

# **Part 1.**

## **Reef-Building Corals of Vietnam as a Part of the Indo-Pacific Reef Ecosystem**



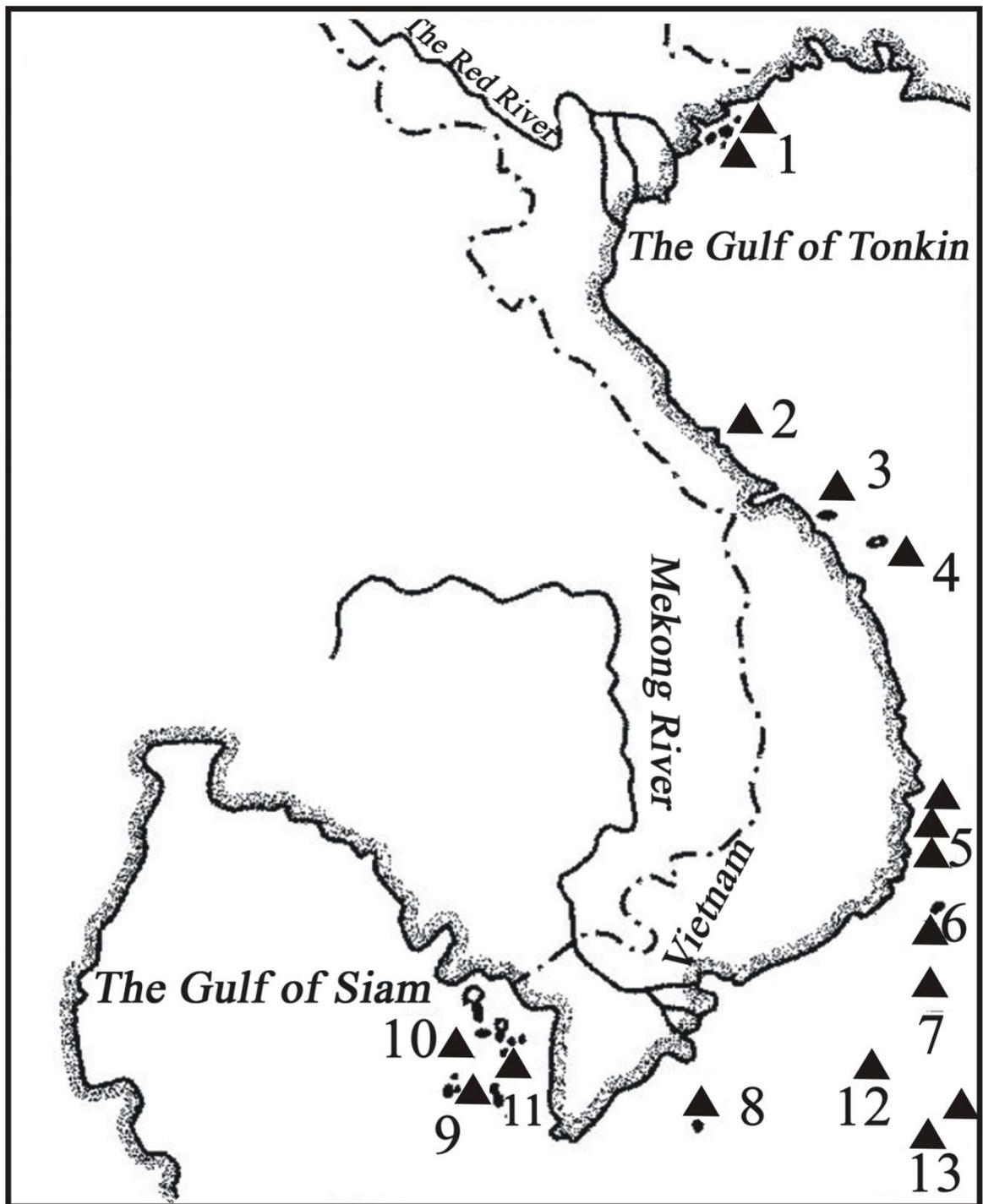
The coastline of Vietnam is over 3200 km long and covers 15 degrees in latitude, from the Gulf of Siam in the south (8°N) to the Chinese border in the north (23°N). The nearshore water area (up to 50-m deep) of Vietnam, including some 3000 islands, is about 206000 km<sup>2</sup>. Vietnam and its coastline are divided into 5 parts, the Gulf of Tonkin, Central and Southern Vietnam, Gulf of Siam, and the Spratly Islands (Thanh, 1999). 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 18–32 °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 (Sorokin, 1986; An, 1994).

