

## Coral reef restoration in the South China Sea

Loke Ming CHOU<sup>1,\*</sup>, Thamasak YEEMIN<sup>2</sup>, ABDUL RAHIM Bin Gor Yaman<sup>3</sup>,  
Si Tuan VO<sup>4</sup>, Perry ALINO<sup>5</sup>, and SUHARSONO<sup>6</sup>

<sup>1</sup> Department of Biological Sciences, National University of Singapore, Blk. S3, 14 Science Drive 4, Singapore 117543, Singapore

<sup>2</sup> Marine Biodiversity Research Group, Faculty of Science, Ramkhamhaeng University, Huamark, Bangkok 10240, Thailand

<sup>3</sup> Marine Parks Section, Ministry of Natural Resources and Environment, 3<sup>rd</sup> Floor, Wisma Awal, Jalan Raja Muda Abdul Aziz, Kg. Bahru, Kuala Lumpur, Malaysia

<sup>4</sup> Institute of Oceanography, 01 Cau Da Street, Nha Trang City, Viet Nam

<sup>5</sup> Marine Science Institute, University of the Philippines, Diliman, Quezon 1101, Philippines

<sup>6</sup> Research Center for Oceanography – Indonesian Institute of Sciences, Jl. Pasir Putih, 1 Ancol Timur, Jakarta, Indonesia

\* Corresponding author: L.M. Chou

E-mail: dbسلم@nus.edu.sg

Communicated by Makoto Tsuchiya

**Abstract** Restoration of coastal reefs in the South China Sea started in the 1990s in response to widespread degradation of reef habitats. A wide variety of restoration techniques is practiced including coral transplantation, substrate modification, and non-coral species stock enhancement. Interesting lessons are derived from these experiences. Protection and management remains the foremost option and should continue to be strengthened. Restoration is more costly and has its limitations, but is at the same time regarded as necessary to address extensive reef loss. Much can be gained from the sharing of information and the combined experience will help to advance the science of reef restoration for the region.

**Keywords** reef restoration, South China Sea, corals

---

### Introduction

Protection of coral reefs is recognized as the preferred management option but the degradation of coral reefs worldwide (Wilkinson 2008) highlights the continued challenge of effective management. Reef restoration is a poor substitute for reef protection but large areas of degraded reefs make it inevitable to completely disregard it. Restoration efforts have expanded in recent years, resulting in a wide range of projects broadly classified as improving the existing condition of reefs that are impacted by human activity.

Early initiatives were based on the concept of artificial reefs with structures better known as “fish-aggregating devices” developed on non-reef platforms mainly to enhance fisheries production (e.g. Aska 1981; D’itri 1985). While this approach is still being expanded (Nakamura et al. 1991; Seaman and Sprague 1991), more recent activities

are directed specifically at restoring degraded reefs (e.g. Maragos 1992; Jaap 2000; Fox et al. 2003).

The diversity and scale of restoration projects vary tremendously. They cover habitat modification, coral transplantation, species re-introduction, and recruitment potential enhancement. Some of these interventions involve large-scale sub-tidal structures designed to facilitate natural colonization of reef-related species (e.g. Jensen 1997; Pickering et al. 1998; van Treeck and Schumacher 1999), while others use simpler and less costly approaches that are more readily replicated and suitable for coastal community involvement (Bowden-Kerby 2001; Franklin et al. 1998; Rinkevich 2000).

Reef restoration will continue to have an increasingly important role and efforts are likely to expand (Jaap and Hudson 2001). However, viable approaches and technologies are in relatively early stages of development, and for most cases are currently difficult to implement over large spatial scales (Edwards and Gomez 2007). Levels of understanding are still largely based on personal experiences (Precht 2001).

The South China Sea is a large marine ecosystem of three million km<sup>2</sup>. Coastlines of the nine states bordering the sea are liberally endowed with coral reefs but degradation of these reefs is well documented (Chou et al. 2004). Most reef restoration activities in the South China Sea region began after 1990 as a common response to the habitat's widespread degradation and have expanded in recent years. Southeast Asia has extensive experiences with artificial reefs (White et al. 1990) but the real benefits have never been fully quantified (Chou 1997). Artificial reef and reef restoration projects continue to be active throughout Southeast Asia (SEAFDEC 2005).

