Article

Current status, crisis and conservation of coral reef ecosystems in China

ShaoHong Wu[1], WenJun Zhang[1,2]

[1]School of Life Sciences, Sun Yat-sen University, Guangzhou, China

[2]International Academy of Ecology and Environmental Sciences, Hong Kong

E-mail: zhwj@mail.sysu.edu.cn, wjzhang@iaees.org

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Abstract

Harboring rich marine species and playing important ecological functions, coral reef ecosystems have attracted widespread concern around the world. Ecosystem diversity, conservation and management of coral reefs are becoming a hot research area. Coral reefs in China are mainly distributed in the South China Sea and Hainan, Taiwan, Hong Kong, Guangdong, and Guangxi coastal waters. In recent years, due to the global climate change and the growing impact of human activities, coral reef biodiversity in China have been reducing and the ecological functions of coral reef ecosystems are severely degenerating. In this paper we summarized the current status, crisis and conservation of coral reef ecosystems in China. Some progress in coral reef research was discussed.

Keywords coral reef; China; degeneration; biodiversity; conservation.

1 Introduction

Coral reefs were generated from accumulation of calcium carbonate and deposition of bones, shells and other debris of corals and some other marine creatures, in which corals and a few other coelenterates, molluscs and algae play a key role in the formation and accumulation of calcium carbonate based limestone matrix. About 110 countries around the world were recorded for owning coral reefs, which account for only 0.1% to 0.5% of the total area of the oceans but as high as 30% of the total number of marine organisms (Smith, 1978).

In all marine ecosystems, coral reef ecosystems harbor the highest biodiversity. They are thus highly productive ecosystems and are known as the “oasis in the tropical ocean deserts” and “tropical rainforests in the ocean”. A healthy coral reef ecosystem can annually produce up to 35t of fishery products per square kilometer. About 10 percent of global fisheries production comes from the coral reef ecosystems (Smith, 1978).

Coral reef ecosystems provide not only a variety of biological resources for human but also many ecological functions and great ecological value. They play important roles in the conservation of biodiversity, biological productivity and ecological balance. In particular, coral reefs have become a hot source for marine drug resources.

Corals require strict growth and reproduction conditions. A subtle change in seawater temperature, salinity, sediment concentration and other environmental factors may lead to bleaching or death of corals. Coral reefs are the most sensitive ecosystems to global climate change. Understanding health status of coral reefs is very

important for climate change research (Zhang and Liu, 2012) and exploitation and conservation of the marine biological resources.

The United Nations Environment Programme (UNEP) reported that by October 2002 more than 400 various coral reefs worldwide were faced with the threat of extinction. Climate change, over-fishing and uncontrolled undersea tourism are the main causes for extinction of coral reefs. Degeneration of coral reef resources is particularly tough in China. In Hainan and the South China Sea islands, at least 50 % of coral reefs are suffering from degeneration (Tao, 1999).

It is estimated that by 2050, 98% of the world's coral reefs will not be able to survive the over-acidified marine environment (Ridd, 2007). The disappearance of large coral reefs will lead to the loss of refuges and habitats for a lot of marine organisms. This will destroy the populations of organisms that rely on coral reefs. Coastline will also lose the natural barrier and has to suffer from the impact of the sea wave. Tourism would be destroyed also. Thus the conservation of coral reef resources has become one of the world's leading tasks.

2 Ecological Environment and Biodiversity of Coral Reefs in China

There are various types of modern coral reefs in China, which include fringing reefs, offshore reefs, atoll reefs, platform reefs, knoll reefs, and flat reefs, etc. In the South China Sea islands, there are many atoll reefs and platform reefs, spreading over the Dongsha (Pratas) Islands, the Zhongsha (Macclesfield) Islands, the Xisha (Paracel) Islands, and the Nansha (Spratly) Islands (including the James Shoal knoll reefs). In the southern East China Sea, Taiwan Strait, the east coast and offshore islands of Taiwan Island, there are also coral reefs due to the effect of the Kuroshio Current and its branches, such as the Penghu (Pescadores) Islands and the Diaoyu (Senkaku) Islands. In the South China coastal waters, seawater temperature is lower, salinity is high and sediment concentration is higher, but corals still grow around some harbors. However only a few coastlines and islands are found to possess fringing reefs, such as the Dengloujiao fringing reef in southwest Leizhou Peninsula, the fringing reefs around the Weizhou Island and the Xieyang Island of Guangxi. A large number of fringing reefs spread along coastline of the Hainan Island but some offshore reefs are also found there (Zhao et al., 1999).

