IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Restoration of Coral Reefs: Challenges and Sustainability concern

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1. Abstract

Coral reefs are one of an incredibly beneficial ecosystems on earth. Coral reefs are important for our world for several reasons. Besides the fact that they are very scenic and attract tourists, thus they function as a very massive income in environmental and economic professional employment, such as tourism, and food, and coastal protection, and they have variant benefits for our marine environment and the world such as symbioses and a source to finding medicament A substantial proportion of the world's living species, including one-third of the reef-building corals, are threatened with extinction and in pressing the need for conservation action. In this paper we point out the importance and possible extinction. Although relatively few coral reef fishes are at risk of global extinction from climate disturbances, a negatory convex relationship between fish species locally vulnerable to climate change vs. fisheries exploitation indicates that the entire community is vulnerable to the many reefs. Techniques to restore the coral reefs impacted by human disturbance are; salvaging sponges and corals, removing loose debris from the reef, rebuilding three-dimensional (3-D) structures onto levelled-scarified reef surfaces, and transplanting sponges and corals back on the cleared reef surfaces. A substantial proportion of the world's living species, including one-third of the reef-building corals, are threatened with extinction and in pressing the need for conservation action.

Keywords: symbioses, corals, coral reefs, coral bleaching

Abbreviations: 3-D: Three-dimensional, mm: Millimetre, km: Kilometres, IUCN: International Union for Conservation of Nature, TCM: Traditional Chinese Medicine

2. Introduction:

2.1. What are corals/types of coral?

Corals are two-layered invertebrates that live in groups (i.e. they are *colonial*) and arewith a ring of tentacles surrounding their mouth and looks like tiny anemone. Polyps withina colony are linked by living tissues and can share their food (Allen &Steene, 1994). Insome corals, the polyp extracts calcium carbonate from the sea and secretes it as a cupof calcium carbonate from the bottom half of its body. These cups provide anchoragefor the polyps, but when threatened, the polyp can retreat into the safety of the hard cup.When the calcium carbonate cups of many billions of these polyps fuse together, theyform coral reefs (Veron, 2000).

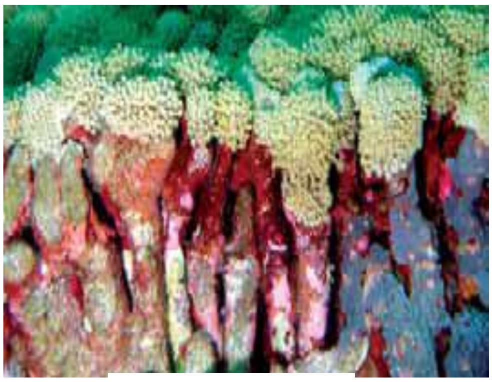
2.2. There are two main types of corals:

2.2.1. Stony (Hard) Corals:

Some stony corals obtain their food from one-celled organisms called *zooxanthellae*.Zooxanthellae are single-celled organisms that use sunlight for photosynthesisand transfer 95% of their food to coral polyps. Both coral and zooxanthellae benefit from this association. The zooxanthellae receive protectionfrom currents and herbivores and some nutrients from waste produced bycoral polyps. This kind of association - where two different kinds of organisms benefit from each other - is called a *mutualistic* association. These corals are called*hermatypic corals***.** Individual polyps of hermatypic corals secrete calcium carbonate(limestone) skeletons which, in time, form coral reefs. Therefore, hermatypic coralsare also known as reef-building corals.

A. Massive

B. Encrusting

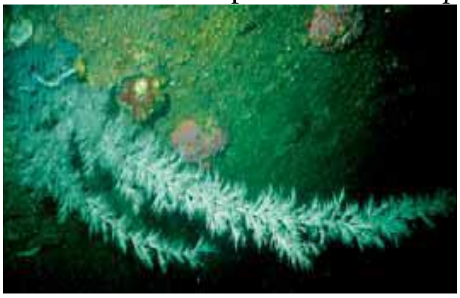


C Columnar

Fig-1 Types of Stony Corals.

2.2.2. Soft corals:

Soft corals lack a calcium carbonate skeleton, hence their common name. However, intheir bodies are tiny hardened calcium particles called *spicules* that provide support.Some selected soft corals are shown below.



A. Fire and LaceCorals

B. Blackor Thorny corals

C. Sea fans

D. Sea whips

Fig-2 Types of Soft Corals

2.3. What are coral reefs?

Coral reefs are skeletons of stony coral polyps cemented together. Corals grow veryslowly - some grow only about 3-20mm per year. Therefore, some reefs form over severalmillion years (Veron, 2000).As these corals grow and die, they leave behind their calcium carbonate skeletons.On these skeletons, other corals grow. As the years pass, walls of coral begin to form:massive walls of rock. As the waves and currents beat upon these reefs, nooks, crannies,ledges, and caverns form in these walls.Just as there are different types of corals, there are different types of coral reefs. Thethree main types of reefs are fringing reefs, barrier reefs, and atolls (Veron, 2000).

2.3.1. Fringing reefs:

Fringing reefs are coral reefs that grow in shallow waters. They closely border the coastline or are separated from it by a narrow stretch of water. Many of the reefs around Sri Lanka and Thailand are fringing reefs.

