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Classification and mapping of marine-island landscape in Nam Yet Island, Truong Sa Islands, Vietnam

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ABSTRACT

Classification and mapping of marine-island landscapes according to an integrated approach not only clarifies the structure and division of natural units of the sea areas but also creates a basis for the orientation of natural resource management resources, environmental protection, and conservation of marine-island biodiversity. The principles of marine-island landscape mapping define terminology and establish a classification system based on taxonomy and criteria. This article represents the establishment of marine-island landscape mapping of Nam Yet Island and adjacent water (scaled at 1:10000) through comprehensive work, including marine-island landscape classification, applied GIS - remote sensing, and field investigation in the two years of 2020-2021. Accordingly, the landscape classification system of the Nam Yet Island area includes 1 system, 1 subsystem, 4 classes, 6 subclasses, 10 types, 29 kinds, and 34 forms of landscape (of which 4 island forms and 30 marine forms). The units of the marine-island landscape fully express the natural components, anthropogenic factors, and biotic and abiotic factors in their relationship and interaction with each other. Depending on each corresponding level, the detailed level of components and landscape elements is shown, in which components and biological factors are studied and analyzed most fully. The research results have clarified the characteristics and the law of differentiation of the marine-island landscape in Nam Yet Island, contributing to supplementing knowledge about Truong Sa Islands of Vietnam, which is a scientific basis for resource management and biodiversity conservation, protecting the marine environment, and at the same time supplementing the theoretical basis for the study of the tropical monsoon tropical island and marine landscape, which has not yet been studied in Vietnam.

Keywords: Marine-island landscape, Nam Yet Island, Classification, Truong Sa Islands, remote sensing.

1. Introduction

The marine landscape is an essential part of the Earth's landscape crust. Russian scientists studied the maritime landscape as early as the middle of the twentieth century. In 1951, Zhivago proposed the definition of an underwater landscape: "Marine landscape is part of the seabed or oceanic seafloor and adjacent water border, in which the detail, correlated and physio-dependent complex of

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the benthic mosaic is being observed with the relevant geologic setting, chemical physics features, water column characteristics, and organism forms" (Zhivago, 1951). Later, many Russian scientists referred to organism elements as part of The marine andscape (Dorokhov D.V., 2018; Preobrazhensky B.V., 2006).

In the United States and European countries, several projects have been completed within the framework of government programs to develop a unified classification system and methodology for habitat mapping, mainly to create maps for environmental and spatial planning professionals. In the United States, the National Oceanic and Atmospheric Administration (NOAA) initiated the establishment of the Coastal and Marine Environmental Classification Standard (CMECS) as a scheme of national standards for the Classification and correction of marine data. They described units of environmental significance in a format that uses generic terms in science, resource management, and environmental protection (Madden & Grossman, 2007). This classification standard has been revised several times, and the most recent version was revised in 2012. This Classification is close to the European Classification.

In European countries, following the entry into force of the EU Guidelines (Commission of European, 1992) in 1992, landscape mapping in Europe has been oriented toward identifying habitat types or biotopes (Ichter et al., 2014), and different classifications have been developed. In 1995, the European Environment Agency (EEA) set the standard European classification system EUNIS (European Nature Information System) (Davies, Moss, & Hill, 2004) to classify terrestrial, aquatic, and marine habitats. EUNIS is a system of 5 quartiles, where the mapping rate is determined at each level, and the details of the habitat division are increased. The minor EUNIS habitat in terms of the party can describe the "microbiota" of small invertebrates and nonvascular plants, which may occupy less than 1 m^2 and contain no upper limit on the area.

The concept of marine landscapes was developed by Roff and Taylor (2000) in their study on Canadian waters or Laffoley et al. (2000) in the United Kingdom (Laffoley D d'A. et al., 2000; Roff J. & Taylor M., 2000). Roff and Taylor assumed that the concept of marine landscape could be applied to water bodies and the seabed (using temperature, water depth, light penetration, and slope). The concept of maritime landscape is also used in UKSeaM maps and Mesh projects, which aim to describe the marine environment with geophysical features, including the seabed and water column (Connor D.W. et al., 2006). Studies on marine landscapes Europe and Asia have also defined marine ecology and marine-island landscapes (Lianyong & Eagles, 2009; Suo, ao, & Ge, 2009; Wedding L., C., S., A., & S., 2011). Advances in technology, including geographic information systems with remote sensing, are an essential step forward in marine ecological research, especially in marine-island landscapes and coastal areas (Hinchey Malloy E., M., R., & E., 2007). The 19th "Marine and Coastal Applications in Landscape Ecology" conference in the United States was organized by the Society for Landscape Ecology from March 31 to February 4, 2014, in Las Vegas to address these issues.

Marine landscape classification has been shown in other studies worldwide. Goding et al. (2004) established a marine landscape map of the nearshore water and seabed of Ireland consisting of 18 landscape types, each of which can extend up to several squared kilometers based on sedimentary and geomorphological characteristics, ecological systems and anthropogenic activities (Golding N., M., & D., 2004). The 2012 project "Natural England" was developed on the "Seascape wheel" using multiple physiological, marine, ecological, social, and cultural elements to zone out particular seascapes and unique components responsible for the original feature of each seascape (Natural England, 2012). Hogg et al. (2018) mapped the marine landscape on a large scale to evaluate the environment-organism relationship on South Georgia Island (Antarctica), which lies in one of the largest marine protected areas in the world (Hogg O., V., H., B., & K., 2016; Hogg O., V., H., & K., 2018). Pittman (2017) proposed a definition and a structural model of marine landscapes in a 2-dimensional benthic habitat map using patch-matrix or patch-mosaic (Pittman S., 2017). These studies began to focus on the components of ecosystems and anthropogenic influences on marine landscapes.

Vietnam is a maritime country with an exclusive economic zone of 1 million square kilometers, three times the land area. However, studies on marine-island landscapes in Vietnam are still minimal. Some studies mainly deal with theoretical, conceptual, and taxonomical issues or studies related to physics, geography, or the analysis of components of the East Sea (Le Duc An & Khanh, 2012; Nguyen Ngoc Khanh, Nguyen Cao Huan, & Hai, 1996). There are only 2 studies for generality and nondetailed data on the landscape of Truong Sa Islands (Tran Anh Tuan, 2013) and the Cat Ba area, Gulf of Tonkin (Lebedev, 2019).

Landscape studies in general and marine-island landscape studies are highly integrated. Landscape hierarchy and classification attributes from the study outcomes allow clarification of landscape characteristics and their differentiation in a given area and represent the internal relationship among biotic and abiotic elements. These foundations provide a better consciousness of the sea and islands and assist in resource management, biodiversity preservation, and environmental protection.

Despite a diverse definition, a unified approach for marine landscape classification is not yet approved, leading to uncertainty in mapping such entities. In Russia, even though it is acknowledged for its extended experience with maritime landscape research, it still lacks a mapping standard at the state level. Dorokhov D.V. (2018) implied that this situation might account for the distinct interest between geomorphologists and biologists - one focuses on the dividing landforms and substrate properties, while the latter fundamental is the distribution range of benthic biomes. In many conservation studies, the main objective of establishing an organism database, a notably significant component of the marine landscape system, is poorly implemented and missing details. Notably, most studies cannot incorporate different methods to increase the efficiency and quality of the results.

