatial distribution vary greatly, ranging between 160,000 to 600,000 km^2 (Green and Short 2003; Duarte et al. 2013; McKenzie et al. 2020).

The Indo-Pacific region, which includes Southeast Asia, is a seagrass hotspot contributing 44% of global seagrass extent (McKenzie et al. 2020). The total estimated extent of seagrass meadows in Vietnam is 156 km^2 (Thrinh and Takeuchi 2019). The most extensive seagrass meadows in the country are located in southern Vietnam around Phu Quoc Island in Kien Giang province (75 km^2, Nguyen et al. 2021). Total seagrass coverage and estimated carbon stocks in Vietnam are summarized in Table 7.

Worldwide seagrass coverage is declining due to coastal development, degradation of water quality and climate change, specifically sea level rise and warming ocean temperature (Duarte 2002). Reduction in seagrass meadow areas in Vietnam is attributed to land reclamation, aquaculture and degradation of water quality due to eutrophication (Thrinh and Takeuchi 2019). Disturbances from typhoons also cause major seagrass losses (Vo et al. 2020). Seagrass coverage in Vietnam was cut in half during the last three decades (Trinh and Takeuchi 2019). Total estimated GHG emissions from seagrass meadow loss in Vietnam over the next decade are summarized in Table 8.

Table 7. Total estimated seagrass coverage and carbon (C) storage in vegetation and soil in Vietnam

Total area (km^2)	Vegetation and soil C (Mg C ha^{-1})	Total C (Tg C)
156[a]	133.2 ± 37.0[b]	2.1 ± 0.6 Tg

Note: Values are mean ± standard error.
a Trinh and Takeuchi 2019
b Stankovic et al. 2021

Table 8. Estimated annual GHG emissions from seagrass meadow loss in Vietnam over 10 years

Year	Cumulative seagrass area loss (ha)	Vegetation carbon loss (Mg CO_2)	Soil carbon loss (Mg CO_2)	Total GHG emissions (Mg CO_2)
1	297	3,267	653	3,920
2	594	3,267	1,307	4,574
3	891	3,267	1,960	5,227
4	1,188	3,267	2,614	5,881
5	1,485	3,267	3,267	6,534
6	1,782	3,267	3,920	7,187
7	2,079	3,267	4,574	7,841
8	2,376	3,267	5,227	8,494
9	2,673	3,267	5,881	9,148
10	2,970	3,267	6,534	9,801
Total	**2,970**	**32,670**	**35,937**	**68,607**

Source: Authors' own calculations.

The estimated potential GHG impact of CO_2 emissions from mangrove conversion in Vietnam over 10 years is 52.7 times greater than the impact of seagrass loss during the same period.

3.2 Spatiotemporal change and CO_2 emissions and removals by mangroves in the Mekong Delta coastal provinces

Mangrove coverage varied significantly across the seven provinces during the assessment period. Overall, the mangrove areas in these provinces have experienced a decrease between 2016 and 2024, based on remotely sensed data (Figure 3).

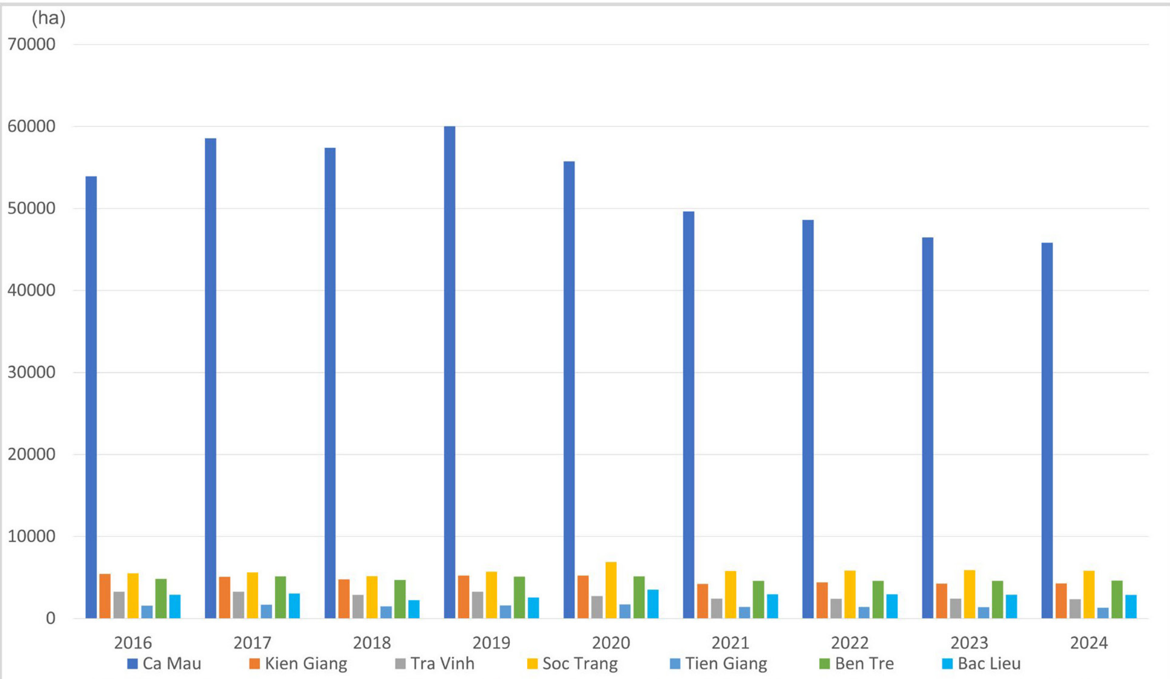

Figure 3. Distribution of mangroves in Mekong Delta coastal provinces of Vietnam 2016–2024

Ca Mau, with the largest mangrove coverage among the three provinces, saw its mangrove extent decline from approximately 53,924 ha in 2016 to 45,830 ha in 2024, a loss of about 8,094 ha. The total mangrove area across all seven provinces showed a general declining trend, decreasing from 77,400 ha in 2016 to 67,050 ha in 2024. While this trend was primarily driven by changes in mangrove area in Ca Mau, every province experienced conversion of mangrove areas over the eight-year study period.

These trends reflect the ongoing pressures of climate change, coastal erosion and other anthropogenic factors that threaten this ecosystem. This reduction affects local biodiversity, and also undermines the essential protective functions that mangroves provide against erosion and storm surges. The declining trend underscores the need for sustainable management practices to mitigate further losses, which could have significant implications for coastal resilience, biodiversity and local livelihoods.

The status of mangrove gain and loss in the study area reveals significant variations across the seven provinces (Figure 4).