2.3.2. Barrier reefs

Barrier reefs grow parallel to the coast but are separated from land by a lagoon. They are found sometimes many kilometres from shore (10–100km). Barrier reefs can grow in fairly deep water, because, often, the living coral builds upon remains of corals that grew in the same area when the sea level was lower, during the last iceage. The Great Barrier Reef of Australia extends about 2,010km parallel to the east coast.

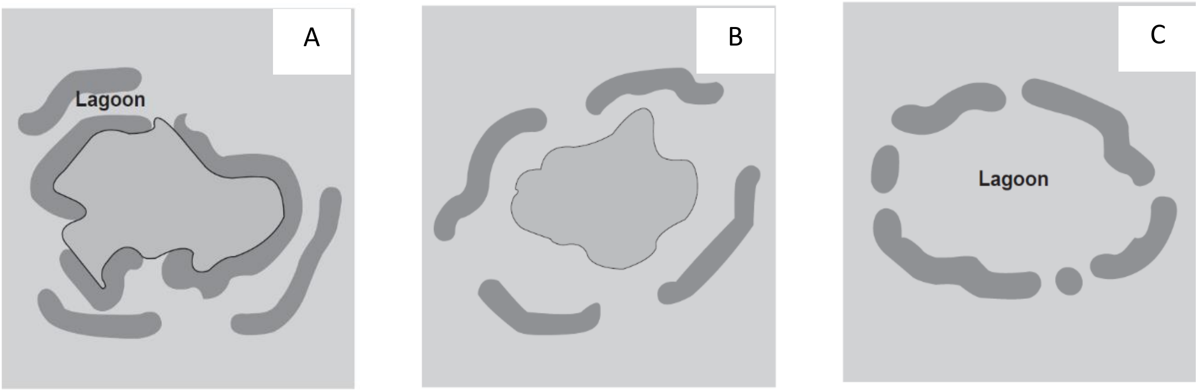


Fig-3 A Fringing reefs B. Barrier reefs C. Atolls

2.3.3. Atolls

Atolls grow to surround (or partly surrounding) an island which then sinks relative to sea level (usually becausevolcanic activity forming the island stops), or was flooded as sea level rose after the last ice age. Atolls surround (or partly surround) a central lagoon. The Maldives consists of 26 atolls. Although these are the three main types of reefs, there are many reefs that do not fit these models.

2.4. Where are coral reefs found in the world?

Coral reefs are found

• where the sea is shallow (less than 100m);

• where the sea is warm (usually between 25° and 29°C);

• and therefore, are located within the latitude of 30°N to 30°S i.e., only in tropical seas.

Warm-water coral reefs are prominent ecosystems within coastal areas of the Pacific, Indian, and Atlantic oceans (Figures A,B), where they are typically found in a broad band (30°S to 30°N) of warm, sunlit, alkaline, clear, and relatively nutrient deficient ocean waters (Kleypas et al., 1999b). Here, Scleractinian or reef-building corals proliferate, depositing copious amounts of calcium carbonate. As corals die, their dead skeletons build up over time and are “glued” together by the activities of other organisms such as encrusting red coralline algae (Glynn and Manzello, 2015).

