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Coral reef restoration projects in Thailand

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Abstract

The degradation and deterioration of coral reefs in Thailand has continued for several decades due to pressures from fishery and tourism activities and, more recently, from bleaching. Several institutions and organizations, from both the government and the private sector, have been involved in programs to restore degraded coral reefs. The objectives, scales and methods of these restoration projects have varied widely. This paper briefly reviews the achievements of selected coral reef restoration projects and provides guidelines for future restoration initiatives. The high cost and limited scale of restoration projects puts the onus on governments and communities to prevent damage to coral reefs in the first place. Where restoration is necessary, basic data on the biology and ecology of target species of corals, socio-economic analyses and the involvement of local communities in all stages of the project are key elements for success.

1. Introduction

Coral reefs are complex, diverse ecosystems that provide food, ecological services (storm and flood protection) and livelihoods (tourism activities) for coastal communities in tropical developing countries [1,2]. Pressures on these valuable habitats and the resources they support have increased due to human population growth, leading to unprecedented rates of degradation [3,4]. Consequently, many coral reef restoration initiatives are underway [5–9].

This paper aims to (1) review the achievements of several coral reef restoration projects in Thailand and (2) provide guidelines for the consideration of future coral reef restoration projects.

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2. Background information on coral reefs in Thailand

2.1. Present status

The coastal areas of Thailand, between latitudes 6° and 13°N, offer suitable environmental conditions for growth of coral reefs. There are approximately 153 km^2 of coral reefs and over 300 relatively small islands along the nation's 2614 km coastline. These reefs can be classified into four groups with different oceanographic conditions: the inner part of the Gulf of Thailand (Chonburi Province); the east coast of the Gulf of Thailand (Rayong, Chanthaburi and Trat Provinces); the west coast of the Gulf of Thailand (Prachuab Kirikhan, Chumporn, Suratthani, Nakhon Si Thammarat, Songkhla, Pattani and Narathiwat Provinces); and the coastline of the Andaman Sea (Ranong, Phuket, Pang-Nga, Krabi, Trang and Satun Provinces).

There are three reef types in these areas: coral communities with no true reef structure (vertical profile), developing fringing reefs and early formation of fringing reefs. A comprehensive survey of coral reefs, covering 251 sites in the Gulf of Thailand and 169 sites in the Andaman Sea, was conducted by the Department of Fisheries between 1995 and 1998. In the Gulf of Thailand, 16.4% of the reefs were rated "excellent", 29% "good", 30.8% "fair" and 23.8% "poor". However, reefs in the "poor" category increased considerably after the severe coral reef bleaching event in 1998. Certain areas of Rayong and Trat Provinces showed reduction in live coral cover of 80–90% from previous levels. In the Andaman Sea, 4.6% of reefs were "excellent", 12% "good", 33% "fair" and 49.8% "poor" (Fig. 1). The 1998 bleaching event affected coral reefs in the Andaman Sea to a much smaller degree than in the Gulf. Some reefs showed a declining trend in live coral cover, but other sites exhibited slight increases of live coral cover. In general, coral reefs in the Andaman Sea have remained relatively unchanged during the last 5 yr.

The monitoring of reef fish was less extensive compared to benthic surveys, and it is difficult to provide a clear indication of reef fish status due to high temporal variations. However, fish populations were more abundant on reef slopes than on reef flats. Reef fish abundance gradients from nearshore to offshore were influenced by reef types and environmental factors.

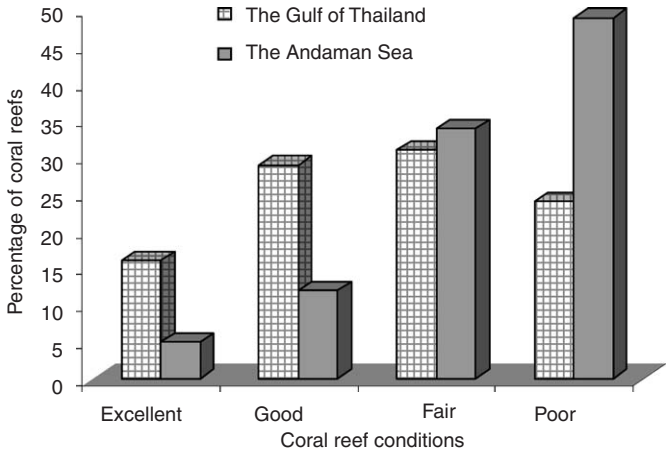

Fig. 1. Status of coral reefs in Thailand [12].

