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Original article

EVALUATING THE HABITAT CONDITIONS OF *BRUGUIERA HAINESII* C.G. ROGERS 1919 IN CON DAO NATIONAL PARK, VIETNAM

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Abstract

Purpose. Con Dao is an archipelago located off the southern coast of Vietnam and is administratively part of Ba Ria – Vung Tau province. Socio-economic development and tourism expansion have exerted pressure on the local environment, increasing the risk of pollution from domestic wastewater and solid waste. Additionally, coastal erosion due to increasingly strong currents has reduced sediment deposition capacity, directly impacting the habitat of the critically endangered mangrove species *Bruguiera hainesii* C.G. Rogers 1919.

Materials and methods. This study analyzed soil samples from mangrove forests surrounding Hon Ba Island in Con Dao National Park to assess the risk of heavy metal pollution in the area. Additionally, the Digital Shoreline Analysis System (DSAS) was applied to monitor and analyze changes in the mangrove shoreline at specific locations, providing an accurate assessment of environmental changes affecting the distribution of Bruguiera hainesii.

Results. The research findings reveal that *Bruguiera hainesii* in Con Dao is influenced by various environmental factors. The low phosphorus (P_2O_5) levels in the soil may hinder tree growth, as phosphorus is a crucial nutrient for the mangrove ecosystem. Although the concentrations of heavy metals such as Cd, Pb, and Zn remain within safe limits, potential environmental concerns persist.

Notably, satellite imagery analysis conducted since 2016 using DSAS, which examined shoreline variations through 571 cross-sections, has provided essential insights into coastal dynamics, erosion patterns, and sediment deposition changes. The results highlight the significant impact of tidal waves, leading to accelerated coastal erosion and reduced sediment accumulation - an essential process for mangrove forest regeneration. These factors threaten the population size and long-term survival of B. hainesii, a species already classified as extremely rare in nature.

Conclusion. The research findings provide essential scientific evidence for Ba Ria – Vung Tau province to develop effective sediment management strategies aimed at protecting and restoring mangrove ecosystems, particularly the habitat of Bruguiera hainesii.

Keywords: Bruguiera hainesii; environmental factors; erosion; DSAS; coastal dynamics

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Introduction

Bruguiera hainesii C.G. Rogers 1919 (*B. hainesii*) is a critically endangered mangrove species with a highly restricted distribution, and Con Dao National Park is its only known habitat in Vietnam. According to Pham et al. (2024), this species thrives in tidal mudflats and mangrove forests, which are highly susceptible to coastal erosion and soil condition changes [15]. However, its natural regeneration capacity is extremely low, further exacerbating the risk of population decline. Therefore, investigating soil conditions and coastal erosion in Con Dao is essential for developing conservation strategies and habitat restoration measures to ensure the long-term survival of this species.

Natural mangrove forests (NMF) are highly productive ecosystems found in tropical and subtropical regions, playing a key role in ecological balance and social sustainability. They provide essential habitats, supporting biodiversity and fisheries by offering food and nursery grounds for various species. Additionally, NMF filter pollutants, trap sediments, and improve water quality. Their complex root systems protect coastlines from erosion, storms, and rising sea levels. These forests also store large amounts of carbon, mitigating climate change. Economically, they support coastal communities through fisheries, timber, and other resources, making their conservation crucial for long-term environmental stability [2]. Con Dao National Park currently has about 31 hectares of mangrove forests. The saline soils of Avicennia, Rhizophora, and Bruguiera mangroves are typically muddy, saline, and rich in organic matter due to the decomposition of leaves and roots. Besides their roles in wind and wave breaking and providing firewood and charcoal, mangrove forests contribute to soil stabilization [12]. The alluvium gradually raises and solidifies the land, helping it escape tidal effects and reducing salinity over time. Coastal mangrove forests are not only crucial for the ecological environment but also play a significant role in reducing wave height and protecting shorelines [15; 20]. Consequently, the evaluation of mangroves' role in coastal protection is gaining increasing attention, especially given the complexities of natural disasters and the negative impacts of climate change.

