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The Study of Species Richness in Coral Communities of Vietnam

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Abstract Dynamics of biodiversity research traced reef-building scleractinian on the reefs of Vietnam for more than 35 years. Found 376 corals species, pertaining to 80 genera (including nine ahermatypic corals), of which 153 species, belonging to 28 genera, were not previously known for that region, and 16 species from six genera were described for the first time. As in most Indo-Pacific reefs, the species diversity of Vietnam's reefs consists mainly of the members of five families: Acroporidae (98 species), Faviidae (42 species), Fungiidae (32 species), Poritidae (31 species), and Dendrophylliidae (26 species), making up altogether 64.48% of the total scleractinian species composition. 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. 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.

Keywords Biodiversity, Coral Community, Reef, Vietnam

1. Introduction

The coastline of Vietnam is over 3200km 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 206,000km^2. 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^3 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 until 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^3) freshwater influx and a substantial (up to 200 tons) terrigenous sediment influx into the sea. The daily suspended matter precipitation rate in the reef reaches 70 - 100 g/m^2 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 first information about the Scleractinia Vietnam appeared in 1937, after the publication of Seren [6] based on the results of his expedition to the "De Lanessan". They noted 64 species Scleractinian belonging to 33 genera. For a more complete list of Scleractinia, mostly of South Vietnam, was given 15 years later, the famous Russian naturalist Dawydoff [7]. It contained about 51 genera and 230 species Scleractinian. Some genera in this list contain from 5 to 12 are synonyms of species names, but the bulk of the whole Vietnamese Scleractinia that could already be quite comparable with corals of Australia and Indonesia, has been installed correctly. The first attempt to analyze the distribution of Scleractinia in the Bay of Nha Trang was undertaken [8], which allocated 4 typical facies types-market dominance to some island and situated on the capes of the reefs, as well as a list of Scleractinia, comprising 78 species. Since 1980, began systematic studies of coral and reefs of Vietnam in the Institute of Marine Biology FEB RAS, Nha Trang Institute of Oceanography, Haiphong Institute of Oceanology, and WWF (World Wide Fund for Nature). Twelve were held offshore and onshore expeditions from the northern part of the Gulf of Thailand to the Gulf of Tonkin and southern

islands Thu, Con Dao and the Spratly Islands. Just more than 60 reefs were studied in 13 different areas (Figure 1). The first study using SCUBA diving were held in the province of Khang Hoa (formerly Phu Khanh) on 22 transects located on different islands and coastal areas. There are founded 119 species of coral and three types of reefs with four different zones (coral communities). On morphology, species diversity and distribution of coral reef studied were comparable with many reefs Indo-Pacific [9].