Despite many efforts from the government to increase mangrove coverage, the data reveal substantial losses in some areas, highlighting the complex dynamics of mangrove conservation. Ca Mau, the province with the largest mangrove area, experienced the most significant decrease, losing 20,315.683 ha in that period. However, it also saw the highest increase in mangrove coverage, with 11,929.245 ha gained, indicating active restoration efforts, especially in a mudflat area.

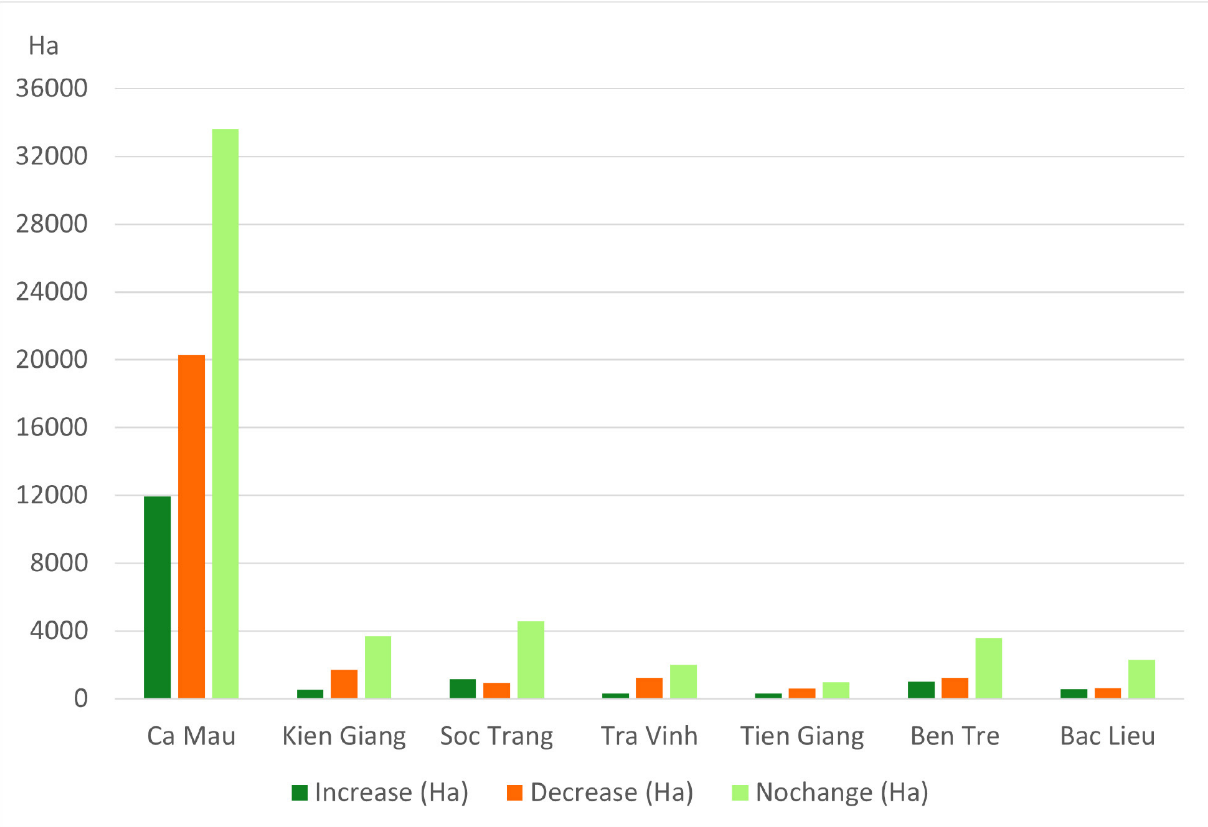

Figure 4. Total areas with mangrove increase, decrease and no change in Mekong Delta coastal provinces of Vietnam 2016–2024

Kien Giang and Tra Vinh also faced notable decreases in mangrove areas, losing 1,729.715 and 1,251.179 ha, respectively. These losses highlight the challenges of these provinces to maintain their mangrove ecosystems. Soc Trang, Tien Giang, Ben Tre and Bac Lieu reported losses as well, although on a smaller scale. Soc Trang, for instance, lost 928.397 ha but managed to increase its mangrove coverage by 1,162.026 ha, reflecting a positive net gain.

In Tien Giang province, the decrease of 598.511 ha was partially offset by an increase of 330.564 ha. Ben Tre saw a decrease of 1,248.364 ha, with an increase of 998.503 ha, while Bac Lieu experienced a decrease of 616.413 ha and an increase of 564.230 ha. These figures illustrate the ongoing efforts and challenges in mangrove restoration across the region.

Overall, the result shows a picture of both increases and decreases in mangrove area in the Mekong Delta. While significant areas have been restored, the losses in some regions highlight the need for continued and enhanced conservation/restoration. The balance between mangrove gain and loss is crucial for the sustainability of these vital ecosystems, which play a key role in coastal protection, biodiversity and local livelihoods. Continued monitoring, effective management strategies and community involvement are essential to ensure the long-term health and resilience of the Mekong Delta's mangrove forests.

Figure 5 displays the spatial distribution of mangrove loss and restoration in the three provinces. The persistence of mangrove loss during the study period underscores the complex dynamics of mangrove ecosystems in these provinces. Significant efforts are needed to address the losses and enhance the gains.