However, mangrove ecosystems are currently facing greater pollution pressures due to increased chemical discharge from various land-based sources [26]. The coastal environment is a dynamic system where physical, chemical, and biological processes contribute to metal biogeochemical cycles. However, human activities have introduced metal pollution into these areas. Major sources include mining, metal production, solid waste disposal, fossil fuel combustion, and wastewater discharge from urban and industrial areas. These pollutants can accumulate in coastal ecosystems, affecting water quality and marine life. Understanding these processes is essential for managing and mitigating the environmental impacts of metal contamination in coastal regions [9]. Industries like casting, paper processing, laundry, tanning, and dyeing discharge wastewater containing toxic metals into estuaries and coastal areas. Additionally, acid rain enhances metal mobility, allowing pollutants to spread more easily. Once introduced into the coastal environment, these toxic metals mainly accumulate in sediments through particle settling, posing potential risks to marine ecosystems and water quality [7]. As industrialization, urban expansion, and population growth accelerate, toxic metals accumulate in sediments, leading to high concentrations in many coastal areas. These pollutants originate from human activities and pose significant environmental risks to marine ecosystems and water quality.

Coastal regions, including mangroves, are increasingly affected by coastal erosion. In Ca Mau province, extensive sections of the coastline and mangrove forests are experiencing severe erosion, which is worsening over time. This phenomenon poses significant threats to the stability of the sea dike system, local properties, and the surrounding environment. If erosion continues unchecked, it could lead to further habitat loss, infrastructure damage, and increased vulnerability of coastal communities to extreme weather events and rising sea levels [19]. In some areas, the sea has pushed the shoreline inland by 300 to 600 meters over the past decade. Coastline stability is influenced by the dynamic interplay between sediment supply and the space available due to rising sea levels and land subsidence. When sediment deposition matches or exceeds the rate of subsidence and sea-level rise, coastal areas remain stable. However, if sediment supply is insufficient, erosion accelerates, leading to shoreline retreat. Maintaining this balance is essential for protecting coastal ecosystems, infrastructure, and communities from the adverse effects of climate change and environmental degradation [14]. If sediment supply exceeds the rate of relative sea level change, the delta will advance; otherwise, coastal erosion will occur. Most previous studies have focused on the overall loss or reclamation of land in the coastal environment but did not provide specific information about coastal dynamics [3]. For detailed information, this study focuses on specific changes at individual coastal points along the coastline at five mangrove sites, which are critical perspectives for planning the protection of mangroves and coastlines in the area. Long-term coastal dynamics can be monitored through multi-year satellite imagery. Comprehensive data on shoreline changes across different sections is essential for effective erosion management. The Digital Shoreline Analysis System (DSAS), an ArcGIS extension, enables precise monitoring of shoreline shifts at specific points using the End Point Rate (EPR). EPR assesses mangrove shoreline changes by calculating positional variations over time [4]. These shifts result from socio-economic activities and environmental factors, including climate change. Understanding both the rate and underlying causes of these changes is crucial. Historical shoreline transformations serve as key indicators for assessing coastal environmental shifts, such as global warming, storm impacts, sea-level rise, pollution, and sedimentation. Additionally, mapping water boundaries is vital in coastal dynamics studies, as tidal fluctuations continuously reshape shoreline interactions. The Modified Normalized Difference Water Index (MNDWI) is used to distinguish permanent water bodies from seasonally flooded areas [1]. Sentinel-2 MSI satellite images from 2016–2022 were used for the study.

Given the critical need for conservation, this study aims to analyze: (i) the potential risks of heavy metal contamination in mangrove sediments within the Dam Quoc area and (ii) the impacts of coastal erosion on this habitat. Understanding these environmental threats is essential for safeguarding the ecological integrity of *Bruguiera hainesii*. The findings will provide scientific evidence to support strategic recommendations for coastal protection and habitat restoration within Con Dao National Park, ensuring the long-term viability of this critically endangered species.

Materials and methods

Study area. This study examines regions where mangrove forests are distributed within the Con Dao National park. Among these areas, Hon Ba Island contains the most extensive mangrove coverage, spanning approximately 5,860 hectares. As the largest mangrove habitat in the islands, this island plays a crucial role in maintaining ecological balance, supporting biodiversity, and protecting the coastal environment. Understanding mangrove distribution in these areas is essential for conservation efforts and assessing the impacts of environmental changes on coastal ecosystems.

Fig. 1. Morphological characteristics of *B. hainesii* in Con Dao National park, Ba Ria - Vung Tau Province, Vietnam: (a) trunk, (b) flower, (c) leaf, flower, and twig, (d) measuring cracks on the tree bark, (e) measuring pH.

