An introduction to assisted restoration of degraded coral environments in Sri Lanka

REEF HELP guide

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Nature Conservation Group

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Colonies of coral killed by the 1998 coral bleaching event

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Reef Keeper Program

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CONTENTS

Dedication

to

my mother;

for instilling

a spirit of adventure in the persuit of knowledge;
wider horizons in perception of the world
love in great measure for even little things
and
a desire to make things better

Replanted coral on Rumassala reef

Colonies of Pocillopora damicornis and Acropora formosa on Coral nursery panels at Rumassala

Introduction

In 1992 the Nature Conservation Group Initiated a survey of the reef beneath the Rumassala hill. This reef secluded by steep cliff faces and facing the Gall bay was at that time unknown to most, and in its isolation remained one of the best preserved coastal reefs in the Southern part of Sri Lanka. Some Natcog members were familier with this reef another decade before as far back as early 1980's. The abundance of life and the peaceful surroundings made it a favourite dive site till the early 1990's. The proposed plan for the development of a major harbour at Galle threatened the reef with complete destruction as it was proposed to bury the reef in tons of concrete to construct a massive jetty and container facility on the site. An intensive study of the reef and its bio-diversity was undertaken in 1992-3, the findings of the survey were pivotal in the campaign to save the reef. Post to the initial surveys the team continued a regular monitoring program on the reef documenting the gradual processors of change and working with the community to reduce harmful impacts. In 1996 a storm caused significant damage to the reef razing a section of the reef to rubble: The storm raged through toppling large coral tables and laid a massive strand of Staghorn coral broken, scattered and piled up in places, the reef base stripped to bare rock except for few hard attached encrusting corals. The damage though intense was fortunately limited to a small section of the reef. The event was quickly followed by what was to be the first of a series of events where previously benign reef organisms began population blooms and turned invasive. This caused significant damage to reef corals. A species of Green coloured colonial Ascidian barely a centimetre across had grown over 20% of the reef surfaces within 2 months. The direct and indirect effects of human activity affecting the reef health too were on the increase. In this background the Nature Conservation Group's field program evolved from general surveys to an endeavor in actively managing and restoring degrading coral environments.

1996

In 1996 a storm raged through the Rumassala reef with 8-foot breakers approaching from the South West and pounding the Rumassala hillsides on the Northern section of the reef. While the Watering point headland sheltered most of the reef, the storm surges left a wide path of destruction on the Northern section of the reef. A large meadow of Staghorn coral stretching over 60 meters long and 15 meters wide close to the reef crest was reduced into rubble as if a huge bulldozer had cut a path across it. Massive table corals 2.5 meters across were broken, toppled and thrown several meters away. Large amounts of broken coral was scattered through out the reef and was dying as they kept rolling and abrading over the reef and being smothered in sand.

Initially the field teams were looking at saving as much of the broken coral fragments as possible and restoring the lost coral cover of the damaged sections of the reef. After a high rate of failure in saving coral through jamming broken coral pieces into crevices on the reef. The team began its initiation into an experiment in coral cover restoration that was to prove a long term and important endeavor.

The 1996 storm left another longer-term legacy that was also to prove a greater challenge for the crew. Within two months post to the storm a massive population explosion of a small green colonial Ascidian was beginning to play havoc with the reef. The centimeter long colonies had spread to cover almost 20% of the reef substrates and were invasive over corals. Settling on the base of the coral colony the ascidians were budding new colonies spreading over the coral in a thick sprawling mat. The Ascidian was identified as belonging to the family Didemnidae and to genera *Didemnum*, *Trididemnum* or *Diplosoma*. The species used shading to kill the coral by starving it as a means of infestation; and did not show the advancing "burn" marks on the coral characteristic of species that use toxins in attacking corals.

The dead reefs after the bleaching event; overgrown with algae was soon populated by large schools of herbivorous fishes

1998

The year 1998 remains the most significant turning point in the natural history of coral reefs in Sri Lanka. The El-nino; Southern oscillation related weather conditions caused significant increase in the average water temperature, which caused the most intensive and widespread coral bleaching event recorded in the Indian Ocean. The warming of the waters caused the corals to bleach their colour and become white over most of the Western, Southern and South-eastern reefs in Sri Lanka; within several months over 50% of the live coral area in Sri Lanka was killed; in the South and Western shores the amount was about 80%. The 1998 bleaching event killed off several reefs and caused massive damage to most others. Many coral species were reduced almost to extinction within the coastline and