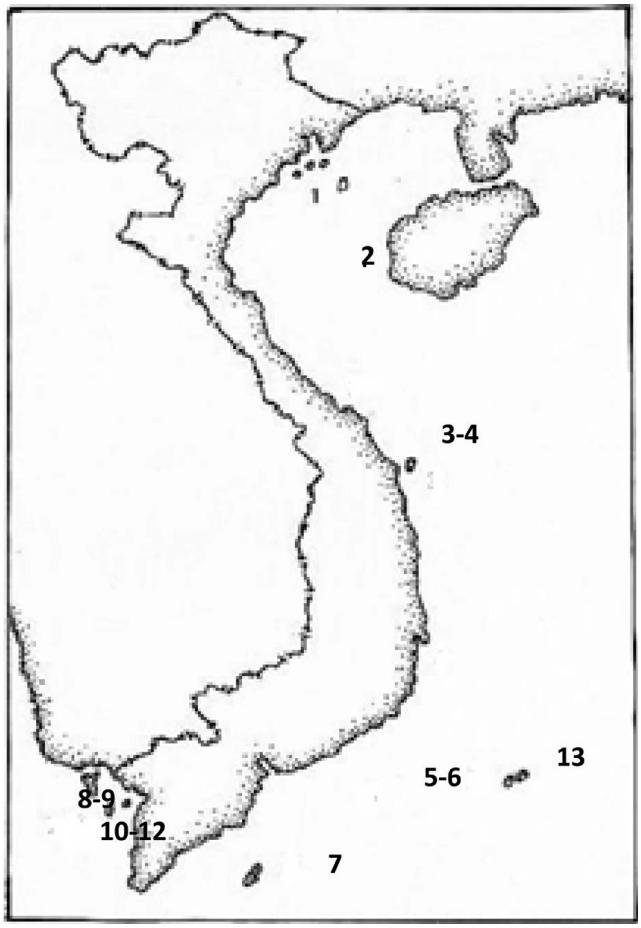


Figure 1. The main research areas of the reef. 1 - Baitylong archipelago, 2 - Bat Long Vi Island, 3-4 -Central Vietnam (4/7), 5-6 - Katuik and Ngũ Phung islands (2/4), banks of Astrolâb and Royal Bishob, 7 - Con Dao islands (1/3), 8-9 - Islands Anthoj, 10-12 - Islands Namsu, Thochu et al., (2/8), 13 - Spratly Islands. In parentheses in denominator - the number of reefs and transects studied again.

2. Materials and Methods

Work performed on a common methodology with the use of hydrobiological accounting framework and transects [10]. Transects were established perpendicular to the shoreline and lay along the bottom of the profile to a depth of 11-15 meters. The profile of each transect was established [11] and the boundaries of the zones were marked. The living coral cover was recorded with the number of dominant taxa (genera and species). Abundance of common species of mollusks and echinoderms, branched, massive, encrusted and funnel-shaped scleractinian colonies, as well as the degree of substratum cover by corals were estimated along a 100 m transect frame $1m^2$ divided into 100 squares with the area of 10 cm^2 each. Photographing every square meter with frame $1m^2$ along the whole transect as well as of reef landscapes and their flora and fauna was conducted. More than 2250 photos by Olympus digital cameras were made for later analysis of species composition ([12], [13], [14]) The number of colonies of corals recorded at transect, is calculated using the Shannon diversity index using the formula H ' =-Σ pi log ***Pi***, where ***Pi*** is the prevalence of colonies giving general [15]). Coefficients of species diversity corals were calculated by the formula: H = -Σ ((ni /N) x (ln ni / N)), where **H** – Shannon Diversity Index, **n**-number of individuals belonging to **i** species, **N** – total number of individuals. The similarities of various communities determined by similarity Serensen [15] and using STATISTICA 6.0.

3. Results and Discussion

In 80-th years of the last century, continued exploring coral reefs along the coast of Vietnam between 9˚ and 13˚ N. 255 species of hermatypic Scleractinian have been identified belonging to 69 genera, 23 of which were first committed to Vietnam. Species richness was seven genera: *Acropora* - 41 species, *Montipora* - 8, *Porites* - 13, *Turbinaria* -12, *Favia*, *Goniopora* -11, *Pavona* - 10, in introducing the 46.06% all species. A comparison of the qualitative and quantities composition of scleractinian of the investigated reefs with that of the reefs of Australia, Philippines, Indonesia, Maldives and Seychelles islands revealed 86.76-92.70% of frequent occurrence on reefs of Vietnam and each the of common species which are foregoing regions. These regions, including Vietnam, have 62.82% of common species of scleractinian. From this, it seems doubtful that there are two centers of coral dispersal in the Indo-Pacific [16]. At the end of 80-th years of the last century geography study the Vietnamese reefs has expanded to the South (to 21° N) at the islands in the open part of the South China Sea. Species composition; density of populations; biomass of mass species of algae, coelenterates, mollusks and echinoderms; and the degree of substratum coverage with macrophytes and corals have been investigated on 104 transects and stations. Six communities changing in connection with vertical zonation and the definite type of reefs have been revealed based on these data. Species composition including 310 species of Scleractinian belonging to 70 genera established for the first time (Table 1). 107 species of 23 genera had not been earlier reported for Vietnam. Various species of Scleractinian (*Acropora cytherea*, *A. nobilis, Montipora aequituberculata, M hispida, Porites nigrescens, P. cylindrica*, and others) may form monospecific settlements that cover 100% of the substrate surface in the areas of reef

