

# Scleractinian Corals and Reefs of Vietnam as a Part of the Pacific Reef Ecosystem

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## Abstract

The paper analyzes both published and unpublished results of the investigations of Vietnamese reef building corals and reefs performed in the last decades of the twentieth century and first decades twenty-first. The state of the art in the study of reef-building scleractinian corals and reefs is presented. The scleractinian fauna of Vietnam is shown to match in species diversity (350 species of 80 genera) the tropical coral fauna of the Indonesian–Malacca fertile center, from which Indo-Pacific reef-building corals originated. The whole Vietnam coast from the Gulf of Tonkin to the Gulf of Siam is a biogeographically single whole and is a part of the Indo-Polynesian Province of the Indo-Pacific Area.

**Keywords:** Vietnam, Reefs, Reef-Building Corals, Pacific Reef Ecosystem

## 1. Introduction

### 1.1. Brief the Ecological Characteristic and a History of Studying

The coastline of Vietnam is over 3200 km long and covers 15 degrees in latitude, from the Gulf of Siam in the south (8°N) to the Chinese border in the north (23°N). The near shore water area (up to 50-m deep) of Vietnam, including some 3000 islands, is about 206,000 km<sup>2</sup>. Vietnam and its coastline are divided into 5 parts, the Gulf of Tonkin, Central and Southern Vietnam, Gulf of Siam, and Spratly Islands [1]. Reef-building corals and reef accumulations are confined to hard grounds, typical of the Vietnam coast. Between 16° and 19°N, the coastline is formed mostly by moving sand with a minor presence of hard substrates. The temperature varies between 18°C - 32°C, and the salinity, 28‰ - 40‰. One hundred and fourteen rivers are registered along the coastline. The spread of the reef is limited near the mouths of two large rivers, the Red River in the north and the Mekong in the south, due to adverse conditions. The ecosystems of the coral reefs of Vietnam feature high bioproductivity, with a primary production of up to 30 - 100 mg·C/m<sup>3</sup> per day, which is almost 100 times that in open waters [2,3].

Vietnam is situated in the tropics, affected by two sorts of monsoons: the wet southwest, lasting from May

till September, and the dry northeast, occurring in October–April. Heavy rain showers during the wet monsoon period result in a huge (5 - 400 million m<sup>3</sup>) freshwater influx and a substantial (up to 200 thous. tons) terrigenous sediment influx into the sea. The daily suspended matter precipitation rate in the reef reaches 70 - 100 g/m<sup>2</sup> and increases tenfold during typhoons [4,5]. This results in a remarkable decrease in water transparency, affecting, together with other factors, the development of coral settlement in this region.

The reef-building corals and reefs of Vietnam attracted scientific attention as early as the first half of the twentieth century [6-8] was the first to analyze the zonation of reef-building corals in reefs of the Khanh Hoa province. He distinguished four scleractinian-dominated facieses. These investigators determined the species composition of scleractinians and demonstrated its similarity to that of Australia and Indonesia. Beginning in 1980, systematic studies of Vietnam corals and reefs have been performed in joint expeditions by the Institute of Marine Biology (Vladivostok), Nha Trang Institute of Oceanography, Haiphong Institute of Oceanology, and WWF (World Wide Fund for Nature). The published results were mainly related to scleractinian composition and distribution, with some papers analyzing common accompanying macrobenthos species and a few publications providing the general characteristics of the reefs. Part of the data obtained was presented only in unpublished reports.

Some findings were published in difficult-to obtain regional works, including Vietnamese ones.

To date, in a region bordered by the Gulf of Tonkin in the north, the Gulf of Siam in the south, and the Spratly Islands in the South China Sea, all reef-building areas including large islands and shoals have been studied (Figure 1).

It is thus topical to review the data available on the coral composition and distribution and development of Vietnam's reefs, as well as on their relation to the Indo-Pacific reef ecosystem. The rapid growth of the country's population of 70 million, together with travel industry development and marine aquaculture intensification [9], has resulted in increased anthropogenic pressure on this unique ecosystem. Generalizing data on the composition, structure, and environmental conditions of Vietnam's reef communities will allow one to evaluate the degree of their degradation and the outlook for their conservation and recovery.

### 1.2. Morphological Features of the Vietnamese Reefs

Both along the coastline and around the islands, reef-building corals form diverse reef topographies. These include small fringing reefs along the coastline, barrier reefs separated from the continent (Re Island and Jang Bo Reef), and atolls (Spratly Islands) in the open South China Sea [10-14]. Vo and Hodgson [5] reported Vietnam's reefs to include both true reef frameworks and coral gardens. Various calcareous structures occurring on reefs might be formed by coral settlements, usually called coral layers, communities, or specialized settle-

ments. Such structures are typical of early reef development stages and lack any geomorphological and vertical-biological zonation [15-19]. All Vietnam reefs display distinct biological and more or less prominent morphostructural zonation. By the specificity of geomorphological and climate conditions, Vietnam's fringing reefs are clearly distinguished into two types (Figure 2).

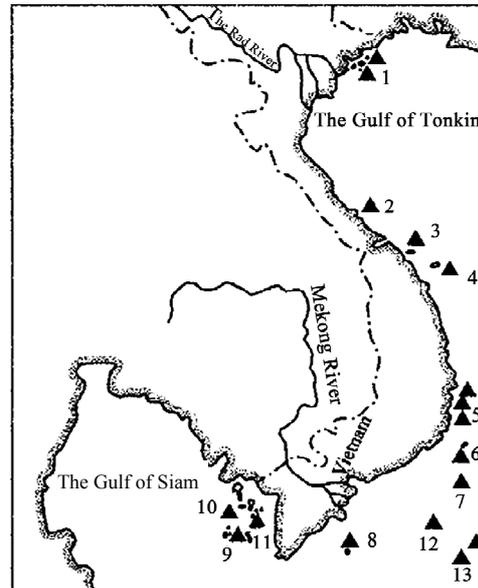


Figure 1. Schematized map of the surveyed regions. 1: Bai Tu Long Archipelago; 2: Ze Island; 3: Cape Danang, Cham and Son Tra islands; 4: Re Island; 5: reefs of the Khanh Hoa Province; 6: Thu Island; 7: Ca Thuik Islands; 8: Con Dao Islands; 9: Tho Chu Island; 10: An Thoi Archipelago and Namsu Islands; 11: Rach Gia bay; 12: Royal Bishop and Astrolab shoals; 13: Spratly Islands.