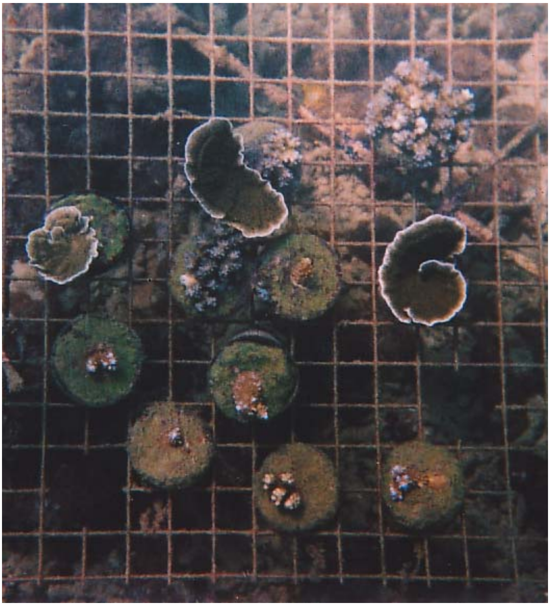
Bleached corals at Rumassala reef

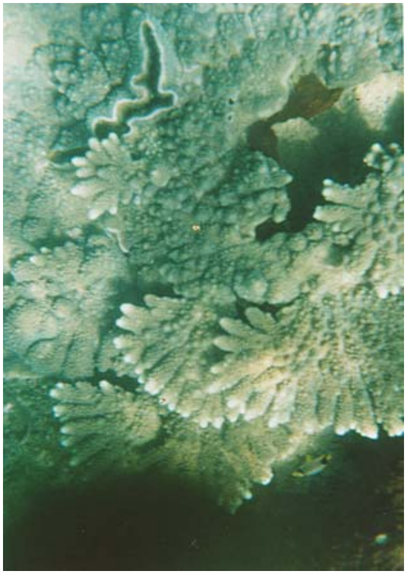
altered the structure and ecology of the reefs in profound ways.

Post to the bleaching event and the massive coral death, the Nature Conservation Group with its partners initiated a program to study and develop ways of assisting the natural re-colonisation of dead reef areas with coral and speeding up the process of restoring the reefs. The team had to experiment with different techniques as there was little or no guidelines available on coral restoration, as the subject itself being a relatively new science, globally. The team developed several techniques that can be used with good results to reduce the mortality of corals and assist in restoring live coral cover of reefs.

This document provides a brief background to the process; as an introduction to the new comers interested in conservation of coral reefs into the basic methods of restoration of shallow coral areas.

Tons of dead coral washed on to the beach at Rumassala reef post to a storm in year 2000





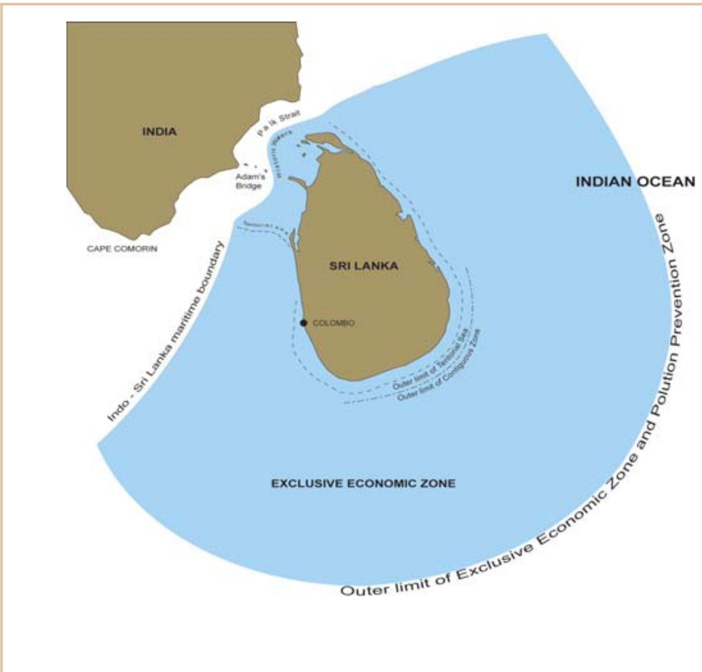
Counter clockwise from top left:

1.Replanteed coral on Nursery panel,
2.same Acropora nubins after two years of growth.
3. Coral newly recruited from planctonic larvae,
4. A transplanted colony of Acropora formosa coral at Rumassala.
5. table corals regrown 6 years after the bleaching event.

Marine Bio-diversity of Sri Lanka

The Island Nation of Sri Lanka,; hangs at the apex of the great Indian continental shelf projecting deep into the open Indian Ocean. This unique location brings in a rich diversity of life within Sri Lankan waters as animals of both the continental shelf and the deep Oceanic waters are found within Sri Lankan maritime zone.

Sri Lanka with a land area of 65,610 Km^2 is surrounded by a coastline approximately 1770km. in length containing many marine habitats including Estuaries, Mangroves, Sand and mud flats, Sea-grass beds, Beaches, Rocky shores, Sand-stone reefs, Coral reefs and open pelagic waters. The Country claims an Exclusive Economic Zone (EEZ) that extends 200 km. and covers over 256,400 Km^2 on all sides except at the boundary with India. All natural resources and spe-



Maritime zones of Sri Lanka showing the territorial sea; Exclusive Economic and Pollution Prevention zone and the boundaries between India.