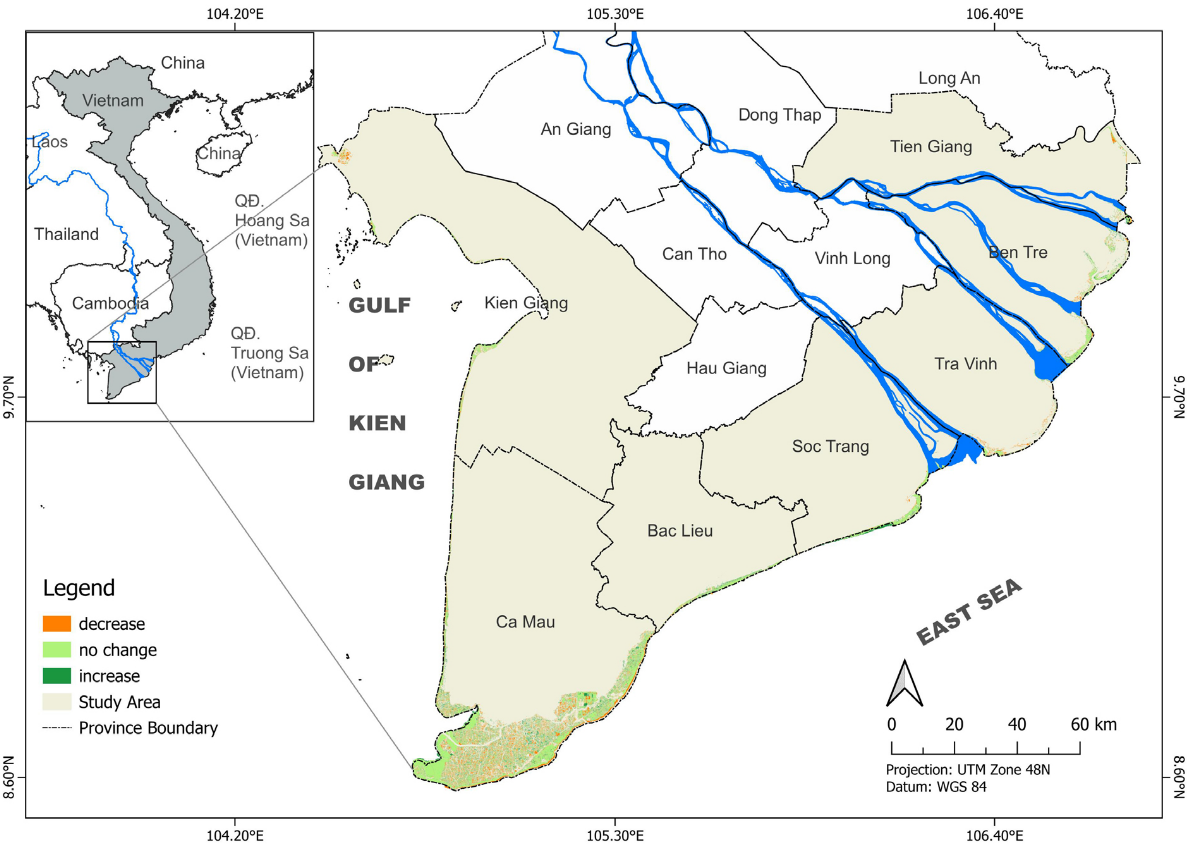

Figure 5. Spatial distribution of areas with mangrove increase, decrease and no change in Mekong Delta coastal provinces of Vietnam 2016–2024

CO_2 removals from mangrove restoration did not offset CO_2 emissions from mangrove loss during 2016–2024 (Table 9). The total net impact of mangrove loss and reforestation in the seven provinces during this period was 14.5 million Mg CO_2, with Ca Mau province contributing 77% of CO_2 emissions.

Table 9. Estimated CO_2 emissions and removals from mangrove loss and restoration in Ca Mau, Kien Giang and Soc Trang provinces of Vietnam 2016–2024

Year	Cumulative mangrove loss (ha)	GHG emissions (Mg CO_2)	Cumulative mangrove restoration (ha)	GHG removals (Mg CO_2)	Net GHG emissions and removals (Mg CO_2)
Kien Giang					
2016–2017	614	142,961	266	-8,154	134,807
2017–2018	1,146	136,344	497	-15,218	121,126
2018–2019	1,273	52,545	1,090	-33,387	19,158
2019–2020	1,783	144,503	1,581	-48,434	96,069
2020–2021	2,931	303,103	1,713	-52,483	250,620
2021–2022	3,171	115,087	2,129	-65,232	49,855
2022–2023	3,526	146,669	2,354	-72,121	74,547
2023–2024	3,801	134,981	2,640	-80,862	54,119
Total	**18,245**	**1,176,193**	**12,271**	**-375,891**	**800,302**
Soc Trang					
2016–2017	421	98,051	523	-16,030	82,021
2017–2018	1,138	175,338	785	-24,036	151,302
2018–2019	1,366	76,024	1,563	-47,877	28,147
2019–2020	1,737	114,083	3,120	-95,582	18,501
2020–2021	2,919	310,241	3,210	-98,324	211,917
2021–2022	3,201	124,408	3,538	-108,382	16,026
2022–2023	3,443	120,918	3,816	-116,905	4,013
2023–2024	3,762	143,749	4,065	-124,524	19,225
Total	**17,987**	**1,162,812**	**20,620**	**-631,658**	**531,154**
Ca Mau					
2016–2017	10,858	2,537,916	15,481	-474,227	2,063,689
2017–2018	23,919	3,281,512	27,374	-838,562	2,442,950
2018–2019	33,217	2,677,016	39,320	-1,204,507	1,472,509
2019–2020	44,134	3,251,553	45,953	-1,407,708	1,843,845
2020–2021	54,467	3,344,827	50,183	-1,537,260	1,807,567
2021–2022	58,839	2,169,332	53,515	-1,639,348	529,984
2022–2023	63,598	2,351,924	56,146	-1,719,953	631,971
2023–2024	67,247	2,192,710	59,153	-1,812,057	380,652
Total	**356,278**	**21,806,790**	**347,126**	**-10,633,623**	**11,173,167**
Bac Lieu					
2016–2017	293	68,328	443	-13,577	54,751
2017–2018	1,210	219,403	914	-28,002	191,401
2018–2019	1,371	61,727	1,408	-43,125	18,602

Continued on next page

Table 9. Continued

Year	Cumulative mangrove loss (ha)	GHG emissions (Mg CO_2)	Cumulative mangrove restoration (ha)	GHG removals (Mg CO_2)	Net GHG emissions and removals (Mg CO_2)
2019–2020	1,500	57,809	2,465	-75,515	-17,706
2020–2021	2,161	184,132	2,576	-78,922	105,209
2021–2022	2,304	76,779	2,719	-83,301	-6,521
2022–2023	2,478	87,139	2,842	-87,054	85
2023–2024	2,649	89,603	2,985	-91,456	-1,853
Total	**13,966**	**844,920**	**16,353**	**-500,952**	**343,968**
Ben Tre					
2016–2017	644	149,854	949	-29,082	120,773
2017–2018	1,561	226,464	1,420	-43,506	182,958
2018–2019	2,019	138,248	2,286	-70,022	68,227
2019–2020	2,851	234,350	3,148	-96,438	137,912
2020–2021	3,691	253,235	3,450	-105,680	147,555
2021–2022	3,934	130,949	3,697	-113,239	17,709
2022–2023	4,157	131,270	3,924	-120,190	11,080
2023–2024	4,366	132,549	4,153	-127,215	5,334
Total	**23,223**	**1,396,920**	**23,026**	**-705,371**	**691,549**
Tien Giang					
2016–2017	208	48,412	323	-9,889	38,523
2017–2018	576	89,825	505	-15,483	74,342
2018–2019	749	51,956	766	-23,479	28,477
2019–2020	921	55,162	1,068	-32,725	22,437
2020–2021	1,301	107,041	1,144	-35,046	71,995
2021–2022	1,399	49,034	1,251	-38,322	10,713
2022–2023	1,521	56,718	1,332	-40,803	15,914
2023–2024	1,670	65,353	1,421	-43,523	21,830
Total	**8,345**	**523,501**	**7,811**	**-239,270**	**284,231**
Tra Vinh					
2016–2017	611	142,361	613	-18,788	123,574
2017–2018	1,452	208,025	1,091	-33,420	174,605
2018–2019	1,802	110,872	1,801	-55,175	55,697
2019–2020	2,699	245,014	2,173	-66,563	178,450
2020–2021	3,112	150,715	2,283	-69,934	80,781
2021–2022	3,336	114,888	2,490	-76,291	38,598
2022–2023	3,504	106,291	2,681	-82,119	24,173
2023–2024	3,745	126,956	2,837	-86,908	40,048
Total	**20,261**	**1,205,122**	**15,969**	**-489,197**	**715,926**

Note: Positive and negative values represent CO2 emissions and removals, respectively.