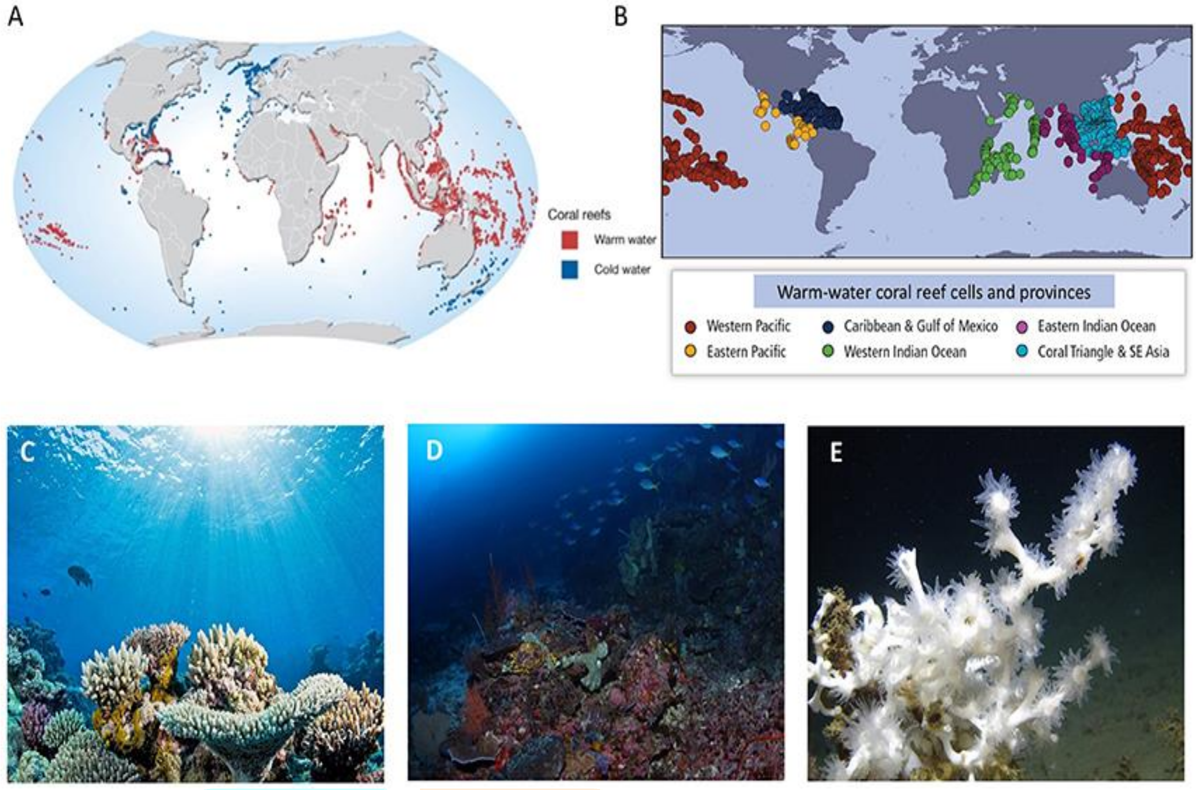


Fig-4 A&B Coral reefs are prominent ecosystems within coastal areas of the Pacific, Indian, and Atlantic oceans. C, D &E 3-D structures of coral reef.

Other organisms such as calcifying green algae, invertebrates, and phytoplankton also contribute to the overall carbonate budget of warm water coral reefs (Hutchings and Hoegh-Guldberg, 2009), leading to three-dimensional calcium carbonate structures that build up over hundreds and thousands of years.

In turn, the three-dimensional structures (Figure C) within warm-water reef systems creates habitat for hundreds of thousands of species, many of which support coastal human populations with food, income, and other ecological goods and services such as coastal protection. Coral reefs are also important sources for bio-prospecting and developing novel pharmaceuticals.

The asset value of coral reefs has been estimated as close to $1 trillion (Hoegh-Guldberg, 2015) with the economic value of goods and services from coral reefs exceeding $375 billion annually, with benefits flowing to over 500 million people in at least 90 countries worldwide (Burke et al., 2011; Gattuso et al., 2014b).

2.5. What are the threats to coral reefs?

Despite their immense ecological, economical and aesthetic values, it is estimated that 20% of the world's coral reefs have been destroyed (Wilkinson, 2004). Another 24% are at high risk of collapse, and yet another 26% at risk from long term collapse as a result of human activities. If the present rate of destruction continues, 70% of the world's coral reefs will be destroyed by the year 2050 (http://www.nature.org/joinanddonate/rescuereef/).

The coral reefs of Southeast Asia are the most threatened in the world (Burke et al. 2002).

In South Asia, 45% of 19,210 km2 of coral reefs have been destroyed, another 10% are critically threatened and 25% are threatened. Only 20% are at low risk from human activities (Tun et al., 2004). In Southeast Asia, 38% of 91,700 km2 of coral reefs have been destroyed, another 28% are critically threatened and 29% are threatened. Only 5% are at low risk from human activities (Tun et al., 2004).

2.5.1. Overexploitation (Over-fishing):

2.5.1.1. For food

A recent report states that 'centuries of over-fishing by man have emptied the world's oceans of giant fish, whales and other large sea creatures, destroying coastal environments' (Jackson et al., 2001).The human global population is expected to double in the next 50 years, and with it, an ever-increasing demand for life essentials such as food. Fish is the primary source of protein for one fifth of the world's population. The demand for fish has doubled in the last 50 years, and fish production would have to double again in the next 25 years to keep up with the demand and population growth. Because coral reefs are within the reach of small boats, they are especially vulnerable to over-fishing. Particular groups of coral reef fish such as groupers, snappers and large wrasses have been overexploited.TheGiant grouper (Epinepheluslanceolatus) and Humphead wrasse (Cheilinus undulates) are listed in the 2007 IUCN Red List as Vulnerable and Endangered, respectively, as a direct consequence of over-fishing (Baillie &Groombridge, 2007).

2.5.1.2. For the aquarium trade

The practice of keeping marine aquaria as a hobby has increased in the last decade. It is reported that, globally, between 1.5 -2 million people keep saltwater aquaria (Wabnitz et al., 2003). As a result, more than 800 species of reef fish, hundreds of coral species and other invertebrates are exported now for aquarium markets. The majority of fish come from reefs in the Philippines and Indonesia, while most stony corals come from Indoneia. The biggest importer is the USA (Sadovy et al, 2003).

2.5.1.3. For the trinket trade

Other species are at risk from overexploitation for use as curios or trinkets. As many as 5000 species of molluscs are processed or used raw to make curios and trinkets; some 40 species of coral are also traded for this purpose; and many sea stars, sea urchins, sand dollars and their relatives are also traded (Vincent, 2006). At least 32 species of fish or fish parts - such as seahorses, porcupine fish, sharks' teeth and the 'noses' of sawfish - are also used for the trinket trade.