The location of Sri Lanka on the South Asian continental shelf and exposed to the open Indian Ocean on three sides.

cies of life found within this zone is regarded to belong to Sri Lanka

Sri Lanka Coastal Physical data

• Shoreline:	1770 km
• Total Area of Land:	65,610 km^2
• Total area of continental shelf:	30,000 km^2
• Total area EEZ	256,410 km^2

The seas around Sri Lanka are rich in Marine life; with habitats ranging from beaches, rocky shores, coastal mangroves, sea grass beds, sandy and muddy floors, reefs, the open ocean and deep sea floors. The reefs itself can be further sub divided according to the depth and the structural material as Rock / granite reefs, Beach-rock / Sandstone reefs and Coral reefs. The first two categories of reefs are commoner and can be found from shallow to the deepest continental areas. The coral reefs in Sri Lanka are restricted to *fringing reefs* lining the coastal shallows and shallow peaks of offshore ridges.

Sri Lanka is situated in an ideal location that provides conditions necessary to support a higher bio-diversity due to several special features.

- Located in the Warm clear waters of the Tropics and within the Indo-West Pacific Zoogeographic zone.

- Located on the Continental shelf of the Indian sub-continent supporting shelf dwelling species and enriched by nutrient outflow from river sediments.

- Located at the tip of the Indian headland extending deep into the Indian ocean, Sri Lanka is enclosed on 3 sides by deep ocean and allow access to oceanic species and currents.

- Flanked by the Chagos-Maldive-Lakshadveep and Andaman- Nicobar chains of coral Islands. Sri Lankan coasts are open to planktonic species replenishment through oceanic currents.

Sri Lanka is rich in marine bio-diversity, the Coral reefs are the richest of the marine ecosystems. Generally reefs or hard substrates support more life than sea grass beds, sandy or muddy sea floors. The open ocean supports a free living community of animals often important for fisheries. The oceanic environments are also important for the marine mammals and sea birds as well. The actual richness of life in our seas is far from adequately assessed; as most groups of life had not been studied properly.

MARINE BIO-DIVERSITY OF SRI LANKA.

Marine Mammals

Cetacea (Whales/Dolphins)	27 species in 6 Families
Sirenia (Dugong)	1 species

Marine Reptiles

Turtles	5 species in 2 Families
Sea snakes	12 species
Salt water Crocodile	1 species

Sea Birds 49 species in 8 Families

Petrels & Sheerwaters	*10*
Storm-petrels	*2*
Tropicbirds	*2*
Boobies	*3*
Frigates	*3*
Skuas	*4*
Terns & Noddies	*18*
Gulls	*7*

Corals >183 species in 68 Genera

Fishes > 1200 species within EEZ limits including
> 700 species of reef fishes

Echinoderms 206 species recorded
(estimated aprox. 250 species)

Mollusks 1000 +?

No proper survey has been carried out to estimate the number of species of Algae, Sponges, Cnidarians, Tunicates, Worms, etc.

Some Coastal Crabs and Hermit Crabs of Sri Lanka

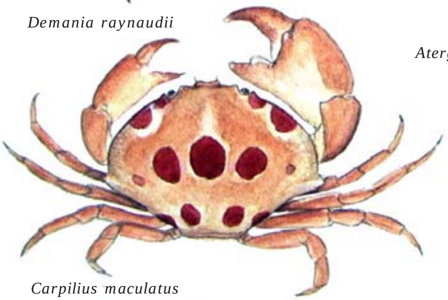
Coenobita rugosa

Dardnus guttatus

Dardanus logopodes

Demania raynaudii

Atergatis interrigimus



Carpilius maculatus

Carpilius convexus

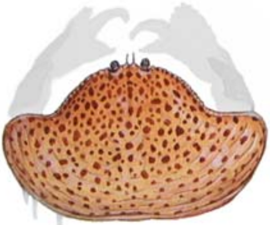
Calappa philargius

Calappa lophos

Trapezia rufopunctata

Trapezia reticulata

Trapezia cymodoce



Calappa calappa

Calappa hepatica

Calappa gallus

What is a Coral reef

A forest is a collection of organisms from trees to mushrooms, beetles to birds and larger mammals. When all its parts are together the forest is an eco-system or a system of life. Though many animals and plants contribute to making a forest a forest, the primary organism responsible for the structure of a forest is the tree. Like wise a Coral reef is an underwater eco-system comprising of thousands of life forms, but like the tree in a forest the coral reef is built by colonies of tiny reef animals known as Coral polyps.