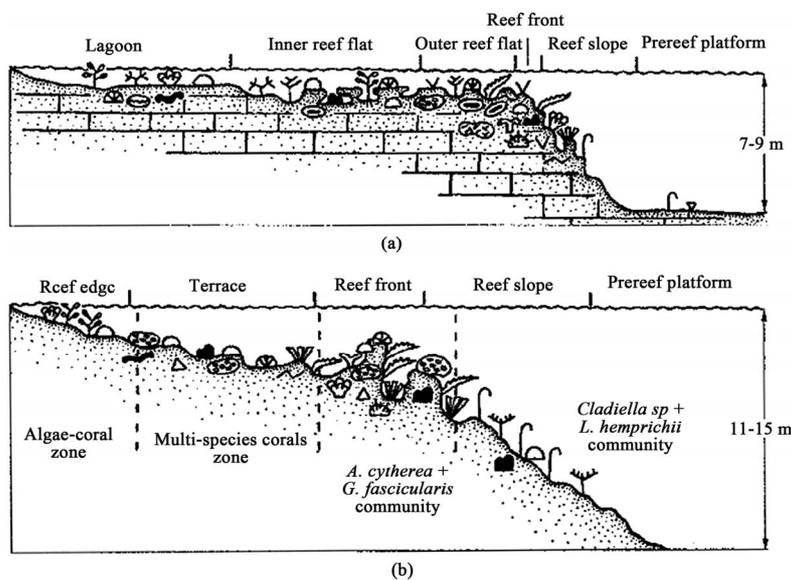


Figure 2. Schematized profiles of structural (a) and unstructured (b) reefs. See the text for comments.

Reefs of the first type have a distinct zonation (reef lagoon, reef-flat, etc.) with a developed carbonate framework, so-called structural reefs [20] common for the tropical zone of the World Ocean. Reefs of the second type display a weak morphostructural zonation, with some zones occasionally absent. Carbonate deposits in such reefs comprise only coral settlements of a low thickness, hardly changing the overall substrate profile. These are so-called structureless [20] or encrusting [18] reefs. Vietnam's structural reefs are mainly formed in closed bights and on the organogenic base of Holocene reefs [21,22], while structureless reefs are formed off promontories and in open bights, mostly on stone and rocky substrates [18,23-25].

Vietnam's reefs pertain to the epicontinental monsoon type [7,11,21,24,26,27]. They are situated at the South China Sea periphery. The shoal waters of this region are highly eutrophicated, and the grounds are highly silted due to the huge amount of terrigenous influx. Other hydrological conditions are also not optimal for reef-building coral growth. Thus, in the Gulf of Tonkin, the salinity may drop to 26‰, and winter water temperature to 16°C. Heavy northeast monsoon winds generate coastal waves up to three meters high with a 6-s period. During southwest monsoons, the Vietnam coast is struck by 5 - 10 typhoons per year with the strongest storm excitements and strong desalination, that sometimes results in almost utter annihilation of coral reef [5,28]. All this renders appreciable influence on features of formation of reefs which occurs, as a rule, on a stony, rock-stony substratum and less often on coralogenous sediments of Holocene reefs. Vietnam's reefs feature a moderate vertical and horizontal spread and low thickness of modern reef-derived deposits. Their offshore spread usually does not exceed 200 - 300 m. They rarely extend to a depth of over 20 m. Sometimes they lack distinct morphological zonation. Most of Vietnam's reefs have an indistinct reef flat and slope. In some reefs, mostly ones on stone and boulder substrates, the only distinct zone is the reef slope. However, they all have a distinct vertical biological zonation, showing up in the dominant species succession and in the change in the composition and structure of coral communities and accompanying macrobenthos. Barrier, platform and fringing reefs on Holocene organogenous deposits always have well expressed morphological zonality, characteristic for the majority of reefs Indo-pacific [12, 27,28].

## 2. Results

### 2.1. Species Diversity

According to the studies performed in the first decades of

the twenty first century, Vietnam's reef-building coral fauna comprises 350 species (see **Table 1**), pertaining to 80 genera (including 9 ahermatypic corals), of which 137 species, belonging to 26 genera, were not previously known for that region, and 13 species from 6 genera were described for the first time [11,18,29-33]). As in most Indo-Pacific reefs [5,19,24,34-36], the species diversity of Vietnam's reefs consists mainly of the members of 5 families, Acroporidae (117 species), Faviidae (42 species), Fungiidae (32 species), Poritidae (31 species), and Dendrophylliidae (25 species), making up altogether 64.48% of the total scleractinian species composition (**Figure 3**). The five genera most diverse and widespread in all reefs comprise *Acropora* (90 species), *Montipora* (28 species), *Porites* (20 species), *Favia* (14 species), and *Fungia* (12 species) are most various and numerous on all reefs, making 47% of all specific riches of scleractinian (**Figure 4**).

In all, some 20 scleractinian species form mono-specific settlements, varying from small "spots" (tens of square meters) to extended zones (hundreds of square meters), with a coverage reaching 60% - 100%. One fifth of all scleractinians occur throughout the Vietnam coast (**Figure 5**).

As a whole, the species diversity of reef-building scleractinians in different areas of the Vietnam coast is quite comparable, ranging from 190 species in the Gulf of Tonkin to 265 in the South Vietnam (**Figure 6**). Similar (193 - 256) numbers of species were reported for reefs of Indonesia, the Philippines, and Western Australia [36,37]. Central and South Vietnam reefs are most similar in species composition and are quite comparable to Spratly reefs). The degree of similarity of specific composition of Scleractinian various areas of Vietnam is resulted on the clustered diagram (**Figure 7**).

The peculiarity of the coral faunas of the Siam and Tonkin gulfs as revealed by cluster analysis (**Figure 8**) is consistent with their ecological peculiarities [7,23,38,39]. Their scleractinian diversity is partly caused by their similar hydrological regimes. Both gulfs are shallows with high water eutrophication and turbidity, with a predominance of clay sediments.

These factors cause a similarity of the biological and morphostructural zonation of reefs and species composition of reef communities in the gulfs. At the same time, certain differences in climatic and geomorphological conditions of the gulfs result in some dissimilarities in their scleractinian species composition. The development, zonation, species composition, and structure of the reefs in the gulfs were reported previously [13,23,39,40], so here, only major similarities and differences will be mentioned.

**Table 1. List species of scleractinian of vietnam.**

Species	Gulf of Tonkin	Gulf of Siam	Central Vietnam	Nhatrang Bay	Island Thu	Kondao Islands	Spratly archipelago
<i>Acantastrea echinata</i> (Dana, 1846)		+	+	+		+	+
<i>Acantastrea hemprichii</i> (Erhenberg, 1834)		+	+	+			
<i>Acantastrea hillae</i> (Wells, 1955)		+	+	+			+
<i>Acropora abrolhosensis</i> (Veron, 1985)	+		+				+
<i>Acropora abrotonoides</i> (Lamarck, 1816)		+	+	+	+	+	
<i>Acropora aculeus</i> (Dana, 1846)						+	+
<i>Acropora acuminata</i> (Verril, 1864)	+	+	+			+	
<i>Acropora anthocercis</i> (Brook, 1892)				+		+	
<i>Acropora aspera</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora austera</i> (Dana, 1846)	+	+				+	+
<i>Acropora brueggemanni</i> (Brokk, 1893)	+		+			+	
<i>Acropora cerealis</i> (Dana, 1846)	+		+	+		+	+
<i>Acropora clathrata</i> (Brook, 1981)			+		+		
<i>Acropora cytherea</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora dendrum</i> (Bassett-Sminh, 1890)				+			
<i>Acropora digitifera</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora divaricata</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora donei</i> (Veron & Wallace, 1984)			+				
<i>Acropora elseyi</i> (Brook, 1892)		+				+	
<i>Acropora fasciculare</i> (Latypob, 1992)			+				
<i>Acropora florida</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora formosa</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora gemmifera</i> (Brok, 1892)	+		+	+	+		+
<i>Acropora glauca</i> (Brook, 1893)	+		+				
<i>Acropora grandis</i> (Brook, 1892)	+	+	+	+	+	+	+
<i>Acropora granulosa</i> (Edw. & Haime, 1860)		+	+	+	+	+	+
<i>Acropora horrida</i> (Dana, 1846)					+		
<i>Acropora humilis</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora insignis</i> (Nemenzo, 1967)		+				+	
<i>Acropora hyacinthus</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora latistella</i> (Brook, 1892)			+	+			
<i>Acropora listeri</i> (Brook, 1893)		+	+	+		+	
<i>Acropora longicyathus</i> (Edw. & Haime, 1860)		+	+		+	+	+
<i>Acropora loripes</i> (Brook, 1892)	+	+		+		+	
<i>Acropora lutkeni</i> (Crossland, 1952)	+	+		+			
<i>Acropora microclados</i> (Ehrenberg, 1834)		+	+				
<i>Acropora microphthalma</i> (Verril, 1869)		+	+		+	+	+

