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The Status of Coral Reefs and Its Importance for Coastal Protection: A Case Study of Northeastern Hainan Island, South China Sea

Meixia Zhao [1,2,3], Haiyang Zhang [1,2], Yu Zhong [1,2,4], Dapeng Jiang [5], Guohui Liu [1,2], Hongqiang Yan [1,2], Hongyu Zhang [1,2], Pu Guo [1,2], Cuitian Li [1,2,*], Hongqiang Yang [1,2], Tegu Chen [1,2] and Rui Wang [3]

1. Key Laboratory of Ocean and Marginal Sea Geology, South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, China
2. Innovation Academy of South China Sea Ecology and Environmental Engineering, Chinese Academy of Sciences, Guangzhou 510301, China
3. Guangxi Laboratory on the Study of Coral Reefs in the South China Sea, Guangxi University, Nanning 530004, China
4. Daya Bay Marine Biology Research Station, Chinese Academy of Sciences, Shenzhen 518121, China
5. Institute of Shenzhen Branch, CNOOC Ltd., Shenzhen 518054, China

* Correspondence: licuitian@scsio.ac.cn

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Abstract: This study evaluated the status of coral communities at the fringing reefs in the northern South China Sea, and their potential role in maintaining nearby coastline stability of northeastern Hainan Island (Puqian Bay, Hainan Bay). Thirty-nine coral species were recorded with mean coral cover of 5.3%, and are dominated by massive *Galaxea*, *Platygyra* and *Porites.* The coral communities were clustered into two groups (Clu-HNB and Clu-PQB) corresponding to different stable coastal conditions. Coral communities at the Hainan Bay with higher diversity and greater cover corresponded to relatively stable coastline, whereas those at the southern Puqian Bay (with the lowest coral diversity and spatial coverage) corresponded to severe coastline erosion. This work provides some direct evidence that declined coral reefs would weaken their functions to maintain a stable coastline, resulting in severe coastal erosion. It is also useful to help coastal managers and local people pay more attention to the importance of coral reefs in coastal protection and encourage them to change their ways to get sustainable use of coral reef resources. It may be beneficial to inspire or initiate coastal engineering to manage coasts with natural coral reef solution.

Keywords: wave-controlled coast; fringing reef; ecological degradation; coastal erosion; shoreline protection

1. Introduction

Approximately 850 million people live within 100 km of coral reefs on which they rely for food resources, recreation opportunities, coastal defense, and building materials [1]. Coral reefs provide shoreline protection services as a first line of defense from erosion through wave attenuation and the production of sediment [2]. The reef crests of fringing reefs can act as breakwaters by dissipating wave energy [3,4] and meta-analyses reveal that coral reefs can provide substantial protection by reducing on average 97% of the wave energy [5]. Since coral reefs are natural, they represent a much more cost effective way of coastal protection than artificial coastal defenses [5,6].

However, coral reefs are a fragile ecosystem and susceptible to various natural and artificial disturbances, such as global warming, strong storms, overfishing, marine pollution, and other destructive practices [1,7]. Global coral reefs have experienced dramatic decline over the past decades [8–10], which consequently reduces their coastal defense capacity [11]. Therefore, nearly 200 million people may lose risk reduction benefits from reefs if these are lost or degraded [5].

Coral reefs provide coastal protection by absorbing and dispersing a significant part of the wave energy that otherwise would be transmitted onshore [4,12]. The critical function as breakwaters is based on the biological calcification of reef-building organisms, especially scleractinian corals, to generate massive carbonate structures that allow them to keep pace with the sea level. Live coral communities also provide geometrical complexity and increase surface roughness, which helps to dissipate wave energy through friction and wave breaking [13]. Thus, the coral species diversity and its cover pattern are important not only for increasing functional redundancy but also for maintaining the ecosystem stability of coral reefs which are vital to protect the coastline behind the reefs [14,15]. Coral mortality in the reef flat increases the wave energy that reaches shores and leads to more severe coastal erosion [16].

Many previous studies focused on the coral reefs monitoring using effective ecological indicators and the changes of coral communities led by climate change, and particularly on the reduction of coral diversity, coverage, and distribution range that indicate the decline of coral reefs and related possible economic loss [8,17,18]. But very few studies are concerned about the relationship between coral reef degradation and coastline erosion [19,20]. This hampers our understanding of the important role of coral reefs in coastal protection and management [21,22], and linking coral reef conditions to coastal stability has been challenging due to the multiple contributing factors.

