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Ecological Status of Coral Communities in the Island Area of the Nha Trang Bay (Vietnam)

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Abstract—The ecological status of coral communities in the island area of the Nha Trang Bay (Central Vietnam) has been evaluated in March to May 2013. The material has been sampled at five stations from depths of 3–6 m using the photoquadrat method. It has been shown that characteristics of these communities markedly change with distance from the Nha Trang City and the sources of eutrophication and sediment influx: the total coral cover and the proportion of acroporids increase from 5.3% to 82.6% and from 0 to 61% respectively, while the abundance of macroalgae decreases from 41.5% to 0; the species richness of corals also increases significantly, from 7 to 68 species per station. Possible causes of the long-term changes in the coral reef ecosystems of the Nha Trang Bay are discussed.

Keywords: coral reefs, status, Nha Trang Bay, Vietnam
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Economic and population growth in Vietnam during the past decades has been outrunning the development of infrastructure for waste treatment and ecological conservation activities, leading to significant intensification of anthropogenic impact on the marine coastal ecosystems. This includes the increase in polluted runoff from land to coastal water areas and, hence, in sediment deposition rate; eutrophication, which results from the development of floating aquaculture; and uncontrolled harvesting of valuable fish and invertebrate species (Pavlov et al., 2004; Latypov, 2006; Vo and Hodgson, 1997; Vo et al., 2002).

The coral fauna of Nha Trang Bay on the coast of Central Vietnam (the South China Sea, 12° N), which comprises 250 scleractinian species according to recent data (Latypov, 2011), is part of the Indonesian–Philippines center of origin of tropical Indo-Pacific corals, i.e. in the Coral Triangle (Latypov, 2005, 2007, 2011), which is characterized by the maximum species diversity. At the same time, the ecosystems of the Nha Trang Bay, especially the coral reefs, suffer from complex anthropogenic impact resulting from bottom dredging in the Be River estuary and Nha Trang harbor, with dredged materials being dumped in neighboring water areas; establishment of resorts and tourist centers on the coastline; increase in the amount of terrigenous runoff resulting from land development and mangrove forest cutting in the estuaries of the Kai and Be Rivers; input of toxic sediments with mutagenic effect from the Kai River; significant increase in the number of floating aquaculture farms, which contribute to eutrophication of the bay; destructive fishing with the use of dynamite and cyanides and uncontrolled harvesting of commercial invertebrates (Vo et al., 2002, 2008; Pavlov et al., 2004; Nguyen et al., 2013).

The coral communities in the bay have significantly deteriorated, compared to the results of the first hydrobiological surveys in the early 1980s, especially on the reefs in the vicinity of the Kai and Be river estuaries (Latypov, 2006; Vo et al., 2008). By the beginning of the 21st century, the average coral cover in the bay was less than 30% (Pavlov et al., 2004). Such a trend to coral reef degradation under anthropogenic impact is unfortunately observed in almost all countries of Southeast Asia (Wilkinson, 2008). This determines the necessity in complex assessment of the ecological status of coral communities in the Nha Trang Bay for understanding the types of their adaptation and recovery rates under the changing environmental conditions. In the spring of 2013, the distribution and taxonomic composition of corals on the reefs within the bay area were estimated at different distances from the Nha Trang City and the estuaries of the Kai and Be Rivers.

MATERIAL AND METHODS

The material was sampled using scuba gear in the Nha Trang Bay at five stations on the coral reefs near Mieu, Mot, Mun, and Tre islands at different distances from the continental coast, Kai and Be river estuaries, and the Nha Trang port area (Fig. 1). The coral reefs at the studied stations are classified as unstruc-