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 reefs reaches 70–100 g/m<sup>2</sup> and increases tenfold during typhoons (Dautova et al. 1999; Vo and Hodgson, 1997). This results in a remarkable decrease in water transparency, affecting, together with other factors, the development of coral settlements in this region.

The reef-building corals and reefs of Vietnam attracted scientific attention as early as the first half of the twentieth century (Sérene, 1937; Dawydoff, 1952). Loi (1967) was the first who analyzed the zonation of reef-building corals in reefs of the Khanh Hoa province. He distinguished four scleractinian-dominated facies. These investigators determined the species composition of scleractinians and demonstrated its similarity to that of Australia and Indonesia. From the beginning in 1980, systematic studies of Vietnam corals and reefs have been performed in joint expeditions by the Institute of Marine Biology, 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. Some of the data obtained was presented only in unpublished reports. Some findings were published in difficult-to-obtain regional works, including Vietnamese ones.

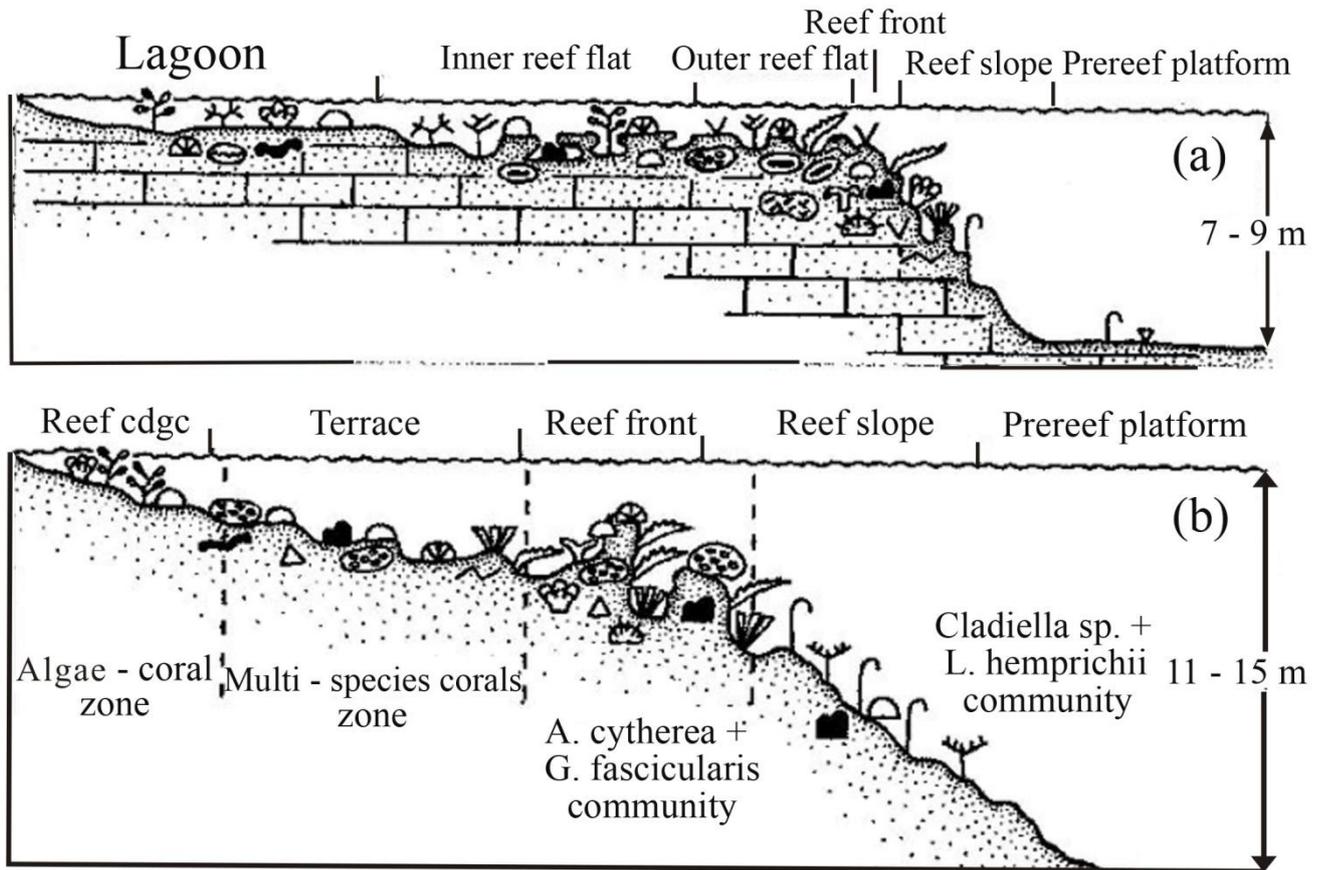
To date, in a region bordered by the Gulf of Tonkin in the north, the Gulf of Siam in the south, and the Spratly Islands in the South China Sea, all reef-building areas including large islands and shoals