The South China Sea (SCS) is a large marine region in the central of the Indo-Pacific, covering an area of more than 3 million km^2 [23]. Abutting the western border of the "Coral Triangle", the SCS hosts significant levels of biodiversity and provides important economic value and ecological services for neighboring countries and people [24–26]. However, these reefs and coastal zones have been subjected to a multitude of anthropogenic stressors due to rapid urbanization and population growth [27,28]. Some coral reefs in the northern SCS have suffered a dramatic decline over the past decades, especially in Hainan Island [29,30].

The aims of this study are to: (1) characterize the coral communities and their status in the northeastern Hainan Island; (2) reveal hydrodynamic conditions and shoreline changes around coral reef over the past 20 years; (3) relate the coral reef degradation to coastal erosion; and (4) evaluate the role of coral reefs in coastal protection and explore various ways to protect coral reefs and adjacent coastlines.

2. Material and Methods

2.1. Study Area

Hainan Island is located in the northern SCS, separated from the mainland of South China by the Qiongzhou Strait (Figure 1). The Hainan coastline is 1500 km long and fringing reefs are distributed widely in the coastal waters [29,31]. Wenchang city is situated in the northeastern (NE) Hainan Island and surrounded by the sea on three sides. This region is characterized by tropical monsoon climate, with distinctive dry (November to April) and wet (May to October) seasons. The annual average air temperature, sunshine duration and precipitation, are 24 °C, 2068 h and 1740 mm, respectively [32]. This favorable climate condition in northeastern Hainan Island enables coral reefs to flourish across the region, and results in the largest area of coral reefs in all of Hainan Island [33]. They are usually found in shallow waters (2–8 m deep) and developed relatively close to shore (200–1000 m). The coral reefs in NE Hainan Island consist mainly of reef flats, crests and slopes.

The NE coast of Hainan Island was suggested to have developed since 4000 years ago [34]. The tidal range is about 0.5 m at neap and 1.5 m at spring tide [35]. Because of the low tidal energy in this mixed semidiurnal tide, it is a wave-controlled coast where wind waves are important in shaping the coastal morphology and stability. Sheltered by two typical capes (i.e., Mulantou bedrock and Nandu River delta) and the molding of wave over thousands of years, coastlines of the Hainan and

Puqian Bays have been stabilized [34]. However, severe weather events, notably typhoons, generate stress to coastal stability around Hainan Island, especially in NE Wenchang and Haikou area where typhoon landfalls are most frequent. Storms usually occur between July and September and the associated rainfall accounts for 35–60% of the total annual precipitation [36]. Therefore, coral reefs around the NE coast of Hainan Island are very important for coastal protection.

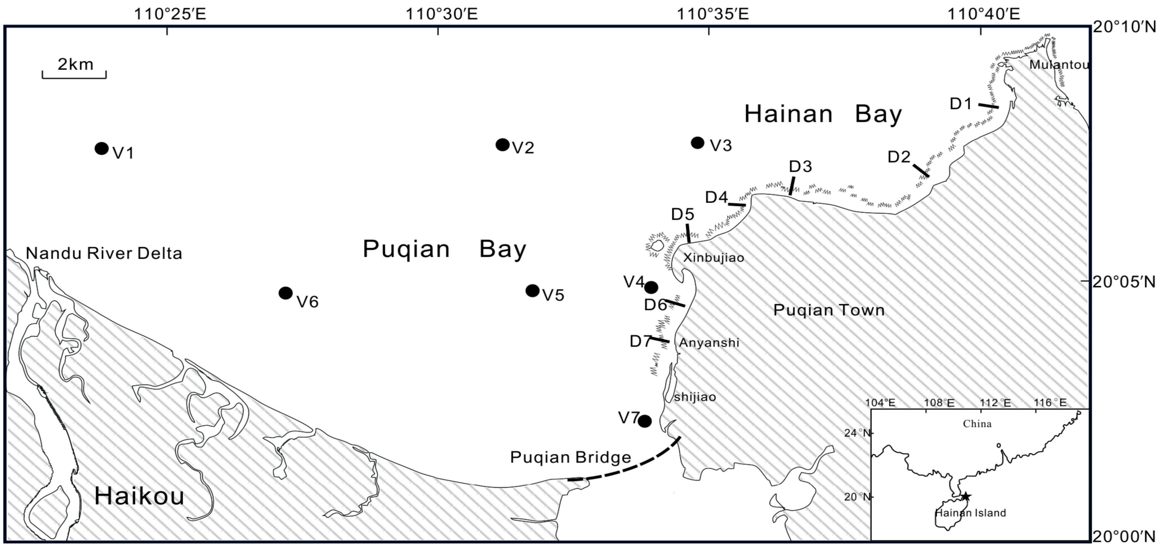

Figure 1. Location map of the studied reefs in the northeastern (NE) Hainan Island, northern South China Sea. (V1–V7: Hydrodynamics monitoring sites; D1–D7: Coral reef survey sites).

