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Characteristics of composition, area and status of coral reefs at submerged banks and shoals on the continental shelf of Southern Vietnam

Nguyen Van Long[1,2,*], Tran Van Binh[1], Thai Minh Quang[1,2], Nguyen Le Thao My[1], Marina Malyutina[3]

[1]*Institute of Oceanography, VAST, Vietnam*
[2]*Graduate University of Science and Technology, VAST, Vietnam*
[3]*A.V. Zhirmunsky National Scientific Center of Marine Biology, Far Eastern Branch, Russian Academy of Sciences (NSCMB FEB RAS). 17 Palchevsky St., Vladivostok 690041, Russia*

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ABSTRACT

The continental shelf off southern Vietnam, from Khanh Hoa to Ba Ria-Vung Tau provinces, contains numerous submerged banks and shoals. These locations are considered to have significant potential, not only for their distinctive landscapes but also for their valuable biodiversity and critical marine resources. This study was based on the compilation and analysis of data from U.S. Navy nautical charts, Vietnamese maps, and previously published reports from before 2001, combined with GIS techniques to build a 3D underwater terrain model and calculate the area of 10 specific submerged banks and shoals on southern Vietnam's continental shelf. Additionally, coral reef conditions at these sites were assessed alongside biodiversity assessments during May-June 2023. The calculations show that the total area of the 10 submerged banks and shoals was approximately 19,144 hectares. Of these, 9 locations, including Grand Bank, De Thuy Trieu Bank, Phan Rang Bay Shoal, Breda Shoal, Hollandias Bank, De Britto Bank, De L Astrolabe Bank, Bishop Bank, and Catwick Bank, had coral reefs distributed over 17,257 hectares. However, coral reefs were absent in the southeastern shoal group near La Gan Cape. Overall, coral reefs in these regions were severely degraded, with live coral cover ranging from 5–30%, except for Phan Rang Bay Bank, which had slightly higher coverage (31–50%). Macroalgal coverage was notably high, ranging from 5% to 75% per site.

Keywords: Submerged banks and shoals, area, benthic covers, coral reefs, Southern Vietnam.

[*]Corresponding author at: Institute of Oceanography, 01 Cau Da, Nha Trang Ward, Khanh Hoa Province, Vietnam. *E-mail addresses*: longhdh@gmail.com

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Introduction

Global coral reef classification is based on four main morphologies included fring reefs, barrier reefs, atoll and platform reefs/patch reefs (Fig. 1). Fringing reefs grow near the shore; barrier reefs are separated from land by a wide, deep lagoon, and atolls are ring-shaped reefs enclosing a central lagoon [1]. Platform reefs (or patch reefs) are different from above isolated structures growing independently on the seafloor or continental shelf [2].

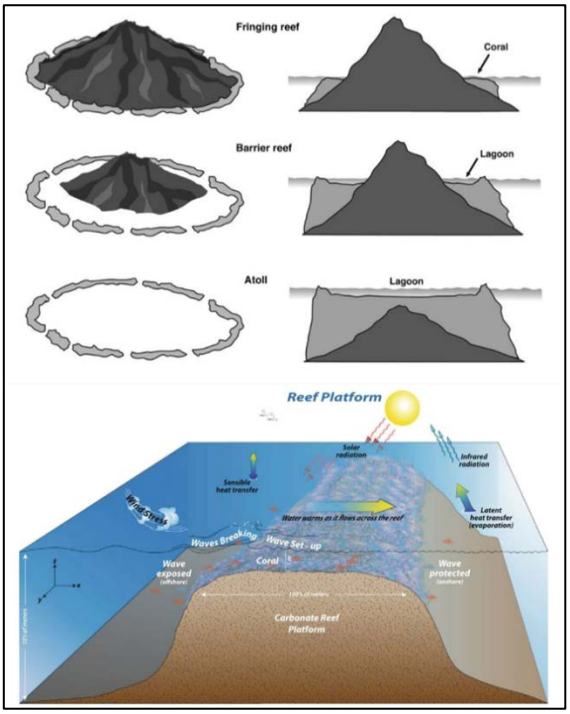

Figure 1. Illustration for the formation of a typical coral reef across the globe: fringing reef, barrier reef and atoll [1], and platform reef [2]

Submerged banks, reefs, and shoals belonging to the platform reefs are defined as submerged reef locations found at varying depths beneath the ocean surface, depending on tectonic processes, but typically range from 30 m to 150 m [3]. Many studies have shown that coral reefs on submerged banks and shoals serve as critical refugia for coral community biodiversity and associated marine groups [1, 4]. Bridge and Guinotte (2012) [4] conducted multiple surveys in deep waters along the continental shelf of Australia's Great Barrier Reef to determine the distribution of coral communities within lagoons and deeper waters. This research introduced predictive models for the distribution of coral communities across a vast area that had not previously been documented. Another study conducted in the Great Barrier Reef region demonstrated that submerged banks and shoals significantly expanded the habitat available for coral reefs [5]. Moore et al. (2017) [6] found that deep-water coral reef habitats (20–80 m) in northwest Australia harbor high biodiversity, with reef fish representing the most diverse, abundant, and unique group. Consequently, these habitats played a substantial role in supporting biodiversity, acting as essential refugia for coral reef communities and other marine life.