2.5.1.4. For medicinal purposes

Species are also overexploited for medicinal purposes, mainly in traditional medicine. Many species such as sea horses and pipefish are over-harvested for Traditional Chinese Medicine (TCM) (Hunt & Vincent, 2006). Another emerging threat is marine bioprospecting. Coral reefs are relatively easy to access and have many species of non-moving, soft-bodied organisms, who are armed with a wide of chemicals as defence weapons. These chemicals have a range of potential medical and industrial uses and because of this, reefs are targeted for bioprospecting. In order to extract enough chemicals for development of medicines and clinical trials, the quantities required are in the order of tons or thousands of tons (Meliane, undated). Therefore, the potential for overexploitation is very high.

2.5.1.5. Destructive fishing practices

Often accompanying over-fishing are destructive fishing practices - such as purse seining, fine-mesh fishing, 'moxy' nets, cyanide fishing and blast fishing - that result in unsustainable damage (Wilkinson, 2004). It should be noted, though, that all of these have been made illegal in South and Southeast Asia.

2.5.2. Coral mining (Overexploitation/ Habitat Destruction):

In South and Southeast Asia, corals are mined for limestone and construction materials.
In this process, the reef is blasted and coral removed, causing immediate destruction but also resulting in indirect detrimental effects such as sand erosion and sedimentation. In 1995, it was estimated that 20,000m3 of coral per year were collected in the Maldives for construction materials (Brown et al, 1995). Coral mining is prevalent in most South and Southeast Asian countries (Rajasuriya et al., 2004).

2.5.3. Sediment, nutrient and chemical pollution:

One of the greatest threats to coral reefs is human development that alters either the marine or land-based physical environment. Certain development activities lead to increases in freshwater runoff, resulting in large amounts of sediment being washed into the sea. To a limited extent, soil washes naturally into rivers, but poor agricultural and land use practices intensify this process, resulting in excessive sedimentation. Upland activities such as logging, land conversion, river modifi cations (dams and diversions) and road construction hugely increase erosion. The sediment from such erosion carries with it not only particulate matter but also high levels of nutrients from agricultural areas or sewage systems. To make this problem worse, many areas in South and Southeast Asian countries lack proper sewage systems and waste is discharged directly into the sea.

2.5.4. Global warming and climate change:

Global warming and resultant climate change is posing an emerging and severe additional threat to already stressed coral reefs (Wilkinson, 2004). Sea level rise and changed weather patterns such as altered El Niño and La Niña events are already affecting coral reefs.

2.5.5. Effects of the increase in ocean temperatures: coral bleaching:

Because reef building coral species can live only within a small temperature range, even tiny change in temperature causes seriously detrimental effects, as exemplifi ed by the wide scale coral bleaching of 1998, as a result of an El Niño event. When hermatypic corals are stressed – such as with an increase in temperature - the critical balance that maintains their mutualistic relationship with zooxanthellae is lost. The coral may lose some or most of their zooxanthellae, a major source of nutrition and colour. In this condition, corals are referred to as 'bleached.' In some species, their life cycles are disrupted.

2.5.6. Effects of sea level rise:

Light is essential for zooxanthellae to photosynthesise in coral reefs. Photosynthesis promotes the production of oxygen, which, in turn, stimulates coral polyp growth and increased deposition of calcium carbonate and coral reef growth. Changes in sea levels and associated water depths will change the amount of sunlight reaching coral reefs. Although healthy reefs are likely to be able to adapt to projected sea level changes, coral reefs already stressed by other human activities - such as sedimentation and erosion - will not.

2.5.7. Effects of more dissolved carbon dioxide:

Increased CO2 dissolves in the oceans forming a weak acid - carbonic acid - making them more acidic and reducing calcium carbonate precipitation by coral polyps. It has been estimated that the precipitation of calcium carbonate has already fallen by an average of between six and 11% since the industrial revolution. If future atmospheric CO2 levels reach double the level of pre-industrial times, then it is predicted that calcium precipitation will fall by a further eight to 17% (Caldeira&Wickett, 2003). This affects the availability of carbonate atoms for building exoskeletons and with it, reduces reef calcifi cation. This, in turn, slows down a reef's ability to grow vertically to keep up with sea-level rise and affects its protective function.

3. Material and Methods:

Coral reef restoration methods Coral reef restoration methods were initially developed from methods used in terrestrial ecosystems. For example, the concept of 'coral gardening' developed in the 1990s, adapted silviculture principles to the mariculture of coral fragments (Rinkevich 1995). Other methods stemmed from emergency response interventions following disturbances that affected the structural integrity of the reef substrate such as ship grounding or extreme weather events (Precht 2006). More recently, scientists and conservationists have worked to develop methods to support coral reef resilience in the face of climate change (e.g., McLeod et al. 2019a) and to restore coral reef ecosystem structure and function to ensure the sustainability of reefs and the services that they provide, for example by implementing ecological engineering approaches (Rinkevich 2020). Below is a list of five of the most widely practiced methods currently used globally to restore coral reefs (Table:).