2.2. Field Surveys

Coral community surveys were conducted at seven sites (D1–D7) on the northeastern coast of Hainan Island in March 2017. Three sites (D1–D3) were located at the Hainan Bay and the other four sites (D4–D7) at the Puqian Bay (Figure 1) (Table 1). At each site, the study transect consisted of a 50-m fiber-glass measuring tape fixed onto the sea floor following the contour depth of 2–3 m below the mean low tide level. One scuba observer used a TG-4 camera (Olympus Co. Tokyo, Japan) with an underwater housing to record a video of the coral community along the transect line. Concurrently, two divers carried out roving surveys of 30–40 min for species observations along random paths near the survey transects at each site. All coral species encountered were recorded with close-up photos. For the colonies that could not be definitively identified in the field, pieces of coral samples were collected for further identification in the laboratory.

Table 1. List of coral reef and hydrodynamics investigations in the NE Hainan Island.

Sites	Methods	Data
D1–D7	Coral communities underwater diving and video surveying	Coral cover, coral diversity, coral community structure
V1–V7	Current monitoring	Flow velocity, flow direction
V3	Tidal monitoring	Tidal level, tidal range, tidal duration

In order to understand the hydrodynamics environment around NE Hainan Island and its effect on the coral reefs and adjacent coastline behind them, one site (V3) for tides and seven sites (V1–V7) for currents were established for real-time monitoring on various hydrological parameters (Figure 1) (Table 1). Tidal monitoring was carried out with two Tide Gauge Recorders (RBR-TGR-2050, Ottawa, Canada) from June 26 to October 13, 2017. The instruments were fixed with special steel, and one recorder was placed on the seabed and the other in the air above the sea level. Water level line and air pressure were recorded at a sampling interval of 10 min. Current monitoring was carried out at seven sites with two measuring instruments during the spring tide of the between July 11 and 12, 2017. Acoustic Doppler Current Profilers (RDI-WHS-600, Silicon Valley, CA, USA) were used at the V1 to V3 sites at >10 m deep. The current meters (Aanderaa-RCM9, Norway) were used at the V4–V7 sites where the depth was <10 m.

2.3. Other Data Collection

To evaluate the shoreline changes, high-resolution satellite images were obtained from Landsat 5TIRS satellite (from 1984 to 2013) for the years 1996 and 2009, and Landsat 8 OLI_TIRS satellite (since 2013) for the years 2013 and 2015. Image resolution was 30 m.

One-year wave observation data were obtained from the nearest Baishamen marine station (20°04′ N, 110°10′ E). Two series of sea level data were collected, including the instrumental data from Haikou station (20°01′ N, 110°17′ E) and the satellite remote sensing data from the NOAA database (https://www.star.nesdis.noaa.gov/sod/lsa/SeaLevelRise/LSA_SLR_timeseries_regional.php). The hurricanes information was downloaded from the NOAA website (https://coast.noaa.gov/hurricanes/, accessed 12 March 2019).

2.4. Data Analysis

Based on close-up coral photographs and coral samples, scleractinian corals were identified to the lowest tractable taxonomic level (usually to species), following the taxonomic work of Zou [37], Wallace [38] and Veron [39]. Classification and nomenclature of the corals was updated according to the World List of Scleractinia (http://www.marinespecies.org/scleractinia/aphia.php?p=taxedit&pid=766556). The percentage of living hard coral cover was measured by calculating the fraction of the length of the line intercepted on the transect rope by living corals [40]. Variance analysis was used to find the differences on the species composition and percentage of cover of different coral communities. Living coral colonies under the transect lines were identified to genus level and analyzed in different growth forms (branching, massive, encrusting, laminar, foliose and solitary). The Bray–Curtis similarity index was used for hierarchical cluster of species composition of coral communities. The statistical analyses on the coral communities were performed with the R software Version 3.5.2 (R Foundation for Statistical Computing, Vienna, Austria). Water level data were corrected according to the measured air pressure by $H = 10^3\left(p - p_a\right)\frac{1}{\rho g}$, where H = water level, p = total pressure, pa = air pressure, ρ = sea density, and g = gravitational acceleration [41], then sorted with the frequency interval of one hour and finally standardized to the tidal level based on the 1985 national elevation datum. The instantaneous current velocity was measured by the vector average of three minutes. Characteristics of the surface, middle and underlying currents were analyzed at each site.

These remote sensing satellite data were subjected to geometric correction, air correction, image cutting and enhancement, and the shoreline was extracted. The fifth band with wavelength of 0.845–0.885 μm was used because for its high accuracy in distinguishing and capturing the water–land boundary.