Bruguiera hainesii C.G. Rogers 1919 is a mangrove species belonging to the family Rhizophoraceae and is classified as Critically Endangered (CR) on the IUCN Red List. This species has an extremely restricted distribution, recorded only in a few coastal regions of Southeast Asia, including Singapore, Malaysia, Indonesia, and Vietnam [15; 21]. *B. hainesii* thrives in mangrove ecosystems, particularly in intertidal mudflats where salinity fluctuates with tidal movements. It is characterized by a sturdy woody trunk. However, its natural regeneration capacity is extremely low, primarily due to the limited number of mature individuals and severe population fragmentation. The major threats to *B. hainesii* include habitat loss caused by urban development, aquaculture expansion, and coastal erosion. Additionally, climate change, particularly rising sea levels, has further reduced mangrove forest areas, significantly impacting the species' habitat. As of 2025, only seven individuals have been recorded in Con Đao by the research from the Joint Vietnam-Russia Tropical Secience and Technology Reseach Center [15, 21], the data was published in GBIF (https://www.gbif.org/dataset/99467e7c-0a15-4b30-b5f1-9da66999f7cd).

Methodology

Soil analysis methods. Soil Sampling: Fifteen soil samples were collected from areas with mangrove distribution in Dam Quoc, where *B. hainesii* species is located (Fig. 2). Samples were taken using a hand auger, drilling to a depth of 0–40 cm. Each soil sample weighed approximately 1 kg, preserved in clean plastic bags, tightly sealed with rubber bands, and placed in sample containers for transportation to the laboratory for analysis. Each sample was labeled with an identification number, date and time of collection, collector's name, and sampling coordinates.

Preparation of Soil Samples for Analysis: The collected soil samples underwent natural air-drying at ambient room temperature before further processing. This step ensured the removal of excess moisture while preserving the samples' physical and chemical properties for accurate analysis. Proper drying conditions were maintained to prevent alterations in soil composition, which could affect subsequent testing. This method provides a standardized approach for preparing soil samples, ensuring reliable and consistent results in laboratory assessments, with any debris and organic residues larger than 2 mm removed. The samples were then finely ground using a porcelain mortar and sieved through a mesh with a diameter of 0.2 mm. Before analyzing N, P, and K content, all soil samples underwent a digestion process. The samples were processed and analyzed at the laboratories of the Joint Vietnam-Russia Tropical Center and the Institute of Geography, Vietnam Academy of Science and Technology.

This species grows in semi-tidal areas adjacent to evergreen forests, so the soil quality in this region is largely influenced by forest land. Soil standards for forest trees are referenced from the *Forestry Handbook* [10]. The analysis results will be evaluated against Vietnamese Standards TCVN 7373:2004, 7374:2004, and 7375:2005, which define indicative ranges for total nitrogen, phosphorus, and potassium in major soil groups. This comparison helps assess soil fertility, nutrient limitations, and environmental suitability for plant growth, providing a scientific basis for sustainable land management and conservation strategies [16-18].

Surface water analysis methods. Surface water samples were primarily collected from the mangrove forest area in Dam Quoc, where *B. hainesii* species is located (Fig. 2). On-site rapid analysis was conducted for pH and salinity using specialized equipment. Heavy metal concentrations were analyzed in the laboratory using atomic absorption spectrometry methods. The analytical results were calculated and processed using Excel and MapInfo software, and the data were statistically analyzed to assess the level of water pollution in the study area based on the National Technical Regulation on Surface Water Quality (QCVN 08:2015/BTNMT). Elements were classified into high, medium, and low concentration groups.

Shoreline study methods. To assess the erosion resistance of the wave-tide dynamics in the Dam Quoc mangrove area and nearby mangrove areas, a method for extracting past and present shoreline positions over an 8-year period (2016–2023) was established to determine the shoreline shift rate. This method includes three stages:

- Collection: Optical satellite images from Sentinel-2 MSI for the period 2016-2023 were collected, preprocessed, and the MNDWI water index was calculated.
- Extraction: Shoreline positions were extracted using the Otsu automatic thresholding method from the MNDWI index.
- Shoreline Change Analysis: The DSAS software was utilized to assess shoreline accretion and erosion rates through a four-step process: (1) Shoreline data preparation, (2) Baseline creation, (3) Transect generation, and (4) Shoreline change rate calculation. Transects were established perpendicular to the baseline at 50-meter intervals to ensure systematic measurement. The End Point Rate (EPR) and Net Shoreline Movement (NSM) methods, widely applied in coastal management, were used to quantify shoreline dynamics and support effective coastal monitoring and decision-making [4, 5].