Source: Authors' own calculations.

3.3 Future threats to mangrove ecosystems in Vietnam

In the Mekong Delta, areas with high human pressure are concentrated around major urban areas, including cities such as Can Tho, Soc Trang and Ca Mau (Figure 6). These cities exhibit intensified human activity, as indicated by high HFI values, which reflect population density, infrastructure and land-use intensity. The extensive road networks throughout the Delta also contribute significantly to elevated human pressure. Roads not only facilitate connectivity but also lead to habitat fragmentation and encroachment, exerting stress on nearby natural ecosystems, including mangrove areas. The concentration of high HFI values in these urban and infrastructural zones highlights the spatial patterns of human influence, where development and economic activities pose ongoing challenges for ecosystem resilience and conservation in the Delta's mangrove regions.

The results of the assessment of HFI to the mangrove change map from 2016 to 2024 revealed a significant correlation between high human pressure and mangrove loss in the Mekong Delta (Figure 7). Areas with high and medium HFI values, particularly where mangrove converted to aquaculture (Ca Mau and Soc Trang provinces), exhibit the most substantial declines in mangrove coverage. These high and medium pressure zones correspond closely with regions of increased aquaculture expansion, indicating that human activities are a driving factor in mangrove degradation. Conversely, areas with low HFI values tend to show relatively stable or even recovering mangrove cover, suggesting that reduced human influence may support better mangrove resilience and restoration. This spatial analysis highlights the impact of human pressure on the vulnerability of mangrove ecosystems, underscoring the need for focused conservation efforts in high HFI regions to mitigate further losses and support sustainable mangrove management.

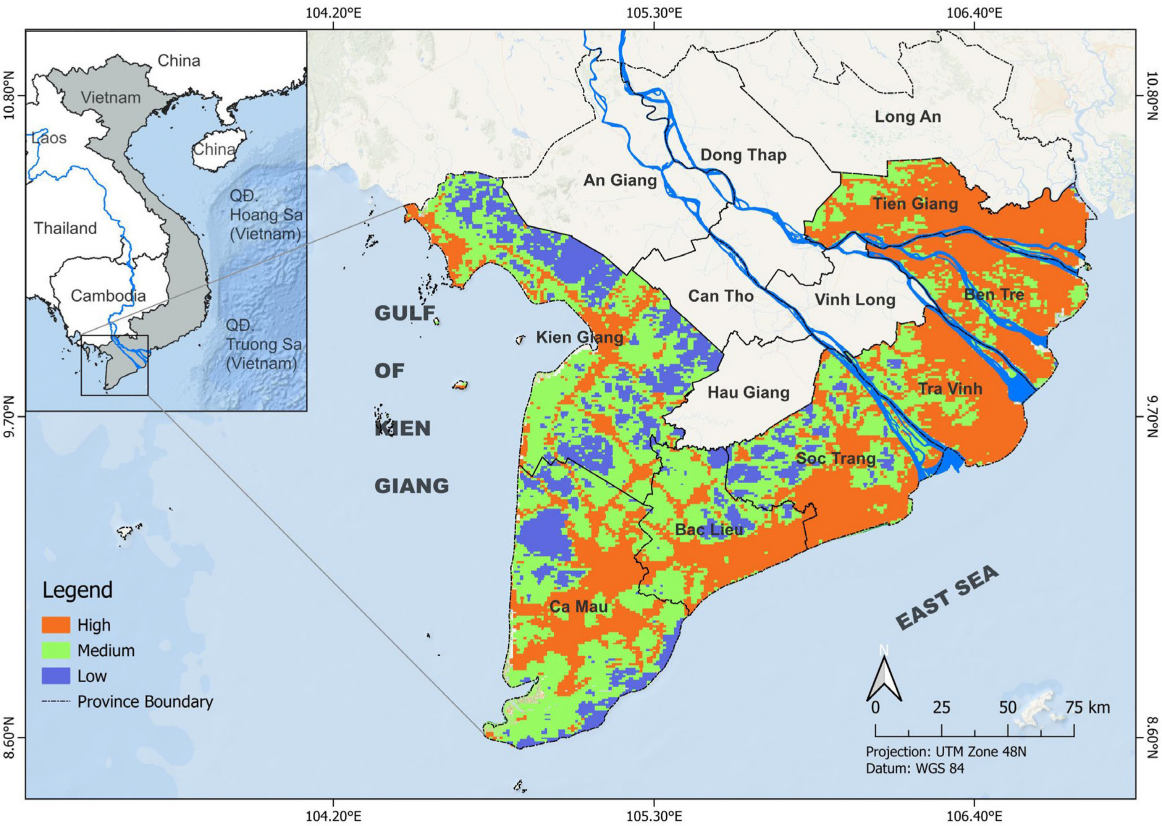

Figure 6. Reclassification of Human Footprint Index for the Mekong Delta coastal provinces of Vietnam