3. Results

3.1. Coral Community

A total of 39 coral species, belonging to 10 families and 19 genera, were recorded in the NE Hainan Island. These corals include 6 *Acropora spp.* 5 *Goniopora spp. and* 4 *Dipsastraea spp* and other coral species (Table 2). Mean live coral cover was 5.3% with the range of 1.0 to 16.0% for the entire region. The highest number of coral species and percentage of coral cover occurred in the northern Hainan Bay (Table 3). Among all the corals recorded, *Galaxea* (29.5%), *Platygyra* (24.6%) and *Porites* (20.6%) were most dominant genera basing on their contribution for the cover among the whole coral community. Massive was the most important growth form (89.7% of living corals on the seven sites).

Table 2. List of Scleractinian coral species and their distributions in the NE Hainan Island

Family	Genus	Species	Hainan Bay	Puqian Bay
Pocilloporidae	*Pocillopora*	*Pocillopora damicornis*	*	
Faviidae	*Dipsastraea*	*Dipsastraea speciosa*	*	*
		Dipsastraea rotumana	*	*
		Dipsastraea favus	*	*
		Dipsastraea matthaii		*
	Favites	*Favites abdita*	*	*
		Favites halicora	*	*
		Favites pentagona		*
	Coelastrea	*Coelastrea aspera*	*	*
	Goniastrea	*Goniastrea stelligera*	*	
	Platygyra	*Platygyra carnosa*	*	*
		Platygyra sinensis		*
		Platygyra daedalea	*	*
	Plesiastrea	*Plesiastrea versipora*	*	*
	Echinopora	*Echinopora gemmacea*	*	
Merulinidae	*Hydnophora*	*Hydnophora exesa*	*	
Pectiniidae	*Echinophyllia*	*Echinophyllia aspera*	*	
Lobophylliidae	*Acanthastrea*	*Acanthastrea echinata*	*	
Poritidae	*Porites*	*Porites lutea*	*	*
	Goniopora	*Goniopora djiboutiensis*	*	*
		Goniopora lobata	*	*
		Goniopora columna	*	
		Goniopora tenuidens		*
		Goniopora stutchburyi		*
Oculinidae	*Galaxea*	*Galaxea fascicularis*	*	
		Galaxea astreata	*	
Acroporidae	*Acropora*	*Acropora solitaryensis*	*	
		Acropora florida	*	
		Acropora hyacinthus	*	
		Acropora austera	*	
		Acropora cytherea	*	
		Acropora pruinosa	*	
	Alveopora	*Alveopora fenestrata*		*
	Montipora	*Montipora danae*	*	
		Montipora foveolata	*	*
Agariciidae	*Pavona*	*Pavona decussata*	*	
		Pavona explanulata	*	
Dendrophylliidae	*Turbinaria*	*Turbinaria peltata*	*	*
		Turbinaria stellulata		*
			32	21

* coral species was recorded.

There were significant differences among the coral communities in species composition and its percentage of cover ($p < 0.05$). Coral communities could be divided into two groups basing on their community structures, i.e., coral communities of Hainan Bay and Puqian Bay (Clu-HNB and Clu-PQB, Figure 2). Coral communities in the Hainan Bay were featured by higher diversity (32 coral species) and greater coverage (>10%) than those in the Puqian Bay.

Table 3. Variations of coral communities in the NE Hainan Island.

Site	Coral Cover (%)	Coral Richness
D1	15.92	18
D2	4.38	15
D3	10.94	16
D4	1.32	6
D5	1.18	4
D6	1.04	5
D7	2.06	8

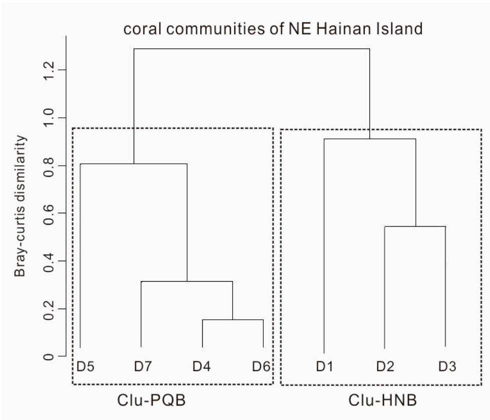

Figure 2. Cluster analysis of coral communities in the study sites at NE Hainan Island.