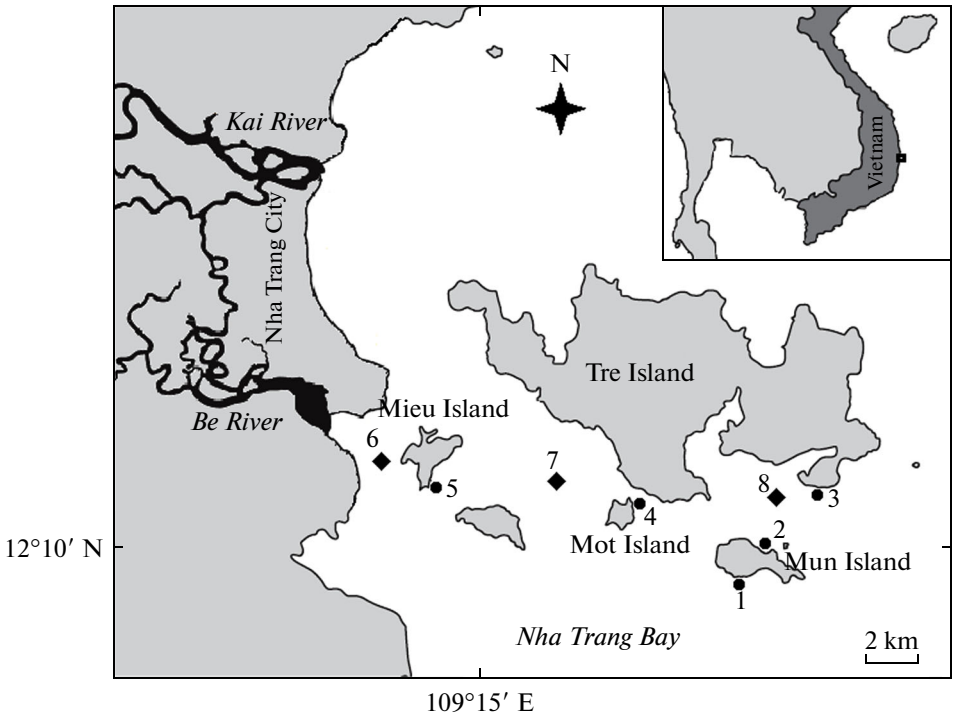

Fig. 1. Schematic map of the study region and locations of stations. Water samples were taken from the upper 10-m layer in 2009 by researchers from the National Institute of Oceanography (Nha Trang) to determine the hydrochemical parameters.

tured (Latypov, 2007), with depths down to 7–9 m, except for Station 2 near Mot Island, where a distinct buttress system has formed (reef banks alternate with sandy depressions and are oriented in the direction of reversing tidal current). The horizon with depths of 2–6 m with the highest coverage and species diversity of corals was surveyed at each station. The coral coverage was estimated along four transects, each 25 m long, established parallel to the isobaths at a distance of 10 m from each other. To study the coverage of major benthic components, the photoquadrat method was used (30 photoquadrats per transect, 0.25 m^2 each). Quantitative analysis of coverage was performed with the CPCe program (Kohler and Gill, 2006), with the percent coverage of objects within the photoquadrat being calculated by 25 randomly scattered points (750 points per transect).

The total coral coverage, contributions of dominant coral taxa, abundance of macroalgae, nonliving substrate area (open reef surface, sand, coral fragments), and species richness of corals were compared between the stations. One-way ANOVA followed by Tukey's test was used to verify differences in coral coverage and species richness between the stations. Before comparative tests, the data on percent coverage and species richness were subjected to square-root and log-normal transformation, respectively. Water samples taken at each station in three replications during April were analyzed for nitrites, nitrates, and phosphates at the National Institute of Oceanography, Nha Trang. Specialists of the Department of Marine Ecology and Environment, National Institute of Oceanography, kindly provided us with data on the contents of organic compounds and chlorophyll *a* collected in 2009 in the areas where the sampling stations were located.

RESULTS

Coral communities. Figure 2 shows data on the coverage of main benthic components. The total coral coverage varied significantly between the stations (ANOVA, $F = 34.6$, $P < 0.001$). Its values were relatively high (55–82.6%) at four out of five stations but proved to be extremely low (5.3%) at Station 5 near Mieu Island, the closest to the Nha Trang City and the estuary of the Be River. Similar values were characteristic of Stations 1 and 2 near Mun Island (Tukey's test, $P = 0.063$) (Fig. 2). The highest abundance of macroalgae was recorded at coastal stations, reaching a peak of 41.5% at Station 5. The proportion of dead corals, mainly acroporids, was especially high in the southern part of Mun Island (St. 1). This was probably explained by the fact that the relative population density of the corallivorous mollusk *Drupella cornus* was higher at this station, with its abundance on some *Acropora* colonies reaching 14–25 ind. The proportion of nonliving substrate, which largely consisted of coral rubble, was higher on the Mun and Mieu Islands. If the average ratio between proportions of rubble and living stony corals for the northern and southern parts