This study integrated geographical information systems, remote sensing, and field surveillance techniques for the establishment of marine-island landscape classification frameworks, thematic maps, and marine-island landscape maps at a scale of 1:10.000 to specify the characteristics and differentiation of landscapes and their components in Nam Yet Island region, Truong Sa Islands of Vietnam.

2. Materials and methods

2.1. Location of the study area

Nam Yet Island is the twelfth largest coral island (7,64 ha, Pléiades satellite image April 2020) of Truong Sa Islands of Vietnam, approximately 600 km to the east of Cam Ranh Peninsula (Khanh Hoa Province) and 33 km from Sinh Ton Island to the north-northeast (Fig. 1). Nam Yet Island belongs to the Sinh

Ton commune, Truong Sa district, Khanh Hoa province, Vietnam. The island has coordinates: 10°10'45" north latitude and 114°22'00" east longitude. Nam Yet Island lies on a coral platform of an ellipsoid shape, with a west-east long axis of 3.5 km and a north-south short axis of 0.9 km (longest 1.1 km). The Nam Yet coral platform is actually a reef flat on the rim of the Nam Yet cluster (Tizard Bank), which stretches approximately 60 km from westernmost.Nam Yet cluster is a typical atoll with a raised rim surrounding a deep lagoon (average depth of 60~80 m) and a few emerged shallow reefs (~8-10 m depth). The whole atoll was raised from the deep seafloor by over a thousand meters, with a very steep outer slope. The atoll basement is not yet defined as either Mesozoic/Cenozoic sedimentary rock or volcanic formation (Tran Duc Thanh et al., 2012) since the deepest boreholes in the area on the neighborhood Fiery Cross reef did not penetrate the biogenic carbonate platform.

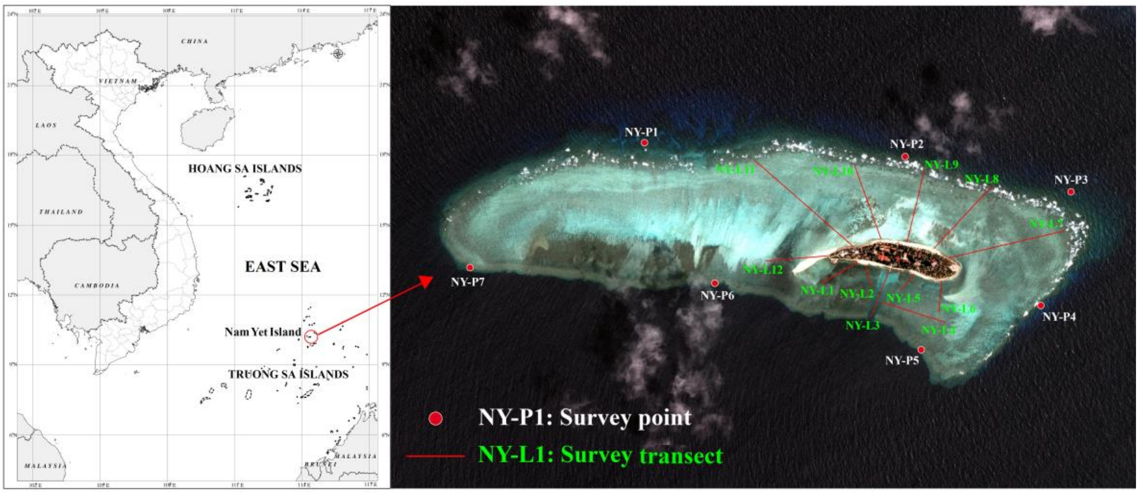

Figure 1. Location of Nam Yet Island and Pléiades remote sensing image in Nam Yet Island area, resolution 0.5 × 0.5 m (including field survey points and transects)

The coral platform beneath the island is divided according to borehole data as follows in ascending order: basement layer is white, crystalized coral boulder, thickness over 20 m; conglomerate (1-1.5 m), limited distribution, dated late Pleistocene using the paleontological and lithological method; biogenic coarse sand, gravels, pebbles, cobbles… composed from detrital coral, shell fragments, animal bones, dated middle Holocene. His layer is approx. 0.2-0.7 m thickness, dated late Holocene. The topmost layer consisted of loose sediment similar to a supratidal beach, ranging from sand to boulders, coral detrital and shell fragments, and seasonal shifting.

The subaerial area of Nam Yet Island is approximately 2-3.5 m in height and composed mainly of coarse sediments, detrital from nearby coral reefs, bivalves, shellfish, etc. The basement layer thickness is approx. 2.5-3 m. Coral reefs and other substrates cover the adjacent area of the island.

Nam Yet Island lies in the subequatorial monsoon climate, which receives approx. 150 Kcal/cm^2 of radiation per year, with a reasonably stable temperature of 26-29°C annually. The precipitation on the island is 2400 mm/year, they are distributed into two distinctive seasons with peak periods of October to December. Two prevailing monsoons are the Southwest and Northeast monsoons from June to September and

November to April of the year after that, respectively. The average wind speed of the former is 10-15 m/s, and the latter is 8-10 m/s. The average tropical depression and storms are 1.9 per year. In the context of global climate change, the Nam Yet area in particular and Truong Sa Islands in general also have quite substantial changes in climate factors, especially rainfall (Thanh Hoa Pham Thi et al., 2021; Huy Hoang Cong et al., 2022) and extreme weather events (Phuong Nguyen Ngoc Bich et al., 2022). The regional wave regime depends on the monsoon: the prevailing wave direction is north-northeast with an average height of 2.5 m and switches to the west-southwest direction with an average height of 1.65 m for the Northeast and Southwest monsoons, respectively. The subsurface current around the coral platform is approx. 10-30 cm/s. The region has an asymmetric diurnal tide regime, with a high water spring of 1.8-2.2 m and a low water neap of 0-0.1 m (Tran Duc Thanh et al., 2012).

Nam Yet Island is distributed on a range of coral reefs of a complex atoll (Altoll Nam Yet), forming a "ring" surrounding a lagoon, and the bottom at a depth of 60-80 m is relatively flat and scattered. Coral reefs protrude to a depth of 10-8 m. This atoll has an outer slope that plunges to over 1000 m. The foundation of the complex atoll coral plateau may be Mesozoic and Cenozoic sediments, or it may also be basalt, which currently does not have enough data to conclude (Tran Duc Thanh et al., 2012).

Nam Yet Island has a high diversity and abundance of coral species, including rare species such as red coral (Do Cong Thung et al., 2014). A total of 166 species of fish have been recorded, including many valuable species, such as king mackerel, red snapper, and queenfish. The coral reef ecosystem in Nam Yet reaches level 4 according to world standards, which means good. Not only the Diversity of geological features, seabed topography, or marine ecosystems but also the hydrological conditions here contribute to the Diversity of the marine-island landscape of Nam Yet (Do Huy Cuong, 2011).