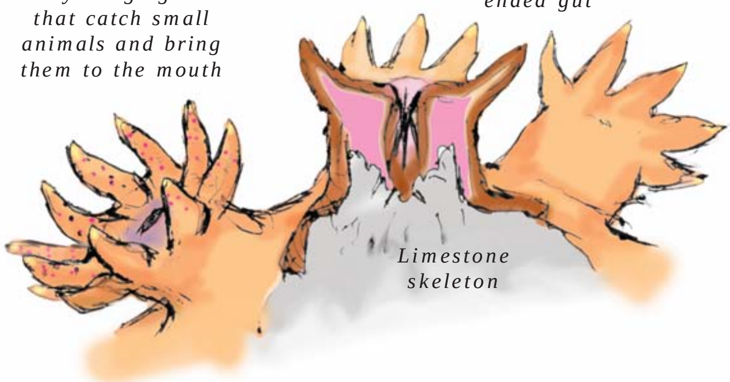
The coral polyp belongs to the Animal phylum Cnidaria (Coelenterata) and its sub class Anthozoa. Individually coral polyps are small and rarely grow bigger than a centimetre across; the coral animals usually live in colonies and each polyp build a limestone skeleton which links with the skeletons of all other members of the colony over generations to form the structures we readily recognise as a coral.

The basic shape of a coral animal consist of a sac like body with a single ended food channel that open in a central mouth; which is surrounded with tentacles that catch pray, clean itself and also provide a surface for photo-synthetic algae. The coral animal unlike most of its relatives secretes a limestone cup at its base that provides support and protects the coral polyp. Aggregation of these limestone cups built by generation upon generation of corals grows in to the large and widely variegated structures we commonly refer to as corals. Colonies of thousands of tiny coral polyps build coral colonies. And aggregations of thousands of coral colonies of many different species form coral reefs.

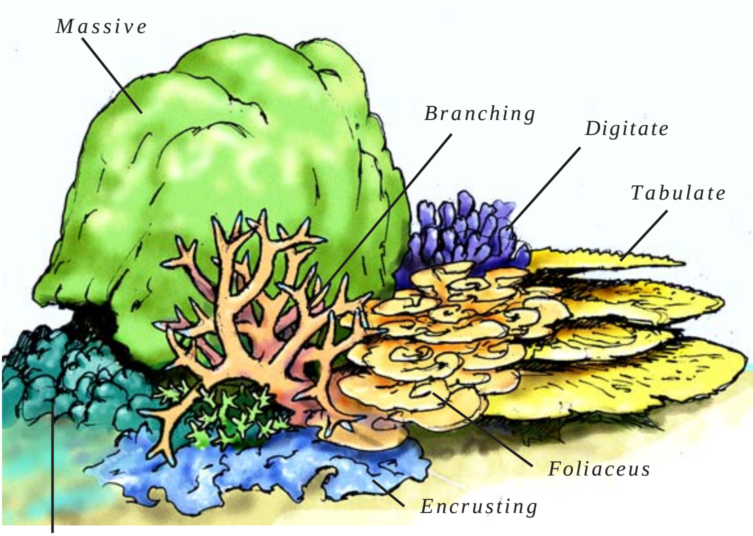
Though there are coral species found from the polar seas to the deepest oceans it is only in the shallow tropical seas that the coral animal can form the massive structures of a coral reef. To be able to do this feat the coral animal forms an association with a single celled algae that would live within the tissue of the coral animal feeding off on the carbon dioxide produced by the coral polyp; in turn the oxygen and nutrients produced by the algae is transferred to the coral providing most of its nutrient and metabolic needs; giving the coral the edge needed to use its energies into growing and reproducing itself to a coral reef. The colour of a coral is also due to the algal tenets living within the coral tissue.

This symbiotic arrangement is not without its drawbacks; relying on the presence of the algae the coral also inherits the limitations of its partner. As the algae depend on well lit warm shallow seas, the corals are also restricted to build reefs within the same sea conditions and with stable high salinities.

The corals come in many species. These colonies can take many shapes. The basic forms are classified as Branching (Staghorns, Elk-horns), Fingerlike (digitate), Plates and tables(tabulate), leaflike (foliaceus), dome like(massive), semi domelike (sub-massive), Encrusting and free living.



Cross section of a coral polyp



Basic growth form categories of coral

Though most corals can be identified into the family it belongs to by looking at the coral colony it is often needed to look closely at the shape of each coral animal to identify corals at a more refined level. Each coral polyp is referred to as a corallite and the structure of the corallites is used to group polyps on the surface of the coral colony into Plocoid (corallites with own walls), Phaceloid (also with own walls but corallites longer and tubular), Cerioid (polyps share walls), Meandroid (brain corals-polyps form valleys), flabello-meandroid (valleys without common walls) and mushroom (solitary, free-living) patterns.

Corals need special conditions to build reefs; and form reefs only in the warm coastal waters between the tropics of Cancer and Capricorn. requiring well lit shallow seas and a hard substrate to grow on and do not proliferate in turbid areas and where the substrate is unstable.

The Tropical coral reef ecosystems are divided into several Zoo-geographic regions where each would contain distinct assemblages of species unique to each. These are formed by natural boundaries barring the intermixing of species between different regions that cause isolation over millennia, resulting in species to evolve independently of the others. In the Ocean; the boundaries could be physical as landmasses or climatic as polar waters separating the regions.

Main zoo-geographic regions of the seas

- Indo-West Pacific
- East Pacific
- West Atlantic
- East Atlantic

The Indo-West Pacific region supports the highest marine Bio-diversity in the world and is recognized as the cradle of coral reefs.