In the East Sea, previous studies have identified several submerged banks and shoals, including Macclesfield Bank and Truro Shoal, located between the Hoang Sa Islands and Scarborough Reef, and the Reed Bank [7]. The Bai Co Rong (Reed Bank) is situated at an average depth of 1,200–1,500 m in the southwestern part of the Truong Sa Islands [8]. The total reef area is estimated at 12,000 km², or 4.7% of the world's total reef surface area, with over 300,000 reef-associated species (about 37% of the approximately 800,000 reef species worldwide) found on the southern reefs of the East Sea [7]. However, no studies have been conducted on the biodiversity and biological resources of the submerged banks and shoals in the Truong Sa Islands.

The southern continental shelf region of Vietnam (from Khanh Hoa to Ba Ria-Vung Tau Provinces) contained numerous submerged banks and shoals distributed in bays and offshore locations. Noteworthy among these are Grand Bank (Bai Can Lon), located north of Nha Trang Bay, De Thuy Trieu Bank (Bai Can Thuy Trieu), south of Cu Hin Cape, and the Phan Rang Bay (including De Chateaurenault and Pateau De Corail Banks). Additionally, Breda Shoal (Bai Can Breda), south of Mui Dinh in Ca Na Bay, while there were groups of banks and shoals located in the southeast of La Gan Cape, including Pecheurs, Banc Amazons, Duchaffaut, and Bourayne. Offshore locations south of Phan Thiet, extending to Vung Tau, hosted reefs such

as Hollandais (Ran Ca), De Britto, De L'Astrolabe, Royal Bishop, and Catwick Banks. In the northern banks and shoals (from Nha Trang Bay to Ca Na Bay), sediment composition was characterized by a carbonate content exceeding 50% [11]. At specific locations, the transition from the bank to the deeper seafloor was abrupt, marked by steep walls, as seen in Grand, De Thuy Trieu, and Breda Banks. In the western and northwestern locations near Phu Quy Islands and in the southern locations extending from Phan Thiet to Vung Tau, the terrain was rugged, featuring accumulative-erosive formations lying only 4–5 m below sea level, including the Vulcan, Hollandais, De Britto, and De L'Astrolabe Banks. In some of these, corals thrived on the upper sections [9].

In addition to information on topography, geomorphology, composition, and geology, a few initial studies have identified submerged banks in southern Vietnam's waters. For instance, Grand Bank in Nha Trang Bay was estimated to cover between 427 hectares [10] and 1,000 hectares [11, 12], while Breda Shoal in Ca Na Bay spanned 2.200 hectares [12]. Recently, individual studies had assessed the coral reef conditions on Breda Shoal, Bishop and Catwick Banks under the project "Investigating the coral reef, biodiversity of benthic communities in a deep-sea, heavy metals and antioxidant compouds in benthic macro-inverbrates and some environmental parameters related to ocean acidification in the continental shelf of southern Vietnam" (Code: QT.RU.04.02/18–19), conducted during 2018–2019 under leading by Dr. Hoang Xuan Ben from the Institute of Oceanography. However, these data remain unpublished except for coral reef fishes [13, 14].

Research on submerged banks and shoals on Vietnam's continental shelf has been limited primarily to isolated studies of geology and geomorphology, species diversity, and reef fish at a few nearshore banks or remote islands. However, the scope and distribution areas, ecosystem status, and biotic communities, particularly coral reefs, at most submerged banks and shoals in deeper, offshore waters have received less attention. Therefore, obtaining a more comprehensive understanding of the condition and resource value of these locations is crucial. This will help establish a foundation for conservation and the sustainable use of biodiversity and marine resources, especially given the current context of climate change.

Materials and methods

Data sources for analysis

Report "Geological investigation and search for coastal seas solid minerals (0–30 m water) in Vietnam, scale 1:500,000" (1991–2000) by the Vietnam Department of Geology and Minerals, Marine Geology and Mineral Center. These include: Surface sediment and coastal marine hydrodynamic maps of the coastal sea (0–30 m water) in Vietnam, scale 1:500,000, with accompanying explanatory reports; Geological maps of the coastal sea (0–30 m water) in Vietnam, scale 1:500,000, with accompanying explanatory reports; Tectonic structure maps of the coastal sea (0–30 m water) in Vietnam, scale 1:500,000, with accompanying explanatory reports;

Scientific reports from the comprehensive survey program of the Thuan Hai-Minh Hai marine area, conducted from 1976–1980;

U.S. nautical charts, scale 1:50,000, covering Vietnam's coastal waters, including sheets: 93E22, 93E23, 93E24, 93E25, and 93E27 [15];

C-Map charts and seabed topography maps (0–30 m depth), scale 1:200,000, developed in 2001.

Data processing and calculations

The collected maps were geometrically rectified and standardized to a unified projection grid. Depth data were digitized, and GIS software was used to gather information and construct depth schematics and digital depth models. These models facilitated depth and area calculations for each submerged bank in the study. Additionally, existing geological data were overlaid to pinpoint the locations of submerged banks and shoals and to identify the primary components that constitute them within the study region. The areas of submerged banks and shoals are calculated based on the horizontal plane on which they are distributed, as shown

on maps (U.S. nautical charts and C-Map). These calculations are limited to the depth ranges indicated on the maps and in Table 1 below, depending on the specific locations. The calculations do not include the coverage area of underwater hills on the seabed.

Rapid ecological assessments of coral reefs

A rapid assessment of coral reef conditions was conducted in conjunction with detailed evaluations of biodiversity and reef health (Figs. 2–5). At each reef site surveyed, observers swam along a 50-meter transect to quickly assess the coverage of key components: live corals (both hard and soft), macroalgae, and dead corals. These components were rated on a scale from 1 to 5, with categories ranging from very poor (1–10%) to excellent (76–100%) [16]. Unfortunately, due to bad weather, the Catwick Bank could not be surveyed. To address this, we incorporated unpublished data from a 2019 project titled "Investigating the coral reef, biodiversity of benthic communities in a deep-sea, heavy metals and antioxidant compounds in benthic macro-invertebrates and some environmental parameters related to ocean acidification in the continental shelf of southern Vietnam" (Code: QT.RU.04.02/18–19) for this location.