According to the most recent survey by the Institute of Ecological Tropical in 2020 and 2021, Nam Yet Island has approximately 51 species of plants, 19 species with few individuals, 31 species with very few individuals, and species with many individuals of *Cocos nucifera*. This island has favorable conditions for developing plants, so the number of species and their individuals is greater than those on Truong Sa Island. There 10 species of woody plants, 7 species of shrubs, 26 species of herbaceous plants, and 8 species of creepers.

The anthropogenic disturbance was introduced on the island early. In the island domain, activities of reclamation of terrain and soil cover are common, changing their structure and natural properties and forming a surface with specific anthropogenic properties, including planted vegetation and a system of construction works.

Commercial fishing and reclamation have been recorded regularly on the island's shallow water and reef. Such activities have already altered the original structure and properties of the coral reef, seagrass meadows, and other components of the marine landscape up to 100 m in depth. Currently, all fishing activities on shallow water are under surveillance by the on-duty law enforcement forces located near outposts, and the precipitation of Vietnamese fishers on either Nam Yet Island surrounding water and the whole Truong Sa Islands.

2.2. Material

In this study, we used 2 PLÉIADES remote sensing images taken on April 10, 2020, and August 13, 2020, to determine the distribution area of coral and seagrass communities in the Nam Yet Island area (Fig. 1). The KCB-TS03 project provided both multispectral and panchromatic products. Multispectral imagery at 1.5 m spatial resolution consisted of four bands: blue

(430-545 nm), green (466-620 nm), red (590-710 nm), and near-infrared (715-918 nm). The panchromatic image consisted of a single band (405-1053 nm) at 0.5 m spatial resolution. The raw multispectral and panchromatic images were combined by the PANSHARP module (Barrell, Grant, Hanson, & Mahoney, 2015) of ArcGIS 10.8 software to create a multispectral image with 0.5 m spatial resolution.

Based on PLÉIADES remote sensing images and the results of the project KCB-TS03, component maps include seabed substrate, geomorphological map, land cover for the subaerial island, and specific organism communities of Nam Yet Island region.

2.3. Methods

2.3.1. Field data collection

Field trips to the study area were taken in two courses (Oct-Nov 2020 and May-June 2021) to collect field data on the subaerial/submerge marine landscape (i.e., main components, morphological features, hydrodynamic conditions, and substrate properties), including typical benthic biomes.

In the subaerial environment, field trips were taken with the aid of using high-resolution remote sensing images to define landscape unit properties (unit boundary, dominant plant communities, and typical surface covers) and then apply ground truth data collected in the field to verify landscape unit extents that were formerly drawn. Field data of the submerged habitat were taken during diving sessions with snorkeling and scuba-diving techniques at different depth ranges. Snorkeling sessions were conducted on the water surface, up to 5 m, to gather information on the sediment composition, featured reef morphology, distribution of coral communities, seagrass meadows, and other organisms. Scuba diving sessions were implemented by a team of 3 divers for sites with depths greater than 5 m. Scuba divers were in charge of collecting data on coral and major organism distribution and composition. Scuba divers and snorkel divers performed sediment sampling to investigate seabed substrates' grain size and composition. To collect data to ensure representativeness and consistency, points and sections were determined according to the differentiation characteristics of the study area, including the relative depth of survey locations according to dive watch measurements (subaerial/tidal zone less than 5 m/shallow water from 5-30 m), wave exposure (exposed/sheltered), and predefined landscape unit boundaries (extracted from high-resolution remote sensing data). The locations of the survey points and transect are shown in Fig. 1.

A pair of waterproof Gopro Hero 7 with GPS built-in and a Canon G7x MkIII with waterproof housing was used to capture still photos and footage videos along the survey lines and surrounding areas in each diving session. Nevertheless, photos of the dual Gopros and Canon compact cameras were set at 12 MP and 20 MP, respectively, with auto white balance and shutter speed to optimize the ground truth data capture. Dual GoPro cameras recorded videos along transects at 2.7k resolution and a frame rate of 30 fps to compensate for light reduction due to water column absorption and cloudy conditions. Both still photos and footage videos were recorded vertically to avoid distortion, especially on the edge of the frame. The data, samples, photos, videos, and measurements from the survey on the island and submerged terrain (Figs. 2, 3) are the basis for the detailed description of the typical landscapes in the Nam Yet, Island area.

In addition to the field data of the research eam, seabed substrate samples were collected using a 40 cm^3 grab sampler placed on the research ship by the Agency for Surveying, Marine Mapping and Research, Vietnam Navy, in October 2020.

Figure 2. Some field survey photos in Nam Yet Island area for the in situ habitats of Nam Yet Island region: A: Subaerial view of shallow seagrass meadow on the southern island reef flat during neap tide; B, C, D: Seagrass biome in the south area; E, F, G: Seagrass biome in the northern region; H, I, K: Coral reefs, coral rubble, and coral debris; L, M, N: Surveying shallow marine landscape by the Scuba method (A÷K: in June 2021; L÷N: in October 2021)

Figure 3. Surveying some landscapes of Nam Yet Island area. A: Landscape of Nam Yet Island gate; B, C, D: Landscape of trees and shrubs on the island; E, F: Exposed conglomerate layer on the northern shoreline during low tide (E - on the intertidal reef flat, partially covered by seagrass, F - on the beach with wave-cut dissolution marks); G1-2: buried conglomerate layer in the island center, interspersed with organic material (June 2021)

2.3.2. Classification and establishment of thematic maps and landscape map

To create a landscape map of Nam Yet Island area at the scale of 1:10,000, the technique of superimposing component maps of the same scale was used, including the following: Sedimentary - soil map, geomorphological map, cover map - benthic biome (Fig. 4) using ArcGIS software based on the Intersect algorithm. This is the method first used by the landscape architect McHarg L. when studying how to design new roadways damaging natural heritage and biodiversity as little as possible. To do that, he developed an eligibility analysis using an "overlay mapping technique". The technique consists of overlapping different thematic maps (McHarg, 1967). The Intersect tool calculates the geometric intersection of any number of feature classes and feature layers. The features, or portions of features, that are common to all inputs (that is, they intersect) will be written to the output feature class. When multiple feature classes or layers are specified in the list of input features, the order of the entries in the list does not affect the output feature type, but the spatial reference of the top access on the tool dialog box (the first entry in scripting) in the list will be used during processing and set to the output (ESRI, 2021).