The reefs serve many purposes in the coastline; they are important centers of bio-diversity, fisheries production and nursery grounds, aesthetics, tourism, coastal stabilization and barriers against coastal erosion.

Most coral reefs are located near the shore where they are easily accessible; they are often subject to the brunt of pollution, human impacts and extreme weather events. Coral reefs in Sri Lanka are under threat and are continually being degraded by both human and natural causes.

Causes of Coral reef Degradation

The Survival of Coral reefs have come under threat from human activities as more and more coastal areas are developed and more resources are extracted from the sea. The coral reefs on the Southern to Western shores of Sri Lanka have taken the impact of it. The threats to coral reefs can be broadly categorized under physical damage, pollution, extraction and natural causes.

The threats to the reefs were prioritized at different times based on our understanding and involvement with the reefs and the most significant causes identifiable at each period. In the 70's and yearly 80's Coral mining was considered the biggest reef related issue as the then non-diving management community could not see the effects down below and could only focus on the coral lime being brought ashore. Post to the setting up of the Coral Reef Research Unit at NARA the list got diversified into Bad fishery practices (both ornamental and food), tourism, and a host of other issues. During the mid 1990's the trend was changing again this time from direct effects of man to far more destructive natural events.

Some of the major causes of coral reef destruction is discussed below.

1. USE OF DESTRUCTIVE FISHING METHODS

Physical damage is caused to the coral structure of the reef from many fishery related activities. These include the use of explosives (dynamite fishing), entanglement of bottom set nets and the "moxy" a net used by the ornamental fish collectors. The ornamental fish collectors cause additional and usually avoidable damage as they break up and over turn coral boulders to collect fish and invertebrates hidden below or within them. The lost pieces of synthetic fishing nets cause degradation of corals by binding onto corals and rubbing on them, referred to as ghost nets they also continue to trap marine organisms.

2. OVER FISHING AND UNMANAGED SELECTIVE COLLECTION

The ornamental aquarium fishery, shellfish and holothurians export trade and spear fishing have had an impact on the reef communities in selectively removing species and individuals of specific size categories. (Extraction of breeders, new recruits etc.) This could lead to alteration of the balance of the ecosystem as key trophic / community elements are affected.

3. REMOVAL OF REEF CORAL FOR THE LIME TRADE.

Coral mining for lime is carried out on some reef areas such as Akurala and Rekawa and constitutes a serious but localized threat to coral reefs, as the basic reef structure is lost the chances of re-colonization of the reef is also lost.

4. UN-REGULATED TOURISM.

Tourism impact on the reefs when the number of visitors to an area exceeds the carrying capacity of the reef to absorb incidental damage by visitors; such as walking, touching and striking coral with swim fins etc. The coastal developers/hoteliers infringe on the coastal dynamics by building close to or on marine areas, and release sewage and refuse into the waters close to the coral reef. Extraction of coral and other shellfish etc. for the souvenir trade also contribute to the tourism impact on the reefs.

5. COLLECTION OF MARINE ORGANISMS FOR SOUVENIRS.

The collection of coral, Shells and other reef organisms has become a significant threat to reefs in some areas.

Though the act of picking up a dead shell on a beach does not cause significant harm, commercial collection of souvenirs for sale and excessive collection by groups on localized sites (eg. At school field trips) can lead to harmful levels of extraction if not controlled.

6. UNPLANNED AND INAPPROPRIATE COASTAL DEVELOPMENT

Development of harbors, revetments, Groins, sea walls and other coastal structures impact the coral reefs directly by building over coral areas and through changes to the coastal sand transport by increasing sedimentation and accretion within coral reefs.

Some planned major development schemes in the South coast such as the proposed Galle harbor development envisaged to build over a rich coral reef leading to extermination of the reef.

The construction of a breakwater at the fishery harbor in Hikkaduwa is believed to be the cause for sand filling of both the Hikkaduwa Marine Sanctuary and the Akurala reef.

The warmed water plumes released by coastal power plants (eg. Proposed Norochchole, and the Trincomale coal thermal plants.) could damage coral reefs in the area as the sea water temperature would be elevated by several degrees over a long period of time, which could trigger local bleaching events and reef death.

7. BOAT AND ANCHOR DAMAGE

Use of coral reef lagoons as anchorages for small and medium sized boats has affected reefs as the heavy anchors and dragging anchor chains break, abrade and over-turn coral colonies (e.g. Hikkaduwa, Kapparathota) . The fishing craft anchorages further affected the reef as fish off-loading and cleaning operations also contribute to pollution of the surrounding areas. Unauthorized channel blasting over the reef flat/crest by fishermen to open access channels for the boats also destroy reef sections. Glass bottom boats damage the reef as the boats are regularly rammed on to the reef to provide better viewing opportunities for the visitors.