Coral reefs provide fishery products as important sources of both food and income [10–12]. Most Thai reefs are used for fisheries but poor records are maintained for reef fish harvesting. Many reefs in rural areas are used by small-scale fishermen, or for the collection of shells and ornamental fish.

2.2. Threats to coral reefs

Coral reefs in Thailand support a variety of human activities that fall into three main categories: tourism and recreation, fisheries-related uses and other uses. A clear pattern of change in coral reef use is evident, as small-scale or traditional fisheries are gradually being replaced by tourism activities. For example, local communities in provinces such as Trat, Chumporn, Suratthani, Pang-Nga, Trang and Satun have begun to convert their fishing boats into tour boats or diving boats.

There has recently been a rapid and steady growth in tourism and recreational activities (i.e., diving, underwater photography, glass-bottom vessels, sea walkers and sport fishing), leading to obvious increases in coral reef-related tourism activities in the Gulf and the Andaman Sea. Coral reefs close to beach resorts, especially those in Chanthaburi, Rayong, Suratthani, Phuket, Trang, Krabi, Pattaya, Koh Samet, Koh Tao, Koh Hae and Mu Koh Phi Phi, are now used intensively for tourism. However, poorly managed tourism affects coral reefs through anchor damage, garbage accumulation, diver damage and wastewater discharge from coastal hotels and resorts. Related problems include: the collection of shell and ornamental fish with the use of chemicals; dynamite fishing (although rarely observed, even in remote islands); sedimentation and wastewater pollution associated with rapid coastal development; jetty construction in several locations, especially in the west coast of the Gulf of Thailand (which resulted in coral reef and seagrass degradation) [12,13]. Live coral coverage on Tao Island in Suratthani, one of the most popular snorkeling sites, for example, has declined by 17% within a 5-yr period. Fortunately, several projects to establish mooring buoys at coral reef sites in the Andaman Sea have successfully reduced anchor damage.

The first extensive coral bleaching phenomenon in the Gulf of Thailand occurred in April–June 1998. There were clear spatial variations in the extent of coral bleaching and the bleaching of coral recruits was observed at many study sites. It was widespread on shallow reefs, but certain coral communities on deeper pinnacles, such as Hin Luk Bat in Trat Province (approximately 10–15 m in depth), showed no signs of bleaching. Long-term studies have revealed that *Acropora* and *Pocillopora damicornis* were severely affected. Several species of *Acropora* showed local extinction in certain locations. This was in contrast to *Goniopora,* which showed complete recovery after the bleaching event (Fig. 2). Coral recovery in the inner Gulf of Thailand will require a longer period of time due to low coral recruitment, although large numbers of coral recruits, mainly *Pocillopora, Acropora, Fungia* and faviid are available on the east and west coasts of the Gulf [12,14].

The first tsunami disaster in history of Thailand occurred on 26 December 2004. The tsunami hit six provinces along the coastline of the Andaman Sea, namely, Ranong, Phang Nga, Phuket, Krabi, Trang and Satun. The Department of Marine and Coastal Resources, nine Thai universities and volunteer diving groups conducted a rapid assessment program from 30 December 2004 to 15 January 2005. A total of 175 study sites were completely carried out and the impacts of tsunami on coral reefs were categorized in to five groups, i.e., no impact, very low impact (1–10% of corals were damaged), low impact (11–30% of