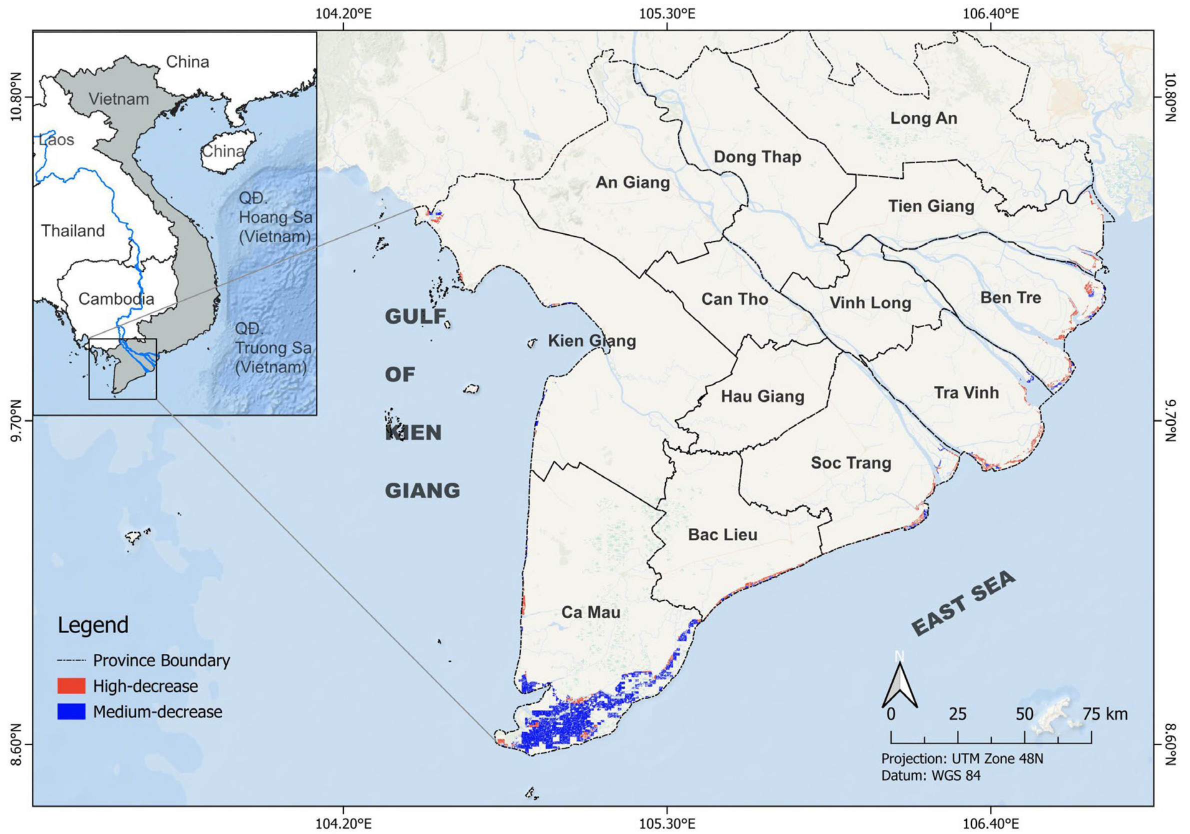

Figure 7. Map of Human Footprint Index (medium to high) overlapping with areas of mangrove loss 2016– 2024 in the Mekong Delta of Vietnam

3.4 CO_2 emissions from seagrass loss in the Mekong Delta coastal provinces

Between 2010–2019, the total extent of seagrass meadows at Phu Quoc Island was reduced from 12,005 to 10,313 ha (Trinh and Takeuchi et al. 2019), equivalent to a loss of 188 ha per year (Table 10). Total estimated CO_2 emissions from seagrass loss at Phu Quoc Island between 2016–2024 was 31,434 Mg CO_2.

Table 10. Estimated CO_2 emissions from seagrass loss at Phu Quoc Island 2016–2024

Year	Cumulative seagrass area loss (ha)	Vegetation carbon loss (Mg CO_2)	Soil carbon loss (Mg CO_2)	Total GHG emissions (Mg CO_2)
2016–2017	188	2,068	414	2,482
2017–2018	376	2,068	827	2,895
2018–2019	564	2,068	1,241	3,309
2019–2020	752	2,068	1,654	3,722
2020–2021	940	2,068	2,068	4,136
2021–2022	1,128	2,068	2,482	4,550
2022–2023	1,316	2,068	2,895	4,963
2023–2024	1,504	2,068	3,309	5,377
Total	**1,504**	**16,544**	**14,890**	**31,434**

3.5 Potential blue carbon project sites

Ca Mau Province, with relatively large areas of mangrove loss that exceeded areas of reforestation, has higher potential for mangrove projects than the other coastal provinces of the Mekong Delta. This is evidenced by its substantial contribution to total net CO_2 emissions from mangroves during the study period. Extensive areas of medium to high human pressure coinciding with areas of mangrove loss in Ca Mau (Figure 7) provide additional evidence of the need for targeted mangrove protection in this province.

Pham et al. (2022) identified two types of restoration activities in Ca Mau: natural regeneration of deforested areas on accreted mud flats and increasing mangrove coverage in shrimp pond systems. Ca Mau recently passed a regulation requiring 70% mangrove coverage in ponds >5 ha; 60% coverage in ponds 3–5 ha; and 50% coverage for ponds <3 ha. Through payment for ecosystem services, the Vietnamese government does provide compensation for meeting compulsory coverage. However, financial incentives are reportedly insufficient to increase forest coverage in and around shrimp ponds. In this context, carbon markets might offer additional funding for increasing coverage. However, to establish project additionality, it will be critical to verify that coverage requirements are not systematically enforced. Although mudflats are deemed to have high potential for natural regeneration (Pham et al. 2022), it will also be necessary to demonstrate that regeneration is not the baseline. Multiple areas with potential for regeneration on mudflats and increasing coverage in shrimp ponds were identified in western Ca Mau. Stakeholders deem areas subject to severe erosion in eastern Ca Mau to be less suitable for restoration.

In terms of reducing emissions and enhancing removals of CO_2, the potential for a carbon project at Phu Quoc Island is much lower than a mangrove restoration or avoided conversion project in Cau Mau Province. The annual GHG impact of mangrove restoration per unit area (30.6 Mg CO_2 ha^{-1} yr^{-1}) is 38.2 times greater than seagrass restoration (1.0 Mg CO_2 ha^{-1} yr^{-1}, n = 3, Kennedy et al. 2014; Marbà et al. 2015; Greiner et al. 2016). Meanwhile, protection of existing mangroves avoids 20.2 Mg CO_2 ha^{-1} yr^{-1} compared to 2.2 Mg CO_2 ha^{-1} yr^{-1} from halting seagrass loss. Furthermore, the estimated carbon loss per unit area from mangrove deforestation (213 Mg CO_2 ha^{-1}) is 19.3 times greater compared to destruction of seagrass beds (11 Mg CO_2 ha^{-1}).

While seagrass restoration projects offer various important co-benefits in addition to reducing atmospheric GHG concentrations, the costs of designing and implementing a carbon project around restoration activities at Phu Quoc Island require careful consideration. By one estimate, the financial benefit of carbon credit sales offsets only 10% of the costs of seagrass restoration projects (Oreska et al. 2020).

3.6 Blue carbon project standards and methodologies

3.6.1 Voluntary carbon market standards and methodologies applicable to blue carbon projects

The VCS, Plan Vivo Standard and Gold Standard are summarized below.