METHOD	DEFINITION
1. DIRECT TRANSPLANTATION	Transplanting coral colonies or fragments without an intermediate nursery phase.
2. CORAL GARDENING	Transplanting coral colonies or fragments with an intermediate nursery phase. Nurseries can be *in situ* (in the ocean) or *ex situ* (flow through aquaria).
3. SUBSTRATE ADDITION (ARTIFICIAL REEF)	Adding artificial structures for purposes of coral reef restoration as a substrate for coral recruitment, coral planting, and/or for fish aggregation.
3.1 Electro-deposition	Adding artificial structures that are connected to an electrical current to accelerate mineral accretion.
3.2 Green engineering	Adding artificial structures designed to mimic natural processes and be integrated into reef landscapes (nature-based solutions, eco-designed structures, living shorelines).
4. SUBSTRATE MANIPULATION	Manipulating reef substrates to facilitate recovery processes.
4.1 Substrate stabilisation	Stabilising substratum or removing unconsolidated rubble to facilitate coral recruitment or recovery.
4.2 Algae removal	Removing macro-algae to facilitate coral recruitment or recovery.
5. LARVAL PROPAGATION	Releasing coral larvae at a restoration site, after an intermediate collection and holding phase, which can be in the ocean or on land in flow through aquaria.
5.1 Deployment of inoculated substrate	Deploying settlement substrates that have been inoculated with coral larvae.
5.2 Larval release	Releasing larvae directly at a restoration site.

Table: 1.Current methods of coral reef restoration adapted fromBoström-Einarsson et al. 2020.

4. Results:

4.1. Restoration actions:

The single most important action in coral reef restoration is the rescue of damaged resources as rapidly as possible by placing them in a safe location until there is an opportunity to transplant them back on the reef. After a ship runs aground on a reef, it may remain there for days until it is pulled from the reef. During this time, the major effort on the part of the trustee [government agency(ies) that has jurisdiction] is to conduct a preliminary damage survey and to provide a triage for damaged benthic resources. This includes righting overturned corals and salvaging broken pieces of coral and caching them into safe areas for temporary storage. For large formations, lift bags (Fig. 5) and portable winches have proven to be an effective means to move large boulders. Plastic milk crates work well for temporary storage of smaller coral pieces and can be moved by two divers. This work is labour-intensive, and, in a large grounding, it might require 2000–3000 h of labour to sort through the debris field. Once the vessel is moved off the reef, the triage salvage continues, while a restoration plan is developed. If the responsible party [ship owner(s) and insurance company(ies)] agrees to accept responsibility, a contractor may be hired to execute the restoration.

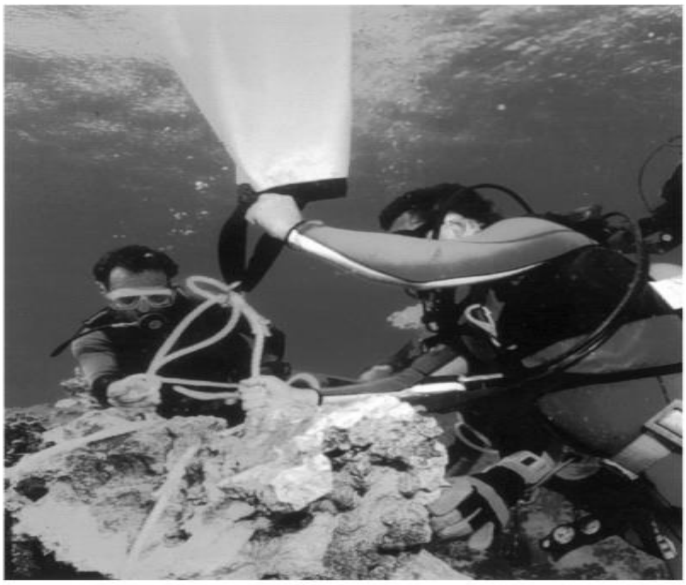


Fig-5 Lift bag, moving George Town, Grand Cayman large boulders, Maasdam restoration, Soto's Reef, , British West Indies. Photo credit: T. Fulton.

4.2. Removing and/or stabilizing loose debris:

Initially, the biggest challenge is determining an expedient way to manage loose debris. Solutions include removing it, stabilizing it with mortar, or capping it with boulders or cement structures. Hudson and Diaz (1988) used Portland cement to stabilize an area at Molasses Reef following the Wellwood grounding in 1984. Limestone boulders, 3–4 ft in diameter, can be barged to the site and lowered to the rubble field with a crane. These boulders, which can be placed either in piles or in a layer to cover the area, will help stabilize the rubble surface and keep it from moving. The boulders provide 3-D structural replacement, and gaps between them provide refuge sites for mobile fauna. Additionally, the boulders recruit algae, sponges, octocorals, and stony corals. A method infrequently used to stabilize loose rubble is an articulated concrete mat that was originally designed to reduce soil erosion along the interstate highway system. The mats are constructed in an open web of cement blocks connected with mylar cables. They were first deployed to stabilize rubble on a reef flat in the Maldives (Brown and Dunne, 1988; Clarke and Edwards, 1994) and subsequently were deployed at the Houston grounding site (1998) off Maryland Shoal in the Florida Keys. Mat survivability in hurricanes is moderate.