Regional experiences are reviewed in this paper and since most of the data have not been published or appear in grey literature or in the national language, the information presented here may be of use to future reef restoration endeavors. The review was carried out by members of the Coral Reef Working Group of the UNEP/GEF Project "Reversing Environmental Degradation in the South China Sea and Gulf of Thailand" (concluded in 2008) who have been involved with reef restoration. It documents the experiences of Malaysia, Indonesia, Philippines, Singapore, Thailand and Viet Nam in reef

restoration within the coastal waters of the South China Sea.

## Restoration techniques and initiatives

### Transplantation of entire colonies

Coral transplantation appears to be the most common and widespread technique used among the countries. Transplantation of whole colonies from sites that were designated for development is a popular management response conducted by both government and non-government agencies. Other projects make use of coral fragments instead of entire colonies, and this appears to be a more widely adopted option. The long-term survival and adaptability of transplants are important considerations determining a project's success (Yap 2003).

A project in Peninsular Malaysia transplanted about 100 branching coral colonies to a 20 m × 10 m area thirty meters from the original site. Wire mesh was placed at the bottom to ensure that the transplanted colonies stayed upright during the six months of monitoring and a 70% survival rate was recorded. This technique is adopted by Malaysia's marine parks authority for the restoration of small shallow reefs (less than 6 m depth) damaged by boat grounding or anchor drop. There are intentions to further refine the technique and increase survival rate by raising transplants half a meter above the bottom.

At Kham Island, one of twelve in Sattahip Bay (inner Gulf of Thailand), a transplantation programme was developed to restore damaged reefs. Transplanted hard (*Platygyra* spp., *Montastrea* spp., *Porites lutea*, *Favia* spp., *Symphyllia radians*, *Galaxea fascicularis*, *Montipora* spp., *Favites abdita*, *Pavona frondifera*, *Diploastrea heliopora* and *Acropora* spp.) and soft corals (*Simularia* sp. and *Xenia* sp.) were observed from 1995 to 1997 and a technique was developed for the rapid fixation of coral branches and 'heads' onto concrete plates using underwater cement. A total of 260 massive and 40 branching hard coral colonies and 3 soft coral colonies representing the 13 genera were manually dislodged from reef sites degraded by high sedimentation and transported by navy boats to the transplantation site. Throughout transportation, the corals were kept submerged in aerated seawater

that was constantly replenished. Overall survival of the coral colonies after 6 months was 92% and only the small *Porites lutea* colonies died. Annual linear growth rates of the surviving colonies were recorded by measuring their maximum diameter and height and newly generated branches of *Acropora* were counted to examine growth rate over a longer term. The project's success led to several subsequent coral transplantation activities supported by the Thai Royal Navy with the participation of various groups of local communities, students, diving clubs and the private sector (Chunhabandit et al. 1999). No further updates of the project are available. However the Thai Royal Navy is still actively supporting reef restoration projects employing several restoration methods.

The Nature Society of Singapore translocated corals from a site that was to be lost to land reclamation in the early 1990s. It was widely publicized as the world's largest coral transplantation program supported by volunteer divers. The group claimed survival of over 90% but surveys by scientists from the National University of Singapore established that less than 11% of the transplants survived, as no attempt was made to secure transplanted colonies to the substratum (Chou and Tun 1997).

### Transplantation of fragments

The use of coral fragments is widely practiced in the region's reef restoration efforts. The first restoration attempt in Thailand by a team from Burapa University made use of fragments cemented onto concrete blocks. Survival rates of three species: *Porites lutea*, *Acropora* sp. and *Pocillopora damicornis*, were 95%, 83% and 42% respectively. Epoxy-cement mixture gave the best adhesion but is costly for large-scale application and an even mixture of cement, gypsum plaster and sand was developed. In 1993, thirty blocks of attached *Acropora* fragments were deployed in the degraded reef at the western side of Krok island, covering a total area of 30 m<sup>2</sup>. Growth of the transplants was vigorous at 6–10 cm/yr even after 12 months. Survival rate was 88.24% after two months (Sirirattanachai 1994; Sirirattanachai et al. 1994). No further monitoring data are available