3.2. Hydrodynamic Environment

The maximum and minimum tidal levels during the 108 observation days were 1.83 m and −0.43 m, respectively. Duration of rising and falling tides was uneven, with the average duration of the spring tides slightly longer than that of the ebb tides. The tidal range was relatively small (average 0.90 m, max 1.80 m). There were obvious spatial variations on the flow velocity and tidal current direction (Figure 3). An E–W flow direction of occurred at sites V1 and V2, NW–SE direction at sites V6 and V7, and NE–SW direction at sites V3 and V5. Except for site V4, there were consistent directions among the surface, middle and bottom currents. Flow velocity at sites V1–V3 (outside of the bay) was significantly higher than that of the sites in the bay, especially at site V3 (max 1.15 m/s, 1.22 m/s and 1.38 m/s at the surface, middle and bottom waters, respectively). Flow velocity of at site V3 was the lowest, with its maximum velocity of the surface, middle and bottom waters being 0.16 m/s, 0.12 m/s and 0.17 m/s, respectively. Therefore, the tides could be categorized as irregular semidiurnal with lower tidal energy.

Compared to the low-energy tidal currents, waves were important energy in this area. Wind-driven waves were dominant with higher frequency (76–85%) than that of surge wave (14–23%). With the influence of monsoon at the eastern entrance of the Qiongzhou Strait, the most frequent incoming waves were from the ENE and NE. The mean annual wave height (*H1/10*) was 0.7 m with periods (T) of 3.5 s, the maximum wave height (*Hmax*) was 3 m and periods (*Tmax*) of 4.5 s. The monthly *H1/10* of winter was higher than in other seasons, but the largest waves during storms could reach up to 3 m high and have significantly longer periods.

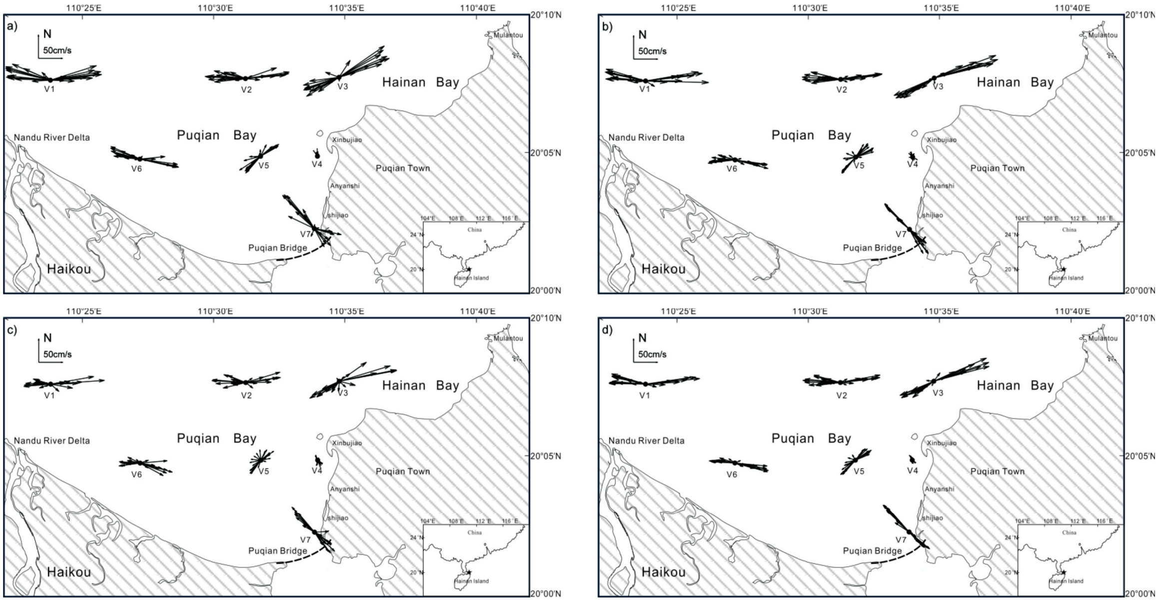

Figure 3. Tidal current directions in different water layers: (**a**) Surface current, (**b**) Middle current, (**c**) Near-bottom current, (**d**) Vertical mean current.

3.3. Coastline Changes

The coastline changes over the past 20 years were variable in different parts of NE Hainan (Figure 4). Northern Hainan Bay was nearly stable, except for some deposition in the middle of the bay. However, changes of coastline in the southern PuqianBay were complex. A nose-shaped sandspit was formed near Xinbujiao from 1996 to 2009. At the same time, there was serious coastal erosion between Xinbujiao and Anyanshi with the maximum retreating distance of about 240 m, and significant deposition in the middle of Anyanshi and Shijiao. Between 2009 and 2013, coastal erosion increased along the coastlines of Anyanshi to a distance of 2 km north and 1 km south, while coastal siltation occurred at about 700 m north of Shijiao. The northern coastal width of the sandspit decreased and those in the central and southern parts increased. There were no significant changes of the Puqian Bay coastline with minor siltation along the northern sandspit and southern Shijiao during 2013 to 2015.