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<i>Acropora millepora</i> (Ehrenberg, 1834)	+	+	+	+	+	+	+
<i>Acropora monticulosa</i> (Brüggemann, 1879)			+	+		+	
<i>Acropora multiacuta</i> (Nemenzo, 1967)				+			
<i>Acropora nasuta</i> (Dana, 1846)		+	+	+	+	+	+
<i>Acropora nobilis</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora palmerae</i> Wells, 1954		+	+			+	+
<i>Acropora parilis</i> (Quelch, 1886)					+		
<i>Acropora paniculata</i> (Verrill, 1902)		+				+	
<i>Acropora papillare</i> (Latypov, 1992)						+	
<i>Acropora pulchra</i> (Brook, 1891)	+	+	+	+	+	+	+
<i>Acropora pulchra</i> (Brook, 1891)	+	+	+	+	+	+	+
<i>Acropora robusta</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Acropora samoensis</i> (Brook, 1891)				+			
<i>Acropora sarmentosa</i> (Brook, 1891)		+	+	+		+	+
<i>Acropora secale</i> (Studer, 1878)		+		+		+	
<i>Acropora selago</i> (Studer, 1878)	+	+	+		+	+	+
<i>Acropora solitariensis</i> (Veron & Wallace, 1984)				+			
<i>Acropora squamata</i> (Latypov, 1992)		+			+		
<i>Acropora speciosa</i> (Quelch, 1886)				+			+
<i>Acropora subglabra</i> (Brook, 1891)		+					
<i>Acropora tenuis</i> (Dana, 1846)		+		+	+	+	+
<i>Acropora valenciennesi</i> (Edw. & Haime, 1860)	+	+		+	+	+	+
<i>Acropora valida</i> (Dana, 1846)							
<i>Acropora vaughani</i> (Wells, 1954)	+		+		+	+	
<i>Alveopora allingi</i> (Hoffmeister, 1925)	+	+					+
<i>Alveopora marionensis</i> (Veron & Pichon, 1982)			+	+			
<i>Alveopora verrilliana</i> (Dana, 1872)			+				+
<i>Anacropora forbesi</i> (Ridley, 1884)				+			+
<i>Astreopora cuculata</i> (Lamberts, 1980)		+				+	
<i>Astreopora listeri</i> (Bernard, 1896)			+	+	+	+	+
<i>Astreopora longiseptata</i> sp nov			+				
<i>Astreopora myriophthalma</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Astreopora ocellata</i> (Bernard, 1896)	+	+	+	+	+	+	+
<i>Australogyra zelli</i> (Veron & Pichon, 1977)		+				+	
<i>Balanophyllia cummingii</i> (Edw. & Haime, 1848)	+	+					
<i>Balanophyllia stimpsoni</i> (Verrill, 1865)	+						+
<i>Barabattoia amicornum</i> (Edw. & Haime, 1850)		+	+	+	+	+	+
<i>Barabattoia mirabilis</i> (Yabe & Sugiyama, 1941)	+	+		+	+	+	+

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<i>Caulastrea furcata</i> (Dana, 1846)		+			+		+	
<i>Caulastrea tumida</i> (Matthai, 1928)		+		+		+		+
<i>Coeloseria mayeri</i> (Vaughan, 1918)		+		+				+
<i>Coscinaraea columna</i> (Dana, 1846)		+		+		+	+	+
<i>Coscinaraea exesa</i> (Dana, 1846)		+		+		+		
<i>Coscinaraea mcneilli</i> (Wells, 1962)				+				
<i>Ctenactis echinata</i> (Pallas, 1766)		+		+		+	+	+
<i>Cycloseris cf. Sinensis</i> (Edw. & Haime, 1851)		+		+				+
<i>Cycloseris costulata</i> (Ortman, 1889)		+		+			+	
<i>Cycloseris cyclolites</i> (Lamarck, 1801)		+		+			+	+
<i>Cycloseris densicolumnelus</i> sp. nov.		+						
<i>Cycloseris patelliformis</i> (Boschma, 1923)		+		+				+
<i>Cycloseris somervillei</i> (Gardiner, 1909)							+	
<i>Cycloseris tenuis</i> (Dana, 1846)				+			+	+
<i>Cycloseris vaughani</i> (Boschma, 1923)				+			+	+
<i>Cynarina lacrymalis</i> (Edw. & Haime, 1848)		+		+				+
<i>Cyphastrea chalcidicum</i> (Forskål, 1775)		+		+		+		+
<i>Cyphastrea japonica</i> (Yabe & Sugiyama, 1932)				+		+		
<i>Cyphastrea microphthalma</i> (Lamarck, 1816)		+		+		+	+	+
<i>Cyphastrea serailia</i> (Forskål, 1775)		+		+		+	+	+
<i>Dendrophyllia aculeata</i> sp. nov.		+					+	
<i>Dendrophyllia arbuscula</i> (Van der Horst, 1922)		+		+			+	
<i>Dendrophyllia cornigera</i> (Lamarck, 1816)								+
<i>Dendrophyllia horsti</i> (Gard. & Waugh, 1939)		+		+			+	
<i>Dendrophyllia japonica</i> (Regberg, 1892)				+			+	
<i>Dendrophyllia laborelli</i> (Zibr. & Brilo, 1984)		+						
<i>Dendrophyllia robusta</i> (Bourne, 1905)						+		+
<i>Dendrophyllia sphaerica</i> (Nemenzo, 1981)		+		+				
<i>Diaseris fragilis</i> (Alcock, 1893)				+		+		+
<i>Diploastrea heliopora</i> (Lamarck, 1816)		+		+		+	+	+
<i>Echinophyllia aspera</i> (Ellis & Solander, 1786)		+		+		+		+
<i>Echinophyllia echinata</i> (Saville-Kent, 1975)		+		+			+	
<i>E. echinoporoides</i> (Veron & Pichon, 1980)		+		+		+	+	+
<i>Echinophyllia nichihirai</i> (Veron & Pichon, 1990)		+				+		+