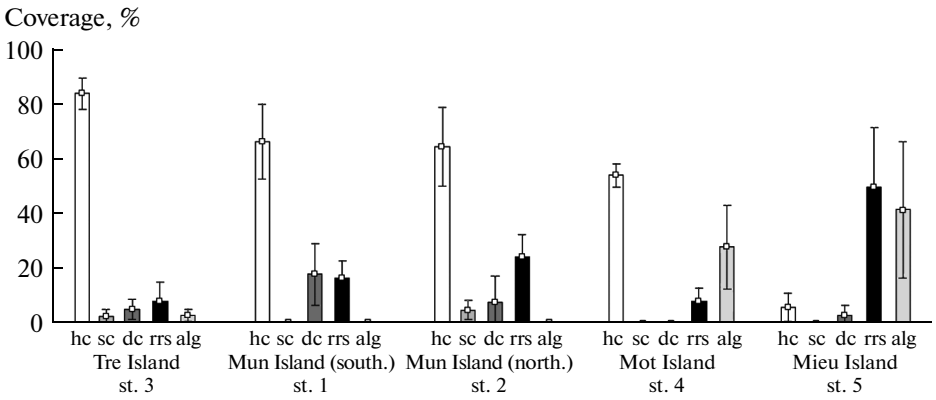

Fig. 2. Coverage of major benthic categories and substrate at the stations (% ± SD): hc, hard corals; sc, soft corals; dc, dead hard corals covered with algae; rrs, open hard surface, coral fragments, sand; alg, macroalgae.

of Mun Island was 0.16, the same ratio on the reef of Mieu Island (St. 5) increased to 5 (26.5% of coral fragments to 5.3% of living coral cover), which testifies to degradation and destruction of this reef.

The coral community at Station 1 (the southern part of Mun Island) consisted mainly of scleractinian corals from the genera *Acropora*, *Porites*, and *Pocillopora*, as well as of *Millepora* hydrocorals (Fig. 3a). At the northern Station 2 near Mun Island, the greatest contribution to the coral composition, along with acroporids, was made by poritids (Fig. 3b). Among them, the branching coral *Porites cyllindrica* formed monospecific stands in the vast area of the reef, accounting for 40% of all poritids in the community. Station 3 in the southeastern part of Tre Island was characterized by the highest coral coverage and proportion of acroporids in the community (Figs. 2, 3c). The dominant species of *Acropora* at all the three stations (1–3) were *Acropora formosa*, *A. nobilis, A. robusta, A. abrotanoides, A. cytherea, A. hyacinthus, A. elseyi*, and *A. secale*. At Stations 2–3, the proportion of nondominant corals in the total coral cover was higher than at other stations (see Fig. 3).

Station 4 near Mot Island differed from other stations in the geomorphological structure of the reef (spur and groove system) and distinct division of the coral community into separate monospecific settlements consisting of one or two species covering the entire area of some bioherms. With respect to contribution to the total coral coverage, the first four positions at the station were held by the settlements of foliaceous *Montipora aequituberculata*, *Echinopora lamellosa*, *Merulina ampliata*, as well as branching *Porites cyllindrica* and *Hydnophora rigida* (Fig. 3d).

At station 5 near Mieu Island, the coral coverage and species richness were the lowest (Figs. 3e, 4). *Porites cyllindrica* was the only relatively abundant scleractinian that formed small-sized aggregations on this reef. Its coverage was 5.3%. The coral reef near Mieu Island was in the state of collapse, being overgrown by macroalgae *Halimeda, Padina, Sargassum* and turf algae *Chnoospora implexa* and *Canistrocarpus cervicornis* (Phaeophyceae). The total coverage of these algae exceeded 40% (Fig. 2). It was dominated *Chnoospora implexa*, which suppressed aggregations of poritids remaining on some elevations, overlaying the living colonies and blocking the access of light to the coral polyps. In addition, single small colonies of *Astreopora myriophthalma, Psammocora obtusangula, Hydnophora rigida, Hydnophora microconus, Pocillopora damicornis*, and *Favia favuus* were found at this station.