4.3. Structural reconstruction:

Damages that destroy 3-D relief or severely crack open the reef platform should be repaired and/or replacement modules should be installed. When large formations are dislodged or turned upside down, consideration should be given to recover these resources and move them back to their approximate, former location. Hudson et al. (1989) tested a concrete hemisphere, the size and shape of which mimicked moderate-sized boulder and brain corals (:2–3 ft [0.6–0.9 m] in diameter) with a hollow interior designed as refuge habitat for mobile organisms. The hemispheres were first deployed off Elliott Key, Biscayne National Park, in 1977, where they have remained in place and recruited an impressive sessile community. In 1989 the census enumerated: 89 octocoral colonies (15 species) and 45 stony coral colonies (7 species). Recent improvements to this design include additional openings for improved internal water circulation and limestone rock embedded in the concrete to add rough texture. Limestone boulders 3–4 ft (0.9–1 m) in diameter and built up in two to three layers on a concrete base, and held together with cement and steel have been successfully deployed off Sunny Isles, Dade County, Florida (Selby and Associates, 1992). These modules were barged to the dredge damage site and installed with a crane, and have remained stable through a major hurricane, Andrew. They provide relief that is natural looking as well as refuge areas for large and small mobile organisms.

4.4. Transplanting sponges and corals:

Transplanting should be considered in coral reef restoration to benefit recruitment, accelerate recovery, and improve the visual perspective. Transplanting has received little systematic evaluating until recently. Harriott and Fisk (1988) summarized the results of five transplanting studies dating from 1974 to 1988; survival of the transplanted corals ranged from 0 to 100%. Success or failure was dependent upon the species, environmental conditions, type and shape of transplants, and if the transplants were attached to the substrate or not. Transplant methods include throwing (sowing) bits and pieces into the damaged area or securing individual pieces or whole organisms to the reef platform with cement, epoxy, hardware (such as stainless threaded rods), or cable ties. Sponges and octocorals (sea fans, sea grounding site whips, and sea plumes) should be transplanted intact with a portion of rock to which they are attached. At the turn of the century, Vaughan (1916) used cement to attach stony corals to small pillars at Dry Tortugas, Florida, and Goulding Cay, Bahamas, for growth rate experiments. The method had minimal impact on the individual corals, and Vaughan's growth rate results are frequently referenced.

A method used to cement corals back on a reef starts with one to four litters of Portland type II mortar mix (Neeley, 1988). The mixed mortar is put in a watertight container (plastic bag, a bowl with a sealed top, or a length of sealed PVC pipe). A diver swims the cement to the work site, or it can be sent to the surface with special care so that the rod is inserted into the holes. A rope and buoy can be used to signal the topside when to send cement to the bottom. The transport of the cement from the boat to the sea floor can be done with a rope to avoid risk (multiple ascents and descents) to divers. Branching corals grow faster and weigh less than equivalent-sized massive corals and frequently recruit by fragments that break, become lodged in the reef, fuse to the reef surface, and may grow into mature corals. Cement, epoxy, corrosion-resistant hardware, and plastic cable ties have been used to secure coral branches on the bottom of a line. The surface area is cleaned, all or part of the mortar is used to build a mound of cement on the reef platform, the coral, sponge or octocoral is inserted into the cement mound, and the diver works the cement around the edges of the transplanted organism (Fig. 6).

Fig. 6. Corals cemented to reef platform following the M/V Ma6ro Vetranic accident, Pulaski Shoal, Dry Tortugas, Florida, October, 1989. A mass of mortar was laid down and the corals were set into it.

If the area experiences currents and wave surge, soft dive weights or a sand bag can be placed around the base of the organisms to stabilize the transplant while the cement hardens. Adding moulding plaster to the cement during the mixing will speed the cement curing time. However, care must be exercised, since the plaster is chemically reactive and causes the cement mixture to become hot. The mixer and diver should wear rubber gloves to protect their hands. Commercial products such as Water Plug™ will also set up rapidly.

Cement will dissolve underwater, leaving grey silt on the bottom. Placing soft dive weights around the base of the cemented organisms and fanning the area removes residue from the sea floor. Marine epoxy works well to reattach small to medium-sized organisms back on the reef platform. Liquid Rock 500 epoxy and hardener are dispensed from twin tubes placed in an applicator with a nozzle containing internal mixing spirals (Fig. 7). The surface must be cleaned with a wire brush. If the organism is going to be transplanted on a vertical surface, a small hole is drilled into the reef surface, the back of the coral, and a small brass or stainless rod is fitted into the hole in the coral. Epoxy is applied to back of the coral and the rod. The coral and rod are placed on the reef. Loose branch fragments may fuse to the reef without securing them. Sponges, octocorals, and other sessile benthic organisms should be transplanted by transplanting the rock to which they are attached. Because demosponges, the most common type of sponge found on shallow-water coral reefs, are soft bodied, they cannot be directly transplanted. Octocorals are flexible and some species (Euniceaspp) are quite sensitive to Portland cement.

Fig. 7. Corals cemented to reef platform following the M/V Ma6ro Vetranic accident, Pulaski Shoal, Dry Tortugas, Florida, October, 1989. A mass of mortar was laid down and the corals were set into it.Photo credit: W. Jaap

5. Discussion:

Coral reefs are extremely productive ecosystems and provide humans with many services.Given that 20% of the world's coral reefs have already been destroyed much has to be done in the future for the conservation of coral reefs.