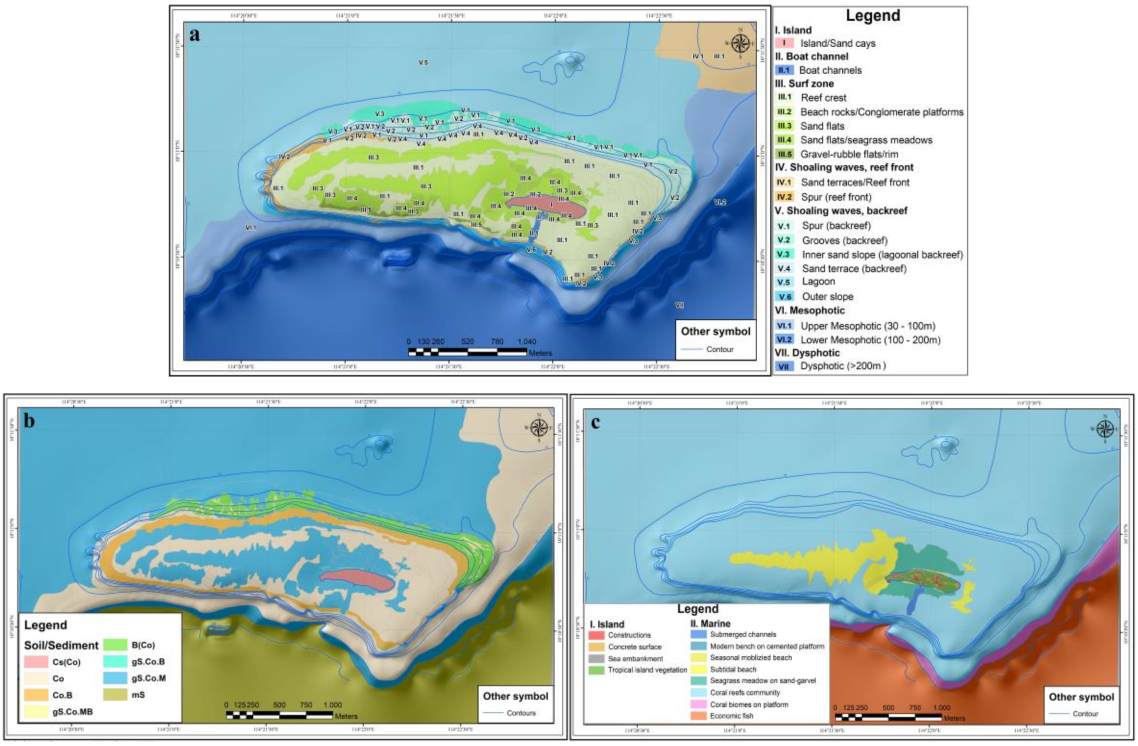

Figure 4. Thematic map of Nam Yet Island region: a. geomorphological map; b. seabed substrate - soil map; c. typical vegetation cover - benthic habitat (Source: KCB-TS.03 project, VRTC)

3. Results

3.1. Marine landscape

The definition of marine landscape relies upon the expertise of the researchers or research approach. In many circumstances, the term "marine landscape" might not adequately represent its components and elements or formation drive force, consequently leading to limited application in managing territorial lands and waters. Therefore, we assume that "The marine landscape is complex, homogenous in origin and development dynamics, but heterogeneous in terms of geological settings and seabed substrates, morphology, climatic-hydrographic type, organism community in a harmonious bond between hydrographic-biological condition and the coast in the shallow water, and between the water column and seabed substrates and its typical organism community in the deep water".

Since then, the marine landscape has included abiotic components, i.e., geologic setting, topology, seabed geomorphology, seabed substrate, oceanographic conditions (current, tide regime, thermohaline conditions, etc.), and biotic components - marine organism communities. Climate conditions consistently influence oceanographic conditions and every element of the maritime landscape with disregard to their category or extension. Every element of the marine landscape has mutual interaction; therefore, any component adjustment may lead to the adjustment of the other.

Abiotic components, including geologic setting, geomorphology, and sediment, are less subject to change; meanwhile, the current regime, thermohaline conditions, and organism community vigorously fluctuate following seasonal change or are sensitive to anthropogenic influence, thus constituting the driving force of marine-island landscapes. Interaction between abiotic components and the island follows the material-energy circulation. Organism communities interact with the island on the foundation of the food chain, of which each species is a link of the universal chain. According to the above definition of marine landscape, a maritime landscape map must contain all the components and elements that makeup it, i.e., every biotic and abiotic should be arranged in order. Elements of a featured organism should be considered an indicator of the corresponding marine landscape system. In the case of the Nam Yet Island region, the maritime landscape is identical to reef-building coral and seagrass species, and the island landscape is characterized by blended organism communities and artificial technical structures.

The dynamics of marine landscapes are represented through seasonal-induced or annual fluctuations based on the rhythmic variations in incorporated components, especially climate and oceanography. Island landscapes, in particular, have similar components to inland landscapes, i.e., climate conditions, geologic settings, geomorphology, soil, island organism biome, and anthropogenic factors. Otherwise, the island landscape is under control by oceanographic conditions such as wave and tide regimes.

3.2. Criteria for marine-island landscape classification of Nam Yet Island region

The landscape classification system of the Nam Yet Island region includes reef islands, sand cays, and marine landscapes up to a water depth of 200 m. These landscapes are classified based on incorporated components under anthropogenic influences. Accordingly, the landscape classification system of the Nam Yet Island area applies to the map at a scale of 1:10,000, including 7 levels: System - Subsystem - Class - Subclass - Type - Kind - Form of landscape (Table 1).

It is noteworthy that on the top-down hierarchy (from the class level), there are differences between landscapes on marine and islands, hence the differences in the classification criteria. The marine landscape is characterized by seabed topography and water column characteristics, with specific abrasion - transportation - deposition of reefal material. Meanwhile, island landscapes lie on topological features with corresponding dryland material-energy cycles, i.e., erosion-deposition. Landscape forms are the most detailed level; therefore, different criteria clusters would be applied for various domains: morphological features and substrate composition for marine fields, dryland surface cover, soil texture and thickness, and significant construction features (Table 1).

Table 1. System and criteria for marine-island landscape classification of Nam Yet Island region

No.	System	Classification criteria		Landscapes of study area
		Marine landscape	Island landscape	
1	Landscape system	Solar radiation and specific temperature on the general atmospheric circulation		System of monsoon tropic landscape
2	Landscape subsystem	Distribution of annual thermal-humidity regime of atmospheric circulation and seasonality of ocean water column		Tropical monsoon with the absence of winter
3	Landscape class	Seabed morphology - water column interaction by specific erosion - deposition processes regarding wave propagation on the reef.	Island morphology which represents the material - energy circles via denudation - abrasion - deposition under anthropogenic stress	04 classes: - Island landscape - Coral reef/tidal landscape - Coral reef/euphotic landscape - Bathyal landscape
4	Landscape subclass	Depth of water column and suspended material concentration decide the availability of light	The differentiation of exogenous processes of lowland and their marine properties	06 subclasses: - Vegetated cay. - Coral reef/tidal (0-5 m, wave break-shoaling/shallow water wave). - Coral reef/euphotic (5-30 m, transitional wave/deep water wave). - Open ocean/upper mesophotic (30-100 m). - Open ocean/lower mesophotic (100-200 m). - Bathyal/aphotic zone (> 200 m).
5	Landscape type	Representative biomes and typical thermal-humidity regimes	Cover type with quantitative characteristics of marine bioclimate	10 types
6	Landscape Kind	Biome of specific water column and seabed characteristics (rocks, sediments)	Vegetation cover or other features on variant heterogeneous soil/solid substrate	29 kinds
7	Landscape form	Morphological characteristics, composition of substrates materials and typical groups of organisms	Land cover, specified by soil texture and thickness, and/or major construction features	34 forms

3.3. Marine-island landscapes of the Nam Yet Island region, Truong Sa Islands

3.3.1. Landscape map

Based on the component maps, field survey results, principles, classification criteria, and hierarchical system for the marine-island landscape map, a landscape map of the Nam Yet Island area was established at a scale of 1:10,000 (Figs. 5, 6). Due to the homogeneity of the landscape system and subsystem in the study area, we do not show these percentile levels in the legend of the landscape map.