The north rim of Chinese coral reefs is fringing reef of the Weizhou Island in Beibu Golf (Golf of Tonkin) and fringing reefs of the Penghu Islands in Taiwan Strait. Due to the effect of the Kuroshio Current, the north rim for coral reef distribution in northeast Taiwan is the Diaoyu Islands. Correspondingly, from south toward north, the species richness of reef building corals (scleractinains) reduces and their distribution becomes sparse; however the molluscs attaching to the reef increase from south toward north.

Coral species in coral reefs include two categories, i.e., reef building corals (hard corals; scleractinains) and non-reef building corals. Reef building corals in the South China Sea are mainly branched staghorn coral, followed by clumping corals such as Porites. There are recorded 21 families, 56 genera, and 295 species of reef building corals around the South China Sea islands, in which there are as many as 50 species of Acropora corals. These corals widely grow in the Xisha, Nansha and Dongsha Islands, and other parts of the South China Sea, and the coastal waters of Taiwan, Hainan, Guangdong and Guangxi. The Nansha Islands have the most diverse of reef building corals, with 50 genera and 200 species there; second by the Xisha Islands, with 38 genera and 127 species, and there are 34 genera and 110 species around Hainan Island. In addition, there are also 7 families, 24 genera and 49 species of non-reef building corals in the South China Sea, including 7 families, 28 genera and 75 species (excepting for 4 species of discovered but not recorded) of gorgonians, and 6 families, 23 genera and 113 species (excepting for 33 species of discovered but not recorded) of Alcyonacea corals (Huang, 2008).

2.1 Coral reefs in the South China Sea

Total area of coral reef ecosystems and nearby shallow waters in the South China Sea islands is about 3×10^4 km^2, representing 5% of the total area of global coral reefs. There are large numbers of coral reefs and the types of coral reefs are much diverse in the South China Sea. In total 330 atoll reefs can be found in the South China Sea islands, among which the Lile Atoll Reef (7000 km^2) is the world's largest atoll reef, followed by the Zhongsha Atoll Reef (6900 km^2). Along the coast of the Hainan Island, there are some intermittent fringing reefs and individual offshore reefs. In the northwest of the Hainan Island, there are the Dachan Reef and the Lingchang Reef. Along the coast of China mainland, fringing reefs are the dominant coral reefs. For the South China mainland, individual fringing reefs spread along the coastline, which are locally connected to mainland or a shallow water pond usually exists between them. For example, in the Leizhou Peninsula (in Xuwen, Guangdong), and Beihai (in Guangxi) (the Weizhou Island and the Xieyang Island), coral reefs spread discontinuously, and the total length of coral reefs is 62.5 km, with an area of 44.6 km^2 (Son et al., 2007).

Coral reef ecosystems in the South China Sea are mainly based on reef building corals, which harbor the most diverse marine species. So far, the reef building corals recorded in the waters of the South China Sea and islands reach more than 50 genera and 300 species (Zen, 1997). Reported species number of fish, crustaceans, molluscs and echinoderms in the South China Sea account for 67%, 80%, 75%, and 76% of China's marine species, respectively.

2.2 Coral reefs in Taiwan islands

Reef building corals in Taiwan islands recorded reach not less than 13 families, 67 genera and 291 species. They distribute in the northern, eastern, and southern parts of the Taiwan Island and the coasts of the surrounding islands (Dai and Hong, 2009a, b). Due to a greater difference in seawater temperature between south and north Taiwan, there is also a significant difference in the species number of reef building corals. In the south Taiwan Island, the Green Island, and the Lanyu Island, the seawater temperature is suitable to the growth of corals, and the reef building corals reach nearly 300 species. And the main species are branching and clumping reef building corals. For the Penghu, Taidong and Hualian waters, there are only about 150 species of reef building corals and the main species are branching and clumping reef building corals. Seawater temperature in the winter of northern and northeastern Taiwan Island is lower and thus not suitable to the growth of corals. There are only about 100 species of reef building corals and the most of them are clumping corals (Dai, 2005).