flat or reef slope and extend for many hundreds of square meters. The comparison of species diversity , degree of similarity and of dominating of Scleractinia species composition in Vietnam, Indonesia, Philippines and the Great Barrier Reef of Australia revealed more similarities than differences in coral faunas of these regions (70% of species are common). In Vietnam, all reef types are known, including barrier reefs that are situated on Re Islands and Jiang Bo Reef in Phu Khanh Province and atolls located around the Spratly Islands. The specificity of geomorphological and climatic conditions clearly determines two types of Vietnamese bordering reefs. In reefs of first type, which reveal a clearly expressed morphological zonation, a carbonate frame develops, which is characteristic of most structural reefs in the tropical World Ocean [17]. Reefs of the other type do not have such a zonation and their carbonate deposits are represented by patchy settlements of corals that form weak crusts covering the reef substrate without making changes in the profile of the reef (unstructured, incrusting reefs [19] (Figure 2, 3). Until now according to the most recent information, the most comprehensively studied reefs of Indonesia and the Philippines and the Great Barrier Reef of Australia have no less than 300 species of reef-building Scleractinian belonging to 70 genera ([20], [21], [22]). This region of the South-Western Pacific is considered as a faunistic center of the origin of tropical corals. The greatest species diversity of Scleractinian is found in the so-called "fertile triangle" [23] with vertexes at the Philippines, Malacca Peninsula, and New Guinea. To the same fertile center, the scleractinian fauna of Vietnam should be referred which comprises 310 species belonging to 70 genera.

Table 1. Relations between the numbers of transect and of species in different regions of Vietnam

Area of studies	Number of habitats	Number of transects	Number of species	Number of common species		
				I	P	J
Tonkin Bay	14	17	176	160	166	138
Da Nang Cape, Cham Island	4	6	140	132	122	98
Ly Son Island	2	4	166	156	159	137
Phu Khanh Province	18	41	211	176	185	159
Thu (Phu Quy) and Ca Thuik Islands	4	6	206	174	181	150
Con Dao Islands	5	10	204	173	180	147
Tho Chu Island	2	4	186	171	172	142
Nam Du Islands	4	8	147	121	131	101
An Thoi Archipelago	6	8	140	122	127	97

Note: I - Indonesia; P - Philippines; J - Japan).