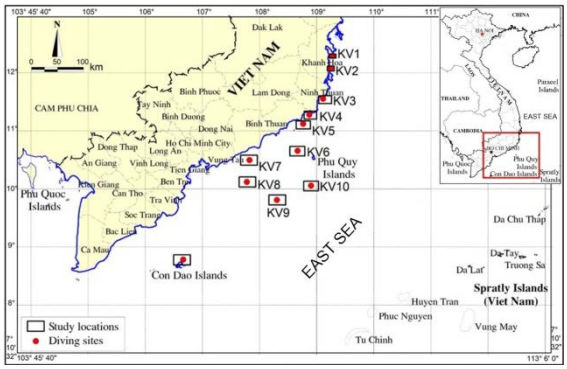

Figure 2. Study locations of submerged banks and shoals in Southern Vietnam

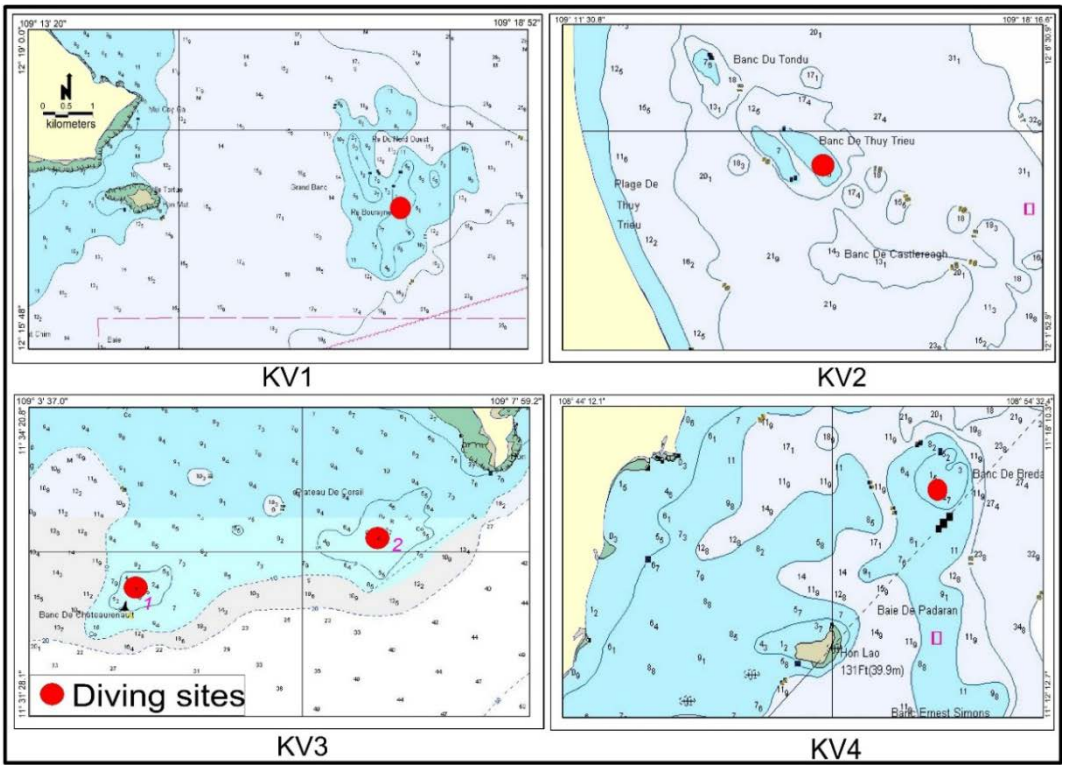

Figure 3. Study sites at the Grand Bank (KV1), De Thuy Trieu Bank (KV2), Pateau De Corail and De Chateaurenault Banks (KV3), and Breda Shoal (KV4)