have been studied (Fig. 1).



**Fig. 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 Thui 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.

It is thus topical to review the data available on the coral composition and distribution and development of the Vietnamese 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 tourist industry development and marine aquaculture intensification (Cheung, 1994), has resulted in increased anthropogenic pressure on this unique ecosystem. Generalizing data on the composition, structure, and environmental conditions of the Vietnamese reef communities will allow any one to evaluate the degree of their degradation and the outlook for their conservation and recovery.



*Fig. 2. Schematized profiles of structural (a) and structureless (b) reefs. See the text for comments.*

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 (Latypov, 1990; Ken, 1991; Yet, 1997). Vo and Hodgson (1997) reported the Vietnamese reefs to include both true reef frameworks and coral gardens. Various calcareous structures occurring on reefs may be formed by coral settlements, usually called coral layers, communities, or specialized settlements. Such structures are typical for early reef development stages and do not have any geomorphological and vertical biological

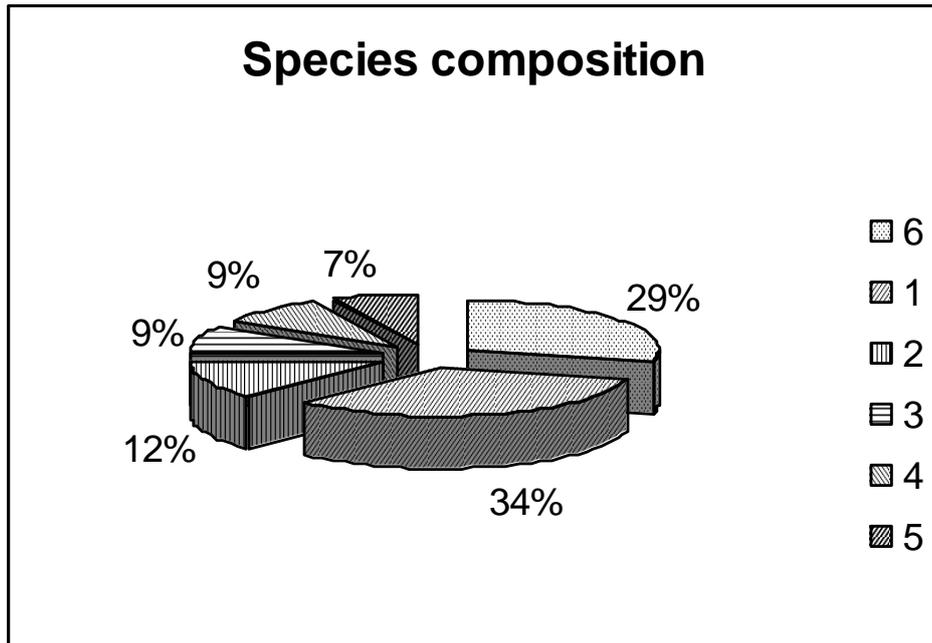
zonation (Habbard, 1974; Pichon, 1974; Loya, 1976a; Latypov, 1995, 1997). All Vietnamese reefs display distinct biological and more or less prominent morphostructural zonation. By the specificity of geomorphological and climate conditions, Vietnamese fringing reefs are clearly distinguished into two types (Fig. 2, C25-3, 4).