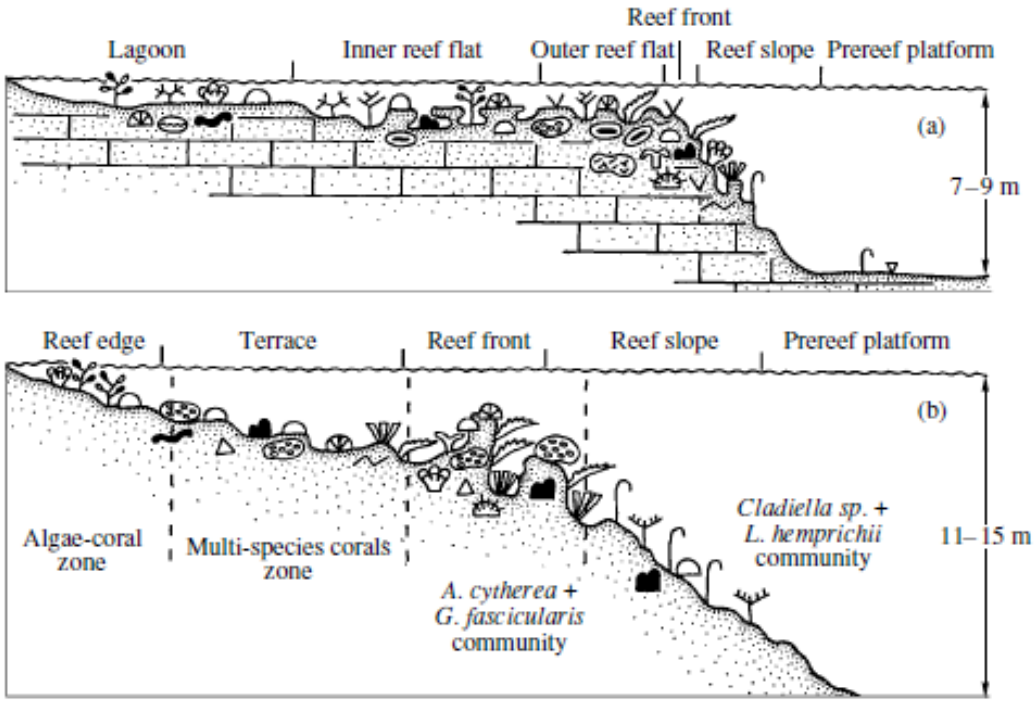
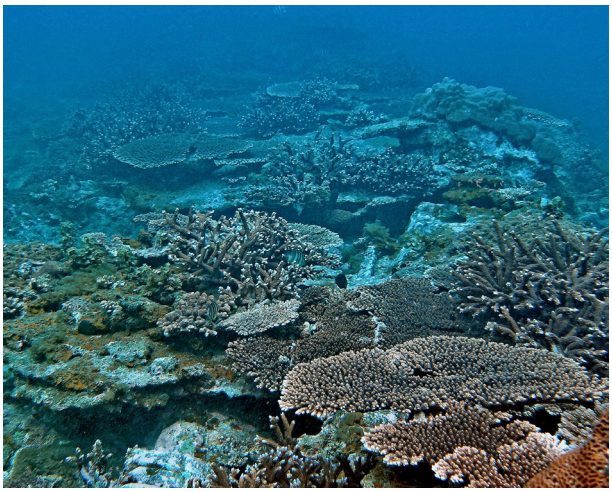
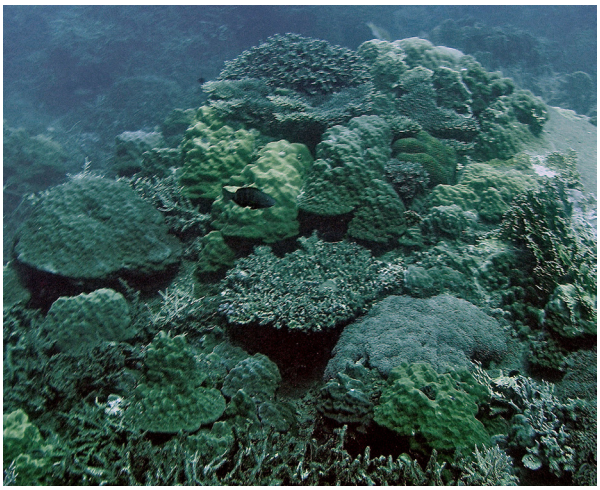


Figure 2. Schematized profiles of structural (a) and unstructured (b) reefs.



(A)



(B)

Figure 3. Two types of Vietnamese bordering reefs. Structural (A) and unstructured (B)