Naturally occurring coral fragments resulting from intensive grazing or boring (also known as “corals of opportunity”) are also suitable for transplantation. Frag-

ments of branching *Acropora* and *Goniopora*, massive *Porites lutea* and faviid corals from a non-reefal coral community at Khang Khao Island (inner Gulf of Thailand) were fastened to hard substrata with underwater cement. The size and type of coral fragments, and habitat, were important factors determining survivability and the approach can be applied elsewhere to restore coral communities and facilitate reef development (Yeemin and Chunhabandit 1999). An interesting restoration effort was initiated in Chonburi in 1995 through the collaboration of a local university and a school, with partial support from the Thai Royal Navy. The activity was conducted mainly by the Marine Science Club of the school. Students attached 58 live branching *Acropora* fragments to specially designed PVC pipe frames within the coral nursery area. The original fragments were re-fragmented to increase the number of fragments to 500 by 2001 and the ultimate target was 10,000 fragments. From experiments to determine optimal fragment size for transplant, fragments of at least 3cm length showed highest survival. Survival in the nursery area was between 90 and 95%. The project demonstrated the importance of raising reef conservation awareness in youth through experiential learning and involvement (Saengpaiboon 2003).

Viet Nam's reef restoration efforts are more recent but commonly make use of fragment transplants taken from good reefs. These are secured to dead coral, concrete blocks, concrete tubs or steel rods. The first rehabilitation trials were initiated in 2000 at Con Dao reefs, which were impacted by typhoon Lynda, followed by other projects in Van Phong and Nha Trang between 2002 and 2005 but little monitoring was carried out and no proper evaluation could be made. More extensive rehabilitation measures were implemented under a national project to restore and manage coral reefs in south Qui Nhon Bay (Binh Dinh province) where coral reefs suffered serious degradation due to coral mining and destructive fishing and systematic data were generated from 2002 to 2004. Fast growth was noted for species such as *Acropora nobilis*, *A. yongei* and *A. microphthalma*. *Porites nigrescens* demonstrated good adaptation to seasonal change. Foliose corals of *Montipora*, *Echinopora*, *Pachyseris*, *Echinopora* and branching *Acropora* and *Porites* were useful for natural rehabilitation. At one experimental site, all restored corals died

during the rainy season after growing well throughout summer, indicating susceptibility to sudden influx of fresh water and sediment (Vo et al. 2005). Within the framework of the UNEP/GEF South China Sea Project, restoration using coral fragment transplantation was initiated for reefs in Phu Quoc archipelago. More than 700 fragments from eight species (*Acropora nobilis*, *A. microphthalma*, *A. millepora*, *A. copiosa*, *A. microclados*, *A. digitifera*, *Pocillopora damicornis*, and *Porites cylindrica*) were transplanted. Average survival rate was over 80% and 70% after six and twelve months respectively. *Porites cylindrica* had the highest survival but slowest growth rate.

Singapore established an *in-situ* coral nursery in 2007 for the sole purpose of conservation, making full use of “corals of opportunity”. Coral fragments lying free on the reef from some impact and unconsolidated coral rubble with settled larval recruits were collected and secured to raised mesh platforms to allow sediment to fall through. The intervention improved survival and growth with fragments increasing to sizes suitable for transplanting back to reefs after one year. The fragments represented various growthforms from a wide generic diversity (*Montipora*, *Acropora*, *Pachyseris*, *Pavona*, *Madracis*, *Stylocoeniella*, *Turbinaria*, *Euphyllia*, *Physogyra*, *Caulastrea*, *Cyphastrea*, *Echinopora*, *Favia*, *Favites*, *Goniastrea*, *Montastrea*, *Oulastrea*, *Platygyra*, *Lithophyllon*, *Podabacia*, *Hydnophora*, *Merulina*, *Acanthastrea*, *Lopophyllia*, *Symphyllia*, *Galaxea*, *Echinophyllia*, *Mycedium*, *Oxypora*, *Pectinia*, *Pocillopora*, *Alveopora*, *Goniopora*, *Porites*, *Psammocora*, and *Pseudosiderastrea*). The project demonstrated a strong partnership between government agencies (National Parks Board and Ministry of Environment and Water Resources), research institution (National University of Singapore) and the private sector (Keppel Corporation).

### Substrate modification

Stabilization of the bottom substrate or the provision of artificial substrate may be necessary if the bottom is damaged, become unstable with loose rubble or silted over to prevent larval recruitment and survival. This approach is somewhat similar to the artificial reef concept, except that it is applied only when substratum damage has

occurred. Various structural configurations have been used ranging from simple cover slabs to high profile complex structures. Materials also vary widely from PVC tubing to concrete and fiberglass.