5.1. Provisioning Services:

Coral reefs support human life and livelihoods and are important economically. Nearly500 million people depend - directly and indirectly – on coral reefs for their livelihoods,food and other resources (Wilkinson, 2004). Further, it is estimated that nearly 30 millionof the poorest human populations in the world depend entirely on coral reefs for their food(Wilkinson, 2004).A km2 of well-managed coral reef can yield an average of 15 tonnes of fish and otherseafood every year (http://www.panda.org/ about _wwf/ what_we_do/marine/blue_planet/coasts/coral_reefs/coral_importance/).In 1985, the world export value of the marine aquarium trade was estimated at 25-40 millionUSD per year. In 1996, the world export value was about 200 million USD. The annualexport of marine aquarium fish from Southeast Asia alone is estimated to be between10-30 million fish, with a retail value of up to 750 million USD (Bruckner, 2006).

Many coral species and species associated with coral reefs have medicinal values. Several species are used in Traditional Chinese Medicine (TCM) and many are now providing novel resources for allopathic medicine. In TCM, 394 marine species are collected globally for their medicinal value. The majority of these species are used in Asia (Hunt & Vincent, 2006). Some hard coral species are used in bone grafts. Others contain chemicals which might be used as natural sunscreen products (Demers et al., 2002; http://www.coralfi lm.com/about.html). The Caribbean Sea squirt (*Ecteinascidiaturbinata)* has a chemical that is being used to treat difficult cancers (http://www.ehponline.org). There are some 500 species of cone snails that live in and around coral reefs. These species have a range of venoms which are being investigated currently for use as non-addictive pain killers (Chivian, 2006).

5.2. Regulating Services:

Coral reefs protect the shoreline and reduce flooding. Very importantly, coral reefs protect the shoreline, providing a physical barrier – a wall –against tidal surges, extreme weather events, ocean currents, tides and winds. In doingso, they prevent coastal erosion, flooding and loss of infrastructure. Because of this, theyserve to reduce huge costs involved with destruction and displacement due to extremeweather events.The value of this protective service of coral reefs is estimated at 314 million USD in Indonesia(Burke *et al.*, 2002).

5.3. Supporting Services:

5.3.1. Coral reefs are an essential part of land accretion.

The natural action of waves breaks pieces of calcified coral and these are washed up onto beaches. Through the process of natural physical breakdown, these larger pieces are broken into smaller and smaller pieces and eventually become part of the rubble, building these beaches. Corals, therefore, contribute, in part, to the process of *accretion* – which is the opposite of erosion.

5.3.2. Coral reefs are very diverse

Corals do not even cover 1% of the Earth's surface, but they are extremely diverse. In factthey are dubbed the rain forests of the sea because of this immense diversity. The nooks andcrannies formed within reefs by constant beating of waves provide shelter to many species. They are the home (they provide shelter and nursery grounds) of 25% of marine fish(Burke *et al.*, 2002). Thirty two out of the 34 described groups of organisms are found in coral reefs. (As a comparison,only nine groups are found in tropical rain forests.) (Wilkinson, 2002).Coral reefs support a complex and interdependent community of photosynthesising organismsand animals. There is an incredible diversity of life on coral reefs such as algae, corals (theremay be as many as 750 species on one coral reef), sponges, marine worms, echinoderms(sea stars and their relatives), molluscs (snails, mussels and their relatives), crustaceans (crabs,shrimps and their relatives) and fish (http://assets.panda.org/).

5.3.3. Coral reefs have high primary productivity

Zooxanthellae photosynthesise and produce their own food (like green plants do on land) and corals benefit from this association. Because of the immense diversity of coral reefs, there is a great deal of exchange of nutrients and primary productivity (food production) is very high. Primary productivity of coral reefs is estimated at 5-10g C/m2/day (Sorokin, 1995). This productivity is derived mainly from algae.

5.4. Cultural services:

Coral reefs have intrinsic, aesthetic and recreational values.

The beauty of coral reefs and their diversity are essential parts of many cultures in different parts of the world. Because of their easy access, visiting coral reefs is an important recreation for snorkelers, scuba divers, recreational fishermen and beach lovers. In Seychelles, tourism was estimated to have generated one fifth of GDP and over 60% of foreign exchange earnings in 1995 (Mathieu et al., 2000). In the Maldives, 'tourism contributes more than 60% of foreign exchange receipts, over 90% of government taxrevenue comes from import duties and tourism-related taxes, and almost 40% of the workforce is employed in the industry' (Emerton, 1997, 2006).

5.5. Establishment of marine protected areas:

One of the key mechanisms of protecting coral reefs is the establishment of MarineProtected Areas (MPAs). Although there are many types of MPAs, in all MPAs, marineareas are set aside from unrestricted human activities. Where restriction is highest,MPAs are set aside as 'no-take' areas where extraction of all marine life is prohibited;even research, education and recreation is restricted. Some MPAs are established andmanaged specifically for a purpose (for example, for recreation, for the preservation ofa historical site or as a refuge for a particular species to breed). Multiple-use MPAs arezoned to allow for complete restriction of harvest in some areas, restricted use in othersand managed use in yet others (Agardy, 1994).

Although more and more MPAs are being established now worldwide, the ratio betweenMPA and terrestrial protected areas still remains low at 1:7 (WRI, IUCN and UNEP1992). Less than 1% of the world's oceans are protected (http://www.unep.org/wed/2004/Downloads/PDFs/Key_Facts_E.pdf.).