As well as the composition of the fauna of Tonkin Bay that is acknowledged to be of a tropical nature ([7], [24]), actually cast doubt on the validity of Hai Nahn Zoogeographical Province [25]. The problem of the demarcation of other provinces of Sino-Japanese sub region also needs improvement. The available information about the coral fauna of Tonkin Bay, South, and the Southeastern China agrees in general with the views of Briggs ([26], [27]) about the position of the northern boundary of the Indo-West-Pacific. This boundary situated on the Asian coast, most probably in the region of the Chinese province of Guangdong. However, it cannot be traced more adequately due to the lack of information about the corals of Eastern China. The data on coral fauna of the southern part of the Korean Peninsula show its similarity to the fauna of Sagami Bay (Honshu Island). The presence of boreal species and the almost complete absence of the representatives of common tropical genera of corals in the southern part of the Korean Peninsula [28] allow us to propose that the northern boundary of the tropical Indo-West-Pacific is located in Asia farther southward than it was traced earlier [23]. Thus, the information obtained allows us neither to separate Tonkin Bay as an individual biogeographical unit nor to draw any biogeographical boundaries in that part of the South China Sea. The composition of Vietnamese coral fauna, its diversity, and high similarity to the fauna of the Southwestern Pacific permit it to be considered as purely tropical fauna belonging to the Indonesian-Philippine center of the origin of Indo-West-Pacific tropical corals. The entire coast of Vietnam from the Bay of Thailand to Tonkin Bay represents a biogeographical unit, which incorporated into the Indo-Polynesian Province of the Indo-Pacific Region [29]. At the beginning of the twenty-first century studies deals with the history and investigations of the reefs and coral communities of the Gulfs of Thailand and Tonkin based on published and unpublished materials, including the author's. The state of the art in the study of reef-building scleractinian corals and reefs of this region is presented. In addition, species richness were installed Scleractinian for these regions (188-Gulf of Tonkin, 221-Gulf of Thailand). The silting and eutrophication of the gulf waters resulted in a change in the composition and structure of the coral reef communities via the reduction or elimination of certain coral species. Instead of Acroporidae, typical for the majority of other reefs, Poritidae and Faviidae dominate reef communities of the Gulfs of Tonkin and Thailand, which form the framework of the reefs. The reefs of the Gulfs of Thailand and Tonkin are somewhat similar to encrusting reefs of highly eutrophicated water shallows in that they do not display typical reef zonality and thick deposits of the reef origin. At the same time, most of their features resemble those of "normal" structural reefs of the South China Sea; characterized by a distinct lagoon, reef flat, and other typical zones. These peculiarities make the reefs these Gulfs unique. Overall, the species compositions of Scleractinian of the two gulfs are quite comparable, both qualitatively and quantitatively. The gulfs share 71.7% of their total numbers of scleractinian species. Characterized by remarkable distinctive features, the coral fauna and reefs of the Gulfs of Thailand and Tonkin exhibit high similarity in coral species composition to other regions of Vietnam and form a single complex of species of the equatorial Indo-Pacific ([31], [32]). In 2005, 2007 I was able to visit several reefs in the Spratly archipelago disputed territorial in joint Russian-Vietnamese expedition to the scientific vessel "Akademik Oparin". The first studies of coral reefs using SCUBA were held at Spratly in 1981, a joint Soviet-Vietnamese expedition on the island Sinton. The results of these studies were given in an unpublished report [33] and several publications in the Vietnamese language ([35], [35]). Were briefly describes the structure of the reef, are lists of scleractinian, including 108 species belonging to 40 genera.

At the end of the 90-ies of the last century on reefs in the archipelago were Vietnamese and Vietnam-Philippine expedition. Appreciation expressed for the characterization of different types of reefs, coral distribution characteristics are analyzed. Are lists of species of Cnidarians, consisting in total of 121 up to 201 of scleractinian, Alcyonarian,