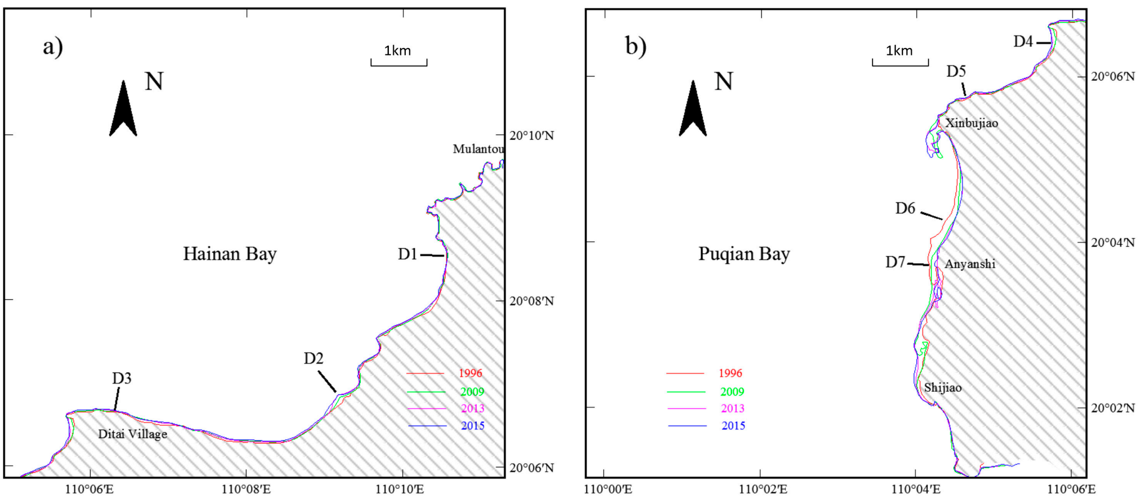

Figure 4. Coastline evolution in the NE Hainan Island. (**a**) Hainan Bay, (**b**) Puqian Bay

There were direct spatial correlation between the coral reefs status and the coastline condition. The Hainan Bay coastline was mostly stable over the past two decades and the nearby coral communities had higher coral diversity and coral cover. Coastline erosion at the Puqian Bay was likely caused by a worsening condition of the coral reefs. Corresponding to the most serious coastal erosion near Anyanshi (mean annual coastline retreat of about 8 m, coral communities on the site of D6 and D7 had the overall lowest diversity (<10 coral species) and cover (<2% coral cover). Coral communities at D1 and D3, where the nearby coastline almost maintained its stability with an average annual change of coastline less than one meter, were characterized as complex coral composition and higher coral cover.

4. Discussion and Conclusions

4.1. The Status of Coral Reefs Along the NE Coast of Hainan Island

The surveys revealed some important features of coral community in coral diversity, coral cover, dominant genus, and growth forms along the NE coast of Hainan Island. Comparing with the coral communities in the other Hainan Island sites and even the whole South China Sea, it is inferred that the health status of coral reefs here are at a low level. There are fewer coral species (39 coral species) here than those in the Xisha and Nansha Islands in the central and southern SCS, respectively [24,42]. The coral diversity is also lower than those at the Luhuitou reef and Qinglan Harbor reef in the southern and eastern of Hainan Island, respectively [9,43]. Mean coral cover in our study area was also lower than those of the above-mentioned coral reefs elsewhere in the SCS. Massive corals such as *Galaxea*, *Platygyra* and *Porites* were observed as the main growth form in the study area. They are different from that of the branching *Acropora* or *Pocillopora* corals at the coral reefs in the southern and central SCS, which are in a relative health condition [42,44], but similar to the massive *Porites* at the Luhuitou reef which is in the early evolution stage after being severely damaged [9].

Due to lack of detailed historical surveys in the NE Hainan Island, it is difficult to know the degradation history of these coral reefs. Coral reefs were suggested to be prosperous and widely distributed to provide rich fishery resources, especially for *Scomberomorus* and *Pseudosciaena* which were the two most popular economic fish in these waters of NE Hainan Island and famous specialties of Puqian Town. With the rapid urbanization and sharp rise in the demand for coral as building materials, coral reefs in NE Hainan Island have experienced serious destruction over the past decades. It was estimated that about 50,000 tons of reef rock were excavated each year during the 1980s [45]. Although this practice was officially banned in the 1990s, scattered reports of reef rock excavation for aquarium sand by local fishermen around the Hainan Bay (2014-10-28, http://www.hinews.cn/news/system/2014/10/28/017061256.shtml) and Puqian Bay (2016-3-22, http://www.hiwenchang.com/article-9313-1.html) still exist. Apart from reef rock mining, destructive fishing and aquaculture sewage discharge are widely accepted to have contributed to reef degradation along the NE coast of Hainan Island [46]. The study area is a popular fishing ground, and despite that this field survey occurred in the fishing ban period, we still found traces of illegal fishing activities in the Hainan Bay, and a large number of aquaculture farms around the Puqian Bay.