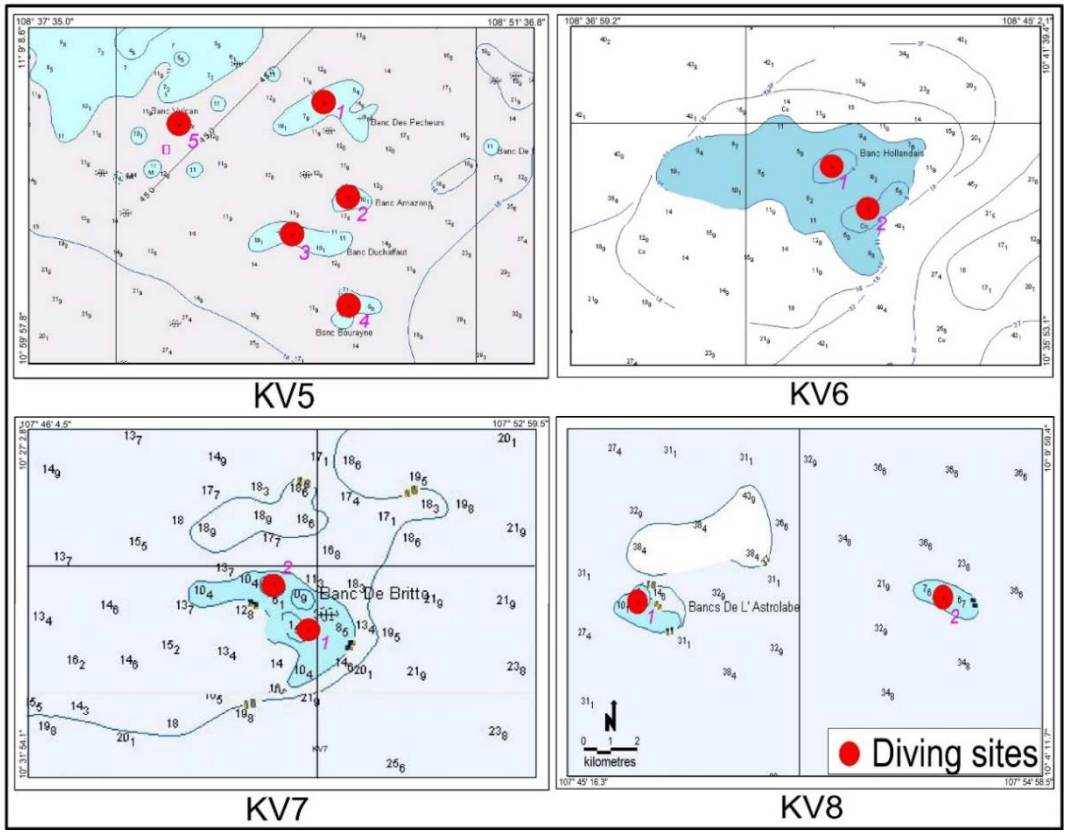

Figure 4. Study sites at the bank group in the southeast of Lagan Cape (KV5), Hollandias Bank (KV6), De Britto Bank (KV7) and De L'Astrolabe Bank (KV8)

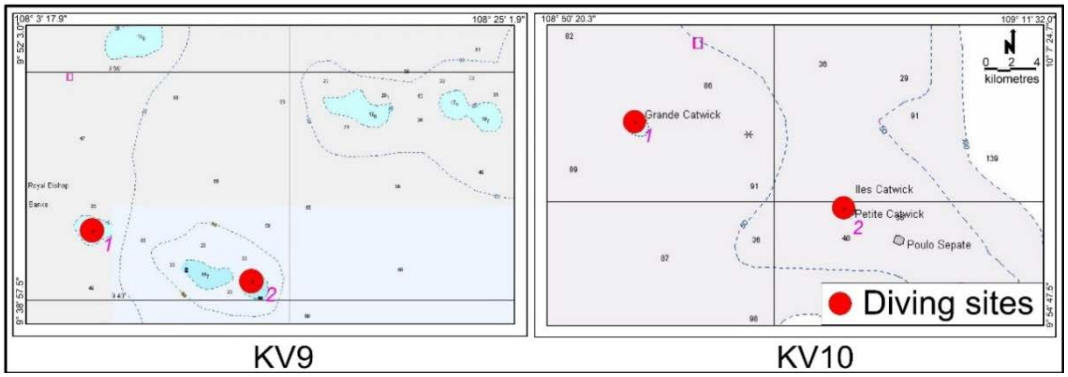

Figure 5. Study sites at the Bishop Bank (KV8) and Catwick Bank (KV10)

Results and discussion

Composition characteristics and area

Based on the synthesized geological and geomorphological data, the main structural components, area, and coverage of specific components in the 10 submerged bank and shoal areas from Nha Trang to Con Dao were summarized in Table 1. Out of the total 19,144 hectares of these areas, approximately 17,257 hectares of coral reefs were distributed across nine submerged banks and shoals (Table 1).

Table 1. Summary of characteristics of submerged banks and shoals in the study region

No.	Name of submerged banks and shoals	Depth (m)*	Area (ha)*	Dominant compositions	Sources
1	Grand Bank	1.2–14	866.3	Surface sediments are rich in bioclastic fragments, coral debris, sand, and gravelly sand. Beneath these lie Pliocene sediments, which consist of conglomerates, sandstones, siltstones, and claystones	[17, 18]
2	De Thuy Trieu Bank	5.5–16	530		
3	Pateau De Corail, De Chateaurenault	1–5	180	Surface sediments are also rich in bioclastic fragments, coral debris, sand, and gravelly sand, underlain by undivided Neogene sediments that include weakly cemented sandstone and gravelstone	[19, 20]
4	Breda Shoal	1.5–11	2,344		
5	Pecheurs	6–11	825	Surface sediments consist of sand, sandy gravel, yellow gravelly sand, muddy sand, and gray to grayish-green mud with limited bioclastic material; the underlying layer is undivided Neogene sediments composed of weakly cemented sandstone and gravelstone	[19, 20]
	Banc Amazons	7–11	205		
	Duchaffaut	9–11	572		
	Bourayne	9–11	285		
6	Hollandias Bank	3.7–20	6,015	Upper sediment layer may include marlstone, with deeper levels potentially containing pre-Tertiary igneous rocks	[21, 22]
7	De Britto Bank	0.9–12	696	Pre-Quaternary bedrock, belonging to the Deo Ca Complex ($\gamma\xi K đc_2$), is composed of medium to coarse-grained biotite (hornblende) granite and granosyenite, sometimes in porphyritic form	[19, 20]
8	De L'Astrolabe Bank	4.6–18	431.7	Carbonate sedimentary rocks, carbonate rocks containing sand, fine-grained sandstone, and iron-rich laterite grains	[7]
9	Bishop Bank	7.9–20	5,804		
10	Catwick Bank	1–25	390	Consisting of sedimentary volcanic rocks and basaltic lava, with sandstone deposits in the upper layers	[23, 24]
Total			19,144		

Notes: Depth range and area calculated were based on the US nautical map and C-map of Vietnam.