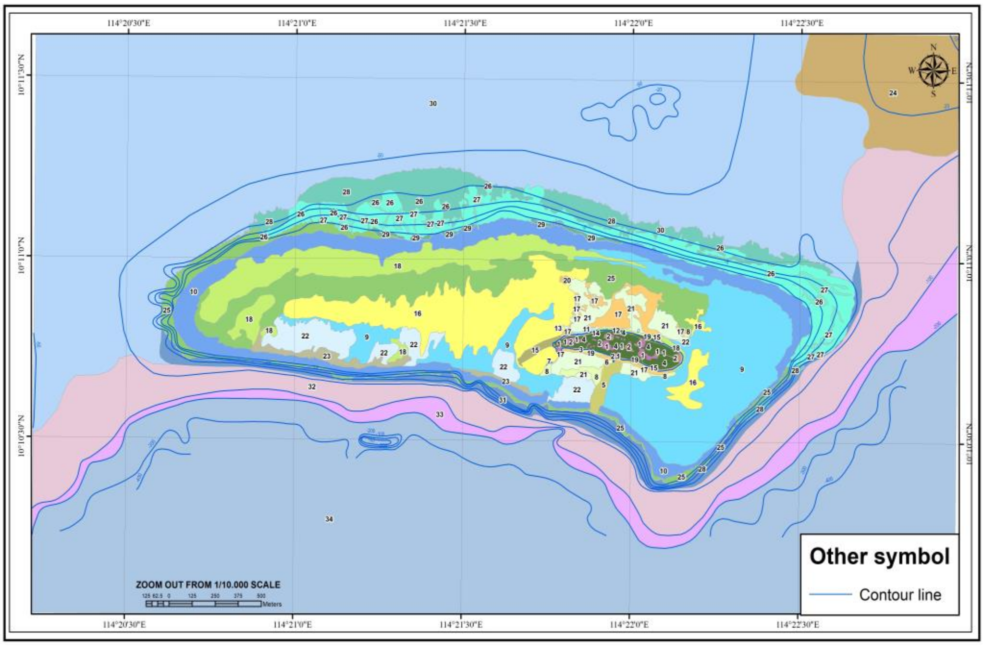

Figure 5. Marine-island landscape map of Nam Yet Island region, Truong Sa Islands (scaled at 1:10.000)

Class	Sub-class	Type		Insland climate conditions - Annual mean temperature: approx~ 27 - Summer (May-Oct) mean temperature ~28,2 - Winter (Oct-Apr) mean temperature ~26,8 - Annual rainfall of 2.000-2.400mm				Marine conditions - Average temperature of sea surface: Summer: 30; Winter: 27 - Average salinity of sea surface: Summer : 33,75 ‰; Winter : 33,25‰							
				Residential - solidworks in tropical monsoon			Trees, shrubs in in tropical monsoon	Submerged channels	Bench and Beach			Seagrass community (saltwater, high salinity)	Coral community (saltwater, high salinity)		Economic fish
		Kind	Form	Contructi-ons	Concrete surface	Sea embankment	Tropical island vegetation	Submerged channels	Modern bench on cemented platform	Seasonal mobilizied beach	Subtidal beach	Seagrass meadow on sand-gravel	Coral reefs community	Coral biomes on platform	Economic fish
ISLAND	Island	Islands/Sand cays	Cs(Co).C	1											
			Cs(Co).S		2	3									
			Cs(Co)				4								
SHALLOW WATER/ EUPHOTIC	Coral reef/ tidal (0-5m)	Boat channels	gS.Co.M					5				6			
		Reef crest	Co								7	8	9		
			Co(B)										10		
		Beach rocks/Conglomerate platforms	gS.Co.B						11	12	13	14			
		Sand flats	gS.Co.M							15	16	17	18		
		Gravel-rubble flats/rims	gS.Co.M							19	20	21	22		
			Co										23		
	Coral reef/ euphotic (5-30m)	Sand terraces (reef front)	Co											24	
		Spurs (reef front)	Co											25	
		Spurs (back reef)	B(Co)											26	
			gS.Co.MB											27	
		Inner slope/sand slope (back reef/lagoonal)	gS.Co.M											28	
		Sand flats (back reef)	gS.Co.M											29	
		Lagoon	gS.Co.M											30	
		Outer slope	Co											31	
MESOPHO-TIC	Open ocean/ upper mesophotic (30-100m)	Upper Mesophotic (30- 100m)	gS.Co.M											32	
	Open ocean/ lower mesophotic (100-200m)	Lower Mesophotic 100- 200m	gS.Co.M											33	
APHOTIC	Bathyal aphotic zone (>200m)	Aphotic	mS												34

Figure 6. Legend of the marine-island landscape map of Nam Yet Island region, Truong Sa Islands

(*) C: Sandy gravel soil interspersed with coral; Co: Coral; B: Boulder and dead; Co. B: Coral and boulder; gS.Co. B: Gravelly sand, coral, and boulder; gS.Co. M: Gravelly sand, coral, and mud; gS.Co. MB: Gravelly sand

3.3.2. The Diversity of marine-island landscapes in Nam Yet Island region (according to the high hierarchical level)

The divergence and combination of sequences and rules of natural and human components and factors have created the richness and Diversity of marine landscapes and island landscapes in the Nam Yet Island area. Accordingly, the area includes 1 system, 1 subsystem, 4 classes, 6 subclasses, 10 types, 29 kinds, and 34 forms of landscapes. The basic characteristics of the marine-island landscape of the Nam Yet Island region are shown in Table 2.

Table 2. The diversity characteristics of the marine-island landscape of Nam Yet Island region

Landscape class	Landscape subclass	Landscape type	Landscape kind	Form of landscape	Acreage (ha)
ISLAND	Island	T.1	K.1	1	1.20
			K.2	2	0.74
				3	0.92
		T.2	K.3	4	4.78
SHALLOW WATER/ EUPHOTIC	Coral reef/tidal (0-5 m)	T.3	K.4	5	1.85
		T.5	K.5	6	0.09
		T.4	K.6	7	0.04
		T.5	K.7	8	1.39
		T.6	K.8	9	60.96
			K.9	10	43.36
		T.4	K.10	11	0.17
				12	0.34
				13	0.10
		T.5	K.11	14	0.16
		T.4	K.12	15	0.99
				16	39.38
		T.5	K.13	17	6.23
		T.6	K.14	18	29.30
		T.4	K.15	19	0.52
				20	0.18
		T.5	K.16	21	10.03
		T.6	K.17	22	14.01
			K.18	23	4.15
	Coral reef/euphotic (5-30 m)	T.7	K.19	24	41.58
			K.20	25	48.00
			K.21	26	37.66
			K.22	27	3.61
			K.23	28	29.75
			K.24	29	1.85
			K.25	30	467.73
			K.26	31	21.42
MESOPHOTIC	Upper Mesophotic (30-100 m)	T.8	K.27	32	134.07
	Lower Mesophotic (100-200 m)	T.9	K.28	33	39.35
APHOTIC	Bathyal/Aphotic	T.10	K.29	34	454.08