8. POLLUTION
(COASTAL, SEWAGE, SEDIMENTATION, RIVER RUNOFF, PETROCHEMICALS, ETC.)

The degradation of the coastal marine environment is steadily increasing as rivers and canals carry heavier loads of untreated domestic sewage , industrial pollution and sediment into the coastal seas. The development of the coastal belt and tourism has also contributed to the addition of non bio-degradable plastics and other solid waste into the waters. Waste from tourist hotels on the coastline, petrochemicals from boats, bilge water pumping and tank cleaning by

strand of bleached Acorpora formosa corals. this species was almost extermi-nated on the South coast by this event.

tanker ships and spills. fishery spoils, coastal industry and sedimentation from river run off cause serious adverse impacts on the reef. This may also contribute significantly in disrupting the ecological balance of the reef and may be causative in increasing coral diseases and triggering attacks by invasive reef organisms.

9. NATURAL DISASTERS

The effects of natural processors and climatic events are becoming a growing threat to coral reefs as the intensity and frequency of such events are steadily on the increase. Currently they are overtaking in importance as the major factor in reef destruction over the normal human causes.

- **Sand filling**

Though coral reefs are a primary agent in acting as a wave barrier in stabilizing eroding shorelines. They are at the mercy of sand filling (accretion) events. The 1997 beach accretion event at Akurala smothered and completely buried the shallow Akurala coral reef under several feet of sand within a time span of about one month. The Hikkaduwa Marine Park is also gradually filling up and is at risk of disappearing under the sand if no remedial action is taken.

- **Global warming/ Coral bleaching**

The changing global climate triggers periodic events which causes warming of the marine environments. These are known to trigger coral bleaching events often resulting in high coral mortality. The coral bleaching in 1998 was the severest such event reported in Sri Lankan waters killing off 70-80% of coral reefs in the Southern coasts and an estimated 50% of Sri Lankan corals.

- **Storms**

Storms and associated wave surges are known to damage reefs periodically, often these affect the shallower more exposed sections of reefs. Storms damage coral reefs as the wave force causes coral breakage, move coral debris and sand on reefs. They can also cause significant re-modeling of reef environments; changing the current patterns. The incidence and intensity of Storms are on the increase with the changes to global climate. On the positive side storms of moderate intensity can help in clearing surface debris from a reef and leaving reef surfaces cleaner and available for new coral settlement.

- **TSUNAMI**

The 26th December 2004 Tsunami is the only properly identified Tidal wave on record in Sri Lanka. The damage to submarine environments from Tidal waves differs from storms in its mechanics. The location, geography both coastal and under water affect the way the reefs are impacted. During the 2004 Tsunami the reefs in the direct path of the tidal wave; especially in the east coast seem to have suffered heavier physical damage, while the Southern and Western reefs received less direct damage as the wave approached the coast more as an accelerated tide. Indirect damage may be caused by erosion from the strong currents created by the receding tidal waters and through the large masses of debris washed off from land areas and being deposited on the reefs causing abrasion and smothering.

- **INFESTATIONS /REEF INVASIVE SPECIES**

Due to yet unidentified reasons, sudden increse in the population of normally insignificant reef organisms spread fast over the reef surfaces at an accelerated speed killing off live coral cover in competition for reef space. The species include both algae and faunal groups ranging from simple sponges to the Crown of thorns sea-star. The reason or triggers for these population bursts are unexplained and may be the result of reduction of predatory species or creation of conditions that favor increased survival of larvae of invasive species.

Coral bleaching events.& 1998

The phenomenon of Coral bleaching is caused by corals subjected to severe environmental or pathological stress evicting or losing the symbiotic algae that reside within their tissues providing most of the food, metabolic needs and pigmentation of the corals. High water temperature and increased UV radiation is known as major trigger factors in causing such events. The corals take on a stark white or very pale color as the pigmentation is lost; and in this state corals are referred to as being "Bleached". The condition can be reversed if the environmental conditions return to normal within a short span of time allowing the coral tissue to be re-colonized by algae. If the bleaching is extensive it could lead to starvation of the coral animal leading to weakening and die off of coral colonies. But the level of recovery/ coral mortality is dependent on the severity, duration, and other environmental stressors that may add to the event.

The year 1998 observed the most severe coral bleaching observed in Sri Lanka in documented times. The event was followed by the death of corals at a scale unprecedented in known history of Sri Lanka.

During March of 1998 an unusually warm mass of seawater was reported to be forming close to East Madagascar and Seychelles Islands in the South Western Indian Ocean. The warm water soon formed a current that kept on spreading Northwards through Seychelles Islands, Maldives and across Sri Lanka to South India and extending up to Lakshadweep islands and even up to Andaman and Nicobar Islands. The warm water plume affected some parts of the central Indo-pacific region around Thailand and Philippines as well. It is believed that this warm water plume was the result of a long and complex series of climatic and ocean-processors that had its inception linked to the famed "El-Niño" Southern Oscillation climatic event in Eastern Atlantic Ocean.

By mid April all shallow water reefs in the South and Western coasts of Sri Lanka was affected with almost all coral being bleached; the once colorful reefs had taken a stark white color as the sea water had become hot. The water temperature at the peak of the event reached temperatures of 36^{o} Celsius. By mid May water conditions were beginning to normalize but some corals remained in a partially bleached even at the beginning of November.