Khanh Hoa:

- *Grand Bank (Bai Can Lon; KV1):* At depths ranging from 1.2 to 14 m, with an area of 866.3 hectares. Grand Bank resembled a submerged ridge with a rugged surface, and its peak lies just 1.2 m below the water surface, with a gentle slope on the Eastern side descending into deeper water (Fig. 6).

- *De Thuy Trieu Bank (Bai Can Thuy Trieu; KV2):* Located at depths of 18–20 m, with a peak 5.5 m below the surface and covering an area of 530 hectares. The topography included elevated blocks with rugged surfaces and deep trenches between 11–12 m, sloping sharply on the Eastern side to depths of 25–30 m (Fig. 6).

Based on geological data, structural morphology, depth, and sediment thickness, it was determined that Grand Bank and De Thuy Trieu Bank belong to a lower structural formation with pre-Quaternary bedrock and Pliocene-aged sediments [18]. These sediments included conglomerates, sandstones, siltstones, and claystones and had a thickness of 200 m. The surface sediments were rich in bioclastic fragments, coral debris, sand, and gravelly sand (offshore tectonic structure map of Vietnam's coastal area 0–30 m, Quy Nhon sheet). However, according to the coastal geological map of Vietnam's 0–30 m offshore area and geological cross-sections, the upper layer was composed of lower-middle Holocene marine sediments (comprising gray, cemented sand and gravelly sand rich in bioclastic material, coral, and Foraminifera), while the underlying layer consisted of Pleistocene marine sediments (mottled clay silt, yellow, and grayish-yellow

gravelly sand) with a thickness of 10–30 m overlying bedrock of the Nha Trang Formation (including rhyolite, dacite, andesite, and their tuff, with a thickness of 450–600 m) [17].

Phan Rang to northern Binh Thuan:

- *Phan Rang Bay Bank (KV3):* At depths of 8–10 m, the Pateau De Corail had a peak just 0.6 m below the surface, while De Chateaurenault's peak is 1.8 m below, with an area of 866.3 hectares. These features resembled submerged mounds with rugged surfaces, descending southward and southeastward into depths of 20–30 m (Fig. 6).

- *Breda Bank* (*Bai Can Breda; KV4):* With a peak 1.5–2 m below the surface and an area of 2,344 hectares, Breda Bank extended north to south. The southern side of the bank was deeper, with the peak located at 8–9 m below the surface (Fig. 6).

According to the coastal tectonic structure map of the 0–30 m, Da Lat - Ho Chi Minh City sheet, the shoals (Pateau De Corail and De Chateaurenault) in Phan Rang Bay, Breda Shoal in Ca Na Bay, and the shoals in the southeast of La Gan Cape (Pecheurs, Banc Amazons, Duchaffaut, Bourayne) were located in an uplifted structural zone with a pre-Quaternary bedrock of Neogene age. The structural components included weakly cemented sandstone and gravelstone, with a thickness ranging from 30 to 120 m [20]. According to the geological map, Pateau De Corail Bank consisted of upper Holocene marine sediments, composed of sand, muddy sand, and gray to grayish-green sandy gravel with few bioclastic fragments containing Foraminifera, with a thickness of 1 to 5 m, overlying lower-middle Holocene marine sediments. At De Chateaurenault Bank, the marine sediments were of lower-middle Holocene age, consisting of sand, sandy gravel, gravelly sand, muddy sand, and gray to grayish-green mud enriched with bioclastic material, paleontological remains, and Foraminifera, with sediment thickness ranging from 1 to 25 m [19]. Breda Shoal consisted of upper Pleistocene marine sediments, with an upper section composed of mottled clay silt containing laterite nodules, red sand, reddish-yellow silty sand with volcanic material, bioclastic calcareous gravel containing Foraminifera remains, with a sediment thickness of 5 to 40 m. Structurally, this bank had a bedrock of undivided Neogene sediments consisting of weakly cemented sandstone and gravelstone.

Central Binh Thuan to Vung Tau:

- *Group of shoals near Southeast La Gan Cape (KV5):* This location includes Pecheurs, Banc Amazons, Duchaffaut, and Bourayne banks and is located at depths of 11–12 m. Their morphology resembled submerged mounds rising slightly above the surrounding seabed by 2–4 m, covering an area of approximately 1,887 hectares. These shoals belong to lower-middle Holocene marine and fluvial sediments, composed of sand, sandy gravel, yellow gravelly sand, gray to grayish-green muddy sand, and clayey sand with minimal bioclastic material, with a thickness of 1–25 m (Fig. 6).

- *Hollandias Bank (Ran Ca; KV6)*: Bank had a morphology resembling submerged hills northwest of Phu Quy Island, featuring depressions resembling channels or saddles to the northwest and southeast (Fig. 6). The rugged surface was at about 4–5 m and supports coral growth [24], classified as a biologically originated terrain [25]. The bank ranged in depth from 4 to 20 m, covering about 6,015 hectares. Limited data were available on the material forming the submerged hills northwest of the basaltic islands of Phu Quy. Marlstone found on Band de La Marne suggested this area may be composed of such rock [7]. Beneath these, pre-Tertiary igneous rocks may be present, similar to those described by Saurin, including basaltic lava rocks with granite containing cordierite, aplite, pegmatite, rhyolite, and siliceous sandstone [21].