- Island landscape class

Nam Yet Island is an ellipsoid-shaped vegetated cay with an east-west long axis that measures 720×140 m at 2-3 m asl. The island is angled north to south, with a northern edge slightly higher than the southern edge. The island is formed on loose material under wave/storm wave actions at first and then aggregated by carbonate cement into a conglomerate layer. The island landscape class is essential in offshore marine-island landscapes with intensive anthropogenic activities. Vegetation cover on the island belongs to tropical monsoon vegetation with high temperature-humidity (Fig. 3). The vegetation in the landscape is divided into 2 layers: the upper layer is dominated by *Cocos nucifera*, *Barringtonia asiatica*, *Calophyllum inophyllum*, *Argusia argentea*, *Coccoloba uvifera*, and *Ficus racemosa*. The lower layer includes *Cerbera manghas*, *Morinda citrifolia*, *Mangifera indica*, *Scaevola taccada*, *Leucaena leucocephala*, *Tamarindus indica*, *Ficus elastica*, and *Chromolaena odorata*. The floor layer has *Cynodon dactylon*, *Ipomoea pes-caprae*, *Canavalia maritima*, *Portulaca oleracea*, *Passiflora foetida*, etc. *Ipomoea pescaprae* dominates the beach habitat outside sea dikes, with coverage of over 90%. In addition to island vegetation, this class is characterized by artificial structures such as buildings and concrete surfaces. Island soil consists of sandy gravel and pebbles with interbedded bird guano and is flowerbed filled by terrestrial soil, which has been carried out from the mainland.

The island landscape class has 1 subclass of offshore island landscapes with 2 landscape types: artificial structures on tropical island landscapes (T.1) and vegetation cover on the tropical island (T.2). The T.1 type consists of 2 kinds (K.1, K.2) and 3 forms (numbered 1, 2, 3). Form (1) is the residence structure, which is essential to island residents. Landscape form 3 is sea dykes acting as protective constructions against seaborne erosion caused by swash and storm surge and stabilizing the island shoreline. Landscape type T.2 has 1 kind (K.3) and 1 form (4) as island vegetation cover for scenery and land cover to prevent soil loss.

- The shallow water/euphotic landscape class

The topography of the reef is in the shape of a diamond extending along the east-west axis, 3.3×1 km in length, located in the south on the edge of the Nam Yet cluster. The terrain is relatively flat, from 0-1 m deep during low tide. The dominant geomorphic process is accumulation. The transported raw material accumulates to form dunes around the island, partly removed from the reef surface to accumulate on the fore reef and reef foot, as well as towards the large lagoon. The differentiation of geomorphological processes, seabed substrate composition, and benthic biomes has made this class the most diverse, with 2 subclasses, 5 types, 23 kinds, and 27 forms of landscape.

<u>+ Coral reef under tidal influence subclass</u>

This is the most diverse landscape subclass in the study area and includes 4 types: dryland artificial structure landscapes (T.3); beach rock/conglomerate benchand beach landscape (T.4); intertidal seagrass meadow landscape (T.5); and subtidal coral patch landscape (T.6). The reef-building coral in this subclass includes scleratinia species such as *Acropora eydouxi, P. verrucosa, P. tailndrina, and P. woodjonnesi.* The most abundant massive coral genera are *Goniastrea* and *Platygyra*. Coral coverage was low (15-20%), with many dead colonies (Fig. 7).

Landscape type T.3 includes 1 kind (K.4) and 1 form (5) of 1,85 hectares. This is an artificial boat channel 2-5 m deep. The seabed substrate is coral detrital sand-gravel-pebble, with a small portion of boulders left by former dredge activities when opening the channel.

Landscape type T.4 includes 4 kinds (K.6, K.10, K.12, and K.15) with 8 forms (7, 11, 12, 13, 15, 16, 19, 20), with a total area of 41,72 hectares, consisting of conglomerate benches and narrow beaches elongated along the shoreline and low elevation sand-gravel shoals/small sheets to the west and east sides of the island. Landscape form 11 is a modern, cohesive coral structure with different cemented layers 10 m in width. The elongated narrow shoal landscape to the west of the island seasonally fluctuates according to the northeast or southwest monsoon.

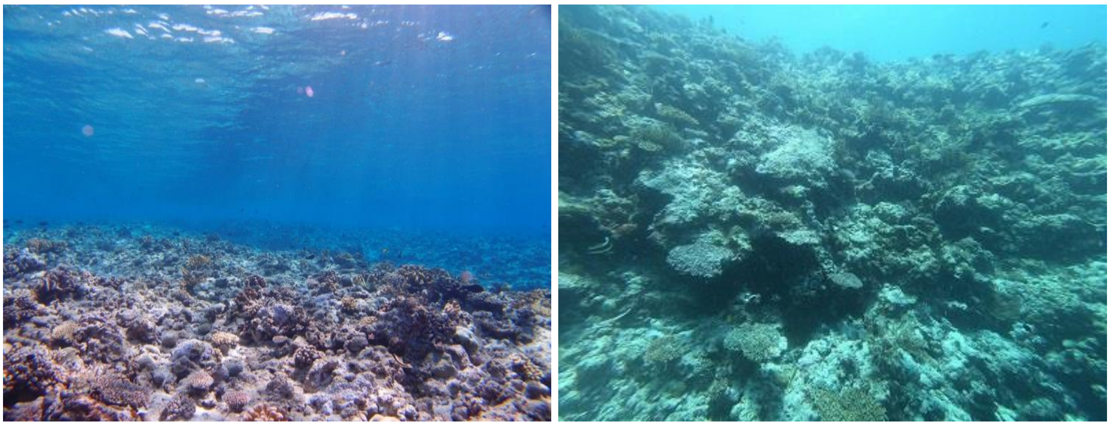

Figure 7. Coral landscape with low coral coverage on reef flat, depth ranges from 3-5 m (June 2021)

Landscape type T.5 includes 5 kinds (K.5, K.7, K.11, K13, and K.16) with 5 forms (6, 8, 14, 17, 21). The total area of 17,9 hectares consists of seagrass meadows growing on coral detrital sand-gravel pebbles to the north and south of Nam Yet Island. The seagrass communities consist of 2 species, *Thalassia hemprichii* and *Halophila ovalis*, with coverage of 81,58% to the south and 63,15% on the northern intertidal bed. Benthic animals are abundant, such as True conchs (Strombidae), Sea urchins (Echinoidea), Conus (Conidae), and Sea anemone (Actiniaria) (Fig. 8).

Figure 8. Seagrass meadow landscape to the south of Nam Yet Island (June 2021)

Landscape type T.6 includes 5 kinds (K8, K.9, K14, K.17, and K.18) with 5 forms (9, 10, 18, 22, 23), with a total area of 151,78 hectares, distributed on subtidal reef flats. Dead coral rubble sheets aggregated into solid coral platforms with coarse coral coverage, mainly *Gorgonacea* sp. Reef fish communities are sparse, and benthic animals include *Asteroidea* sp., *Actiniaria* sp., *Echinoidea* sp.