4.2. Coral Reef Degradation and Shoreline Stability

This study indicated a link between reef degradation and coastal erosion. There were two pieces of evidence: (i) most of the shoreline in the Hainan Bay is stable, (ii) good correspondence between the differences in the status of coral reefs and the change of shoreline. Coral communities in worse condition with lower diversity and cover correspond to severe coastline erosion in the Puqian Bay. Declined coral communities would result in the decline in carbonate production and biological geomorphological complexity of reef framework [19,47]. This could threaten coral reef growth and its bottom roughness, which are critical factor for protecting coastline by wave breaking and energy dissipation [4,12]. Some other coastal erosion occurrences in the Hainan Island [48,49] may also be connected to reef degradation. For example, the Bangtang Bay (eastern Hainan Island) has seen certain destructive activities at the coral reef area, including reef rock excavation and bomb fishing, which both destroyed the reef structure and increased water-depth of the reef flat. As a consequence, coastal erosion at Bangtang had started from the 1950s with the highest erosion rate of 8 m/a in the 1980s when the reef degradation was the most severe [50].

With the influence of rising sea levels and frequent severe tropical cyclones caused by climate change in the future, degraded coral reefs area were unable to provide coast protection function. A total of 79 tropical storms and typhoons of varying intensity had passed through the area from the year 1946 to 2016 (Figure 5). Coastal area of the region was hit by 40 tropical storms and 39 hurricanes (mainly during July to September) with the Saffir–Simpson scale of "H1"to "H5". Among these strong typhoons, the H5-scale 'Rammasun' typhoon in 2014 had a maximum suspend wind of 140 kts (72 m/s) and pressure of 890 mbar (89 kPa) [51]. When 'Rammasun' hit the coastal areas, the surge level reached a maximun height of 5.5 m, damaging 90% of the houses, 50% of the trees and many fish-farms and ships along the coast. Sea levels have been increasing from 1976 to 2017 at a rate of 4.7 mm/a (Figure 6), higher than the overall SCS (3.5 mm/a) but lower than around the Xisha Island in the northern SCS (4.9 mm/a, [52]).

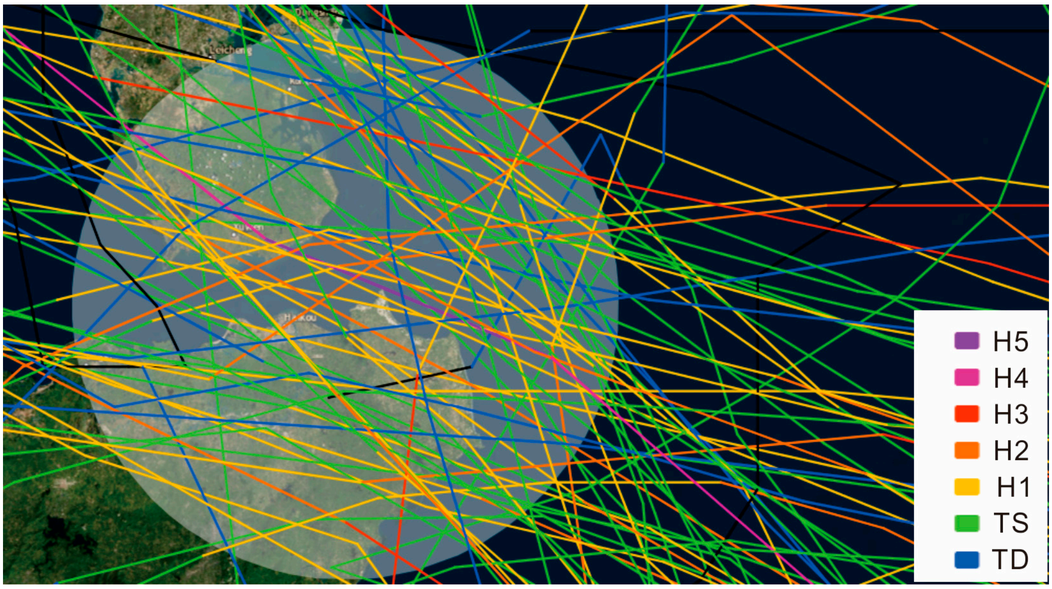

Figure 5. Hurricanes that affected NE Hainan Island since 1946. (data from https://coast.noaa.gov/hurricanes/).