The secondary reef building corals in Taiwan islands are coral algae, dividing into two categories by their appearance, the chlamys coralline algae and the comb coralline algae. In the waters of the north and northeast Taiwan Island, comb coralline algae accumulate and cover over the matrix and thus form algal reefs. Along the coast of Taoyuan County of northwest of the Taiwan Island, and the coast from Dansgui to Shimen of Taipei County in northern Taiwan, there have well developed algal reefs. The former is about 27 km long, and the latter is about 13 km long (Dai et al., 2009).

Although the coverage of reef building corals in some areas of the north Taiwan Island reaches up to 40%. But large-scale coral reefs are not found. In the northeast waters of the Taiwan Island, there are about 100 species of reef building corals. However the coverage in this area is not high and there is almost not any developed coral reef. The coral reefs in the east coast are incomplete and showed a discrete distribution. In Shitiping of Hualian (Hualien) County and Sanxiantai of Taidong (Taitung) County, coral reefs have well developed (Dai, 2005). Coastal coral reefs in the southern tip of the Hengchun Peninsula develop completely. There are more than 280 species of reef building corals, and at least 50 species of alcyonacea and 50 species of gorgonians in these coral reefs. In addition, there are more than 1200 species of reef fish, and at least 130 species of algae (Dai, 2005).

Around the waters of the Taiwan Island, there are nearly 150 species of reef building corals in the Penghu Islands, mainly distributing in shallow coastal waters and intertidal zones, and rarely exceeding a depth of 15m (Hsieh, 2008). Little Liuchiu is Taiwan's only coral island. Corals in this island are mainly reef building corals (more than 200 species of reef building corals), among which clumped *Favites sp* and *Porites porites* are common species. There are about 300 species of reef building corals and more than 100 species of octocorallians in the Green Island (Dai, 2005).

3 Coral Reefs in China

Reef building corals are rich in China, which account for 1/3 of the world species. They distribute mainly in the waters of the South China Sea and the Hainan Island. There are 21 genera and 45 species along the coasts of mainland Guangdong and Guangxi; 21 genera and 49 species in Hong Kong waters; 34 genera and 110 species or subspecies in Hainan waters; 38 genera and 127 species in waters of Xisha Islands; 19 genera and 46 species in Huangyan Island waters; 34 genera and 101 species in waters of Dongsha Islands; 58 genera and 230 species in Taiwan waters, and 56 genera and 163 species in the Taiping Island waters. Zou (2001) systematically organized corals in China and thought that there are totally 14 families, 54 genera and 174 species of reef building corals.

However, the coral reefs of China have been severely damaged. In addition to natural disasters such as storms and El Niño, etc., human activities caused a large-scale loss and degeneration of coral reef habitats in the South China Sea waters. Global Coral Reef Monitoring Network (GCRMN; 2004) reported that more than 90%of the coral reefs in the South China Sea have been destructed. Coral reefs in Hainan waters account for more than 98% of the total area of that in China and the species number and distribution area of corals in Hainan waters are the number one in China. But in recent decades coral reefs and their ecosystem functions in Hainan waters are being destructed and degenerating quickly. The waters of Xuwen, Guangdong Province, is the only well developed and conserved large-scale coral reef ecosystem. But the coverage of coral reefs has been declining in recent years, from 30-40% in 2000, 20-30% in 2002, less than 10% in 2004, to less than 7% in 2008. The severe degeneration of coral reefs in China was mainly attributed to irrational development and exploitation by humans.

Since 1950s, 80% to 90% of coral reefs in the Hainan Island waters has been destructing at different extents, in which the deterioration and degeneration of offshore coral reefs is more severe. As a consequence, ecological environment in the waters has greatly degenerated, marine resources depleted and coastline was eroded. Sanya has attracted large numbers of tourists around the world, with its unique geographical conditions and the colorful underwater coral reefs. However, with the increasing population and economic development, the coral reefs in Sanya are being destructed. The coverage of coral reefs along Luhuitou declined to 22% in 2002 from 40% in 1998-1999, while the bleaching rate of coral reefs in west tourism area of Yalongwan (Peninsula Dragon Bay) reaches 70% in recent years, due to human activities.