<u>+ Coral reef in the euphotic condition subclass</u>

This subclass has 1 landscape type (T.7), 8 kinds (K.19÷26), and 8 forms (24÷31), with a total area of 651,6 hectares. Coral is excessively diverse in this subclass. Coral is distributed on the surface of the reef flat and expands to the back of the reef and lagoon to the north, and the reef front and reef slope to the south of Nam Yet Island region down to 30 m with great coverage. The reef-building coral species are *Acropora plumosa*, *A. bifurcata*, *A. divaricata, A. subglabra, A. echinata, A. granulosa*, and và *A. caroliniana* (Fig. 9). The genus *Acropora* in the coral communities accounts for 30-40% of the species and 40-50% of the total coral coverage. Reef fishes are prolific, and large schools are more abundant and have high commercial value, such as grouper, red snapper, kingfish, cowfish, and trevally. The total number of species in the Nam Yet Island region is 246, distributed mainly in this euphotic reef landscape and graded as the most abundant coral site in species, including rare red coral.

Figure 9. Coral landscape at 20-30 m water depth with reef building coral of genus *Acropora*, coverage rate to 60-70% (June 2021)

- *The mesophotic landscape class*

This class is distributed around the coral reef of Nam Yet Island to the north into the back reef and lagoon (sheltered condition) and to the south down to approx. 200 m of depth. The topology of this class is different between the two domains. On the sheltered back reef and lagoon to the north of the reef, there is a steep sand slope and coral platform to a depth of approximately 25-28 m (clearly shown on the satellite image). Then, the sand slope continues to decline to around 60 m below the lagoon bottom. This domain is sheltered from incoming waves in both monsoon seasons; therefore, it creates a calmer environment for the sedimentation of reefal material transported from reef flats and other sources. To the south of Nam Yet Island reef, the topology changes abruptly from a steep, narrow reef front to a relatively vertical reef slope (~70 degrees) down to several hundreds of meters deep. Soft corals and sponges dominate the reef platform at such depths; thus, it is considered an "ancient reef/antecedent platform" associated with the reef build-up process in the context of global sea level rise since 10 ka BP (Braithwaite C. J. R, 2014). Destruction of material by wave processes in the upper zone is transported through this vertical platform and accumulates on the deeper seabed below. This class includes 2 subclasses, 2 types, 9 kinds, and 9 forms, distributed in the shallow water of the reef front and outer reef slope and having higher salinity.

+ Upper Mesophotic landscape subclass (approx. -30 - 100 m)

There is 01 type of coral landscape in this upper mesophotic zone, which is developed on sand-gravel sediment, aggregated coral basement, and mud (T.8), with 1 kind (K.27) and 1 form (32), and covers a total of 134.07

hectares. Coral communities distributed on the reef slope and lagoonal seafloor are remarkably diverse, with total coverage of 30-50%; in some locations, it could reach up to 70%. In addition to common schleratinians, such as *Acropora plumosa*, *A. bifurcata*, *A. divaricata, A. subglabra, A. echinata, and A. granulosa*, giant sponges of *Xetospongia testudinaria* have been recorded. This sponge species is a long-standing representative of West Pacific coral reefs and could be aged up to 2000 years, together with a soft coral community (Fig. 10).

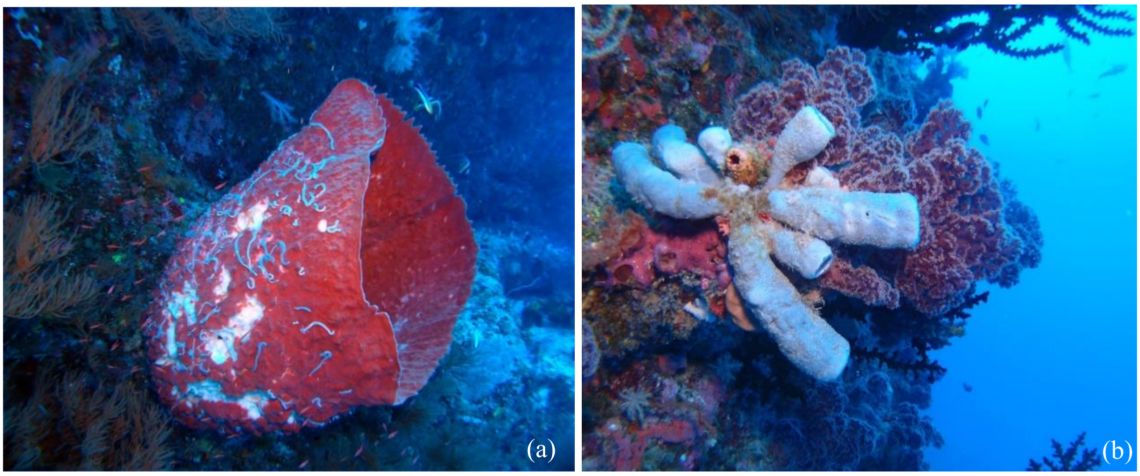

Figure 10. Coral communities of landscape type T.8: (a) Giant Sponge *Xestospongia testudinaria* on the southern slope at 30-40 m depth; (b) Sponge of *Siphonochalina siphonella* and soft coral *Dendronephthea* on the southern outer reef slope of Nam Yet Island at 30-40 m depth (October 2020)

+ Lower mesophotic landscape subclass (depth of 100-200 m)

This subclass has 1 landscape type of dysphotic water column (T.9), includes 1 kind (K.28) and 1 form (33), and has a total area of 39.25 hectares. This landscape type is characterized by a steep topology with a relatively vertical cliff. Coral detrital minerals, such as sand-gravel, are dominant in depression holes on the slope. From the samples obtained using a 40 cm^3 grab sampler placed on the research ship, only a few species of *Acropora* have been recorded alive at depths of 100-110 m, and reefal sediment from dead coral dominates the lower topology.

- *Aphotic landscape class*

This class is distributed to the south of Nam Yet Island reef. Its morphology is a steep slope from approx. 200 m depth downwards to the bathyal seabed. The accumulation of reefal detrital material is the dominant process. This class consists of 1 subclass, 1 type (T.10), 1 kind (K.29), and 1 form (34), for a total area of 454,08 hectares. This class is located to the south of Nam Yet Island and does not include lagoon basins, which are distributed from 200 m depth to deeper, steep slopes. Muddy sand is the dominant cover. There are various commercial fishes in this class's water column, including *Scomberomorus cavalla, Thunnus alalunga, Thunnus albacares, Thunnus tonggol,* and species of *the Lutjanus* genus.

3.3.3. Diversity of marine landscapes according to spatial division

The Diversity of the landscape of the Nam Yet Island area, especially the marine landscape, is reflected in the differentiation of geomorphological, oceanographical, and biological factors. It is expressed between the northern and southern parts of Nam Yet Island, representing the distinction between the back reef's sheltered environment and lagoon and the open ocean, respectively.