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<i>Echinophyllia orpheensis</i> (Veron & Pichon, 1979)	+	+	+	+	+	+	+
<i>Echinophyllia patula</i> (Hodgson & Ross, 1981)				+			
<i>Echinopora gemmacea</i> (Lamarck, 1816)	+	+	+	+		+	+
<i>Echinopora hirsutissima</i> (Edw. & Haime, 1849)		+		+		+	
<i>Echinopora horrida</i> (Dana, 1846)			+			+	+
<i>Euphyllia ancora</i> (Veron & Pichon, 1980)				+			
<i>Euphyllia cristata</i> (Chevalier, 1971)				+		+	
<i>Euphyllia divisa</i> (Veron & Pichon, 1980)				+	+	+	+
<i>E. glabrescens</i> (Chamisso & Eysenhard, 1821)	+	+	+	+	+	+	+
<i>Euphyllia grandiseptata</i> sp. nov.				+			
<i>Euphyllia yaeyamaensis</i> (Shirai, 1980)			+	+			+
<i>Favia fava</i> (Forskål, 1775)	+	+		+		+	+
<i>Favia laxa</i> (Klunzinger, 1879)	+	+		+			
<i>Favia lizardensis</i> (Veron & Pichon, 1977)	+	+	+	+	+	+	+
<i>Favia maritima</i> (Nemenzo, 1971)	+	+	+	+	+	+	+
<i>Favia matthai</i> (Vaughan, 1918)	+	+		+	+	+	+
<i>Favia maxima</i> (Veron <i>et al.</i> , 1977)	+	+		+	+	+	+
<i>Favia pallida</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Favia rotumana</i> (Gardiner, 1889)	+	+	+	+	+	+	+
<i>Favia rotundata</i> (Veron & Pichon, 1977)		+			+	+	
<i>Favia speciosa</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Favia stelligera</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Favia truncatus</i> (Veron, 2000)		+					
<i>Favia veroni</i> (Moll & Best, 1984)		+		+			
<i>Favites abdita</i> (Ellis & Solander, 1786)	+	+	+	+	+	+	+
<i>Favites chinensis</i> (Verrill, 1866)	+	+	+	+	+	+	
<i>Favites complanata</i> (Ehrenberg, 1834)	+	+	+	+			+
<i>Favites flexuosa</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Favites halicora</i> (Ehrenberg, 1834)		+		+		+	
<i>Favites pentagona</i> (Esper, 1794)	+	+	+		+		+
<i>Favites russelli</i> (Wells, 1954)				+			
<i>Favites solidocolumellae</i> sp. nov.				+			
<i>Favites virens</i> (Dana, 1846)						+	+
<i>Fungia concina</i> (Verrill, 1864)		+		+		+	

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<i>Fungia corona</i> (Döderlein, 1901)								+
<i>Fungia danai</i> (Edwards & Haime, 1851)	+	+	+	+			+	+
<i>Fungia fungites</i> (Linnaeus, 1758)	+	+	+	+	+	+	+	+
<i>Fungia granulosa</i> (Klunzinger, 1879)	+	+					+	
<i>Fungia horrida</i> (Dana, 1846)								+
<i>Fungia repanda</i> (Dana, 1846)					+		+	+
<i>Fungia scabra</i> (Döderlein, 1901)							+	
<i>Fungia scruposa</i> (Klunzinger, 1879)								+
<i>Fungia scutaria</i> (Lamarck, 1801)					+	+	+	+
<i>Fungia seychelensis</i> (Hoeksema, 1993)							+	
<i>Fungia valida</i> (Verrill, 1864)	+							+
<i>Galaxea astreata</i> (Lamarck, 1816)	+	+	+	+	+	+	+	+
<i>Galaxea crassiseptata</i> (Latypov, 1998)							+	
<i>Galaxea fascicularis</i> (Linnaeus, 1767)	+	+	+	+	+	+	+	+
<i>Galaxea vesiculosa</i> sp. nov.							+	
<i>Gardineroseris pavonoides</i> sp. nov.							+	
<i>Gardineroseris planulata</i> (Dana, 1846)							+	
<i>Goniastrea aspera</i> (Verrill, 1865)	+	+	+	+	+	+	+	+
<i>Goniastrea australiensis</i> (Edw. & Haime, 1857)							+	
<i>Goniastrea cf. palauensis</i> (Yabe <i>et al.</i> , 1936)							+	
<i>Goniastrea edwardsi</i> (Chevalier, 1971)							+	+
<i>Goniastrea favulus</i> (Dana, 1846)							+	+
<i>Goniastrea pectinata</i> (Ehrenberg, 1834)	+	+	+	+	+	+	+	+
<i>Goniastrea retiformis</i> (Lamarck, 1816)	+	+	+	+	+	+	+	+
<i>Goniopora columna</i> (Dana, 1846)	+	+	+				+	+
<i>Goniopora djiboutiensis</i> (Vaughan, 1907)								
<i>Goniopora fruticosa</i> (Saville-Kent, 1893)							+	+
<i>Goniopora lobata</i> (Edwards & Haime, 1851)	+	+	+	+	+	+	+	+
<i>Goniopora pandoraensis</i> (Veron & Pichon, 1982)							+	
<i>Goniopora stokesi</i> (Edwards & Haime, 1851)	+	+	+	+	+	+	+	+
<i>Goniopora stutchburyi</i> (Wells, 1955)	+	+	+					
<i>Goniopora tenuidens</i> (Quelch, 1886)	+	+	+					+
<i>Halomitra pileus</i> (Linnaeus, 1758)	+							+
<i>Heliofungia actiniformis</i> (Quoy & Gaimard, 1833)							+	

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<i>Herpolitha limax</i> (Esper, 1797)	+	+	+	+	+	+	+
<i>Herpolitha weberi</i> (Van der Horst, 1921)		+	+				+
<i>Heterocyathis aequicostatus</i> (Edw. & Haime, 1848)		+					
<i>Heteropsammia cochlea</i> (Spengler, 1781)		+					+
<i>Hydnophora exesa</i> (Pallas, 1766)	+	+	+	+	+	+	+
<i>Hydnophora microconos</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Hydnophora rigida</i> (Dana, 1846)			+	+	+	+	+
<i>Isopora cuneata</i> (Dana, 1846)		+	+	+	+	+	+
<i>Isopora palifera</i> (Lamarck, 1816)		+	+	+	+	+	+
<i>Leptastrea bottae</i> (Edwards & Haime, 1849)	+	+					
<i>Leptastrea pruinosa</i> (Crossland, 1952)	+	+	+	+		+	
<i>Leptastrea purpurea</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Leptastrea transversa</i> (Klunzinger, 1879)	+	+	+	+	+		
<i>Leptoria phrygia</i> (Ellis & Solander, 1786)	+	+	+	+	+	+	+
<i>Leptoseris explanata</i> (Yabe & Sugiyama, 1941)		+	+	+		+	+
<i>Leptoseris gardineri</i> (Van der Horst, 1921)		+				+	
<i>Leptoseris hawaiiensis</i> (Vaughan, 1907)	+	+					
<i>Leptoseris mycetoseroides</i> (Wells, 1954)	+	+	+	+			+
<i>Leptoseris scaba</i> (Vaughan, 1907)		+		+			
<i>Leptoseris var. mycetoseroides</i> (Wells, 1954)	+	+		+			
<i>Leptoseris yabei</i> (Pillai & Scheer, 1976)		+	+	+		+	+
<i>Lithophyllon bistomatium</i> (Latypov, 1995)	+						
<i>Lithophyllon mokai</i> (Hoeksema, 1989)	+	+		+			+
<i>Lithophyllon undulatum</i> (Rehberg, 1892)	+	+	+	+	+		+
<i>Lobophyllia grandis</i> sp. nov.	+			+			
<i>Lobophyllia corymbosa</i> (Foskål, 1775)	+	+	+	+			+
<i>Lobophyllia flabelliformis</i> (Veron, 2000)				+			
<i>L. hattai</i> (Yabe, Sygiyama & Eguchi, 1936)	+	+	+	+	+	+	+
<i>Lobophyllia hemprichii</i> (Ehrenberg, 1834)	+	+	+	+	+	+	+
<i>Lobophyllia pachysepta</i> (Chevalier, 1975)		+	+	+			
<i>Lobophyllia robusta</i> (Yabe & Sugiyama, 1936)	+			+			+
<i>Madracis kirbyi</i> (Veron & Pichon, 1976)	+	+	+	+	+	+	
<i>Merulina ampliata</i> (Ellis & Solander, 1786)	+	+	+	+	+	+	+
<i>Merulina scabriscula</i> (Dana, 1846)					+		