On the whole, 110 species of reef-building corals out of 37 genera (including 2 species of *Millepora* hydroids) were recorded at the stations. Species richness varied significantly between the stations (ANOVA, $F = 26.7$, $P < 0.001$), reaching a peak of 68 species at Station 3 (the most distant from the Nha Trang City) and decreasing to the minimum at Station 5 (the closest to the city) (Fig. 4). The species richness of stony corals at Station 2 near Mun Island was similar to that at Station 3 (Tukey's test, $P = 0.057$). Therefore, the ecological status of the coral community is the highest in the open southeastern part of Tre Island (Station 3) and the lowest near Mieu Island, close to the Nha Trang City.

The content of organic substances at the stations. The results of chemical water analysis, obtained earlier and in the course of this study, showed that the concentration of chlorophyll *a*, phosphates, and nitrites at Station 5 (Mieu Island) and other stations (more distant from sources of nutrient enrichment) may differ by a factor of 10 or even more (table). According to the Google Earth imagery of 2013 (www.google.com/earth/index.html), 22 floating aquaculture farms are found in a bay on Mieu Island near Station 5, which inevitably affects water quality. Each floating raft carries at least two people and consists of 40–50 mesh cages of 2–4 m^2 in size each where fish, shrimps, or mollusks are reared, and all waste from the raft is dumped directly into the sea. According to questioning of aquaculture farmers, each cage contains about 200–500 kg of fish or shell-

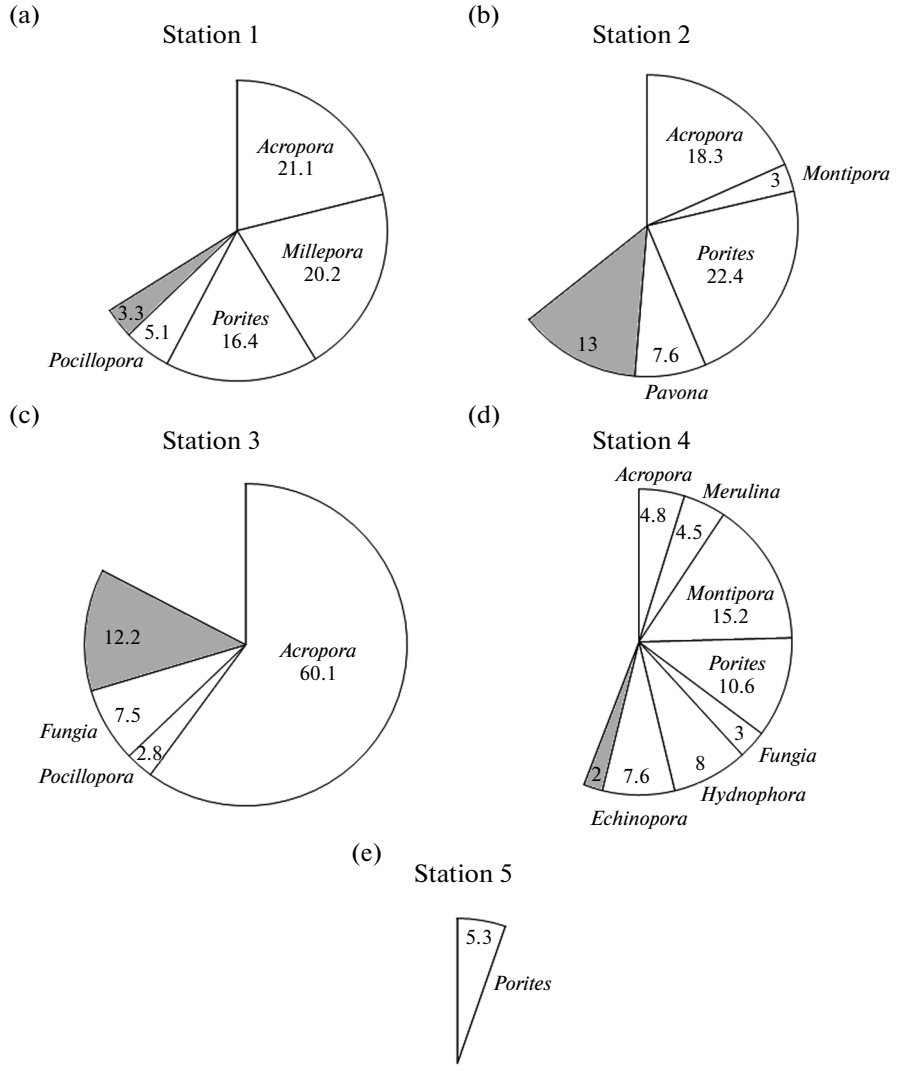

Fig. 3. Proportion (%) of dominant coral genera in the benthic cover at the stations. Shaded sector refers to other recorded genera of hard corals with coverage varying from 0.1 to 1.1%.