• In 1970, there were 118 MPAs in 27 countries (Kelleher Kenchington, 1992).
• In 1985, there were 430 MPAs in 69 countries (De Silva et al. 1986).
• In 2006, there were 5,877 MPAs, in 143 countries (http://www.mpaglobal.org).
•Currently, in South, Southeast and Far eastern Asia there are 1,125 MPAs.

However, a major problem with MPAs is that they are often only parks on paper and amajority of MPAs fail to meet their management objectives: in 1995, only 31% (1306)MPAs were found to have met their management objectives (Jameson et al., 2002). Eventhough MPAs may be gazetted legally, enforcement of relevant laws (zoning, prohibitingcertain activities) is often poor.

5.6. Prevention of over-harvesting through legislation:

Many species are protected under general species protection laws across the region. Mostof this protection is afforded to marine vertebrates, but some countries - such as India andSri Lanka - have laws protecting several species of coral, molluscs and echinoderms.

• In India, all Stony corals, all Black corals, all Fire corals, and all Sea fans are protected by law (Wildlife Protection Act, 1972).
• In Sri Lanka, all Stony corals are protected by law (Flora and Fauna Protection Act, 1993).

5.7. Monitoring:

Monitoring of coral reefs is essential for the development of effective management strategies. It is only through monitoring that trends and patterns of use and the health of reefs can be assessed.
Worldwide, there are several organisations that monitor the status of coral reefs. TheGlobal Coral Reef Monitoring Network (GCRMN) coordinates efforts to improve themanagement of coral reefs through knowledge sharing and capacity building, and worksclosely with Reef Check and Reef Base. The latter is a global database of coral reefrelated information.

After the 1998 coral bleaching event, and with the ongoing threat ofcoral degradation as a consequence of other human activities, Coastal Ocean Researchand Development in the Indian Ocean (CORDIO) was commenced in 1999. CORDIOfunds and supports scientists and institutions in the Indian Ocean Region, to ensure thatthe status of coral reefs in the region is monitored, focussing both on the ecological andsocio-economic effects of coral reef degradation. Many other organisations partner thesemajor players to provide an annual status report of coral reefs across the world.

5.8. Building awareness:

Building awareness about coral reefs, their diversity and the services they provide, helpsgreatly in mitigating the threats to these fragile ecosystems. Awareness at the communitylevel is most effective as it can help to encourage users of coral reefs to change theirbehaviour to sustainable use of these ecosystems. Awareness at national level – throughthe media and conservation education - is essential to ensure that policy makers integratecoral reef conservation into all stages of development. It is also critical to ensure that landbasedenvironmental issues – such as unplanned or badly planned inland developmentand pollution – are prevented to safeguard coastal ecosystems such as coral reefs.

5.9. Reef Resilience:

Adapting to climate change is, perhaps, the biggest challenge that coastal managers facetoday in respect to coral reef conservation and management. Understanding why somereefs do not succumb to bleaching while others nearby do (i.e., why they are *resistant*)and why some 'bounce' back quickly while others do not (i.e., why they are *resilient*) hasbecome extremely important. The Nature Conservancy and its partners have developedan R2-Reef Resilience Toolkit that is designed to help managers prepare for and respondto coral bleaching events (Wilkinson, 2004).

5.10. Supporting participation and sustainable livelihoods in reef dependent communities:

The connection between poverty and coral reef ecosystems is significant: two thirds offal countries with reef areas are developing countries, and a quarter of these are least developed countries (UNDP, 2002).

• In 2001, the World Atlas of Coral Reefs was produced by the UNEP World ConservationMonitoring Centre (UNEP-WCMC). This includes data on the natural history of coral reefs,their distribution, threats and MPAs.

• In 2003, IUCN Sri Lanka produced a book on Coral Reefs, in all three nationallanguages, as supplemental resource book for both students and teachers of GCEAdvanced Level Biology.

Coral reefs provide important resources for the poor, and contribute to nationaleconomies. The current trend of increasing threats to reef resources is likely toaffect poor communities, who are dependent on coral reefs. To make things worse,management of coral reefs for conservation purposes often restricts community accessto these resources, leaving them even fewer livelihood options. Often, these restrictionsare not followed by communities, who have little understanding of or involvement in themanagement process. (Whittingham *et al.*, 2003).

5.11. New management initiatives:

It is now understood that 'standard' methods of coastal zone management have not beensuccessful in achieving sustainable development and conservation goals and that a shiftin approaches is needed (Wilkinson, 2004).

Shifting from small, isolated management efforts to large-scale networks using collaborative management is now the trend. Increasing the area of reefs under high protection is amajor thrust of this shift and 33% of the Great Barrier Reef has now been declared as highprotection zones or no-take areas - where harvesting is not permitted.

Collaborating tocreate more extensive networks of MPAs is another approachfavoured by majorNGOs such as Conservation International, The Nature Conservancy, and the World WildlifeFund who are developing training modules to identify and develop a network of MPAs in Asiabased on areas of highest biodiversity. Others are assisting managers in coping with climatechange impacts. Another change is the effort to focus research on real-life problems thatresource managers face (Wilkinson, 2004).

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