As a contrary, for example, the Yongxing (Woody) Island was seldom disturbed by human activities. Thus the higher coverage of coral reefs in the waters may be well conserved.

4 Causes for Degeneration of Coral Reef ecosystems in China

Coral reef ecosystems have high productivity and species diversity, but they are also relatively fragile and vulnerable to changes in the external environment. Various eco-environmental changes will affect the growth, metabolism, zooxanthellae algae symbiosis, behavioral responses, mucus secretion and reproduction of corals. Natural forces like violent storms, volcanic eruptions, El Nino events, excessive sediment, etc., and human

activities like environmental pollution, excessive resource exploitation, etc., have lead to the catastrophic deterioration of coral reefs. The causes for degeneration of coral reefs in China are summarized as follows:

(1) Natural disasters and coral bleaching. Temperature tolerance range of the corals is relatively narrow. The desirable annual average seawater temperature for reef building corals is 25℃ to 28 ℃. Several weeks' temperature fluctuation beyond the desirable range will lead to coral bleaching, and a longer duration of this situation will lead to the death of corals. For example, the El Nino event in 1998 led to a maximum temperature increase of 2℃ to 3 ℃ in the most of the South China Sea waters. As a result, a wide range of coral bleaching occurred and coral mortality reached 70% to 90% (UNEP, 2004). In the past two decades, coral bleaching in the South China Sea were very common. Influenced by winter cold flow from north China, along with human activities, the coral bleaching of fringing reefs in Sanya exceeded 70%. Coral bleaching in Weizhou Island waters also occurs frequently, and has showed very obvious signs of degeneration.

Heat will disrupt the symbiotic relationship between corals and zooxanthellae. The zooxanthellae provide the necessary nutrients, especially carbon-based nutrients, for corals through photosynthesis, while zooxanthellae obtain refuges and the sunlight that coral reefs provide. Zooxanthellae also provide colors to corals which have not their own color. However, as seawater temperatures rose, the zooxanthellae disappeared, leaving corals to starve and finally leading to coral bleaching (Gates, 1990).

(2) Overfishing and destructive fishing practices. Overfishing and inappropriate fishing practices are one of the reasons that cause severe degeneration of the coral reefs of China. About 50% to 60% of coral reefs in the South China Sea have subjected to the threat of fish-exploding, fish-poisoning and other destructive fishing practices. Fish-exploding leads to 50% to 80% of the mortality of coral reefs (Burke et al., 2002). Most of the reef building corals in the South China Sea suffered from human destruction and excessive exploitation, leading to the deterioration of large numbers of acropora (staghorn) corals. Reduction of coral species resulted in the decline of richness, population size and distribution of reef-living animal species.

Fig. 1 A vendor (Sanya, Hainan) is promoting her marine products, including coral reefs pieces.

(3) A large-scale coral exploitation. The residents of coastal areas in the South China Sea always exploited coral reefs for the production of lime. And some of the cement plants usually used coral reefs as the raw materials of limestone. In the past 20 years, as the high-speed development of China's economy and construction, the demand for construction materials has been increasing, and the destructive use of coral reefs resources intensified. In addition, the corals are usually used to make souvenirs and sold to tourists and

customers (Fig. 1; in addition, http://importer.alibaba.com/corals-importer.html). As a result, coral reefs, their aesthetic values and fisheries production were destructed, and coastal erosion exacerbated.

(4) Marine environmental pollution. Rapid economic development in coastal areas produced a huge amount of living and production sewage, agricultural waste water containing chemical fertilizers and other solid waste. However, because many coastal cities are short of comprehensive sewage treatment systems, a large amount of sewage containing high concentrations of nutrients was directly discharged into the waters of coral reefs. This led to the growth of harmful algae; sunlight was obscured; oxygen content in water reduced, and the growth and reproduction of corals is inhibited. The pollutant purification ability of coral reefs communities significantly declined also. Meanwhile, a large number of reef-living organisms lost their habitats, which led to decline of both population and ecosystem functions of coral reefs.