Gorgonarian and hydroid coral ([37], [38]). The species diversity on Spratly reef, as on most reefs Indo-Pacific ([32], [36]), provides representatives of five genera: *Acropora* (42 species), *Montipora* (21), *Porites* (13), *Favia* (10), *Fungia* (8), representing 27.8% of the total hermatypic scleractinian identified in the archipelago. At the islands of archipelago formed four morphological types of reefs: typical for most reefs of Indo-Pacific; reef with short and long reef flat zones; the reefs with steep reef slope; as well as typical atolls sizes up to 34 km long and 5 km wide. In various zones of coral reef species richness varies from 102 to 179 species. The largest number of species observed on the reef slope and in the lagoons of atolls (214 and 190 species respectively). In these same zones usually have the highest degree of substrate cover corals and other related animals. In general, on reefs in the archipelago discovered 261 species of Scleractinia [39]. The overall picture of communities is largely similar, but their qualitative and quantitative composition is markedly different. The number of coral species ranges from 102 to 214. How closely the various communities kept within 24.8-37.5 only in communities of soft soil at the base of the slope of the reef it slightly lower - 11.2-24.6. Complexes of Scleractinian differs small difference degree of similarity, difference extremes – 34.5-41.3. The taxocene clams how closely do not fall below 32.0 in 50 per cent of communities. Reduce the level of similarity, with the largest community's macrophytes dispersion degree of similarity in species from 7.1 to 30.7. It should be noted that similarities between neighboring communities one reef higher than similar communities on isolated reefs [37] neighbor. Analysis of Shannon biodiversity index using encountering frequency of coral genera partly reflects biodiversity of coral fauna in study area. Although, length of transect was only 100 m, the number of encountered coral genera was from 17 to 24 genera and biodiversity index is from 0.856 to 1,041. The respective values for scleractinian corals alone are 0.807-0.934 and 0.877±0.044. On the reefs of Australia, Vietnam, Indonesia and the Philippines found 360-370 species scleractinian attributed to 70 genera ([33], [39]). On reefs Spratly archipelago revealed 261 species of coral, belonging to 66 genera that make up 76% of the total species scleractinian the entire coral fauna of the Pacific and Indian oceans. Comparison of scleractinian around the descent of wealth and Vietnam's Spratly reveals a high degree of its descent diversity (Table 2).

Table 2. Generic diversity of Scleractinia in various reefs of Vietnam

Areas	Number of genera		Value H'	
	Variation	Average	Variations	Average
Central Vietnam	9-17	13.0	0.79-0.91	0.67
Khan′ Hoa Province	15-27	18.5	0.90-1.20	1.08
Spratly Archipelago	15-22	17.6	0.81-1.11	0.99
Kon Dao Islands	10-22	15.5	0.67-1.20	0.91
Gulf of Thailand	6-20	12.5	0.60-1.19	0.92

In broad terms, the Spratly islands reefs are important ecologically, with abundant and relatively undeveloped resources, which have undergone depression coastal species still abound. Is currently in a complex dispute over the Spratly islands being involved Vietnam, China, Malaysia, Taiwan and the Philippines claim all the islands in China and Vietnam; of them want to annex the Philippines Malaysia. Brunei in 1984 established an exclusive fishing zone encompassing Louisa Reef in the southern part of the archipelago without public ownership in their islands. In the year 2000, China joined the ASEAN discussions to establish for the South China Sea "code of conduct" - is not a legally binding measure, to resolve the problems between the countries involved in the dispute on the Spratly islands. Dispersal of larvae of the Spratly islands reef ecosystems may contribute to the production of fish and other seafood coral reefs in nearby regions. Thus, coral reefs in the archipelago can be seen as a "savings bank" where the commercially important invertebrate and fish are preserved from overfishing, and this is a constant flow of maggots to areas depleted marine resources. Latypov and Mc Manus proposal on the conservation of genetic diversity of reef ecosystems and the region, it proposed to establish cross-border international maritime reserve zone (Park, Reserve) Spratly archipelago under possible protectorate of Vietnam, China and the Philippines ([40], [41]).