Verified Carbon Standard: The VCS is managed by Verra, a non-profit organization based in Washington, DC. Established in 2005, the VCS accounted for the largest share of voluntary carbon market trades (32%) in 2022 (Forest Trends' Ecosystem Marketplace 2023). It is the leading international voluntary carbon market standard with approved project methodologies applicable to blue carbon ecosystems. The VCS blue carbon methodology, VM0033 Methodology for Tidal Wetland and Seagrass Restoration, covers restoration of mangroves, salt marshes and seagrass meadows. Avoided deforestation and degradation of mangroves is covered by VM0007 REDD+ Methodology Framework. VM0033 is under revision to combine mangrove, salt marsh and seagrass conservation and restoration under one methodology.

Plan Vivo: The Plan Vivo Standard is managed by the Plan Vivo Foundation, a charity registered in Scotland. First developed in 1994, Plan Vivo is oriented towards smaller community-based projects. Nonetheless, it also ranks among the top 10 voluntary carbon market standards worldwide (Forest Trends' Ecosystem Marketplace 2023). It has a methodology applicable to mangrove ecosystems (Agriculture and Forestry Benefit Assessment Methodology), with a new blue carbon methodology under development. This emerging methodology will focus initially on the quantification of carbon in mangrove forests, with seagrass ecosystems added at a later stage.

Gold Standard: Gold Standard is a non-profit organization headquartered in Geneva, Switzerland. It manages the second largest voluntary carbon market standard by volume traded after VCS (Forest Trends' Ecosystem Marketplace 2023). Gold Standard was founded in 2003 by the World Wildlife Fund and other international non-governmental organizations to ensure environmental integrity and sustainable development outcomes for the United Nations (UN) Clean Development Mechanism. Today, Gold Standard continues to focus on strong safeguards to maximize positive impact and minimize potential risk. All certified activities must deliver impact towards at least three UN Sustainable Development Goals. The Gold Standard released its first methodology for mangrove projects in late 2024. While there is no approved methodology for seagrass, several more blue carbon methodologies are under development.

General methodology components and methodology components specific to blue carbon projects are described below.

Scope: Scope refers to the types of project activities (e.g. tidal wetland conservation and restoration) to which the methodology applies. It includes specific applicability criteria that further define project eligibility, such as geographic location, historical land use and any other conditions under which the methodology is applicable.

Monitoring approach: Methodologies provide criteria and procedures, including relevant equations and permitted data sources, for accounting for net GHG emissions and removals from all sources and sinks in the baseline and project.

Non-permanence: GHG emission reductions and removals by land-based systems such as mangroves, salt marshes and seagrass meadows are subject to reversal by human and natural disturbances. Each standard determines its own approach to managing the risk of non-permanence.

Leakage: Leakage refers to the transfer of GHG emissions from inside the project boundary to outside the project boundary as a result of project activities. Leakage may occur as the result of activity shifting or a reduced supply of a commodity (e.g. timber, charcoal) that causes others to increase supply. The latter is known as market leakage.

Allochthonous carbon: Blue carbon project methodologies specify the treatment of allochthonous carbon that originates outside the project area and is deposited inside the project area.

Sea level rise: Blue carbon methodologies include requirements for the consideration of sea level rise impacts on the project area.

3.6.2 Comparison of blue carbon project methodologies

VCS and Plan Vivo blue carbon methodologies under, respectively, revision and development, are compared in Table 11. Draft versions of the methodologies will be made available for public comment prior to their final approval by the standards. When these methodologies are approved, they will replace existing VCS and Plan Vivo methodologies for blue carbon ecosystems. Both methodologies will be applicable in Vietnam. Overall, the revised VCS VM0033 offers a more comprehensive approach to larger-scale blue carbon projects compared to Plan Vivo. On the other hand, the Plan Vivo methodology will likely be more advantageous than VM0033 for small-scale community-based projects.

Table 11. Comparison of VCS and Plan Vivo blue carbon methodologies

	VCS	Plan Vivo	Gold Standard
Methodology	VM0033	Coastal Blue Carbon Methodology	Sustainable Management of Mangroves
Eligible ecosystems	Mangrove, marsh, seagrass	Mangrove	Mangrove
Eligible activities	Conservation, restoration	Conservation, restoration, sustainable management	Restoration
Geographic applicability	Global	Global	Global
Status	Under revision	Under development	Active
Scale	Applicable to standard (≤ 300,000 Mg CO_2 yr^{-1}) and large (>300,000 Mg CO_2 yr^{-1}) projects	Plan Vivo is the leading standard for community-based carbon projects, focusing on small-scale activities	Applicable to project sizes ranging from micro- (≤ 10,000 Mg CO_2 yr^{-1}) to large-scale (no annual cap)

4 Conclusions and recommendations

Key takeaways from the assessment are summarized below:

- In terms of potential GHG emission reductions, mangrove conservation and restoration activities represent a much greater opportunity for blue carbon projects in Vietnam than comparable activities in seagrass. However, protection of seagrass meadows is critical for preserving the important ecosystem services they provide in addition to carbon sequestration. Therefore, it is strategic to seek opportunities to combine mangrove blue carbon project activities with seagrass conservation and restoration.
- Among the seven studied coastal provinces of the Mekong Delta, Ca Mau holds the greatest opportunities for development of blue carbon projects to conserve and restore mangrove ecosystems, followed by Kien Giang. Potential GHG emission reductions in Ca Mau are two orders of magnitude higher compared to the other provinces. Consequently, it could be strategic to consider a jurisdictional approach to implement region-wide mangrove protection in the Mekong Delta.
- Restoration of mangrove forests in the Mekong Delta did not offset CO_2 emissions from mangrove deforestation from 2016 to 2024. Therefore, avoiding continued deforestation is critical, despite gains in mangrove areas.
- Restoration projects to increase mangrove coverage in and around shrimp ponds in Ca Mau Province will need to establish that existing coverage regulations are not systematically enforced. Restoration projects that support natural regeneration of mangroves on mudflats must verify increased GHG emission removals compared to the baseline scenario.

References

Alongi DM. 2014. Carbon cycling and storage in mangrove forests. *Annual Review of Marine Science* 6(1):195–219. http://dx.doi.org/10.1146/annurev-marine-010213-135020

Baatz M and Schäpe A. 2000. Multiresolution Segmentation: An optimization approach for high quality multi-scale image segmentation. *In* Strobl J, Blaschke T, Griesbner G. eds. *Angewandte Geographische Informationsverarbeitung XII*. Heidelberg: Wichmann 12–23.