The criteria adopted by Malaysia for selecting the type of artificial reef structure include mobilization ease, low cost and non labor-intensive. Trials in mid-1990s used PVC tubing of different designs and size. One design was finally adopted for further testing and in 1995, five units were installed at 5m depth within reef areas at two sites (Pulau Perhentian and Pulau Redang) in Terengganu. The study showed that coral colonization on PVC material was slow, taking 10 years to achieve the desired size.

In the sediment-impacted reefs of Singapore, hemispherical domes made of fiberglass indicated their suitability in attracting natural recruits and supporting growth of fragment transplants (Loh et al. 2006). Fiberglass was used as each unit was sufficiently light to be deployed by a diver. This ensured that units were secured at exact locations of a reef without damaging or affecting existing live coral.

Instead of introducing man-made materials, restoration attempts have been made in the Philippines using giant clam shells. These are suitably large and effective for stabilizing soft bottoms. Live coral colonies have been observed growing on the shells of live clams and shells of dead clams provide a calcium carbonate substrate for the attachment of coral transplants (Guest et al. 2009).

In Viet Nam coral fragments were attached directly to dead coral substratum when present. Steel poles were used to increase stability of dead coral substratum if needed. Where dead coral is not available, concrete tubs were used, which had the advantages of stability and sediment rejection slopes.

### Stock enhancement

Species re-introduction is another reef restoration option that is widely adopted especially in the Philippines. It can help to improve ecosystem balance of degraded reefs by replenishing highly overfished species and at the same time involve and benefit dependent coastal communities. Giant clams have been successfully reseeded in Batangas, Masinloc and the Lingayen Gulf. Other invertebrates such as, sea urchins, top shells (*Trochus*), sea

cucumbers and abalone have been reseeded in four community-managed marine sanctuaries in Bolinao, Anda, San Fernando and La Union. Livelihood grow-out efforts are also promoted in Ilocos Sur Province. Restocking of high-value species, which improve the livelihood of coastal communities, ultimately benefits the whole reef by increasing community participation in its management.

Restoration of reef invertebrates such as giant clams and cone shells is now being tested in Viet Nam's Nha Trang bay and Phu Quoc archipelago by staff of the Institute of Oceanography in collaboration with the private sector and local communities.

## Lessons learned

The various experiences in reef restoration have provided valuable lessons. A common observation is that prevention and mitigation of coral reef degradation are more important management options than restoration. This is because restoration cost is high and impractical for large areas. In Thailand, it is recognized that local governments and communities should prevent coral reef damage in the first place as they are likely to lack resources to repair reefs, except for small-scale damage (Yeemin et al. 2006). The high cost currently limits Indonesia's initiatives to training, awareness raising and community participation, most of which are facilitated through the Coral Reef Rehabilitation and Management Program (COREMAP).

There is growing realization in Viet Nam that protecting and managing reefs is a less costly option, requires less effort and is more acceptable to local communities than restoring damaged reefs. Similarly, coral transplantation in Malaysia is viewed as costly if a rigorous procedure is to be followed to ensure good survival. This has prompted a management response in Malaysia recognizing that the best option is to zone the damaged area to be rehabilitated and control its use to allow natural regeneration, which is considered to be the most cost effective, requires minimal intervention, and does not involve introduction of artificial structures. The Malaysian experience indicates that rehabilitation of coral at sites impacted by water quality change is not economical because of low survival. This

view is shared by Thailand, stressing that site selection should consider the intensity of human-induced physical changes and avoid areas that are too heavily impacted.

Techniques and monitoring are also important considerations. Restoration methods involving the use of hard substrata should be applied in areas where larval supply is good but suitable settlement substrate is scarce. Transplants should be considered in areas where natural recruitment is not favored. Natural coral fragments should be used in reef restoration projects in order to enhance their survival, as they are likely to be lost through high mortality. It is also useful for techniques and methods employed to be simple and making use of locally available low-cost materials. In Viet Nam, suitable material for transplant attachment is dead coral substratum, followed by concrete blocks. From Malaysia's experience, live coral is only suitable for transplanting to nearby areas (less than 100 meters away), if it is to be moved underwater. It is also observed that coral colonization of artificial structures installed at shallow depths of 3 to 5 meters is slow in Malaysia.