The Digital Shoreline Analysis System (DSAS) is a computational tool designed to analyze shoreline displacement across spatial and temporal scales by extracting transect-based shoreline data. This method involves generating transects perpendicular to a reference baseline and multi-temporal shorelines. In this study, a manually defined baseline was established along the coastline, adapting to shoreline discontinuities. Transects were created by assigning attributes to both shorelines and the baseline [4]. These transects intersect with shorelines to provide position and time data, which are used to determine shoreline change rates. DSAS outputs include statistical estimates of shoreline dynamics over the study period. The End Point Rate (EPR) and Linear Regression Rate were applied to quantify shoreline variation in the Con Dao islands. EPR measures shoreline movement by calculating the distance between the oldest and most recent shoreline positions, divided by the number of years between them, providing an annual shoreline change rate (m/year) [5]. EPR is expressed by the following formula (1):

$$ERP = \frac{D_1 - D_2}{t_1 - t_2} \tag{1}$$

The End Point Rate (EPR) is determined by calculating the distance ($D_1 - D_2$) between the earliest and most recent shoreline positions, divided by the time interval ($t_1 - t_2$) between their recorded dates. This parameter reflects the overall shoreline change during the observation period but only provides a general trend between the two recorded shorelines. A negative EPR value signifies shoreline retreat inland, whereas a positive EPR value indicates seaward advancement, helping to assess coastal erosion or accretion trends.

Fig. 2. Survey plots in the Con Dao Islands, Vietnam. Plots 1, 2, 3, 4, and 5 are located in the mangrove forest, among which Plot 1 is the area where the *B. hainesii* species is found).

Fig. 3. Mangrove forest in Hon Ba island of Con Dao, Vietnam.

The DSAS software assessed shoreline accretion and erosion at five sites, including Plot 1, which hosts the endangered *B. hainesii*. This study compares shoreline dynamics to inform conservation strategies, mitigate environmental impacts, and support habitat stability. Findings will guide data-driven conservation efforts, balancing ecological preservation with coastal development.

Results and discussion

Soil environmental characteristics in mangrove distribution areas. Soil sample analysis (Table 1) from mangrove forests reveals nutrient-deficient, sandy soil with low acidity. Potassium levels are generally high, with certain areas exhibiting exceptionally elevated concentrations, indicating potential variations in soil composition across different mangrove regions.

The observational results depicted in the table below show the highest pH value reaching 6.77, with an average pH value of 5.93. Based on the pH evaluation scale from the Forestry Handbook [10], the analyzed soil in these habitats is classified as acidic, suggesting potential impacts on mangrove ecosystem health and nutrient availability.

Comparing with standards for nitrogen (%N), phosphorus (%P_2O_5), potassium (%K_2O) according to TCVN 7373:2004 [16], TCVN 7474:2004 [17], TCVN 7375:2004 [18], the soil in this area is characterized as silver-gray soil, with little humus.

Total nitrogen content in soil compared to the mean value specified in TCVN 7373:2004 for of saline soil group [16], with N (%) in saline soil ranging from 0.078–0.325, the average total N content (%) in the research area falls within the permissible range for the saline soil category, however it shows great volatility.

Table 1.

Analysis indicators of soil samples in mangrove forest areas distributed by species

No.	Parameters	Unit	Analytical Method	Min-Max	Mean ± Std
1	Sand	%	TCVN 8567:2010	90.33–94.62	92.10 ± 1.39
2	Silt	%		2.85–6.36	5.41 ± 1.08
3	Clay	%		1.19–3.92	2.48 ± 0.93
4	Acidity (pH_{KCl})	-	TCVN 5979:2007	4.75–6.77	5.93 ± 0.74
5	Hydrolyzable acidity (H)	meq/100g	TCVN 4404:1987	0.70–6.81	3.04 ± 1.87
6	Organic matter content CHC (%)	%OM	TCVN 8941:2011	2.22–9.21	3.74 ± 2.23
7	Easily digestible nitrogen (mg/100gđ)	mg/100g	TCVN 5255:2009	22.91–70.32	31.18 ± 15.18
8	Easily digestible phosphorus (mg/100gđ)	mg P_2O_5/100g	TCVN 5256:2009	1–5.5	2.16 ± 1.43
9	Easily digestible potassium (mg/100gđ)	mg K_2O /100g	TCVN 8662:2011	27.72–68.99	52.65 ± 28.8
10	Total nitrogen (%)	%N	TCVN 6498:1999	0.078–0.325	0.13 ± 0.08
11	Total phosphorus (%)	%P_2O_5	TCVN 8940:2011	0.016–0.049	0.03 ± 0.02
12	Total potassium (%)	%K_2O	TCVN 8660:2011	0.35–0.47	0.39 ± 0.04
13	Cl^- concentration	%	TCVN 12616:2019	0.63–2.62	1.22 ± 0.79
14	SO_4^{2-} concentration	%	TCVN 6656:2000	0.11–0.61	0.22 ± 0.15