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<i>Montastrea annuligera</i> (Edw. & Haime, 1849)	+	+	+	+	+	+
<i>Montastrea colemani</i> (Veron, 2000)				+		
<i>Montastrea curta</i> (Dana, 1846)	+	+	+	+	+	+
<i>Montastrea magnistellata</i> (Chevalier, 1971)	+					
<i>Montastrea valenciennesi</i> (Edw. & Haime, 1848)	+	+	+	+	+	+
<i>Montipora aequituberculata</i> (Bernard, 1897)	+	+	+	+	+	+
<i>Montipora angulata</i> (Lamarck, 1816)			+	+	+	
<i>Montipora australiensis</i> (Bernard, 1897)	+	+			+	+
<i>Montipora caliculata</i> (Dana, 1846)	+	+		+	+	+
<i>Montipora crassituberlata</i> (Bernard, 1897)			+	+	+	+
<i>Montipora danae</i> (Edwards & Haime, 1851)	+		+		+	
<i>Montipora digitata</i> (Dana, 1846)	+	+	+	+	+	+
<i>Montipora efflorescens</i> (Bernard, 1897)		+				+
<i>Montipora foliosa</i> (Pallas, 1766)		+		+		+
<i>Montipora grisea</i> (Bernard, 1897)		+		+	+	+
<i>Montipora hispida</i> (Dana, 1846)	+	+	+	+	+	+
<i>Montipora hoffmeisteri</i> (Wells, 1954)		+	+	+	+	
<i>Montipora informis</i> (Bernard, 1897)		+				
<i>Montipora millepora</i> (Crossland, 1952)		+	+	+	+	+
<i>Montipora molis</i> (Bernard, 1897)					+	
<i>Montipora monasteriata</i> (Forskål, 1775)	+		+			+
<i>Montipora nodosa</i> (Dana, 1846)	+	+	+	+		
<i>Montipora porites</i> (Veron, 2000)			+			+
<i>Montipora spongodes</i> (Bernard, 1897)	+	+	+	+	+	+
<i>Montipora spumosa</i> (Lamarck, 1816)	+	+				+
<i>Montipora stellata</i> (Bernard, 1897)		+	+			
<i>Montipora tuberculosa</i> (Lamarck, 1816)	+	+	+	+	+	+
<i>Montipora turgescens</i> (Bernard, 1897)	+	+	+	+	+	+
<i>Montipora turtlensis</i> (Veron & Wallace, 1984)	+			+		
<i>Montipora undata</i> (Bernard, 1897)	+	+	+	+	+	+
<i>Montipora venosa</i> (Ehrenberg, 1834)	+	+			+	
<i>Montipora verrucosa</i> (Lamarck, 1816)		+	+	+	+	+
<i>Montipora vietnamensis</i> (Veron, 2000)				+		
<i>Moseleya latistellata</i> (Quelch, 1884)		+				+

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<i>Mycedium elephantotus</i> (Pallas, 1766)	+		+	+	+	+	+
<i>Oulastrea alta</i> (Nemanzo, 1981)		+					
<i>Oulastrea crispata</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Oulophyllia bennettiae</i> (Veron & Pichon, 1977)				+		+	
<i>Oulophyllia crispa</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Oulophyllia levis</i> (Nemanzo, 1959)			+				+
<i>Oxypora glabra</i> (Nemanzo, 1959)				+			
<i>Oxypora lacera</i> (Verrill, 1864)	+	+		+		+	+
<i>Pachyseris rugosa</i> (Lamarck, 1801)	+	+	+	+	+	+	+
<i>Pachyseris speciosa</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Pachyseris monticulosa</i> sp. nov.				+		+	+
<i>Palauastrea ramosa</i> (Yabe & Sugiyama, 1941)						+	
<i>Pavona cactus</i> (Forskål, 1775)	+	+		+			
<i>Pavona clavus</i> (Dana, 1846)	+	+		+	+	+	+
<i>Pavona decussata</i> (Dana, 1846)	+	+		+	+	+	+
<i>Pavona distincta</i> sp. nov.					+		
<i>Pavona explanulata</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Pavona frondifera</i> (Lamarck, 1801)		+		+			
<i>Pavona maldivensis</i> (Gardiner, 1905)		+		+			+
<i>Pavona minuta</i> (Wells, 1954)		+	+				+
<i>Pavona varians</i> (Verrill, 1864)		+	+	+			+
<i>Pavona venosa</i> (Ehrenberg, 1834)		+				+	
<i>Pectinia alcicornis</i> (Saville-Kent, 1871)	+			+	+	+	+
<i>Pectinia lactuca</i> (Pallas, 1766)	+	+	+	+	+	+	+
<i>Pectinia paeonia</i> (Dana, 1846)	+	+		+	+	+	+
<i>Physogyra lichtensteini</i> (Edw. & Haime, 1851)		+	+	+	+	+	+
<i>Platygyra daedalia</i> (Ellis & Solander, 1786)	+	+	+	+	+	+	+
<i>Platygyra lamellina</i> (Ehrenberg, 1834)	+	+	+	+	+	+	+
<i>Platygyra pini</i> (Chevalier, 1975)	+	+		+	+	+	+
<i>Platygyra sinensis</i> (Edw. & Haime, 1849)	+	+	+	+	+		
<i>Plerogyra sinuosa</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Plesiastrea versipora</i> (Lamarck, 1816)	+	+	+	+	+	+	+
<i>Pleuractis moluccensis</i> (Van der Horst, 1919)		+				+	
<i>Pleuractis paumotensis</i> (Stuthbury, 1833)		+		+	+		+