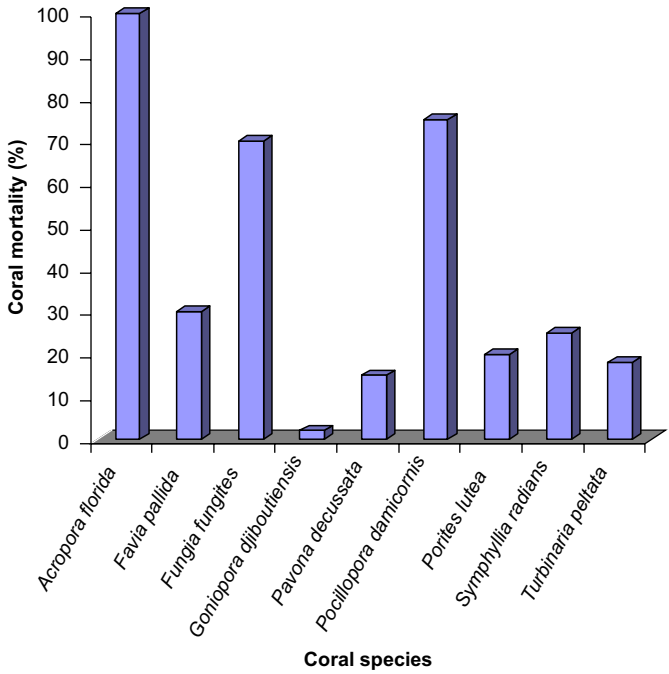

Fig. 2. Percentage of coral mortality at a study site in Prachuab Kirikhan Province after the coral bleaching phenomenon in the Gulf of Thailand during April–June 1998 [28].

Table 1
Summary of the tsunami impacts on coral reefs along the coastline of the Andaman Sea (% of total study sites)

Province	No impact (0% damaged coral)	Very low impact (1–10% damaged coral)	Low impact (11–30% damaged coral	Moderate impact (31–50% damaged coral)	High impact (>50% damaged coral)
Ranong	0.0	16.7	16.7	8.3	58.3
Pang Nga					
Mu Koh Surin	0.0	23.8	33.3	23.8	19.0
Mu Koh Similan	28.9	18.4	21.1	13.2	18.4
Other areas	29.2	16.7	22.2	13.9	18.1
Phuket	57.1	23.8	14.3	4.8	0.0
Krabi					
Mu Koh Phi Phi	33.3	26.7	13.3	20.0	6.7
Other areas	40.0	26.7	13.3	13.3	6.7
Trang	25.0	50.0	25.0	0.0	0.0
Satun	71.0	16.1	9.7	0.0	3.2
In total (%)	39.7	20.7	17.2	9.2	13.2

corals were damaged), moderate impact (31–50% of corals were damaged) and high impact (>50% of corals were damaged). Only 13% of the study sites were in ''high impact''. No impact study sites were around 40%. Study sites in ''very low impact'', ''low impact'' and ''moderate impact'' were 21%, 17% and 9%, respectively (Table 1).

3. Coral reef restoration projects in Thailand

Several institutions and organizations, from both the government and the private sector, have expended much effort to restore degraded coral reefs in Thailand. Coral reef restoration projects have been developed in many locations and implemented with a range of objectives, at various scales, and using different methods. The lessons from these projects need to be documented to assist the development of a national strategic plan for sustainable coral reef management and maintenance of marine biodiversity [15].

The methods used to restore coral reefs vary according to the objectives, the projected time scales of recovery and conditions of degraded areas. The methods used in Thailand during the last decade include coral transplantation and translocation, reattachment of coral fragments and the provision of artificial substrata for natural recruitment. Larval supply, settlement and recruitment of planulae, regeneration of damaged corals, fragmentation, and consolidation of substrata are also important factors in the planning of restoration programs. Several case studies on coral reef restoration in Thailand are outlined below.

3.1. Initial development of coral transplantation techniques

The first attempts at coral restoration involved monitoring the survival rate of small pieces of coral mounted on concrete blocks. The experiments were conducted by a coral reef research team of Burapa University with three species of coral: *Porites lutea, Acropora* sp. and *Pocillopora damicornis*. Survival rates were 95%, 83% and 42%, respectively. Epoxy–cement mixture was the best agent for fixing coral pieces to concrete blocks. However, it is too expensive to use for coral transplantation in large areas. A later experiment used a mixture of cement, gypsum plaster and sand in a ratio of 1:1:1 as an adhesive.

This general approach was used to transplant *Acropora* sp. in 1993. Thirty blocks of *Acropora* sp. were placed on the deteriorated area at the western side of Krok island, covering a total area of 30 m^2. The growth rate of the transplanted *Acropora* sp. was high, i.e., up to about 6–10 cm/yr. The survival rate was 88.24% after 2 months. After 12 months, the growth rate of transplanted corals was still about 6.5 cm/yr. [16,17].