Total P content in soil indicates that the values across various habitats range from 0.016% to 0.049% (Table 1). In comparison to TCVN 7374:2004 [17], the total P content in these habitats is below the permissible average threshold of saline soil group (0.09%). With mean total P value of 0.03%, as indicated in the Forestry Handbook (Table 3), the soil is classified as silver-gray and low in P. This deficiency may act as a limiting factor in plant growth.

Total P content in soil serves many vital functions in plant metabolism, ensuring root system development and enhancing resistance to adverse factors. Therefore, maintaining sufficient P concentration in the soil is essential. Monitoring results indicate that soil in the research area is prone to P depletion if not properly managed and controlled, including both natural and artificial restoration measures.

Total K content in soil (Table 1) indicates that K content ranges from 0.35% to 0.47%, classifying it as potassium-rich according to the Forestry Handbook (Table 4). However, the K_2O content in the soil is lower than the TCVN 7375:2004 standard [18] for saline soil groups.

Nevertheless, this potassium level remains sufficient to support normal crop growth. Potassium plays a crucial role in photosynthesis, water regulation, and protein synthesis; therefore, the current concentration does not negatively impact plant development. However, if K_2O levels continue to decline, soil fertility may gradually deteriorate, adversely affecting plants' nutrient absorption capacity.

The disparity among the three values of N - P - K in the soil samples around the species distribution area indicates that the soil in the research area is characteristic of mangrove soil. This result is quite consistent with soil samples in the wetland areas of Cu Lao Dung [11] and mangrove forests in Indonesia [22] in terms of %N and K_2O indices. However, the percentage of P_2O_5 total is at a low alert level.

Table 2.

Assessment of total N content in soil [16]

Level	Categories	N (%) in soil
I	High	≥ 0.15
II	Medium	≥ 0.08–0.15
III	Poor	<0.08

Table 3.

Assessment of total P_2O_5 content in soil [17]

Level	Categories	P_2O_5 (%) content in soil
I	High	≥ 0.1
II	Medium	≥ 0.06–0.1
III	Poor	<0.06

Characteristics of water environment in areas with mangrove distribution. The result presents data on the physicochemical environment of surface seawater at Dam Quoc, Con Dao islands, compared to the national standard QCVN 08:2015/BTNMT. Salinity ranges from 30.8‰ to 32.8‰, with an average of 31.8‰ ± 1.0‰, reflecting typical seawater conditions. Ammonium (NH_4^+) is below the detection limit (<0.01 mg/l), meeting the permissible standard of 0.3 mg/l, indicating low levels of organic pollution. Arsenic (As) has an average concentration of 0.0036 ± 0.0018 mg/l, below the limit of 0.01 mg/l. Mercury (Hg) is below 0.0005 mg/l, lower than the permissible limit of 0.001 mg/l. Copper (Cu) averages 0.0226 ± 0.0032 mg/l, within the acceptable threshold of 0.1 mg/l. Lead (Pb) has an average concentration of 0.0030 ± 0.0015 mg/l, well below the limit of 0.05 mg/l. Zinc (Zn), Manganese (Mn), and Iron (Fe) are also within safe levels. Overall, the seawater quality at Dam Quoc meets national standards, with low concentrations of heavy metals, indicating a relatively clean marine environment. However, continuous monitoring is necessary to ensure the long-term sustainability of the ecosystem. (Table 5).

Table 4.

Assessment of total K2O content in soil [18]

Level	Categories	K_2O (%) content in soil
I	High	≥ 2
II	Medium	≥ 1-2
III	Poor	<1

Table 5.