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<i>Pocillopora capitata</i> (Verrill, 1864)								+
<i>Pocillopora damicornis</i> (Linnaeus, 1758)	+	+	+	+	+	+	+	+
<i>Pocillopora eydouxi</i> (Edwards & Haime, 1860)			+	+	+	+	+	+
<i>Pocillopora kelleheri</i> (Veron, 2000)								+
<i>Pocillopora meandrina</i> (Dana, 1846)			+	+	+		+	
<i>Pocillopora verrucosa</i> (Ellis & Solander)	+	+	+	+	+	+	+	+
<i>Pocillopora woodjonesi</i> (Vaughan, 1918)			+	+	+	+	+	+
<i>Podabacia crustacea</i> (Pallas, 1766)	+	+	+	+	+	+	+	+
<i>Polyphyllia novaehiberniae</i> (Lesson, 1831)								+
<i>Polyphyllia talpina</i> (Lamarck, 1831)	+	+	+	+	+	+	+	+
<i>Porites annae</i> (Crossland, 1952)				+	+	+		+
<i>Porites attenuata</i> (Nemenzo, 1955)							+	+
<i>Porites australiensis</i> (Vaughan, 1918)	+	+	+	+	+	+	+	+
<i>Porites cylindrica</i> (Dana, 1846)			+	+	+	+	+	+
<i>Porites deformis</i> (Nemenzo, 1955)							+	+
<i>Porites densa</i> (Vaughan, 1918)	+	+						
<i>Porites lichen</i> (Dana, 1846)	+	+	+	+	+	+	+	+
<i>Porites lobata</i> (Dana, 1846)	+	+	+	+	+	+	+	+
<i>Porites lutea</i> (Edwards & Haime, 1860)	+	+	+	+	+	+	+	+
<i>Porites mayeri</i> (Vaughan, 1918)	+	+	+	+	+	+	+	+
<i>Porites monticulosa</i> (Dana, 1846)							+	+
<i>Porites mordax</i> (Dana, 1846)	+	+						+
<i>Porites murrayensis</i> (Vaughan, 1918)	+	+	+	+	+			
<i>Porites nigrescens</i> (Dana, 1848)			+	+	+	+	+	+
<i>Porites rus</i> (Forskål, 1775)	+	+	+	+	+	+	+	+
<i>Porites solida</i> (Forskål, 1775)	+	+	+	+	+			
<i>Porites sp. 1</i>								+
<i>Porites sp. 2</i>	+	+	+	+	+			
<i>Porites stephensoni</i> (Crossland, 1952)	+	+	+	+	+			
<i>Porites vaughani</i> (Crossland, 1952)							+	+
<i>Psammocora contigua</i> (Esper, 1979)	+	+	+	+	+	+	+	+
<i>Psammocora digitata</i> (Edwards & Haime, 1851)	+				+	+	+	+
<i>Psammocora explanulata</i> (Van der Horst, 1922)			+	+				
<i>Psammocora nierstraszi</i> (Van der Horst, 1921)	+	+	+	+			+	+

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<i>Psammocora profundacella</i> (Gardiner, 1898)	+	+	+	+	+	+	
<i>Psammocora superficialis</i> (Gardiner, 1898)	+	+	+			+	+
<i>Pseudosiderastrea tayamai</i> (Yabe & Sug., 1935)	+	+	+	+	+	+	+
<i>Sandalolitha dentata</i> (Quelch, 1884)	+	+	+	+	+	+	+
<i>Sandalolitha robusta</i> (Quelch, 1886)	+	+	+	+	+	+	+
<i>Scolymia aff. Vitiensis</i> (Brüggemann, 1877)		+	+	+		+	
<i>Scolymia australis</i> (Edw. & Haime, 1849)		+		+	+	+	+
<i>Seriatopora caliendrum</i> (Ehrenberg, 1834)		+					
<i>Seriatopora hystrix</i> (Dana, 1846)		+	+	+	+	+	+
<i>Stylocoeniella guentheri</i> (Basset-Smith, 1890)	+			+	+	+	+
<i>Stylophora pistillata</i> (Esper, 1797)	+	+	+	+	+	+	+
<i>Stylophora subseriata</i> (Ehrenberg, 1834)		+			+		
<i>Symphyllia agaricia</i> (Edwards & Haime, 1849)	+	+		+		+	+
<i>Symphyllia erythraea</i> (Klunzinger, 1879)				+			
<i>Symphyllia hassi</i> (Pillai & Scheer, 1976)	+	+					+
<i>Symphyllia radians</i> (Edwards & Haime, 1849)	+	+	+	+	+	+	+
<i>Symphyllia recta</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Symphyllia valenciennesii</i> (Edw. & Haime, 1849)	+	+	+	+	+	+	+
<i>Trachyphyllia geoffroyi</i>				+	+	+	+
<i>Tubastrea aurea</i> (Quoy & Gaimard, 1833)	+	+	+	+	+	+	+
<i>Tubastrea coccinea</i> (Ehrenberg, 1834)	+	+		+	+	+	+
<i>Tubastrea diaphana</i> (Dana, 1846)				+	+	+	
<i>Tubastrea micrantha</i> (Ehrenberg, 1834)	+	+	+	+	+	+	+
<i>Turbinaria bifrons</i> (Brüggemann, 1877)	+	+	+	+	+	+	
<i>Turbinaria conspicua</i> (Bernard, 1896)		+	+				+
<i>Turbinaria contorta</i> (Bernard, 1896)		+		+			
<i>Turbinaria crater</i> (Pallas, 1766)	+	+					+
<i>Turbinaria frondens</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Turbinaria mesenterina</i> (Dana, 1846)	+	+	+	+	+	+	+
<i>Turbinaria patula</i> (Dana, 1846)		+	+	+			
<i>Turbinaria peltata</i> (Esper, 1794)	+	+	+	+	+	+	+
<i>Turbinaria radicalis</i> (Bernard, 1896)	+	+		+			+
<i>Turbinaria reniformis</i> (Bernard, 1896)	+	+	+	+	+	+	+
<i>Turbinaria stellulata</i> (Lamarck, 1816)		+					

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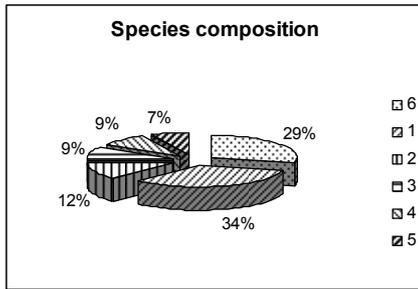


Figure 3. Relative species diversity of major coral genera in Vietnam. 1: Acroporidae; 2: Faviidae; 3: Fungiidae; 4: Poritidae; 5: Dendrohillidae; 6: The rest genera.

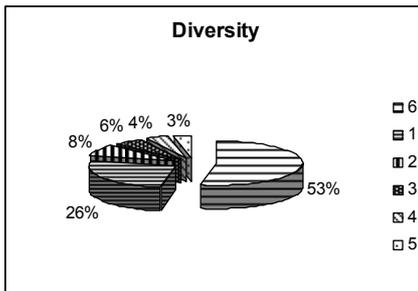


Figure 4. Relative species diversity of major coral species in Vietnam. 1: Acropora; 2: Montipora; 3: Porites; 4: Favia; 5: Fungia; 6: The rest species.



Figure 5. Monospecific settlement on reef Myeu Island at Nhatrang Bay, depth 2 m.