(5) Sediment silting. Increasing amount of suspended solids and sediment deposition in the seawater is one of the reasons leading to the severe degeneration of the coral reefs. The large amount of input of sediment and pollutants led to turbidity of seawater, reduction of sunlight projected onto the reefs, and frustration of rapid calcification of corals and zooxanthellae, which resulted in lower growth rate of corals. Corals cost more energy to clear surface sediments. This not only reduces its growth rate and change the growth morphology and viability, but also affects their respiration, causing the coral die of asphyxiation. Deposition of sediments hindered the growth of new corals, resulting in the death of a large number of reef building corals and other living corals. Furthermore, reef-living organisms reduced.

All in all, too much sediment changed the physical and biological processes of coral reefs, which adversely affected the structure and function of coral reef ecosystems.

Fig. 2 Excessive tourism in Sanya, Hainan.

(6) Eutrophication. Land runoff, the wastewater discharge from sewage and livestock breeding, atmospheric precipitation, aquaculture wastewater discharge, rising currents carrying would be input of various nutrients. They would have resulted in the eutrophication of coral reef ecosystems. In many areas of coral reefs human population is dense and these areas have often been developed as tourist attractions (Fig. 2). Almost all the coral reefs became or will soon become eutrophication and the ecosystems are gradually destroyed.

Eutrophication of coral reef ecosystems impacts coral reef ecosystems through both direct and indirect ways (Allan, 2002). Eutrophication affects physiological activities of coral - zooxanthellae symbiotic system, such as reduce coral growth rate and reproduction rate, or increase the susceptibility of coral - zooxanthellae

symbiotic system to diseases, and thus have a direct impact on the health of coral reef ecosystems. By stimulating the growth of reef building corals or algae species, eutrophication promotes some algae to become the dominant species, which can indirectly change the community structure of coral reef ecosystems.

(7) Carbon dioxide increase and ozone depletion. With the global climate change, the increase of atmospheric carbon dioxide concentration leads to the increase of carbon dioxide in seawater, and this results in lower carbonate concentration in seawater. Thus the carbonate absorption ability of corals reduces and the calcification rate of coral bones reduced. When carbon dioxide levels in seawater reaches 550μmol/mol seawater, coral and other marine life will not be able to absorb and enrich carbonate from seawater, and corals will stop to grow (Hoegh-Guldberg et al., 2007).

Because of the substantial leakage of PFCs and other chemicals, ozone layer becomes thinner. The thin ozone layer intensifies ultraviolet radiation. Although the coral has a layer of protecting against tropical sunlight, but increasing ultraviolet radiation would cause the damage of coral reefs in shallow water areas (Kuffner, 2002).

5 Research Progress

In China, the coral reefs-related research have mainly concentrated in the paleoclimate of coral reefs, bio-geomorphic process of coral reefs, comprehensive surveys of coral reefs resources, biodiversity surveys of coral reef ecosystems, coral reef conservation and management, etc. Various geo-science and biological methods were used to investigate and study coral reef ecosystems.

5.1 Carbon cycling of coral reef ecosystems

Carbon cycling of coral reef ecosystems is jointly regulated by two biological metabolic processes, photosynthesis / respiration, and calcification / dissolution. Photosynthesis of the coral reefs plants is an effective complement of organic carbon. Animal feeding and microbial degradation drive the efficient cycling of organic carbon in coral reefs waters. Coral reefs possess efficient and stable carbonate sedimentation rate, which to some extent alleviates the significant increase in atmospheric CO_2 concentration.

Coral reefs are both source and sink of atmospheric CO_2. When corals dominate ecosystem communities, calcification can control seawater's CO_2 concentration and releases CO_2 to the atmosphere; when macroalgae dominate the ecosystem, plant photosynthesis will increase and coral reefs will then purify CO_2.

External environmental factors such as natural factors, temperature, atmospheric CO_2 concentration, input of terrigenous matter, and human activities such as fishing, collecting coral, the discharge of sewage, and other human activities, can directly affect coral reefs' community structure, physiological and ecological characteristics, and thus indirectly affects the carbon cycling of coral reefs.

In recent years, some researchers have carried out research on use, migration and transformation of carbon in the coral reef ecosystems. Zheng et al. (2004) investigated the content, distribution and diurnal variation of dissolved organic carbon in the Zhubiqiao Reef waters of the Nansha Islands. They found that the area of reef flat is more productive than outside-reef and lagoon. A substantial proportion of carbon was transferred out from reef flat. DOC concentration in surface water of reef flat is higher than that in outside-reef and lagoon waters. POC was higher in day than in night.