According to the studies performed in the first decades of the twenty first century, Vietnam's reef-building coral fauna comprises 376 species, pertaining to 80 genera (including 9 ahermatypic corals), of which 153 species, belonging to 28 genera, were not previously known for that region, and 16 species from 6 genera were described for the first time ([19], [25], [30], [31], [35], [41]). As in most Indo-Pacific reefs ([17], [21], [35]), the species diversity of Vietnam's reefs consists mainly of the members of five families, Acroporidae (98 species), Faviidae (42 species), Fungiidae (32 species), Poritidae (31 species), and Dendrophylliidae (26 species). The five genera most diverse and widespread in all reefs comprise *Acropora* (61 species), *Montipora* (28 species), *Porites* (21 species), *Fungia* (12 species) and *Favia* (14 species), are most various and numerous on all reefs, making 65.94% of all specific riches of scleractinian (Figure 4).

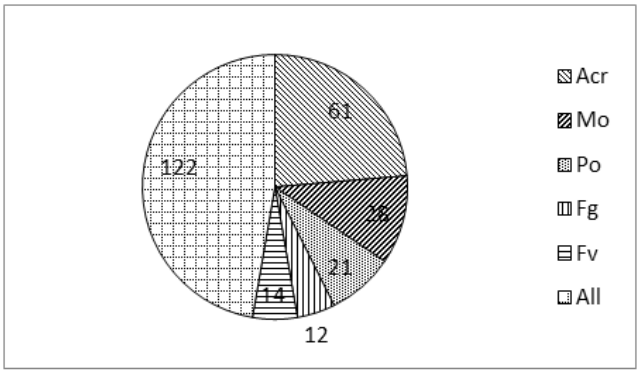


Figure 4. Relative species diversity of major coral species in Vietnam. Acr – *Acropora*, Mo – *Montipora*, Po – *Porites*, Fg – *Fungia*, Fv – *Favia*, All - the rest species.

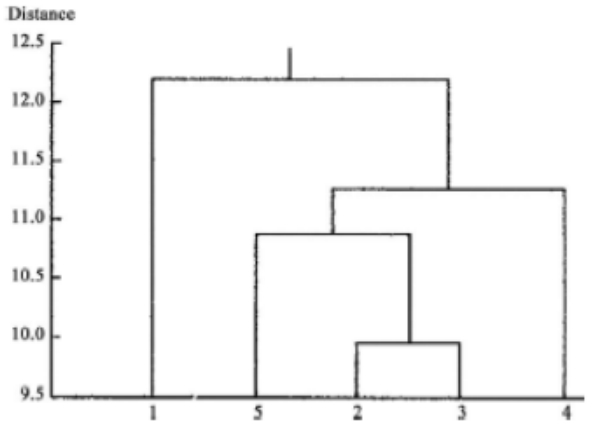


Figure 5. Similarity dendrogram of scleractinian faunas in different regions of Vietnam. 1: Gulf of Tonkin; 2: Central Vietnam; 3: South Vietnam; 4: Gulf of Siam; 5: Spratly Island.

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 scleractinian (66 species) occur throughout the Vietnam coast. As a whole, the species diversity of reef-building scleractinian 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. Similar (193 - 256) numbers of species were reported for reefs of Indonesia, the Philippines, and Western Australia ([32], [42]. 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. The peculiarity of the coral faunas of the Siam and Tonkin gulfs as revealed by cluster analysis (Figure 5) is consistent with their ecological peculiarities ([7], [11], [38], [43]). 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 ([11], [32], [43]), so here, only major similarities and differences will be mentioned.

4. Conclusions

In reefs of Indonesia and Philippines and in the Great Barrier Reef, a total of 360 - 410 reef-building scleractinian pertaining to 70 - 80 genera have been recorded [31]. 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 ([13], [31], [44], [45], [46]) with apices in the Philippines, the Malacca Peninsula, and New Guinea. To same fertile the center should expense and coast of Vietnam, scleractinian fauna which totals 376 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 scleractinian, as well as those of alcyonarian and gorgonian, 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 ([14], [19], [47], [48]). 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. 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.

Competing Interests

Authors declare that they have no competing interests.

Authors' Contributions

IBM DVO RAN performed field study and drafted manuscript, helped in preparation and finalized manuscript. Authors have equal role in preparation and finalizing the manuscript.

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