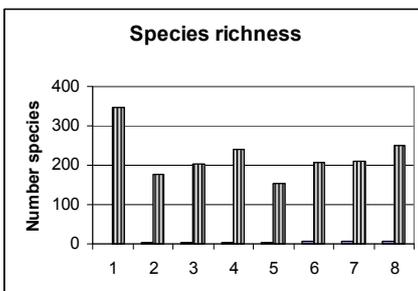


Figure 6. Scleractinian species diversity in different regions of Vietnam. 1: total number of species (347); 2: Gulf of Tonkin (177); 3: Central Vietnam (204); 4: South Vietnam (240); 5: Thu Island; 6: Con Dao Islands (211); 7: Spratly Island (211), 8: Gulf of Siam (251).

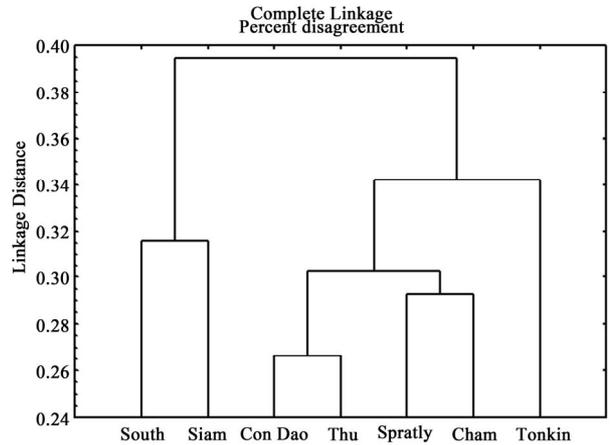


Figure 7. Cluster analysis of similarity species composition on different regions of Vietnam.

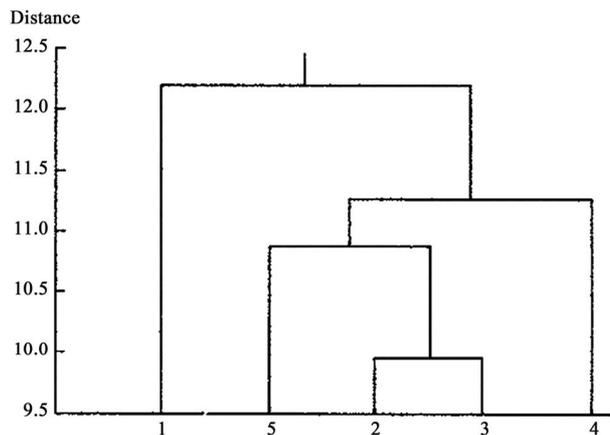


Figure 8. Similarity dendrogram of scleractinians faunas in different regions of Vietnam. 1: Gulf of Tonkin; 2: Central Vietnam; 3: South Vietnam; 4: Gulf of Siam; 5: Spratly Island.

The reef communities in both gulfs lack members of *Palauastrea* and *Caulastrea* and *Acropora cuneata*, the latter occurring in most Vietnam reefs. *Plerogyra* and *Physogyra* are absent in the closed part of the Gulf of Tonkin, and *Pachyseris*, *Mycedium*, and *Pectinia*, in the innermost and coastal areas of the Gulf of Siam. However, some members of the latter three genera and rare *Physogyra* and *Plerogyra* species are found in the open parts of both gulfs, off Hainan and Tho Chu islands. Corals having large polyp forms and capable of self cleaning—*Galaxea*, *Echinopora*, *Lobophyllia*, *Echinophyllia*, *Turbinaria*, *Podobacia*, *Lithophyllon*, *Fungia*, and *Goniopora*—are widespread in both gulfs. The reefs in both gulfs are dominated by many species of these genera (*Galaxea fascicularis*, *Goniopora stokesi*, *Echinopora lamellosa*, and *Lobophyllia hemprichii*), as well as by *Acropora cytherea*, *A. nobilis*, *Montipora hispida*, *Porites lobata*, and *P. cylindrica*, widespread in Indo-

Pacific reefs. Altogether, these species cover 60% - 80% of the substrate. Massive *Porites* colonies (at least 10 species) forming vast monospecific settlements are typical of both gulfs. At the same time, members of *Pocillopora*, abundant in most Indo-Pacific reefs (5-7 species), only rarely occur in the innermost parts of the gulfs (2 species maximum) but are common for island reefs in the open parts of the gulfs (Tho Chu, Hainan). By and large, the two gulfs are quite similar in coral diversity and share 74.3% of species.

## 2.2. Communities

The distribution and peculiarities of benthic communities in the coastal part of Vietnam reefs is rather constant (See **Figure 2**). As a rule, these are algal-coral communities, composed of several biocenoses (zones, facieses), dominated by individual algal or coral species or by groups of species (**Figure 9**). The predominance of *Laurencia*, *Turbinaria*, and *Sargassum* algae in the coastal zones of the reefs has been reported for many reef development areas. This may be indicative of an increase in water eutrophication or later stages of reef development [38,41-43].

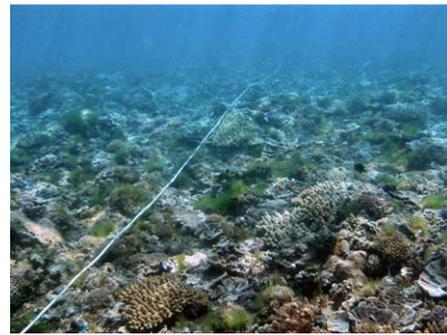
Both along the Vietnam coast and in the whole Indo-Pacific, in reef zones characterized by relatively stable conditions (lagoons, deep stony and coral terraces, and reef slopes), branched, plate, and trumpet colonies of *A. cytherea*, *A. hyacinthus*, *Montipora danae*, *M. foliosa*, *Porites cylindrica*, *P. nigrescens*, and others successfully compete with differently shaped scleractinian colonies [43-45].

A wider distribution of encrusting and plate colonies of *Euphyllia*, *Echinophyllia*, *Mycodium*, *Pachyseris*, and *Turbinaria* compared to that of branched forms is directly caused by lowered illumination. This is also the case in many reefs of the Indo-Pacific and Caribbean basins [46-48]. In Vietnam's reefs, such corals are common for communities of the slope base, byoherms zone, and fore reef platform.

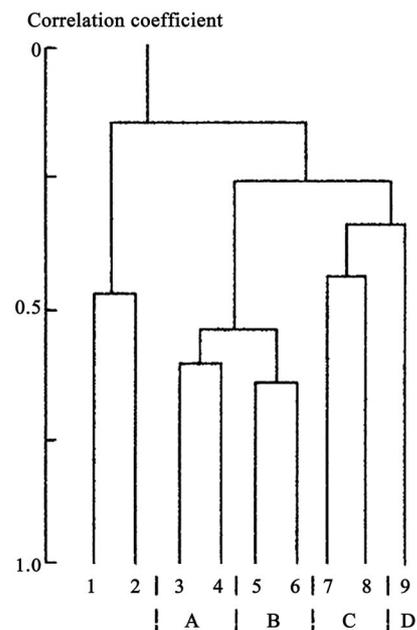
Caused by abiotic factors, the vertical distribution of reef-building corals has a strong effect on the development of biotic zonation across a whole reef community, beginning with settlement-site choice and ending with interspecific trophic relationships. The relationships between the species composition of benthic communities of some reefs as revealed by cluster analysis correlated with the ecological and physiographical zonation of the reefs (**Figure 10**).