5.2 Impact of eutrophication on coral reef ecosystems

In recent decades, many scientists in the world have studied the impact of eutrophication on symbiotic systems and community structure of coral reefs. However, the corresponding research in China has lagged far behind the world. Only some preliminary and macroscopic studies were conducted. Zhao et al. (2001) studied bio-geochemical cycle of biogenic elements of coral reef ecosystems in the Nansha Islands, and proposed the pattern of synergistic nutrition. Wang et al. (2004) experimented the influence of environmental change on

coral bleaching and believed that excessive N will lead to coral bleaching at different extents. Based on the changes of coral reefs coverage, Wang et al. (2006) and Shi et al. (2007) studied the impact of human activities on coral reef ecosystems.

Many ecologists conducted laboratory simulation experiments and in situ experiments by adding nutrients, such as inorganic nitrogen and phosphorus, in order to study the direct impact on coral calcification, tissue growth and zooxanthellae, and to study how eutrophication affects corals and their symbiotic zooxanthellae (Fabricius, 2005). It was found that high concentrations of inorganic nitrogen may increase the density of zooxanthellae, chlorophyll content, N content and photosynthetic efficiency, but high concentrations of inorganic P had no effect on zooxanthellae density.

Adding nutrients at the state of low pH state or supersaturated CO_2 will lead to the prior use of CO_2 by zooxanthellae for photosynthesis, competing CO_2 with coral's calcification process and thus reducing corals' calcification rate (Allan, 2002). Furthermore, eutrophication makes most of the nutrients to form particulate matter and causes the water getting cloudy. In this case, the photosynthesis of some coral symbionts is inhibited due to the inhibition of symbiotic algae. The calcification rate, total photosynthetic product, and respiratory rate are much lower than normal state (Chen et al., 1995). After a loner time, metabolism and calcification process of coral may be greatly affected and coral communities will become vulnerable.

In summary, eutrophication affects corals' metabolism and calcification process, inhibits coral's fertility by stimulating the growth of reef building algae to break the competitive balance between the slow growth of corals and the rapid growth of algae, and further affects the community structure of coral reefs.

5.3 Health assessment of coral reef ecosystems

Strengthening the evaluation of health status of coral reefs is important for the reasonable protection of China's coral reef resources. Traditionally Chinese researchers have conducted some basic biological and ecological research, but few studies were carried out on health assessment of coral reefs. At present, scientists begin to study the repair of damaged coral reef ecosystems and the health assessment. Some scientists suggested that multi-layered and three-dimensional monitoring and risk assessment on coral reefs, based on various techniques from satellite remote sensing to the methods of molecular biology, should be conducted (Wang, 2007).

The health assessment of coral reefs is still in experimental and exploratory stage. So far we have not yet formed a mature and widely accepted indicators or methods for health assessment of coral reefs. The health assessment requires an investigation and field monitoring of coral reefs. Ecological data, social and economic pressure on coral reef ecosystems, and human activities are all focus in the investigation and monitoring.

A viable monitoring plan should not only ensure the reliable comparisons between different types of coral reefs, but also ensure its application is simple and does not need continuous surveys in order to provide the health status of coral reefs. It should also provide the health trend of coral reefs (evolution or degeneration), rather than just provide the current status of coral reefs (Ben-Tzvi et al., 2004).

5.4 Ecological restoration of coral reef ecosystems

As the primary means for repairing coral reefs, coral transplantation has been playing a significant role in the past years. Coral transplantation means that corals are in whole or in part transplanted to degenerated waters to improve the biodiversity. Some researchers studied species choice of coral and coral's survival rate and others approached the possible factors that affect the survival of coral transplants

Corals being transplanted usually sources from picking donor reef and the corals arte gradually changed from farmed corals to transplanting corals. The survival of transplanted corals is dependent upon the coral species, community composition, transplanting matrix, etc. Some scientists studied the impact of different transplanting techniques on the survival of corals. The factors affecting corals' survival and growth include the

source of corals, the initial length, tissue damage, as well as the placement of corals. However, coral transplantation is not always applicable to all restoration practices of coral reefs.