Baker F, Smith C and Cavan G. 2018. A combined approach to classifying land surface cover of urban domestic gardens using citizen science data and high resolution image analysis. *Remote Sensing* 10(4):537. http://dx.doi.org/10.3390/rs10040537

Campbell AD, Fatoyinbo L, Goldberg L, Lagomasino D. 2022. Global hotspots of salt marsh change and carbon emissions. *Nature* 612(7941):701–706. https://doi.org/10.1038/s41586-022-05355-z

Duarte CM. 2002. The future of seagrass meadows. *Environmental Conservation* 29(2):192–206. http://dx.doi.org/10.1017/S0376892902000127

Duarte CM, Kennedy H, Marbà N, Hendriks I. 2013. Assessing the capacity of seagrass meadows for carbon burial: Current limitations and future strategies. *Ocean & Coastal Management* 83:32–38. http://dx.doi.org/10.1016/j.ocecoaman.2011.09.001

Duarte CM, Middelburg JJ, Caraco N. 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2(1):1–8. http://dx.doi.org/10.5194/bg-2-1-2005

Forest Trends' Ecosystem Marketplace. 2023. *State of the voluntary carbon market 2023*. Washington, DC: Forest Trends Association.

Fourqurean J, Kennedy H, Marbá N, Holmer M, Mateo MA, Apostolaki E, Kendrick GA, Krause-Jensen D, McGlathery KL, Duarte CM, et al. 2012. Seagrass ecosystems as a globally significant carbon stock. *Nature Geoscience* 5:505–509. http://dx.doi.org/10.1038/ngeo1477

Giri C. 2016. Observation and monitoring of mangrove forests using remote sensing: Opportunities and challenges. *Remote Sensing* 8(9). http://dx.doi.org/10.3390/rs8090783

Goldberg L, Lagomasino D, Thomas N, Fatoyinbo T. 2020. Global declines in human-driven mangrove loss. *Global Change Biology* 26(10):5844–5855. https://doi.org/10.1111/gcb.15275

Green E and Short F. eds. 2003. *World atlas of seagrasses.* Berkeley, CA: University of California Press. https://environmentalunit.com/Documentation/04%20Resources%20at%20Risk/World%20Seagrass%20atlas.pdf

Greiner JT, Wilkinson GM, McGlathery KJ, Emery KA. 2016. Sources of sediment carbon sequestered in restored seagrass meadows. *Marine Ecology Progress Series* 551:95–105. http://dx.doi.org/10.3354/meps11722

IFC (International Finance Corporation). 2023. *Deep blue: Opportunities for blue carbon finance in coastal ecosystems*. Washington, DC: IFC. https://www.ifc.org/en/insights-reports/2023/blue-carbon-finance-in-coastal-ecosystems

Jia M, Wang Z, Mao D, Ren C, Song K, Zhao C, Wang C, Xiao X, Wang, Y. 2023. Mapping global distribution of mangrove forests at 10-m resolution. *Science Bulletin* 68(12):1306–1316. https://doi.org/10.1016/j.scib.2023.05.004

Kennedy H, Alongi DM, Karim A, Chen G, Chmura GL, Crooks S, Kairo JG, Liao B, Lin G, 2014. Coastal wetlands. *In* Hiraishi T, Krug T, Tanabe K, Srivastava N, Jamsranjav B, Fukuda M, Troxler T. eds. 2013. *Supplement to the 2006 IPCC guidelines for national greenhouse gas inventories: Wetlands: Methodological guidance on lands with wet and drained soils, and constructed wetlands for wastewater treatment*. Geneva: Intergovernmental Panel on Climate Change.

Krause-Jensen D and Duarte CM. 2016. Substantial role of macroalgae in marine carbon sequestration. *Nature Geoscience* 9(10):737–742. https://doi.org/10.1038/ngeo2790

Luong C and Nga NT. 2017. Research on carbon storage capability of seagrass through biomass (in the case of Thi Nai lagoon, Binh Dinh Province). *Vietnam Journal of Marine Science and Technology* 17(1):63–71. http://dx.doi.org/10.15625/1859-3097/17/1/7900

Macreadie PI, Costa MD, Atwood TB, Friess DA, Kelleway JJ, Kennedy H, Lovelock CE, Serrano O, Duarte CM. 2021. Blue carbon as a natural climate solution. *Nature Reviews Earth & Environment* 2(12):826–839. https://doi.org/10.1038/s43017-021-00224-1

Macreadie PI, York PH, Sherman CDH, Keough MJ, Ross DJ, Ricart AM, Smith TM. 2014. No detectable impact of small-scale disturbances on “blue carbon” within seagrass beds. *Marine Biology* 161:2939–2944. https://doi.org/10.1007/s00227-014-2558-8

Marbà N, Arias-Ortiz A, Masqué P, Kendrick GA, Mazarrasa I, Bastyan GR, Garcia-Orellana J, Duarteet CM. 2015. Impact of seagrass loss and subsequent revegetation on carbon sequestration and stocks. *Journal of Ecology* 103:296–302. https://doi.org/10.1111/1365-2745.12370

MARD (Ministry of Agriculture and Rural Development). 2016. *Vietnam’s modified submission on reference levels for REDD+ results based payment under UNFCCC*. Bonn: United Nations Framework Convention on Climate Change. https://redd.unfccc.int/media/2016_submission_frel_viet_nam.pdf

McKenzie LJ, Nordlund LM, Jones BL, Cullen-Unsworth LC, Roelfsema C, Unsworth RK. 2020. The global distribution of seagrass meadows. *Environmental Research Letters* 15(7):074041. http://dx.doi.org/10.1088/1748-9326/ab7d06

McKenzie LJ, Finkbeiner MA, Kirkman H. 2001 Methods for mapping seagrass distribution. *In* Short FT and Coles RG. eds. *Global seagrass research methods*. Amsterdam: Elsevier 101–121 https://doi.org/10.1016/B978-044450891-1/50006-2

Mcleod E, Chmura GL, Bouillon S, Salm R, Björk M, Duarte CM, Lovelock CE, Schlesinger WH, Silliman BR. 2011. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. *Frontiers in Ecology and the Environment* 9(10):552–560. https://doi.org/10.1890/110004

Mcowen C, Weatherdon LV, Bochove J, Sullivan E, Blyth S, Zockler C, Stanwell-Smith D, Kingston N, Martin CS, Spalding M, et al. 2017. A global map of saltmarshes (v6.1). *Biodiversity Data Journal* 5:e11764. https://doi.org/10.3897/BDJ.5.e11764

Mitsch WJ and Gosselink JG. 2000. The value of wetlands: Importance of scale and landscape setting. *Ecological Economics* 35(1):25–33. http://dx.doi.org/10.1016/S0921-8009(00)00165-8

Murdiyarso D, Swails E, Hergoualc’h K, Bhomia R, Sasmito SD. 2024. Progress and promise for science in Indonesia: Refining greenhouse gas emission factors for Indonesian peatlands and mangroves to meet ambitious climate targets. *Proceedings of the National Academy of Sciences of the United States of America* 121(17). http://dx.doi.org/10.1073/pnas.2307219121