Reefs of the first type have a distinct zonation (reef lagoon, reef-flat, etc.) with a developed carbonate framework, so-called structural reefs (Wainwrite, 1965) common for the tropical zone of the World Ocean. Reefs of the second type display a weak morphostructural zonation, with some zones sometimes 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 (Wainwrite, 1965) or encrusting (Latypov, 1995) reefs. The Vietnamese structural reefs are mainly formed in closed bights and on the organogenic base of Holocene reefs (Latypov, 1982; Preobrazhenskii, 1986), while structureless reefs are formed off promontories and in open bights, mostly on stone and rocky substrates (Latypov, 1986, 1987; 1995, Yet and Ken, 1996; Yet, 1997).

Reefs of Vietnam pertain to the epicontinental monsoon type (Dawydoff, 1952; Latypov, 1982; Sorokin, 1990). 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 coast of Vietnam is struck by 5–10 typhoons per year (Vo and Hodgson, 1997). Reefs of Vietnam demonstrate 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 up to a depth of over 20 m. Sometimes they lack distinct morphological zonation. Most of the Vietnamese 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.

According to the studies performed in the last decades of the twentieth century, Vietnam's reef-building coral fauna comprises 382 species, belonging to 80 genera (including 9 ahermatypic corals), of which 131 species, belonging to 26 genera, were not previously known for that region, and 12 species from 6 genera were described for the first time (Latypov, 1987, 1990, 1995, 2003a,b; Ken, 1991a; Vo, Yet, 1997; WWF Vietnam., 1994). As in most Indo-Pacific reefs (Latypov, 1987, 1997; Best et al. 1989; Veron and Hodgson, 1989; Veron, 1995; Vo and Hodgson, 1997), the species diversity of the

Vietnamese reefs consists mainly of the members of 5 families, Acroporidae (118 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 (Fig. 3).



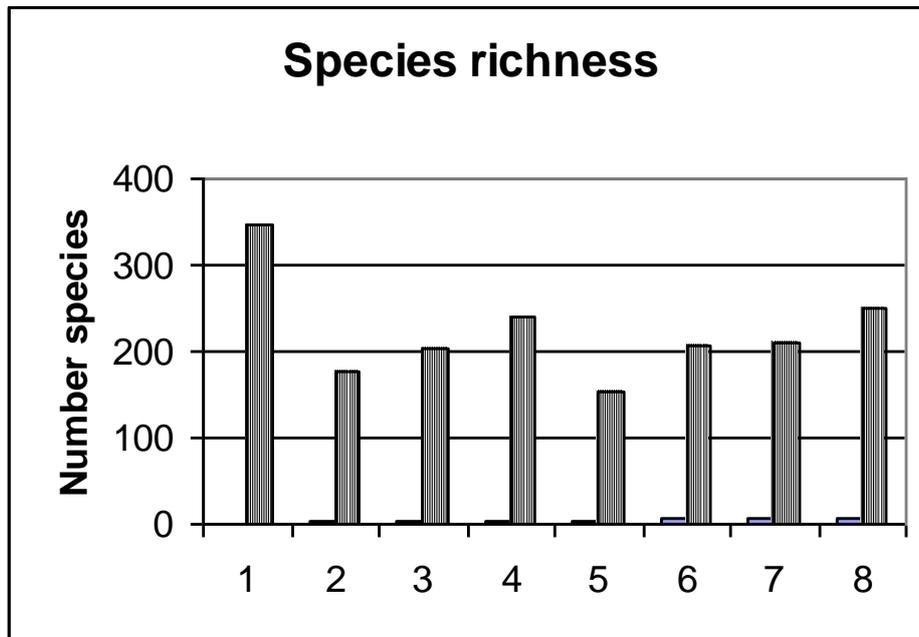
**Fig. 3.** Relative species diversity of major coral genera in Vietnam. 1-Acroporidae, 2-Faviidae, Fungiidae, 4-Poritidae, 5-Dendrophylliidae, 6-the rest genera.