The long-term success of reef restoration projects should be considered and further research is useful for identifying appropriate strategies. For example, transplanted species should be selected for their tolerance of future environmental changes and sustainable exploitation. In Thailand, it is recognized that projects should be limited to demonstration areas where they can be easily controlled and managed for the benefit of ecosystem restoration, education, research and ecotourism. Restoration has to be fully integrated with management. Basic data on coral biology (fragmentation, reproduction, settlement, recruitment and partial colony mortality) are urgently required for better selection of species and restoration techniques for a particular situation. Techniques for using natural planula larvae in reef restoration should be developed, e.g. using artificial substrates for coral settlement, coral cultivation and rearing planula for settlement in the field but cost may negate benefit until cheaper solutions are developed. There is also a need to consider bottom sand movement during monsoon seasons.

Community involvement is paramount to the success of reef restoration efforts and it has the added benefit of raising awareness. The observation that local communi-

ties must participate actively in the planning and implementation processes so that they benefit fully from the project is common to most of the countries. Local communities in Viet Nam were involved and provided with skills training to win their support for the restoration effort and management. In Indonesia, action was initiated to ensure strong local community involvement in all aspects of reef management. Communities were trained to participate in establishing of baseline conditions with particular attention to live coral cover, reef fish diversity and benthic diversity. Field facilitators were appointed to develop community-based management frameworks that included provision of alternative income-generation activities, and to involve local communities in selecting, securing, controlling and monitoring Marine Protected Areas. Experience from the Senayang-Lingga Sub District of the Riau Island Province indicated that from 2000 to 2001, live coral cover increased 5.1% following implementation of community-based management.

## Discussion

Reef restoration is an inevitable intervention that can assist, to some extent, in slowing down the rate of degradation. The common message is that protection should remain as the prime management option as restoration is costly, labor intensive and cannot be applied practically across large spatial scales. The slow growth of corals makes it difficult to assess long-term efficacy. The science of reef restoration is still new and many questions constantly surface. This has resulted in many different attempts throughout the South China Sea region using a wide variety of techniques and with varying results.

Interesting lessons are emerging from all these various attempts and a sharing of information together with regular synthesis of what works where, when and why, will help to improve reef restoration strategies and techniques throughout the region. For example, Malaysia has formulated guidelines for transplanting corals based on national experiences (Table 1). Information gaps can be filled through the sharing of regional experiences and help to strengthen the region's capability in reef restoration. It is also noteworthy that reef restoration has increased the

awareness of coastal communities to reef management and offers ample opportunities for direct community participation and ownership.

Based on existing experience, it appears best if reef restoration be attempted only after seriously considering the following:

1. does site condition favor restoration?
2. will restoration have a lasting effect?
3. is there a management framework in place for the restoration site?
4. has the adopted technique been tested on a pilot scale at site?
5. is the technique scientifically sound and tested?
6. will there be long-term monitoring?

Two recent international reef restoration projects targeted field research in the region to address many of the open questions in restoration science and to examine the scientific validity of different techniques in use. The World Bank/GEF Coral Reef Targeted Research and Capacity Building for Management Project, now in its second phase, has a component dealing with reef remediation and restoration focusing on long-term efficacy and cost-effectiveness of restoration interventions, larval recruitment and coral transplantation. Most of the research was conducted in Bolinao (Philippines). The recently-concluded European Commission INCO-DEV project "Developing ubiquitous restoration practices for Indo-Pacific coral reefs" conducted field investigations in Bolinao, Phuket and Singapore. It had a strong focus on restoration using nubbins and small coral fragments. The results from both projects will help to strengthen the scientific understanding of reef restoration that will benefit all stakeholders and make reef restoration more effective.