3.2. An alternative method for coral reef restoration

The natural occurrence of coral fragments provided the basis for a different approach. Fragmentation is a significant process of asexual reproduction in many scleractinian corals, especially branching forms. Fragments of scleractinian corals in a non-reefal coral community were surveyed quantitatively at Khang Khao Island (inner Gulf of Thailand). There, the intensive grazing activities of *Diadema setosum* and many coral borers had accelerated the fragmentation process for *Acropora*, *Goniopora,* massive *Porites lutea* and faviid corals. Many fragments of the massive corals were observed to be partially dead and buried, but others were suitable for reattachment. A special, underwater cement or ''water proof plug'' was used for reattaching those coral fragments on hard substrata. The size and type of coral fragments, and habitat, were important factors determining the success of reattaching coral fragments. Nevertheless, this method can be applied in certain areas to restore coral communities and facilitate coral reef development [18].

3.3. Public participation in coral reef restoration

Kham Island (latitude 13°14′N; longitude 100°52′E) is one of 12 islands in Sattahip Bay (inner Gulf of Thailand). A coral transplantation program was carried out to restore coral reefs damaged by coral reefs. The transplantation of hard corals (i.e., *Platygyra* spp., *Montastrea* spp., *Porites lutea, Favia* spp., *Symphyllia radians*, *Galaxea fasicularis, Montipora* spp., *Favites abdita, Pavona frondifera, Diploastrea heliopora* and *Acropora* spp.) and soft corals (i.e., *Sinularia* sp. and *Xenia* sp.) was studied from 1995 to 1997. A technique was developed for the rapid fixation of coral branches and "heads" on concrete plates, using special cement, applied in air and underwater.

A total of 260 massive coral colonies, 40 coral branches and three soft coral colonies representing 13 genera were removed by hand from reef sites degraded by high sedimentation and transported by navy boats from the collection site to the transplantation site. During transportation, the corals were kept submerged in aerated seawater that was exchanged regularly. After 6 months, the overall survival of the coral colonies was 92%; only the small colonies of *Porites lutea* died. The annual linear growth rates of the surviving colonies were recorded by measuring the maximum widths and heights. Newly generated branches of *Acropora* were also counted to examine growth rate over a longer term. The success of the project led to several subsequent coral transplantation activities supported by the Thai Royal Navy with the participation of various local community groups, students, diving clubs and the private sector [19].

3.4. Coral reef restoration in the Andaman Sea, Thailand

The study of coral reef restoration in the Andaman Coast of Thailand started in 1994 in degraded areas of Phuket Province. It is a project of the Marine Ecology Unit, Phuket Marine Biological Center, Department of Fisheries (recently reorganized as the Marine and Coastal Biology and Ecology Unit of the Phuket Marine Biological Center, Department of Marine and Coastal Resources). Two main methods are used: (1) provision of artificial substrates for natural coral recruitment and (2) coral transplantation. Different shapes of artificial substrates were deployed to test their relative effectiveness in enhancing the natural recruitment of corals (Fig. 3). This was applied particularly in areas where natural substrates were not suitable for coral larvae to settle and grow on. The coral transplantation method was appropriate for degraded areas where substrates and the environment seemed to be suitable for coral growth but no coral recruits of live coral fragments were present. *Acropora formosa* and *Porites lutea* were used. Survival and growth depended on various environmental factors [20]. The recovery of staghorn corals from the donor coral reef was feasible if a small portion of corals was used. The effectiveness and expense of the two methods provide a conceptual framework for future coral reef restoration projects.