- *De Britto Bank (KV7):* lying at depths of 14–15 m with its peak 0.9 m below the surface. Its morphology resembled an isolated hill on the seabed, with a steeply sloping surface, particularly on the eastern slope, which descends to greater depths (Fig. 6). The bank spanned 696 hectares at depths of 0.9–12 m. Geologically, De Britto Bank lies within an uplifted structural zone with pre-Quaternary bedrock, part of Phase 2 of the Deo Ca Complex, comprising medium- to coarse-grained biotite (hornblende) granite and granosyenite, sometimes porphyritic. Surrounding the bank, upper sediments comprised lower- to middle-Holocene marine

deposits, including gray to grayish-green sand, sandy gravel, gravelly sand enriched with bioclastic fragments, paleontological remains, and Foraminifera.

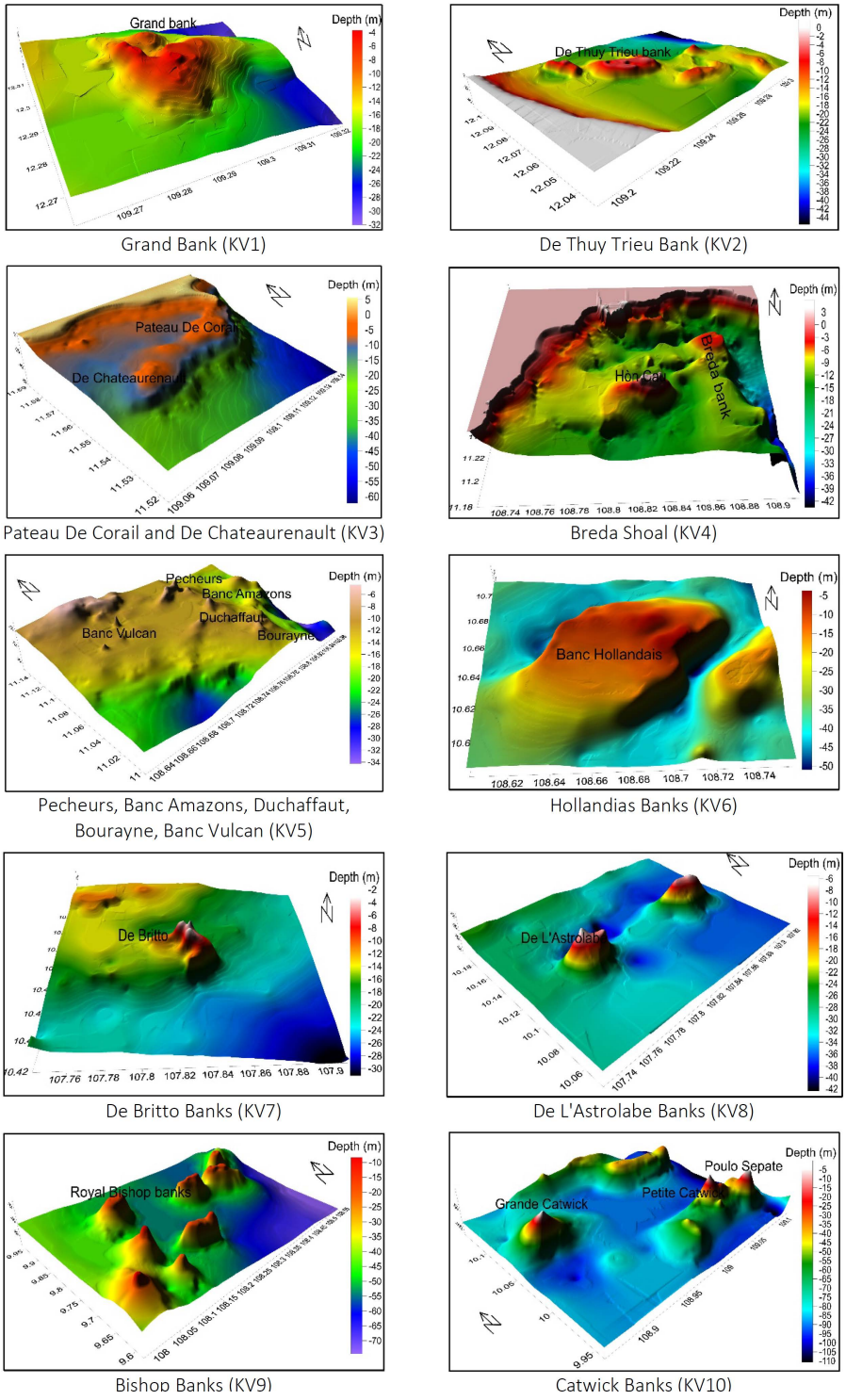

Figure 6. The 3D numerical models of the seabed terrain of submerged banks and shoals in the study region

- *De L'Astrolabe Bank (KV8) và Bishop Bank (Royal Bishop banks; KV9):* Banks had morphologies resembling underwater hills with biologically originated rugged surfaces and numerous depressions supporting coral growth (Fig. 6). Currently, these terrains developed over sedimentary rocks, and erosion processes constantly occur on the surface, with eroded material accumulating in depressions. Bishop Bank featured hill-like terrain with many protruding and elevated sections above the surrounding seabed, located at depths of more than 40–55 m below sea level. Covering 5,804 hectares in depths from 7.9–20 m, De L'Astrolabe and Bishop Banks consisted of carbonate sedimentary rocks, carbonate rocks containing sand, fine-grained sandstone, and iron-rich laterite grains [7].

- *Catwick Banks (KV10):* Having geo-morphological features of eroded volcanic hills in a wave-affected zone, developing on uplifted domes or protrusions along with the Phu Quy and Hon Hai Islands. These volcanoes erupted underwater in multiple phases from the Neogene to modern times. The prominent basaltic eruptions formed islands (Grande Catwick, Petite Catwick, Poulo Sepate), with submerged portions representing Neogene sandstone domes.