Physicochemical environment of surface seawater of Con Dao National park

Variables	Unit	Analytical Method	Min-Max	Mean ± Std	National-ISO: QCVN 08:2015/ BTNMT
Salinity	$^0/_{00}$	Instrumental measurement	30.8-32.8	31.8 ± 1.0	
NH_4^+	mg/l	SMEWW 4500 NH4+.F:2017	<0.01		0.3
As	mg/l	SMEWW 3125B:2017	0.002-0.006	0.0036 ± 0.0018	0.01
Hg	mg/l		<0.0005		0.001
Cu	mg/l		0.019-0.026	0.0226 ± 0.0032	0.1
Pb	mg/l		0.0012-0.0046	0.0030 ± 0.0015	0.02
Zn	mg/l		0.0489-0.0876	0.0704 ± 0.017	0.5
Mn	mg/l		0.0099-0.1343	0.0450 ± 0.06	0.1
Fe	mg/l		0.1632-0.9361	0.4829 ± 0.33	0.5

This result was compared with coastal areas in Vietnam [13] and China [23]. Some areas are significantly affected by the Hau River, where high levels of copper (Cu) contamination are detected at most sampling locations in Dinh An and Rach Gia [8]. Research conducted in other coastal regions worldwide also highlights the ecological risks associated with heavy metal pollution. These contaminants can cause environmental harm, particularly when their concentrations exceed safety thresholds. Furthermore, spatial variations in contamination levels indicate that pollution is not uniformly distributed, posing different levels of ecological and health risks across coastal zones. Effective monitoring and management strategies are essential to mitigate these risks and protect both marine ecosystems and human populations [25]. In the case of Con Dao, while the concentration of heavy metals remains within acceptable limits, continued industrialisation and increased maritime activities could lead to future contamination risks [6]. Regular water quality and sediment composition assessments are crucial to detecting early signs of heavy metal accumulation. Additionally, understanding the bioaccumulation patterns of these metals in local marine organisms can provide further insights into potential ecological threats.

Characteristics of the shoreline in Con Dao National park. The average annual shorelines, representing the boundary between land and water, were derived from yearly land-water classification maps. These maps facilitated the assessment of shoreline dynamics using the DSAS tool. Between 2016 and 2023, shorelines in natural mangrove forest (NMF) areas exhibited both expansion and retreat. Figure 4 illustrates the baseline and DSAS-generated cross-sections utilized for shoreline change analysis. In total, 571 cross-sections were employed to evaluate shoreline variations, providing a comprehensive understanding of coastal dynamics. This analysis is essential for monitoring long-term shoreline shifts and assessing the impact of environmental and anthropogenic factors on coastal ecosystems. These are perpendicular sections with the baseline and along the shoreline of the 5 plots as follows: 200 transects in plot 1, 44 transects in plot 2, 79 transects in plot 3, 117 transects in plot 4, and 131 transects in plot 5. The identification follows a sequential numbering system from left to right. A positive EPR value signifies shoreline expansion, whereas a negative EPR value indicates a landward shift, representing shoreline retreat.

Xu et al. (2009) stated that when the observation frequency reaches 30, shoreline position uncertainty is below 1 meter, and the shoreline change rate uncertainty is under 0.02 m/year [24]. In this study, 29 satellite images were used in 2016 and 61 in 2023. Thus, despite the satellite images having a 10-meter pixel size, the shoreline position uncertainty remains within a few tens of centimeters. This suggests that the analysis provides a high level of accuracy in detecting shoreline changes over time, ensuring reliable assessments of coastal dynamics and environmental shifts in the study area.