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. In all, some 20 scleractinian species form monospecific 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 species occur throughout the coast of Vietnam.

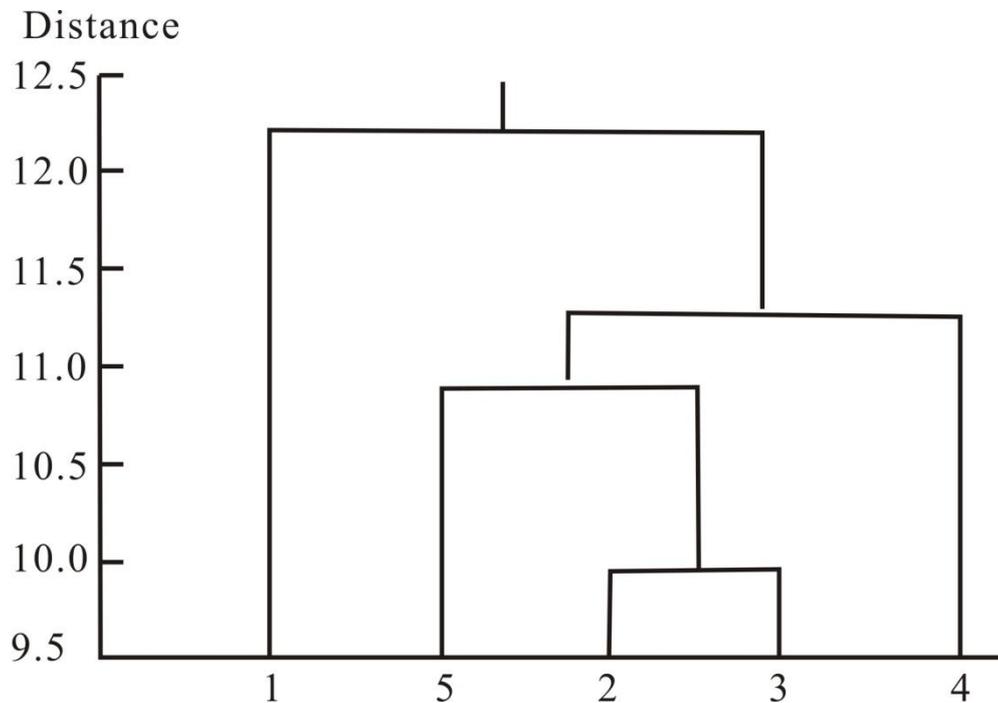
As a whole, the species diversity of reef-building scleractinians in different areas of the coast of Vietnam is quite comparable, ranging from 190 species in the Gulf of Tonkin to 265 in the South Vietnam (Fig. 4). Similar (193–256) numbers of species were reported for reefs of Indonesia, Philippines, and Western Australia (Veron, Marsh, 1988; Veron, 1995). Central and South Vietnam reefs are most similar in species composition and are quite comparable to Spratly reefs.

The peculiarity of the coral faunas of the Siam and Tonkin gulfs as shows by cluster analysis (Fig. 5) is consistent with their ecological peculiarities (Dawydoff, 1952; Latypov, 1986, 1999, 2000). 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.



**Fig. 4.** Scleractinian species diversity in different regions of Vietnam. 1 - total number of species (350), 2 - Gulf of Tonkin (177), 3 - Central Vietnam (204), 4 - South Vietnam (240), 5 - Thu Island, 6-Con Dao Islands, 7-Spratly Island (211), 8- Gulf of Siam (251).