fish fed once every 2–3 weeks. The proportion of forage per each cage comes to approx. 7% of the total weight of cultured organisms in a cage. The food is supplemented with polyvitamins and antibiotics such as cefoxitin and erythromycin.

DISCUSSION

Specific features of the current system and prevailing winds, the presence of islands shielding the coastal area, and the influence of nearby upwelling and fresh water discharge from two rivers make Nha Trang Bay a unique area for the entire coast of the Indochina Peninsula (Pavlov et al., 2006). The coral reefs at Stations 1 and 3 are characterized by the highest wind and wave load as they are open to winds blowing from the southwest with the speed of 6–10 m/s. These winds have the largest contribution to the mean annual wind rose in the bay (Long and Chung, 2006). Sedimentation and accumulation of lighter fine-dispersed fractions of the terrigenous sediment are lower on these coral reefs than at other stations. Due to the constant inflow of clean water from the open sea, water transparency on these reefs exceeds 20 m, compared to 5–7 m at other stations, where it becomes higher only on calm days at high tide and during the dry season.

The spatial distribution of corals along the stations clearly illustrates the sedimentation regime in the bay: the wave-washed reefs are dominated by *Acropora*, branching *Millepora*, and eurybiontic massive *Porites*. In the channels between the northern part of Mun Island, Mot Island and Tre Island acroporids are replaced by the corals that are more resistant to increased sedimentation, such as some *Montipora* species, as well as *Hydnophora*, *Echinophora*, *Pavona*, massive and branching *Porites* (Rogers, 1990; Veron, 2000). At Sta-

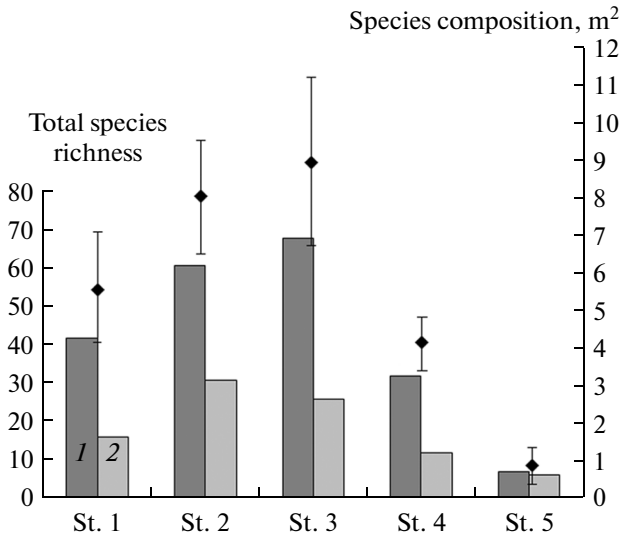

Fig. 4. Species richness at the stations: (*1*) number of species, (*2*) number of genera. Vertical lines in the dot diagram show standard deviation.

tion 5 near Mieu Island, which is the closest to the continental coast and Nha Trang City, only branching poritids that are most resistant to silting can be found. Over the past 20 years, the sedimentation regime in the Nha Trang Bay has changed significantly due to the coastline development, cutting of the mangrove forests along the Be and Kai river estuaries, and general increase in the pollution level. Thus, the amount of sediment at Station 5 near Mieu Island increased from 32 to 48 g/m^2/day between 2003 and 2005 (Latypov, 2006).

Coral communities are strongly affected by the river inflow that brings suspended matter containing photoinhibitory dioxin herbicides used as defoliants during the Vietnam War (Pavlov et al., 2004). The resulting toxic sediment is stirred up during storms, reducing the amount of physiologically active radiation and the rate of photosynthesis in coral endosymbionts. According to Pham Van Tom (1998), the level of pollution with organic phosphorus at the end of 20th century reached 43.0 μg/L, and with organic nitrogen, 577 μ/L. Another important factor is pollution with petroleum hydrocarbons over almost the entire water area of the bay. Although their average concentration is 1.1–1.2 mg/L, its peak values may be as high as 637 mg/L (Pavlov et al., 2006).