Accordingly, although there are 2 classes and 3 subclasses, the differences among them are minor, including only 3 landscape types (T.8, T.9, T.10), 3 landscape kinds (K.27, K. .28, K.29), and 3 landscape forms (32, 33 and 34). The mesophotic landscape class consists of 2 subclasses (upper mesophotic 30-100 m and lower mesophotic 100-200 m), and each subclass has only 1 landscape type, 1 landscape kind, and 1 landscape form. These landscape units are distributed at a depth of over -30 m in the region of Nam Yet - Son Ca atoll. Similarly, the aphotic landscape class also has only 1 subclass, 1 type (T.10), 1 kind (K.29), and 1 form of landscape (34). This area has over 200 m deep, steep slopes, mainly reef detrital sediments with dominant economic fish communities.

The northern area belongs to the complex lagoon, with only 1 tidal zone class, 1 lower tidal subclass, and 1 type, but differentiated into 8 kinds (K.19 to K.26) and 8 forms of landscape (24 to 31). These landscapes have typical features of relatively gentle terrain, not great depth (up to 30 m), which is the place of solid development of coral communities, especially the Acropora coral group and coral fish communities.

4. Discussions

A complex approach for establishing a classification system with detailed criteria for marine-island landscapes contributes to recognizing the role of each landscape component. The differentiation of topology and seabed morphology controls other landscape components on a large scale. Classification provides an overview of the natural units and contributes to spatial planning for an island or cluster.

The problem of the marine landscape of the region formed from coral detrital material and living coral communities growing together with other diverse organism groups is the practical capability of regional resource consumption directives, which are aquatic organism communities (of marine landscapes) and plant communities (of island landscapes). Therefore, these are criteria to classify the type, kind, and form of landscape. These criteria help enhance the specification of the study in top-down order.

Integrating very high-resolution satellite imagery and in situ surveillance in underwater environments using Scuba diving and snorkeling provides a practical approach for landscape mapping of the Nam Yet Island region on a larger scale. This approach is scientifically reasonable in encouraging new findings on the natural and anthropogenic stressors on sea and island regions and providing feasible proposals or solutions for resource management and environmental protection (Petrov K.M., 1971; Zhariko V., B., & E., 2017). A classification system for the establishment of the Nam Yet marine-island landscape map was created by the objective fusion of different components into a relatively unified matrix condition (Whitfield, 1994). The marine-island landscapes of the Nam Yet Island region include biotic-abiotic features on the subaerial island and submerged habitat concerning solid stratum, temperature, bathymetry, light penetration, and slope, as Roff et al. (Roff & Taylor, 2000).

The classification framework of the Nam Yet landscapes has clarified the distribution of organism communities following complexes of marine elements. Physical and biological processes determine the allocation and Diversity of marine organism communities (Steele J., 1991). The landscape diversity of the Nam Yet Island region, especially on the island and in the tidal zone, is intensively disturbed by anthropogenic stressors. Anthropogenic impacts modify geomorphological and hydrodynamic processes and ecosystems and change the forms of resources, including biological resources. This finding is consistent with the Amstrong study on Chrismas Island and Cocos Island (Armstrong, 1992). Study results from the Nam Yet Island region address the difficulty and challenge of quantifying the benthic habitat in marine landscape mapping due to spatial variations and more significant depths (over 40 m, which is restricted for novice divers). In general, these are mutual and global difficulties of other scientists when conducting marine-island landscape research (Zajac R. et al., 2003).

The landscape system and subsystem were classified based on the typical circulation of the monsoon tropical climate and heat-humidity characteristics, similar to inland studies by Nguyen Dang Hoi (Nguyen Dang Hoi & Ngo Trung Dung, 2017; Nguyen Dang Hoi, Ngo Trung Dung, Dang Hung Cuong, Kolesnikov S.I., & Tishkov A.A., 2019) and Truong Sa Islands by Tran Anh Tuan (Tran Anh Tuan, 2014). Landscape classes represented tidal and shallow water up to 200 m water depth, similar to Milkov (Milkov F.N., 1966). Moreover, this classification system was integrated with all the landscape components and elements into the minor form of marine-island landscape. This was considered the advantage and distinguished the modified classification framework for Nam Yet Island region when compared to other approaches of Golding, which had not incorporated temperature and salinity following water column depth (Golding N. et al., 2004) or EUNIS (Davies et al., 2004; Golding N. et al., 2004).

Organism community distribution is the indicator criterion of marine-island landscapes and is considered the most significant component of the landscape. In this study, these criteria were unified and represented with enhanced specification following top-down order from type to form of landscape. This contribution is novel and has not been mentioned in the latest study of Doornenbal et al. on the seabed landscape mapping of the Netherlands (Doornenbal P., Schokker, D., T., & S., 2021). Likewise, Tran Anh Tuan did not refer to organism elements while mapping the seascape of the Truong Sa Islands (Tran Anh Tuan, 2014). In addition, we included anthropogenic factors as classification criteria for the type, kind, and form of landscape. In former studies, these factors have not been considered part of the landscape but are more likely to be external influencers of the marine landscape (Lebedev et al., 2020).

The Diversity of the marine-island landscape of the Nam Yet Island region was also represented via specific organism groups with consideration of human purposes, such as commercial fish, reef-building corals, and the result of anthropogenic activities such as concrete cover and construction on the island. This aspect was appropriately applied to propose a directive on managing and utilizing marine-island landscapes for different purposes. The results also highlight that the island and shallow water landscapes could easily access and classify using remote sensing and ground truthing data extracted via in situ surveillance. However, the marine landscape of the less-lighting region and deep water required proper sampling techniques, interpolation, and evaluation approaches to delineate the extension of each landscape unit. This obstacle was mutual among scientists in studying marine-island landscapes, especially in remote and access-restricted regions. Nonetheless, clarification of marine landscape definition and Classification and mapping at a larger scale is theoretically valuable and practical for oceanic nations, including Vietnam.

5. Conclusions

The marine landscape was proposed from the systematic and complex viewpoint as follows: "The marine landscape is a complex, homogenous in origin and development dynamics, homogeneous in geology and seabed substrate, topographical type, climate-hydrographic type, organism community in a unified combination between the hydrographic-biologic conditions and the coast shore in the shallow zone, between the benthic substrate and the water column and its typical organism in the deep zone".

The marine-island landscape is a hierarchy classified using specific criteria. A higher rank represents the general pattern, while a lower level increases the specifications, demonstrating the characteristics of morphology, biological factors, and anthropogenic activities.

Integrated remote sensing, in situ surveillance, and visual descriptions of subaerial and subaqueous environments provided adequate data for landscape classification and marine-island landscape mapping of the Nam Yet Island region at the scale of 1:10.000. The landscape of the Nam Yet Island region was classified into 1 system, 1 subsystem, 4 classes, 6 subclasses, 10 types, 29 kinds, and 34 forms, of which the island and marine landscape forms were 4 and 30 forms, respectively.

Clarifying the Diversity of the marine-island landscape of Nam Yet Island according to classification level and spatial division. The variety of the marine landscape (on both island and submerged domains) was divided according to the classification level and horizontal-vertical distribution. The study showed the significance of determining specific features and main species as landscape components and recognizing the relationships among elements in each ranking. Therefore, the landscape classification could provide a sufficient scientific foundation to establish directives on resource management, environmental protection, and biodiversity conservation for Nam Yet Island reef and Truong Sa Islands in general.

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