3.5. Colonization and assemblage patterns of fishes on coral reef restoration sites

Colonization of fishes was monitored in the experimental plots of three different concrete structures used for the coral restoration study in Maithon Island, Phuket Province. Fish abundance was assessed during four sampling occasions—the first sampling or T0 (held about 1 month before the placement of the concrete structure), and three

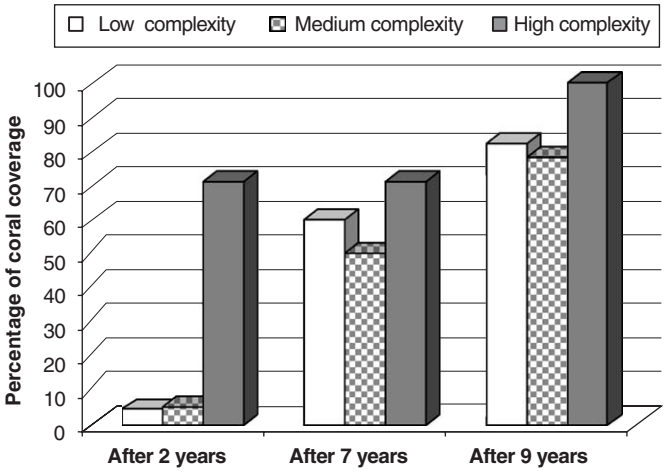

Fig. 3. Percentage of coral coverage on artificial substrates of different complexity at 2, 7 and 9 yr after the placement [20].

subsequent assessments at the fourth (T4), nineteenth (T19) and eighty-fifth (T85) month after the placement of the structures.

Early colonization of fishes, in terms of both numbers of species and individuals, was largely affected by the immigration of fishes from nearby coral patches in the reef. Most of population parameters measured at T4 were significantly greater compared to T0, but not with the following samplings (T19 and T85). Fish assemblages did not differ among the plot types of different concrete structures, while they were distinguishable over time. This was notable, especially when comparisons were made between the assemblages at T85 (as more stable in species composition) and those of the earlier periods (with much more variation in species composition) (Figs. 4 and 5). The development of fish assemblages seems, therefore, to be related to the habitat-use patterns of fishes which also coincide with the establishment and development in the community of fouling organisms, particularly corals, on the concrete structures. Because of this development, the plot area either increases or diversifies in relation to both food sources and microhabitats for fishes, ultimately promoting the assemblage of fishes in the area [21].

3.6. Coral reef restoration project for youth learning

Coastal restoration efforts in Chonburi (in the inner Gulf of Thailand) make for an interesting case study. Activities are carried out through the collaboration of a university and a local school, with partial support from the Thai Royal Navy, and mainly conducted by the Marine Science Club of the school.

In 1995, a group of students tried to save 58 live coral fragments of a branching *Acropora* sp. by attaching them with screws to designed PVC pipe frames in the coral nursery area. In order to increase the number of coral fragments in the area, they undertook coral transplantation by using the former coral fragments as donors. In 2001, they had 500 coral pieces and were expecting 10 000 in the near future. Survival rates of the transplanted corals in the nursery area were ~90–95%. The project, not only successfully

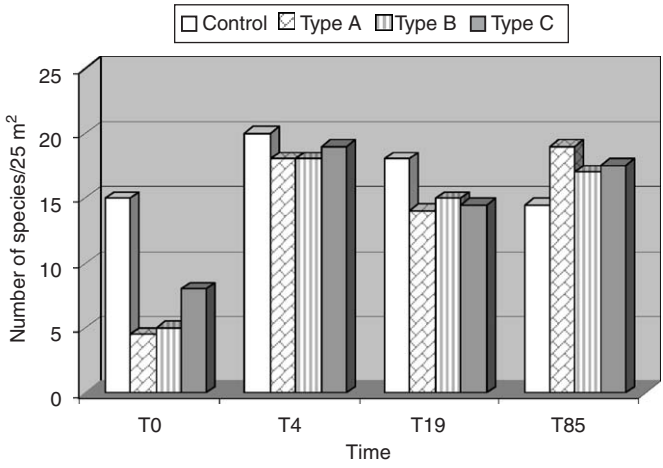

Fig. 4. Number of fish species found in the experimental plots of three different concrete structures during four sampling occasions [21].