**Fig. 5.** 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.

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 (Latypov, 1986, 1990, 2000; Sakai et al. 1986; Ken, 1991a), so here, only major similarities and differences will be mentioned.

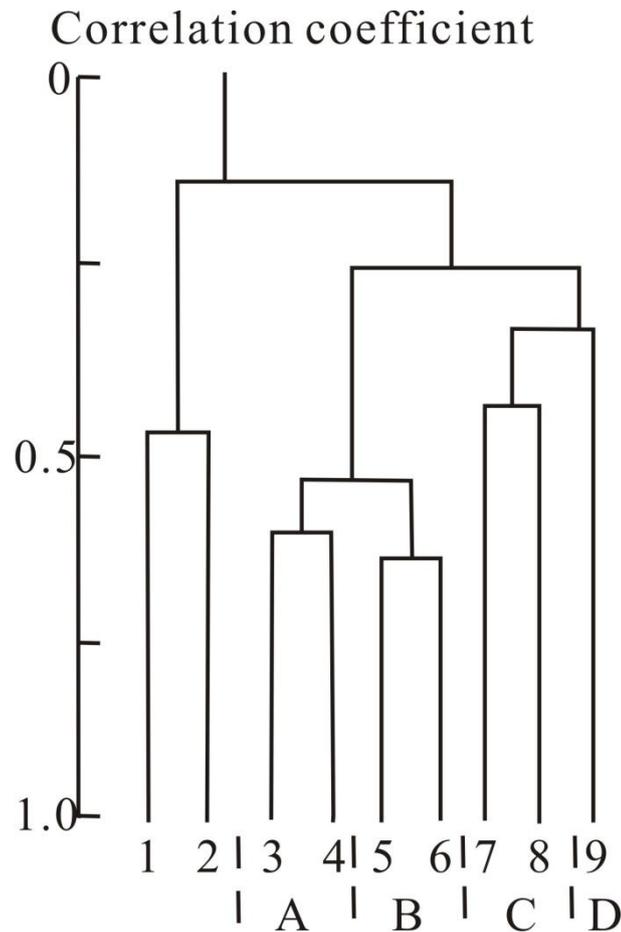
The reef communities in both gulfs lack species of *Palauastrea* and *Caulastrea* and *Acropora cuneata*, the latter occurring in most reefs of Vietnam. *Plerogyra* and *Physogyra* are absent in the protected part of the Gulf of Tonkin, and *Pachyseris*, *Mycedium*, and *Pectinia*, in the innermost and coastal areas of the Gulf of Siam. However, some species 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 selfcleaning - *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 for both gulfs. At the same time, species 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 common species.

The distribution and peculiarities of benthic communities in the coastal part of Vietnam reefs is rather constant (See Fig. 2). As a rule, these are algal–coral communities, composed of several biocenoses (zones, facies), dominated by individual algal or coral species or by groups of species. 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 an indicative of an increase in water eutrophication or later stages of reef development (Mergner, 1979; Dollar, 1982; Dai, 1993, Latypov, 1999).

Both along the coast of Vietnam 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 (Liddel and

Ohlhorst, 1987; Latypov, 1988; Dai, 1993).

A wider distribution of encrusting and plate colonies of *Euphyllia*, *Echinophyllia*, *Mycedium*, *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 (Loya, 1976b; Porter, 1976; Tomascik and Sander, 1987). In the Vietnamese reefs, such corals are common for communities of the slope base, bioherm zone, and forereef platform.



**Fig. 6.** 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.

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 from settlement-site and ending with interspecific trophic relationships. The relationships between the species composition of benthic communities of some reefs as shows by cluster analysis correlated with the ecological and

physiographical zonation of the reefs (Fig. 6).

Algal–coral lagoon and reef flat communities dominated by red and brown algae and similar in coral and common macrobenthos species composition form 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 form a distinct cluster.