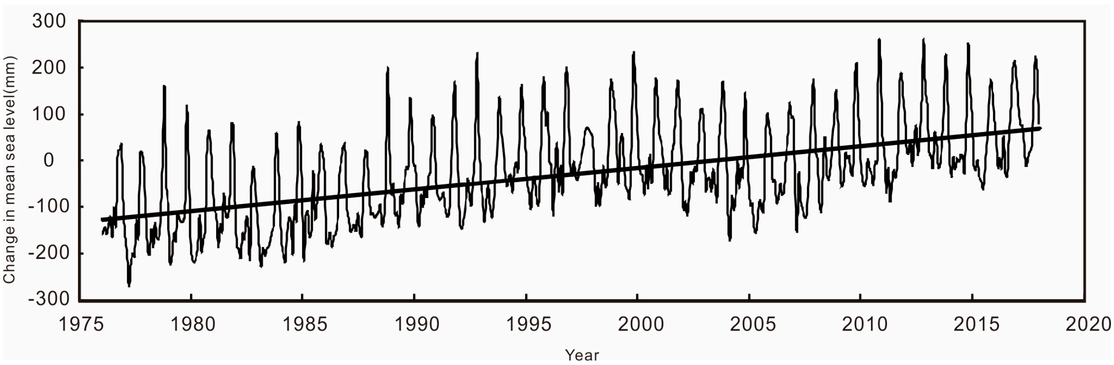

Figure 6. Change in mean sea level since 1976 (data from Haikou Marine Monitoring Station).

Another proof that coral reef could protect the coast is the response of shoreline stability to the influence of strong typhoon. Healthy reefs can provide coastal protection, even during cyclones with strong wind and wave conditions [20,53,54]. For example, there was very little coastal erosion on a section of Australia's largest fringing reef (Ningaloo Reef) from a direct impact of the Tropical Cyclone Olwyn whose significant wave heights reaching 6 m and local winds of 140 km/ h. Their results indicated that the erosion was due to locally generated wind waves within the lagoon rather than the offshore waves that were dissipated on the reef crest [55].

4.3. Implications for Coral Reef Management and Coastal Protection

This study highlights the effectiveness of coral reefs in providing natural coastal protection. The study sites with serious coral reef degradation correlate with adverse coastal erosion. Around the world, there are many positive examples where the accretion rate of healthy coral reefs can keep pace with the sea-level rise, and the recovered coral communities have increased carbonate productivity [56,57]. For example, basing on the analysis on the change of coral communities and carbonate budgets of 21 Seychelles reefs from 1994–2014, more than half reefs recovered from the 1998 global bleaching event and have positive budgets post-bleaching and coral communities structure especially the scale of massive corals played a critical role in the reef accretion and framework maintenance [57].

In order to protect the coral reef, reducing threats to coral reefs, such as overfishing and poor water quality, and establishing marine reserves, can all directly benefit reefs and maintain their shoreline protection services [1,2,7]. The recent opening of the Puqian Bridge connecting Wenchang and Haikou in 2019 is expected to promote economic development and tourism in/around the Puqian town. The anthropogenic stress on this coral reef coast would likely increase, yet the development of eco-tourism may introduce incentive for the local government to conserve/restore the coastal environment. Changing the destructive "high-risk, low-gain" into "low-risk, high-gain" approaches to get the economic goods, social services, and ecological functions from coral reefs is recommendable. For example, developing ecological tourisms is a better choice comparing the old and simple provision of aquatic products. The government could take some measures to restore the coastal environment and beautify the beach. Local people could be encouraged to use an environmentally friendly way to exploit the coral reef resources.

Reef restoration has been shown to be cost effective in comparison to the development of artificial submerged breakwaters [5,58]. Active coral-reef restoration measures may include biological restoration, physical restoration, and artificial reefs [22,59]. Among them, physical restoration involves repairing or adding to the structural integrity of the reef framework, typically with some combination of limestone and cement. Some studies found that artificial breakwaters or seawalls could support higher coral cover and/or diversity around them [60,61], which may be applicable for the southern coral reefs in the Puqian Bay, where existing reef framework is largely inadequate and the nearby coastline has been severely eroded.

To conclude, our results provide direct evidence for the importance of coral reef status in coastal management and protection. They could help coastal communities to: (i) better assess the coastal protection offered by coral reefs and their role on shoreline stability, (ii) identify how reef degradation can result in severe coastal erosions, and (iii) while there is no one-size-fits-all solution, the coral reef protection and restoration measures in this area may be applicable for other coastal regions fringed by coral reefs.

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