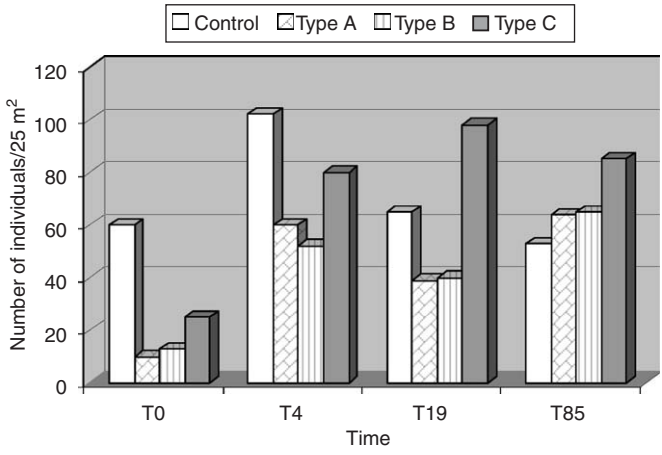

Fig. 5. Densities of fishes (individuals/25 m^2) found in the experimental plots of three different concrete structures during four sampling occasions [21].

demonstrates the importance of raising the youth's public awareness on coral reef conservation, but also provides local students with a natural "study room" and teaches them how to solve problems scientifically [22].

3.7. *Biological and ecological data for coral reef restoration*

Information obtained from the intensive studies on coral reef ecosystem in Thailand can be an important source of biological and ecological data for designing and planning coral reef restoration projects.

Koh Tao, one of the most popular tourist destinations (especially for snorkeling and scuba diving) over the last two decades, is a good case study. The degradation of coral communities here was caused by both natural and human factors. The severe coral bleaching in 1998 (the first in the Gulf of Thailand) resulted in high mortality rates for several coral species, especially *Acropora* spp., and typhoons caused patchy coral damages in certain reef sites. A variety of human forces—such as land development, wastewater discharges, increased sediment in the water (due to illegal trawling near the island), trampling by tourists, divers and anchoring—resulted in the deterioration of coral communities.

Data from the recent (2002) surveys clearly showed signs of natural recovery in Koh Tao's coral communities, however. Recruits of several coral species were found on dead coral colonies, rocky substrates and soft bottoms, and the average density of juvenile colonies was 6.44/m^2. The dominant species of juvenile colonies were *Fungia* spp., *Pocillopora damicornis* and *Echinopora lamellosa*, and other dominant coral recruits were *Pavona* sp., *Porites* spp., *Goniastrea* spp., *Favites* spp., *Leptoria* sp. and *Montipora* spp. Other observations were as follows:

- coral community conditions in deeper zones were better;
- increased abundance of macroalgae was found in certain areas; and
- there was partial mortality on head of massive corals, e.g., *Favia* spp., *Favites* spp. and *Porites lutea*, as clearly observed in shallow zones of certain study sites, such as Sai Ree Beach and Chaloak Bankao Bay.

In light of the above, a future challenge for coral reef management in Koh Tao is the implementation of integrated coastal management plans and effective tourism management. Studies on carrying capacity at Koh Tao are also urgently required to sustain coral reef resources [23–31].

4. The economic costs and benefits of coral reef restoration

Coral reefs provide a variety of goods and services resulting in socio-economic benefits to both local communities and countries [32]. The cost–benefit analysis framework is very important in assessing the justification of coral reef restoration initiatives and in helping to improve the overall effectiveness of such initiatives (Table 2). Restoration of degraded coral reefs through coral transplantation is expensive and therefore not suitable to apply to large areas of coral reef. For example, the expenses involved in coral reef restoration and maintenance, based on the project conducted by the Thai Royal Navy, was 1600–2300 baht/m^2 for transplantation and 160–230 baht/m^2/yr for maintenance [20].

5. Policy and strategic planning for coral reef management

Approximately 42% of Thailand's coral reefs lie within its 21 Marine National Parks and Fisheries Sanctuaries. Many are in good condition and are essentially "protected areas" as they are under the strict control and protection of the Thai Royal Navy and bird nest concession holders. Over 50% of Thai coral reefs are

Table 2
Framework for coral reef valuation adapted from [32]