The sensitivity of corals to the heat varied with *Montipora aequituberculata* being the most resistant, most colonies of this species did not bleach even at the peak of the event. Colonies of *Porites rus*, *Montipora*, *Leptoria,* Favids, and some Pocilopora species were among the first species to recover. Almost all Staghorn coral *Acropora formosa, Fire coral Millipora* was killed and suffered near extinction on the coastline. The live coral cover of coastal reefs in Southern Sri Lanka was reduced by 80%. Sri Lanka is estimated to have lost about half its live coral cover within this event with most of the surviving reefs located in the East coast of Sri Lanka.

STATUS OF CORAL REEFS OF SRI LANKA.

The coastline of Sri Lanka contain many fringing coral reefs. Prior to 1998 coral reefs were recorded from Akurala, Hikkaduwa, Galle, Rumassala, Unawatuna, Mihiripanne, Habaraduwa, Kabalana, Kapparathota, Polhena, Mirissa, Tangalle, Rekawa, Ussangoda to the Basses on the South west and Southern shores to Pothwil, Thirukowil,Kalmune,

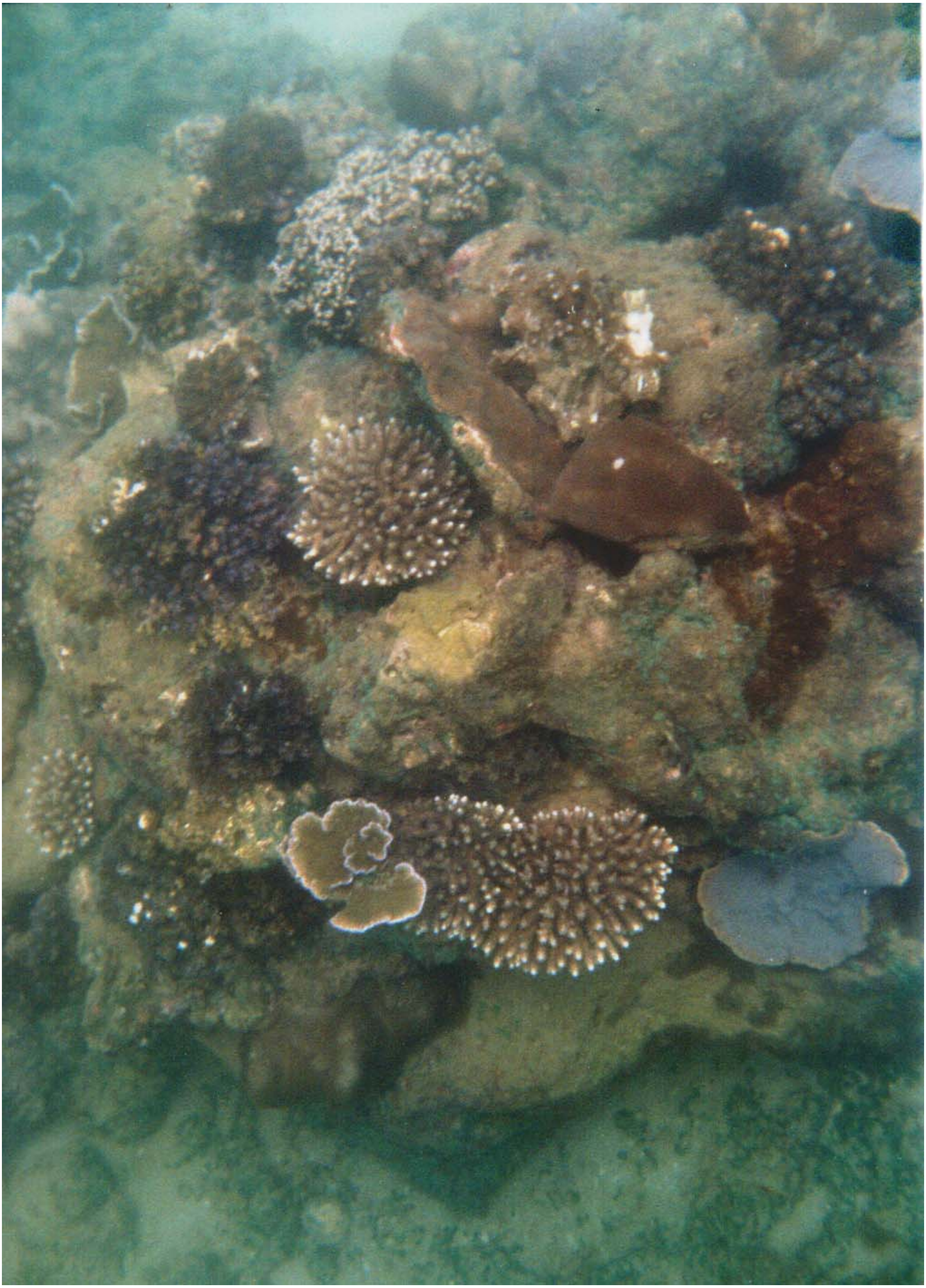
A dead reef in unawatuna killed by the 1998 bleaching event