## References

- Aska DY (ed) (1981) Artificial reefs: conference proceedings. Florida Sea Grant College, Report No. 41
- Bowden-Kerby A (2001) Low-tech coral reef restoration methods modeled after natural fragmentation process. *Bull Mar Sci* 69: 915–931
- Bryant D, Burke L, McManus J, Spalding M (1998) Reefs at risk, a map-based indicator of threats to the World's coral

**Table 1** Guidelines for transplanting corals (Marine Park Authority, Malaysia)

Corals experience stress and will ultimately die if exposed for extended periods to poor water quality with high sediment load. Water quality could be affected by coastal development projects. Marine Park Authority, is tasked with preserving coral reefs in the vicinity of such projects. Its first priority is to consider all things possible to avoid the construction or to minimise identifiable changes in order to avoid harming the natural reef systems. As a last measure but not promoting it as a feasible option, corals need to be translocated to a suitable and safe location. Not all coral types can be transplanted, and only the fast growing branching *Acropora* spp. are suitable.

These guidelines were tested, revised and finally adopted for used in future transplantation of coral for restoration of small reef areas.

- a) Survey the area and document existing species and relative abundances.
- b) Locate a suitable new receiving location for the corals that has similar water quality and substrate quality parameters.
- c) Before commencing any coral transplanting project, a written approval must be obtained from the Director, Marine Parks Section, Ministry of Natural Resources and Environment, Malaysia. Conditions are imposed, and amongst others, the transplantation work will have to be monitored and supervised by staff of Marine Parks.
- d) The location where the source of coral transplants is to be gathered must be approved by the Director, Marine Parks Section, Ministry of Natural Resources and Environment, Malaysia.
- e) Coral transplants must be removed manually and the use of mechanized equipment is prohibited.
- f) Diver care and prudence should be adhered to during the collection of coral transplants. Divers are prohibited from trampling on the coral, handling or touching coral other than that to be transplanted. Churning of sediment should be avoided during the operation.
- g) Before removing the transplants, mark the north orientation on the coral. Transplanted coral should be aligned with the original orientation prior to removal.
- h) Coral transplants should be selected from a coral reef that is healthy, i.e. more than 80% of the surface is in good condition, not broken or of poor health.
- i) During the transfer process, coral transplants should not be raised more than 2 meters above the original depth where the transplants were collected from. Avoid sudden changes in depth during the transfer process.
- j) Coral transplants should be placed on a substrate of dead corals, or platform, preferably half a meter above the sea bed. Coral transplants should not be placed on living coral as a base.
- k) Distance between each clump of coral transplants should be more than 0.5 meters for branching corals and 0.2 meters for boulder corals.

reefs. World Resources Institute

Chou LM (1997) Artificial reefs in Southeast Asia – do they enhance or degrade the marine environment. *Environ Monit Assess* 44: 45–52

Chou LM, Tun KPP (1997) Coral transplantation as a reef conservation tool – the Singapore experience. *PACON 97 Proceedings*. PACON International, Hawaii

Chou LM, Ridzwan AR, Kim S, Suharsono, Abdul Khalil AK, Alino PM, Yeemin T, Vo ST, Jiang Y (2004) Coral reefs in the South China Sea. *UNEP/GEF/SCS Technical Publication No.2*, UNEP Bangkok

Chunhabandit S, Teva-aruk N, Yeemin T, Thapanand (1999) Studies on coral restoration by transplantation at Kham Island Marine Park, Sattahip naval base, the Thai Royal

Navy, upper gulf of Thailand. International Workshop on the Rehabilitation of Degraded Coastal Systems, Phuket Marine Biological Center, Thailand

D'itri FM (ed) (1985) *Artificial reefs: marine and freshwater applications*. Lewis Publishers, Michigan

Edwards AJ, Gomez ED (2007) Reef restoration concepts and guidelines: making sensible management choices in the face of uncertainty. *Coral Reef Targeted Research & Capacity Building for Management Programme*. St. Lucia, Australia

Fox HE, Mous PJ, Muljadi A, Purwanto, Pet JS (2003) Enhancing reef recovery in Komodo National Park, Indonesia: coral reef rehabilitation at ecologically significant scales. Report from The Nature Conservancy, Southeast Asia Center for