Presently, erosion has created a wave-cut terrace surrounding the islands. Numerous basaltic hills had been eroded at the tops and slopes, forming cliffs [23]. Covering 390 hectares, this submerged area spanned depths of 1–25 m (Fig. 6). Geologically, the islands consisted of volcanic sedimentary rocks and basaltic lava [23, 24]. Surface volcanic sediments are products of Quaternary and modern volcanic activity, composed of volcanic rock fragments, lava, and volcanic ash [22].

Compared to previous studies, the total area identified in this study was 1.3 times larger than the 13,355 hectares recorded in 21 nearshore and island reefs in 2014 [26], and exceeds the 13,426 hectares reported for 28 reef locations in 2019 [27]. Specifically, the area of Grand Bank in the current study was 866.3 hectares, which was double the 427 hectares reported in 2015 [9], but 1.2 times smaller than the approximately 1,000 hectares published in 2005 [8, 9]. Meanwhile, the area of Breda Shoal was 2,344 hectares, which was comparable to the 2,200 hectares reported in 2022 [9].

Status of coral reefs

Data analysis from the rapid ecological assessment of significant components, as outlined in Table 2 and Figure 7, indicates that most banks and shoals in the study region were in a severely degraded state, with live coral cover generally ranging between 5–30%; macroalgal cover was notably high, ranging from 5 to 75%.

Table 2. Cover (%) of major benthic substrata at submerged banks and shoals

No.	Name of submerged banks and shoals	Live corals (%)	Hard corals (%)	Soft corals (%)	Macro-algae (%)	Dead corals (%)
1	Grand Bank	1–10	1–10	1–10	50–75	30–50
2	De Thuy Trieu Bank	1–10	1–10	0	11–30	51–75
3	Phan Rang Bay Bank	31–50	1–10	31–50	1–10	31–50
4	Breda Shoal	1–10	0	1–10	11–30	51–75
5	Pecheurs	No corals				
	Banc Amazons					
	Duchaffaut					
	Bourayne					
	Banc Vulcan					
6	Hollandais Bank	1–10	1–10	0	11–30	31–50
7	De Britto Bank	11–30	11–30	1–10	1–10	31–50
8	De L'Astrolabe Bank	1–10	1–10	1–10	31–50	31–50
9	Bishop Bank	1–10	1–10	1–10	50–75	31–50
10	Catwick Bank*	11–30	11–30	1–10	1–10	31–50

Note: * Unpublished data from the project code: QT.RU.04.02/18–19 surveyed in 2019.