According to Latypov (2006), the coral reef at Station 5 near Mieu Island was characterized in 1981 by a well-developed limestone framework and reef zones, with coral cover up to 70% in the upper part of the reef slope and *Acropora*, *Montipora*, *Millepora* and branching *Porites* as the dominant taxa. In 2005, the coral cover in the upper part of the slope decreased by more than 20%, *Acropora* and *Millepora* disappeared and were replaced by the monospecific settlements of branching *Montipora* and *Porites*. By 2013, this reef came to collapse stage, with a phase shift from the coral-dominated to algae-dominated community with several small-sized aggregations of branching *Porites*. At the same time, the species composition of dominant corals at Station 1 near Mun Island did not change sig-

Concentrations of organic substances in water areas under study

Study area*	Substance, mg/L				
	NO_2^-	NO_3^-	PO_4^{3-}	Chl*a*	POC**
April 2013					
Mieu Island (Station 5)	1.26	33.6	8.8		
Mot Island (Station 4)	0.33	33.6	7.9		
Mun Island (Station 1)	0.7	33	9		
Tre Island (Station 3)	0.9	31.6	8.1		
June 2009					
St. 6	0	28	10.4	2.77	265.4
St. 7	0	27	5.3	1.93	242.6
St. 8	0	29	4.1	0.8	181.8
October 2009					
St. 6	14	37	34.1	10.9	856.2
St. 7	0	36	10.4	1.37	269.6
St. 8	0	35	10	0.65	168.9

* Locations of stations are shown in Fig. 1.

** POC is suspended particulate organic carbon (C_{org}).

nificantly over for 24 years, and no significant changes occurred in the total coral coverage and sedimentation rates. The first marine protected area (MPA) in Vietnam was founded in 2002 around the Moon Island, the abundance and species diversity of benthos and fish were estimated in MPA and adjacent area in the same year (Tuan et al., 2002). By 2013, the coral coverage at Mun Island has shown a tendency to increase, especially in the northern part of the island (St. 2), while the coral coverage near Mieu Island remains very low and almost unchanged: 5.1% in 2013 vs. 8.7% in 2002.

Along with the increase in the amount of suspended matter near the islands located most closely to the Nha Trang City, eutrophication has a strong impact on coral communities (in particular, near Mieu Island). This process develops as a result of pollution with terrigenous run-off and activities of floating aquaculture farms. The latter greatly contribute to water enrichment with substances stimulating algal and inhibiting coral growth. Further increase in the concentration of dissolved inorganic nutrients impairs gametogenesis, fertilization, development and settling of planulae, planula density, and increases mortality of coral recruits (Fabricius, 2005). At the same time, as the content of nitrogen and phosphorus compounds rises, the feeding of corals increases due to the increment in the concentration of symbiotic zooxanthella algae. However, on the other hand, these changes in the chemical composition of water significantly enhance the growth and abundance of macrophytes, which in some cases inhibit the development of corals and prevent settling of coral larvae under conditions of long-term eutrophication and low abundance of herbivores (McCook et al., 2001; Fabricius, 2005).

At Station 5 near Mieu Island, the coral communities suffer most strongly from the combined impact of the following stress factors:

(1) increased sedimentation, which affects settling and survival of coral planulae, especially when the sediment is bound at the bottom with algal turf; in addition, the sediment is toxic for corals due to the increased content of dioxin in it;

(2) increased content of dissolved nitrogen-phosphorus compounds inhibiting the reproductive cycle of corals and simultaneously promoting rapid development of algae;

(3) significant decrease of natural control over the growth of algae as a result of overfishing in the Nha Trang Bay and the removal of the functional group of herbivorous fish from the ecosystem.

The coral cover remains sufficiently high at other stations, which are more distant from the impact of suspended matter brought by the Be and Kai Rivers and of nearby floating aquaculture farms. However, the increased anthropogenic load in the bay reduces the ability of corals to recover after global natural disturbances such as typhoons or abnormal seasonal increase in water temperature, which caused mass coral bleaching and mortality, therefore the probability of phase shift towards alternative benthic communities becomes more probable.

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