Algal-coral lagoon and reef flat communities dominated by red and brown algae and similar in coral and common macrobenthos species composition formed a single cluster group, that of communities developing

under similar conditions. The high similarity between coral faunas from different sites reflected similar, sometimes extreme, conditions of reef flat and shallow-water stone terrace. At the same time, communities of these reef zones were set apart from those of neighboring reef zones. Both in structural and unstructured reefs, polyspecific reef slope communities sharing a relatively greater number of corals also formed a distinct cluster. Polyspecific coral communities of a reef slope of structural and unstructured reefs distinctly stands apart on the greatest level of similarity of their specific variety.



**Figure 9.** Algal-coral community on reef Bathlongvi, depth 2 m.



**Figure 10.** Cluster dendrogram of the species composition of benthic communities. Algal-coral community, unstructured (1) and structural (2) reefs; *Acropora* community, unstructured (3) and structural (4) reefs; *Acropora* + *Diploastrea* community, unstructured (5) and structural (6) reefs; (7) bioherm community (reef slope); (8) *Junceella* + *Diaseris* community; (9) *Maleus* + *Junceella* community. A: lagoon, B: reef flat and terrace zone, C: reef slope, D: for-reef platform.

### 3. Discussion and Conclusions

To summarize the above, both structural and unstructured reefs feature vertical biological and geomorphological zonation. The latter is mainly determined by peculiarities of the underwater reef slope substrate. Similar biological zonation reflecting interzonal differences in environmental conditions (substrate, wave regime, sedimentation rate, illumination) has been reported for many of Vietnam's reefs and various Pacific and Caribbean reefs [21,23,40,42,43].

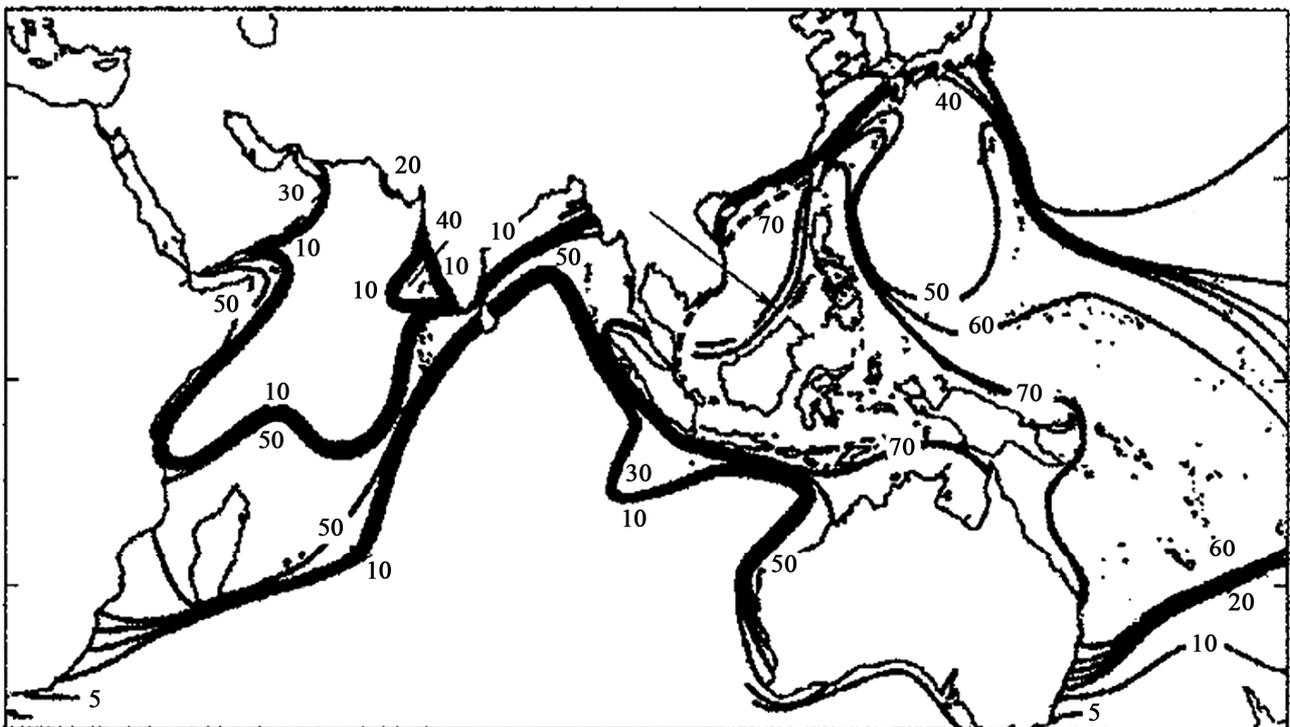
Shallow-water Vietnam reefs growing in highly eutrophic conditions lack thick reef deposits [18,23] and feature high coral diversity and distinct biological zonation, that is, the presence of inner heterotrophic (lagoon, reef flat) and outer autotrophic (reef slope) zones [26,49,50], which is characteristic of typical Indo-Pacific reefs.

In reefs of Indonesia and Philippines and in the Great Barrier Reef, a total of 360 - 410 reef-building scleractinians pertaining to 70 - 80 genera have been recorded [36]. This region of the Western Pacific is considered the center of origin of tropical coral faunas. The maximum coral diversity is observed in the so-called Coral Triangle [36,51,52] with apices in the Philippines, the Malacca Peninsula, and New Guinea (**Figure 11**). To same fertile the center should expense and coast of Vietnam, scleractinian fauna which totals 350 species belonging to 80

genera.

Vietnam's reefs, too, obviously belong to this center, which is evidenced by their high similarity in coral species composition to reefs of Thailand, Indonesia, and the Philippines (76.4%, 72.3%, and 81.6%, respectively). In the greater Western Pacific Coral Triangle (with apices in Vietnam, South Japan, and the Great Barrier Reef), coral faunas are also highly similar and homogenous. The similarities between the Vietnam coral fauna and those of Japan and Australia are 77.5% and 86%, respectively, suggesting homogeneity of the coral fauna of the Western and Southwest Pacific. As a whole, the species complex of Vietnam scleractinians, as well as those of alcyonarians and gorgonarians, belongs to the tropical fauna as the majority of Vietnam corals are also common for the equatorial Indo-Pacific reef zone. The scleractinian species composition of this area exceeds 80% of that of the Pacific, and the alcyonarian diversity of Vietnam's reefs is one of the greatest in the Indo-Pacific [18,31,53].

The species composition and high diversity of Vietnam's coral fauna, as well as its close similarity to the Southwest Pacific coral fauna, allow one to refer it to the Indonesia-Polynesian center of origin of the coral faunas of the tropical Indo-Pacific (**Figure 12**) The whole Vietnam coast, from the Gulf of Tonkin to the Gulf of Siam, is a biogeographically single whole and is part of the Indo-Polynesian Province of the Indo-Pacific Area.



**Figure 11.** Schematized map of the generic diversity of reef-building corals in different regions of the Indo-Pacific (partly after Veron, 1995). The dotted line and arrow indicate new and old 70 genera diversity isolines, respectively.



Figure 12. Optimal Vietnamese coral reef.

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