- Marine Protected Areas in collaboration with Komodo National Park Authority
- Franklin H, Christopher A, Muhando A, Lindahl U (1998) Coral culturing and temporal recruitment in Zanzibar, Tanzania. *Ambio* 27: 651–655
- Guest JR, Dizon RM, Edwards AJ, Franco C, Gomez ED (2009) How quickly do fragments of coral “self-attach” after transplantation? *Restor Ecol* (doi: 10.1111/j.1526-100X.2009.00562.x)
- Jaap WC (2000) Coral reef restoration. *Environ Eng* 15: 345–364
- Jaap WC, Hudson JH (2001) Coral reef restoration following anthropogenic disturbances. *Bull Mar Sci* 69: 333
- Jensen AC (Ed.) (1997) European artificial reef research. Proceedings of the 1st EARRN (Europe Artificial Reef Research Network) Conference, March 1996, Ancona, Italy. Southampton Oceanography Centre, Southampton, U.K.
- Loh TL, Tanzil JTL, Chou LM (2006) Preliminary study of community development and scleractinian recruitment on fiberglass artificial reef units in the sedimented waters of Singapore. *Aquat Cons: Mar Freshwater Ecosys* 16: 61–76
- Maragos JE (1992) Restoring coral reefs with emphasis on Pacific reefs. In: Thayer GW (ed) Restoring the nation’s marine environment. Maryland Sea Grant College (UM-SG-TS-92-06), pp 141–221
- Nakamura M, Grove RS, Sonu CJ (Eds) (1991) Recent advances in aquatic habitat technology. Proceedings of the JAPAN-U.S. Symposium on Artificial Habitats for Fisheries, June 11–13, 1991, Tokyo. Southern California Edison Company, Environmental Research Report Series 91-RD-19
- Pickering H, Whitmarsh D, Jensen A (1998). Artificial reefs as a tool to aid rehabilitation of coastal ecosystems: investigating the potential. *Mar Pollut Bull* 37: 505–514
- Precht WF (2001) Improving decision-making in coral reef restoration. *Bull Mar Sci* 69: 329–330
- Rinkevich B (2000) Steps towards the evaluation of coral reef restoration by using small branch fragments. *Mar Biol* 36: 807–812
- SEAFDEC (2005) Proceedings of the Second Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia, 9–12 November, 2004, Thailand. Training Department, Southeast Asian Fisheries Development Center
- Saengpaiboon P (2003) Techniques and methods for coral reef rehabilitation. In: Department of Marine and Coastal Resources (ed) Proceedings of the Workshop of Coral Reef Rehabilitation, Bangkok, Thailand, 2003 (in Thai)
- Seaman Jr W, Sprague LM (eds) (1991) Artificial habitats for marine and freshwater fisheries. Academic Press, California
- Sirirattanachai S (1994) Transplantation for coral rehabilitation. In: Sudara S, Wilkinson CR, Chou LM (eds) Proceedings of the Third ASEAN-Australia Symposium on Living Coastal Resources Volume 2, Department of Marine Science, Chulalongkorn University, Bangkok, Thailand, p 185
- Sirirattanachai S, Boonphadee T, Singkoravat N (1994) An approach to the rehabilitation of coral reef with coral transplantation in the eastern coast of Thailand. In: Sudara S, Wilkinson CR, Chou LM (eds) Proceeding of the Third ASEAN-Australia Symposium on Living Coastal Resources Volume 2, Department of Marine Science, Chulalongkorn University, Bangkok, Thailand, p 193
- van Treeck P, Schumacher H (1999) Artificial reefs created by electrolysis and coral transplantation: an approach ensuring the compatibility of environmental protection and diving tourism. *Estuar Coast Shelf Sci* 49: 75–81
- Vo ST, Nguyen HY, Nguyen VL (2005) Coral reefs of Viet Nam. Publishing House of Science and Technique, Ho Chi Minh City
- White AT, Chou LM, De Silva MWRN, Guarin FY (1990) Artificial reefs for marine habitat enhancement in Southeast Asia. ICLARM Education Series 11. International Center for Living Aquatic Resources Management, Manila, Philippines
- Wilkinson C (ed) (2008) Status of coral reefs of the world: 2008. Australian Institute of Marine Science, Townsville
- Yap HT (2003) Coral reef “restoration” and coral transplantation. *Mar Pollut Bull* 46: 529
- Yeemin T, Chunhabandit S (1999) Reattachment of coral fragments using special cement in non-reef coral communities in the inner Gulf of Thailand. International Workshop on the Rehabilitation of Degraded Coastal Systems, Phuket Marine Biological Center, Thailand
- Yeemin T, Sutthacheep M, Pettongma R (2006) Coral reef restoration projects in Thailand. *Ocean Coast Manag* 49: 562–575

Received: 10 September 2009

Accepted: 13 October 2009