To summarize the above, both structural and unstructured reefs demonstrate vertical biological and geomorphological zonations. 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 reefs of Vietnam and various Pacific and Caribbean reefs (Dollar, 1982; Latypov, 1986; Sakai et al. 1986; Dai, 1993).

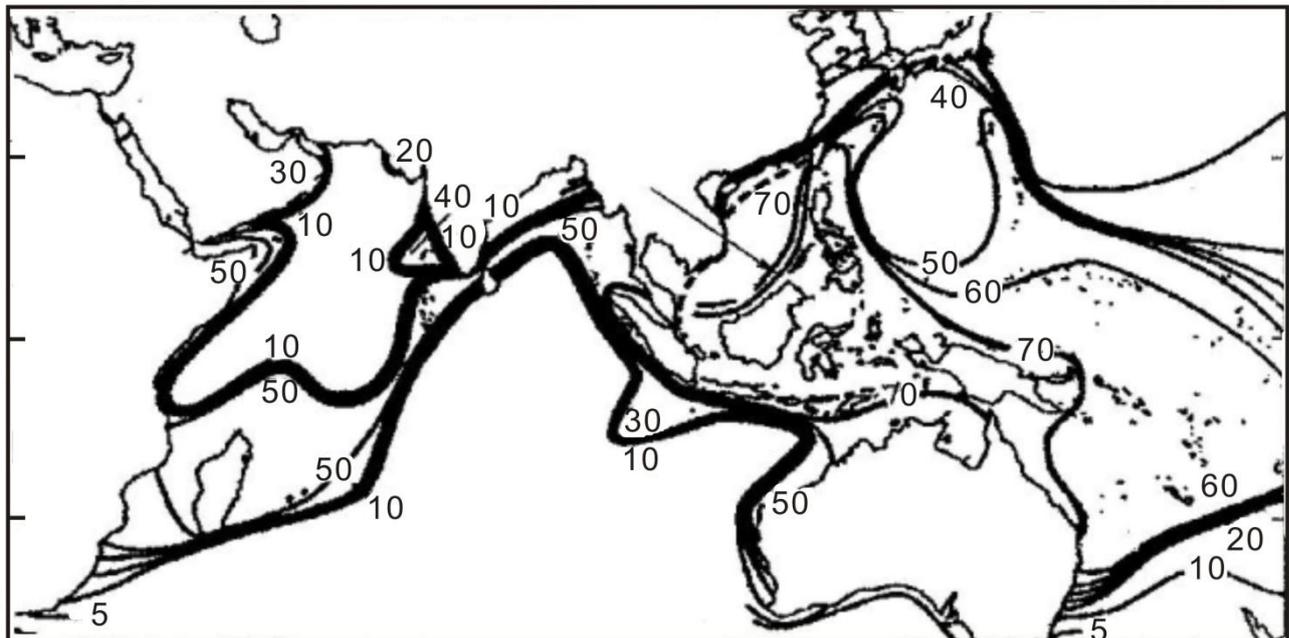
Shallow-water Vietnamese reefs growing in highly eutrophic conditions lack thick reef deposits (Latypov, 1986, 1995) and demonstrate high coral diversity and distinct biological zonation, that is, the presence of inner heterotrophic (lagoon, reef flat) and outer autotrophic (reef slope) zones (Preobrazhenskii, 1982; Sorokin, 1990; Latypov, 1994), 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 scleractinian species belonging to 70 genera have been recorded (Veron, 1995). 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 (Ekman, 1953; Stehli, Wells, 1971; Veron, 1995) with apices in the Philippines, the Malacca Peninsula, and New Guinea (Fig. 7).

Reefs of Vietnam also 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 coral fauna of Vietnam 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 corals of Vietnam 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 reefs of Vietnam is one of the greatest in the Indo-Pacific (Malyutin and Latypov, 1991; Latypov, 1995).

The species composition and high diversity of the Vietnamese coral fauna, as well as its close similarity to the Southwest Pacific coral fauna, allow 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 united whole and is part of the Indo- Polynesian Province of the Indo-Pacific Area.



*Fig. 7. Schematized map of the generic diversity of 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.*