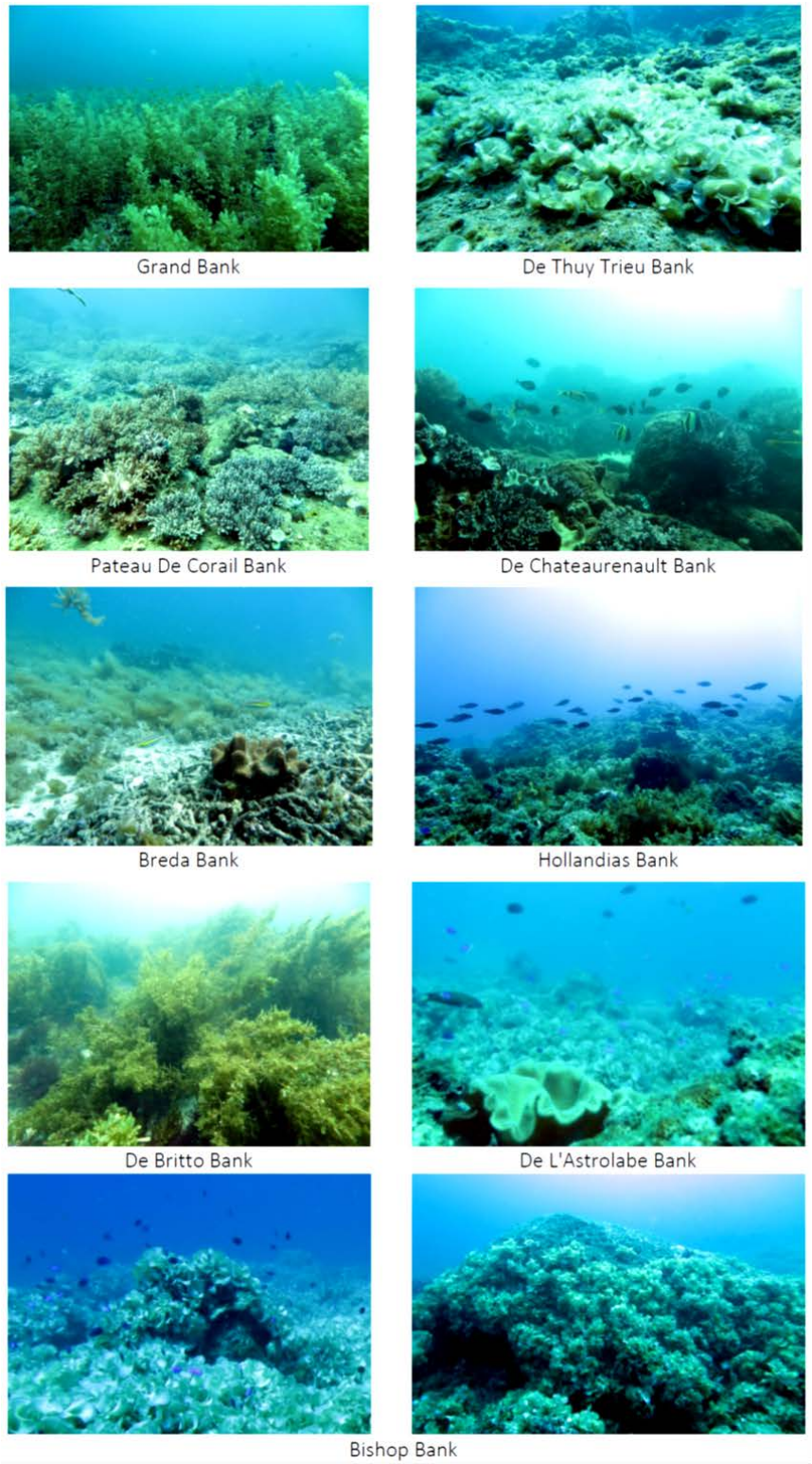

Figure 7. Photos demonstrating major components covering the reefs at submerged and shoals in the study region

In the Phan Rang Bay area, coral cover was relatively stable at 30–50%, but primarily consisted of soft corals. Comparative analysis of benthic cover at specific banks and shoals revealed distinct patterns (Table 2). The Grand Bank was dominated by *Sargassum*, which covered 50–70%, with live coral limited to soft corals (1–10%). The De Thuy Trieu Bank featured predominantly dead corals, with 11 to 30% seaweed and only 1 to 10% live coral. In contrast, the Phan Rang Bay shoals were covered mainly by soft corals of *Sinularia* (31–50%), with minimal seaweed presence. The Breda Bank showed minimal live coral cover (1–10%), primarily composed of soft corals, alongside moderate seaweed cover (11–30%).

The shoals near the southeast of La Gan Cape exhibited no coral reef presence. The Hollandias reef had limited live coral (1–10%) and seaweed covering 11–30%. The De Britto Bank maintained relatively stable coral cover (11–30%), with a higher proportion of hard corals and low macroalgal cover (1–10%). The De L'Astrolabe and Bishop Banks were severely degraded, dominated by *Padina* seaweed (31–75%) and minimal live coral (1–10%). Survey results from the Catwick Islands (Hon Bo and Hon Kham) in 2019 indicate that corals grew on the vertical walls surrounding the islands, with live coral cover ranging from 11–30% and macroalgal cover ranging from 1–10%.

The comparison of hard coral cover from submerged banks and shoals in the study region (midpoint of range: 0–15%) was significantly lower than the coverage recorded at 26 nearshore and island reef locations from 2010 to 2019 (3.8–27.8% [27]) and at seven key sites in Southern Vietnam from 2015 to 2017, including Cu Lao Cham, Van Phong, Nha Trang, Nui Chua, Con Dao, Phu Quoc (2.5–69.4%; mean: 29.2 ± 20.3% [28] and Quy Nhon (27.2 ± 22.8% [29]). Several factors, including overfishing, coral bleaching, outbreaks of crown-of-thorns starfish (COTS), and typhoons, have been identified as major drivers of coral reef degradation in several locations in the coastal waters of Vietnam [28, 30–33]. These impacts have also contributed significantly to the heavy degradation observed in the coral reefs of submerged banks and shoals.

Recent studies in Vietnam indicate that some submerged banks and shoals in waters deeper than 20 m serve as crucial habitats and spawning grounds for large, high-value reef fish species. These include the mangrove red snapper (*Lutjanus argentimaculatus*), orange-spotted grouper (*Epinephelus coioides*), and malabar grouper (*E. malabaricus*) outside the Tu Hien inlet and north of Hai Van Pass in Thua Thien Hue Province [34], along with the gold-spotted rabbitfish (*Siganus guttatus*) at Ran Manh and Ran La (Manh and La reefs) in Cu Lao Cham MPA [35, 36]. Therefore, the establishment and management of large reef areas in these submerged reefs and shoals are essential. This strategy will significantly contribute to limiting exploitation and impact, helping to restore degraded coral reefs, increase live coral cover and biodiversity, and simultaneously sustain local fisheries.

Conclusion

There are notable differences in the composition and sediment types between the submerged banks and shoals in the study region. The Grand Bank and De Thuy Trieu Bank share similar Pliocene sediments, while undivided Neogene sediments characterized the Phan Rang and Breda Shoals. In contrast, the De L'Astrolabe and Bishop Banks were composed of carbonate sediments and rocks, whereas the Catwick Bank features sedimentary volcanic rocks and basaltic lava. The banks and shoals near Southeast La Gan Cape had distinct surface sediments (including sand, sandy gravel, yellow gravelly sand, muddy sand, and gray to grayish-green mud with limited bioclastic material), setting them apart from other banks and shoals in the region.

Of the 10 studied submerged banks and shoals, nine areas including Grand Bank, De Thuy Trieu, Phan Rang Bay Shoals, Breda Shoal, Hollandias, De Britto, De L'Astrolabe, Bishop, and Catwick Banks hosted an area of approximately 17,257 hectares of coral reefs, exceeding previous records by 1.3 times of the area of coral reefs alongside shoreline of the mainland and islands as previously reported.

Among them, the group of shoals in the southeast of La Gan Cape lacked coral reefs due to differences in the composition and characteristics of the surface and undivided Neogene sediments.

Coral reefs in these submerged banks and shoals were severely degraded, with live coral cover mostly in poor condition (< 10–30%) whilst macroalgal cover was notably high (5–75%) across reef locations, except for the Phan Rang Bay in fair condition (31–50% of live coral cover).

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