Uses	Use values			Non-use values			Value basis		Suggested techniques
	Direct	Indirect	Option	Quasi-option	Bequest	Existence	Market	Non-market	
Extractive use									
Fish	X						X		Market price
Crab	X						X		Market price
Prawn	X						X		Market price
Molluscs	X						X		Market price
Sea cucumbers	X						X		Market price
Seaweed	X						X		Market price
Ornamental/aquarium trade	X						X		Market price
Raw materials for medicines	X						X		Market price
Non-extractive use									
Tourism/Recreation	X						X		Travel cost
Research and education	X							X	Actual cost (Gov. NGO, Academic)
Aesthetic	X							X	Hedonic price method
Sustaining the livelihood of communities	X							X	Contingent valuation method
Generation of coral sand		X						X	Replacement cost
Support of cultural, religious and spiritual values								X	Contingent valuation method
Environmental services									
Shoreline protection		X						X	Replacement cost
Nursery, feeding and breeding ground		X						X	Market Price
CO_2/Ca budget control		X						X	Replacement cost
Climate, pollution and monitoring record		X						X	Replacement cost
Biological diversity services									
Genetic diversity and resources			X					X	Contingent valuation method
Species diversity			X					X	Contingent valuation method
Migratory species		X						X	Contingent valuation method
Endangered species					X			X	Contingent valuation method
Coral reef Ecosystem						X		X	Contingent valuation method

under some form of protection and various government and non-government institutions are involved in coral reef monitoring. The main coral reef monitoring methods used are the manta tow survey, line intercept transect, permanent quadrat, fish visual census and Reef Check.

Coral reef management in Thailand rests on laws and regulations that apply to all coral reefs and on additional measures applicable only to marine protected areas. The laws and regulations that protect coral reefs in Thailand are the Fisheries Law of 1947, the National Park Act of 1961 and the Enhancement and Conservation of National Environmental Quality Act (NEQA) of 1975, among others. These are mainly enforced by the Department of Fisheries, the Department of Marine and Coastal Resources, and the Natural Parks, Wildlife and Plant Conservation Department. These agencies have encountered problems in enforcing the legislation and regulations, however. For example, a National Coral Reef Strategy was adopted by the cabinet in 1992 but did not function at the local level, so there was no evidence of reverses in coral reef degradation.

In recent years, central agencies, provincial governments, local district administration authorities and the private sector have undertaken non-regulatory action aimed at improving coral reef conditions through restoration, preventive measures and raising public awareness at all education levels.

Prevention measures and the mitigation of coral reef damage, through coral reef zoning and temporary closure of degraded coral reefs, are important interventions under the integrated coastal zone management approach. Coral reef restoration projects are obviously important activities which promote the adequate protection of important areas for reproduction (such as spawning and nursery areas) and restoration of such locations and other important habitats for marine living resources, under the work program of the Jakarta Mandate on Marine and Coastal Biological Diversity [12,33].

6. Guidelines for the consideration of coral reef restoration projects

The lessons learned in Thailand have highlighted the following points as regards coral reef restoration projects:

- The prevention and mitigation of coral reef degradation are more important than the development of coral reef restoration projects.
- Coral reef restoration projects have high costs and therefore cannot be applied in large areas. The strong implication here is that governments and communities should prevent damage to coral reefs occurring in the first place because they are unlikely to have the resources to repair them, except when damage is limited to a small area.
- Restoration methods involving the use of hard substrata should be applied in areas where the supply of larvae is good but suitable settlement habitat is scarce, whereas transplants should be targeted at areas where there are obstacles to natural recruitment.
- Projects should be carried out in limited demonstration areas where they can be easily controlled and managed for the benefit of ecosystem restoration, education, research and ecotourism.

- The long-term success of coral reef restoration projects should be ensured. For example, the projects have to select appropriate transplanted coral species for future environmental changes and sustainable uses.
- Local communities must participate actively in the planning and implementation processes for their direct and indirect benefits from the project.
- Techniques and methods used in coral reef restoration projects should be kept simple and use cheap materials available in local areas.
- Natural coral fragments should be used in coral reef restoration projects in order to increase the survival of natural coral fragments that might otherwise have had low survival because they were susceptible to being buried.
- Techniques and methods for using natural planula larvae in coral reef restoration projects should be developed, e.g., using artificial substrates for coral settlement, coral cultivation and rearing planula for settlement in the field but the cost benefit of these techniques should be compared because some will be too expensive in some situations.
- Basic data regarding coral biology—coral fragment, reproduction, settlement, recruitment and partial mortality of coral colonies—are urgently required for the planning of coral reef restoration projects in order to select the best method for a local situation.

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