Nguyen XV, Lau VK, Nguyen-Nhat NT, Nguyen TH, Phan KH, Dao VH, Ho-Dinh D, Hayashizaki K, Papenbrock, J. 2021. Update of seagrass cover and species diversity in Southern Viet Nam using remote sensing data and molecular analyses. *Regional Studies in Marine Science* 44:101803. http://dx.doi.org/10.1016/j.rsma.2021.101803

Olson KR and Morton LW. 2018. Polders, dikes, canals, rice, and aquaculture in the Mekong Delta. *Journal of Soil and Water Conservation* 73(4):83A–89A. http://dx.doi.org/10.2489/jswc.73.4.83A

Oreska MP, McGlathery KJ, Aoki LR, Berger AC, Berg P, Mullins L. 2020. The greenhouse gas offset potential from seagrass restoration. *Scientific Reports* 10(1):7325. https://doi.org/10.1038/s41598-020-64094-1

Pham TT, Vien NN, Vo QT, Tang TKH, Nguyen TL, Tran NMH, Nguyen TTA, Nguyen TVA, Nguyen NQ. 2022. Opportunities and challenges for mangrove restoration in the Mekong Delta: Status, policies and stakeholder outlook. Occasional Paper 233. Bogor, Indonesia: CIFOR. https://www.cifor-icraf.org/publications/pdf_files/OccPapers/OP-233.pdf

Sanderson EW, Fisher K, Robinson N, Sampson D, Duncan A, Royte L. 2022. The march of the human footprint. *EcoRxiv*. https://ecoevorxiv.org/repository/view/3641/

Serrano O, Ruhon R, Lavery PS, Kendrick GA. 2016. Impact of mooring activities on carbon stocks in seagrass meadows. *Scientific Reports* 6(1):23193. http://dx.doi.org/10.1038/srep23193

Short F, Carruthers T, Dennison W, Waycott M. 2007. Global seagrass distribution and diversity: A bioregional model. *Journal of Experimental Marine Biology and Ecology* 350(1):3–20. http://dx.doi.org/10.1016/j.jembe.2007.06.012

Son N, Chen CF, Chang NB, Chen CR, Chang LY, Bui XT. 2014. Mangrove mapping and change detection in Ca Mau Peninsula, Vietnam, using Landsat data and object-based image analysis. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 8(2):1–8. http://dx.doi.org/10.1109/JSTARS.2014.2360691

Stankovic M, Ambo-Rappe R, Carly F, Dangan-Galon F, Fortes MD, Hossain MS, Kiswara W, Van Luong C, Minh-Thu P, Mishra AK, Noiraksar T, et al. 2021. Quantification of blue carbon in seagrass ecosystems of Southeast Asia and their potential for climate change mitigation. *Science of the Total Environment* 783:146858. https://doi.org/10.1016/j.scitotenv.2021.146858

Tinh PH, MacKenzie RA, Hung TD, Hanh NTH, Hanh NH, Manh DQ, Ha HT, Tuan MS. 2022. Distribution and drivers of Vietnam mangrove deforestation from 1995 to 2019. *Mitigation and Adaptation Strategies for Global Change* 27(4):29. https://doi.org/10.1007/s11027-022-10005-w

Trinh XT and Takeuchi W. 2019. 30 years national scale seagrass mapping in Vietnam with Landsat and Sentinel imagery on Google Earth Engine. *Proceedings of the 40th Asian Conference on Remote Sensing (ACRS 2019*). Daejeon, Republic of Korea: ACRS. 14–18. https://acrs-aars.org/proceeding/ACRS2019/ThD2-1.pdf

Veettil BK, Ward RD, Quang NX, Trang NTT, Giang TH. 2019. Mangroves of Vietnam: Historical development, current state of research and future threats. *Estuarine, Coastal and Shelf Science* 218:212–236. https://doi.org/10.1016/j.ecss.2018.12.021

Vo TT, Lau K, Liao LM, Nguyen XV. 2020. Satellite image analysis reveals changes in seagrass beds at Van Phong Bay, Vietnam during the last 30 years. *Aquatic Living Resources* 33(4). https://doi.org/10.1051/alr/2020005

Waycott M, Duarte CM, Carruthers TJB, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL Jr., Hughes AR, Kendrick GA, et al. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences* 106(30):12377–12381. https://doi.org/10.1073/pnas.0905620106

Zweifel L, Meusburger K, Alewell C. 2019. Spatio-temporal pattern of soil degradation in a Swiss Alpine grassland catchment. *Remote Sensing of Environment*. 235(September):111441. https://doi.org/10.1016/j.rse.2019.111441

DOI: 10.17528/cifor-icraf/009370

***CIFOR-ICRAF Working Papers* contain preliminary or advanced research results on important tropical forest issues that need to be published in a timely manner to inform and promote discussion. This content has been internally reviewed but has not undergone external peer review.**

Marine and coastal ecosystems, including mangroves and seagrass meadows, are global hotspots for “blue carbon” storage in vegetation and soils, but face mounting pressure from human activities and climate change. Mechanisms that mobilize foreign direct investment to reduce anthropogenic greenhouse gas emissions and enhance sustainable development, such as voluntary carbon projects, offer financing that can complement government efforts. We assessed blue carbon opportunities in Vietnam focusing on mangroves and seagrass in the Mekong Delta coastal provinces (Kien Giang, Ca Mau, Bac Lieu, Soc Trang, Tra Vinh, Ben Tre and Tien Giang). Object-based image analysis was used to quantify changes in the extent of mangroves from 2016 - 2024. To assess fluctuations in seagrass meadow areas we projected historical changes in seagrass coverage reported in the literature. Emissions of CO_2 resulting from changes in mangrove forest and seagrass meadow coverages were estimated using literature-based emission factors. Overall, mangrove coverage in the Mekong Delta coastal provinces declined between 2016 and 2024, despite areas of mangrove expansion. CO_2 removals from mangrove area increase did not offset CO_2 emissions from mangrove loss during 2016–2024. Our analysis revealed substantial losses in some areas, highlighting the complex dynamics of mangrove conservation. The total net impact of mangrove loss and reforestation in the seven provinces during this period was 14.5 million Mg CO_2, with Ca Mau province contributing 77% of emissions. The magnitude of potential CO_2 emissions from seagrass loss was smaller, at 31.4 thousand Mg CO_2, concentrated in the area of Phu Quoc Island in Kien Giang province. Our results emphasize the need to avoid continued conversion of mangroves, despite gains in mangrove forest areas.

UBS Optimus Foundation | UBS

Global Affairs Canada | Affaires mondiales Canada