The earliest coral transplantation experiment in China was made in 1995 by Chen (Wang, 2007). The South China Sea Institute of Oceanography and South China Sea Fisheries Research Institute have successfully transplanted corals of Dayawan in 2006 and 2007. Nevertheless, China's research and practices in this area is still in its infancy compared to that in developed countries.

It should be noted that artificial fish reef, usually placing over sea bed to provide refuge for fish and invertebrates, will restrict the restoration of coral reefs.

5.5 Conservation and management of coral reefs

Many scientists have suggested a series of plans for the conservation and management of coral reef biodiversity in China. For example, establish international cooperation mechanisms for conservation and management of coral reef ecosystems in the South China Sea; establish a dynamic monitoring network for long-term monitoring of and information collection about the status and dynamics of coral reefs for management and decision making; strengthen studies on assessment of ecological function of coral reefs in order to provide a theoretical basis for the rational use and sustainable development of coral reef resources and to provide the basis for government's decision making on conservation and management of coral reef ecosystems.

During the past 20 years, China's government formulated and promulgated several laws and regulations of the conservation of coral reefs biodiversity and developed a number of action plans and management measures. "Marine Environmental Protection Law", "Sea Area Use Management Law", "Wildlife Protection Act", "The Nature Reserve Ordinance", "The Marine Nature Reserve Management Law", "The Fisheries Act", "Water Pollution Control Act", and some other laws and regulations are related to resources, environment and ecology of coral reefs. In the "China Marine Biodiversity Conservation Action Plan", the conservation of the coral reefs is particularly put in a prominent position. In addition, local governments also issued a series of laws and regulations on the conservation of coral reef ecosystems. For example, "Hainan Coral Reef Protection Provisions", "Protection of Coral Reef Resources Management Regulations" of Beihai, Guangxi. The Scientific Committee for Endangered Species of China clearly defined corals as endangered species for protection in order to end the use of corals as souvenirs.

Governments at all levels have established a number of coral reefs nature reserves, such as Hainan Sanya Coral Reef Nature Reserve (national) and Coral Reef Nature Reserve (provincial) of Dongshan County, Fujian Province, establishing in 1990. Xuwen Coral Reef Nature Reserve (provincial) was established in 2003 and updated to national level in 2007. The Weizhou Island set up its monitoring and research station of coral reef ecosystems at the end of 2001, aiming to monitor species composition, distribution changes, and biomass of coral reef ecosystems, and impact of human activities. However, various coral reef reserves need to improve management and conservation, pay attention to the coordination of the buffer areas and core areas, and ease the pressure of tourism on the coral reef reserves.

6 Outlook

In China, coral reef research has touched various fields, such as topography and near surface deposits, geological development and evolution, coral records of environment change, etc. We also carried out a lot of work in terms of biological diversity.

In the future a long-term observation mechanism should be established, especially the use of a number of automated monitoring equipment, and combined use with remote sensing technology, etc., in order to conduct a comprehensive, long-term and quantitative survey and research on coral reef ecosystems. Special focus

should be put on multiple coral reefs for different positions and different types of coral reefs. We need to strengthen the studies for impact of climate events, such as El Nino and La Nina, on the coral reef ecosystems. We should further understand the impact of changes in various environmental factors on coral biodiversity and community structure, and understand the mechanisms of coral reefs' symbiotic system and ecological functions. Response mechanisms for rising atmospheric CO_2 concentration, changing temperature, ultraviolet light, natural disasters and other external factors need to be in-depth approached, which has an extremely important role in the conservation of coral reefs.

The economy in China coastal areas is developing at the cost of the environment. Local governments usually lack of knowledge on the ecological functions of coral reef ecosystems, who always seek only short-term economic interests and thus leads to irrational or even predatory exploitation of coral reef resources.. Therefore it is necessary to strengthen the environmental education to citizens. It is necessary to raise public awareness of environmental protection of coral reef ecosystems, and to strengthen community involvement. The environmental protection departments should implement stricter emission standards for emission of industrial wastewater and pollutants, strengthen monitoring and management of pollutants, and control the transport of a variety of sediments. Local governments should also strictly control the exploitation of coral reef-related resources.

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