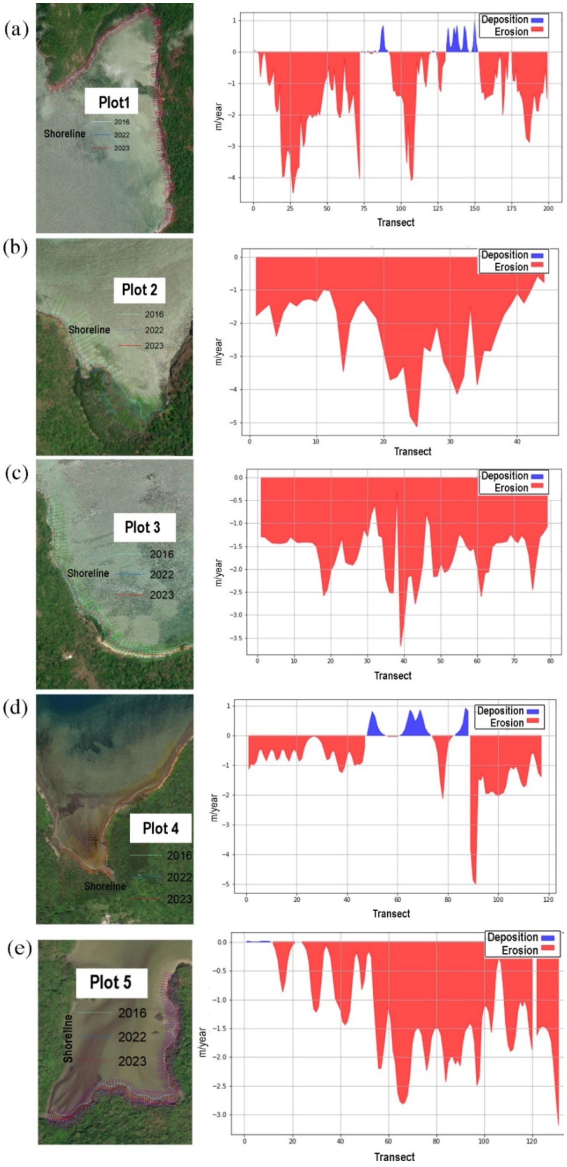

Fig. 4. Shoreline evolution in Con Dao National park, Ba Ria – Vung Tau Province, Vietnam

Once the annual shorelines of the Con Dao islands were identified, the DSAS software was utilized to examine shoreline changes over time and space. Each shoreline was assigned attributes such as date, length, and shape. To ensure accuracy, a baseline was established 500 meters from the shoreline using buffering techniques. This method is considered the most precise and reliable for defining the baseline, enabling a detailed analysis of shoreline dynamics. By applying this approach, the study effectively tracks coastal evolution, supporting better understanding and management of shoreline changes in response to environmental and climatic factors.

The novelty of this study lies in providing information on the impacts of NMF on the coastal erosion dynamics and erosion risks in Dam Quoc and four other NMF-distributed locations in the area. The data in Fig. 4 illustrated the erosion risks with varying degrees of shoreline retreat. The highest erosion risks are observed in plots 2, 3, and 5, with shoreline fluctuations ranging from -3.1 m to -5 m. Meanwhile, plot 1 and plot 4 concurrently exhibit erosion and accretion risks, although erosion predominates. The erosion/accretion rates in these areas are calculated from the forest edge with the degree of exposure to contrasting waves, as follows: NMF of plot 1: EPR values range from 1.61 to -4.5 m/year. NMF plot 2: EPR values range from -0.6 to -5.1 m/year. NMF of Plot 3: EPR values range from -1.3 to -3.7 m/year. NMF of Plot 4: EPR values range from 0.9 to -5 m/year. NMF of Plot 5: EPR values range from 0.1 to -3.2 m/year.

Conclusion

This study sheds light on critical environmental challenges affecting the distribution of *Bruguiera hainesii* in the Dam Quoc area, Hon Ba Island, within Con Dao National Park. The findings indicate that the soil exhibits poor nutrient levels, particularly low P_2O_5, while heavy metal concentrations remain within acceptable limits. However, ongoing industrialization and increasing maritime activities pose potential contamination risks. Furthermore, the mangrove ecosystem across five distinct areas faces considerable threats due to tidal dynamics and coastal regression. The EPR metric plays a vital role in tracking mangrove changes over time.

The combined effects of socio-economic development, environmental shifts, and climate change have significantly contributed to mangrove ecosystem degradation. Historical shoreline analysis from 2016 to 2023 offers valuable insights into coastal environmental changes, reflecting influences such as global warming, storm impacts, rising sea levels, pollution, and sedimentation. Understanding these shoreline variations is crucial for assessing long-term ecological dynamics and guiding conservation efforts.

For the highly vulnerable *B. hainesii* population in Dam Quoc, these findings highlight the urgent need for targeted conservation measures. Enhancing coastal resilience through sustainable management and habitat restoration is essential to mitigating future threats. This research provides critical data to support decision-making processes for regional managers, assisting in the development of strategies to safeguard and potentially expand the mangrove forest area that sustains *B. hainesii*.

Compliance with ethical standards. This article does not contain any studies with human participants performed by any of the authors.

Conflict of interest information. The authors declare that they have no conflicts of interest.

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