Kalkuda, Pasikuda, Trincomalee, Nilaweli and Kutchaweli in the East coast, Kandakuliya, Talawila, Kalpitiya Silawathurai in the North west and around many Islands in the North. The live coral cover on most major coral reefs averaged around 70-80% of its surface cover, most reefs contained a high diversity of reef fauna. Over 530 species of Reef fish was recorded from surveys at Rumassala reef between 1992 and 1995. The diversity of the reef fish family Chaetodontidae (Butterflyfishes) is taken as an indicator of the richness of a reef. 39 species of Butterflyfish species were recorded from Sri Lankan reefs with major reefs regularly containing about 20-25 species of Butterflyfishes.

The sequence of climatic events during the last decade changed the fate of Sri Lankan coral reefs dramatically. The emergence of several severe storms, increasing infestations of invasive reef species, and most importantly the Coral bleaching event of 1998 caused the loss of about half or more of Sri Lankan coral reefs. The 1998 event alone is estimated to have reduced the coral cover in the south west coast down by about 70-80%. Many reefs were killed outright, few once grand reefs barely survived and the structure and species composition of surviving reefs were changed drastically. Many of the previous dominant species on the reefs had disappeared; the storms had rearranged coral structures and removed tones of dead coral from the reefs. Reef habitats were dissapearing and reef fauna was changing in adaptation to the new situation. While all this was going on naturally the loss of fisheries was forcing local fisher folk to adopt harsher fishing methods to extract a living off what ever resources that remained. The 2004 Tsunami caused more direct damage to the east coast reefs that survived the 1998 bleaching event. Pollution, and other human causes was also on the increase adding to the burden.

The reefs though badly degraded and still under pressure; are still struggling to survive and do grow back slowly. If the current trends continue it is very doubtful if Sri Lankan coral reefs would survive another decade of battering.

It is no longer sufficient to conserve coral reefs; it is time to go one step further and Restore the lost reefs back.



A reef rebuilt using dead coral boulders to create a new reef base with replanted live croal; after one year of growth.

Can Coral Reefs be Restored?

As the trees build the matrix within which the complex web of life that is a forest is created. The living corals form the structure of a coral reef. As the "forest" is also lost when the trees are gone; when the corals are dead the "reefs" degrade and crumble away.

If the forest is destroyed no one can expect to physically restore the forest in its entirety, but by restoring the tree cover and structure the return of the forest could be accelerated. In the restoration of degraded forests the practices of re-planting trees as a means of habitat enrichment has been practiced for long and has well established guide-

Replanting coral

lines. Any approach to coral reef restoration is firstly faced by the problem that no such guidelines exist. Coral reef restoration is a new science/art. Those who endeavor having to find suitable techniques mostly by trial and error. But this is not to say that such things could not be achieved. Though much work remains tobe done.

The coral reefs around the world keep slipping away; and mere conservation practices seem inadequate to keep pace with the loss. While Scientists around the world continue to debate the pros and cons of the many newly emerging restoration techniques; the need for restoration is becoming a priority in preserving coral ecosystems for the future.

It is difficult to focus on preserving the large number of species that form these ecosystems individually. Conserving a habitat and restoring environments lead to a cascade of benefits that will eventually lead to the conservation of all the species that make up the reef.

HELPING THE REEF

Coral reefs need all the help they could get to survive. And it is not difficult for a concerned diver to contribute to the improvement of a reef and help coral survive just a little better. The first thing is to be responsible and sensitive to the reef. Being a good diver and avoiding unnecessary physical contact with coral reduces the stress you impose on the reef just by diving. Mind where your fins hit, be careful where you grab on to rocks, don't kick up so much sand and silt and don't stand and walk over coral. If you need to do more you could help by collecting and removing junk and debris from the reef. This will help the corals survive and make the reef look better for you and others; and will go a long way to keep a reef healthy. And if you are dead serious you could get involved in restoring corals.

This is easier said than done, restoring a reef should be carried out only with a good knowledge and understanding of what you are doing; or you would end up doing far more damage by your mistakes. This guide is not meant to be a manual for reef restoration but an introduction and a reference source. It is important to seek training to gain a strong knowledge base if you aim at initiating serious restoration work.

ASSESSING REEF HEALTH

The first step in restoration is finding out if there is a need for it on any reef. If so a preliminary survey should be carried out to assess the status of a reef before any activity is undertaken.

It is important to be able to check and record the health and condition of a reef over time. To do this one need to identify the criteria used in assessing reef condition and be able to interpret them. One of the most important indicators is the composition of the sea floor (substrate) of the reef and check how much of it is covered by living coral and how much coral has died recently, in addition it is also important to identify the trends in changes of other organisms occurring and competing with coral on a reef. There are many ways in which this can be measured but one of the easiest and practical methods is the “point transect” (a system now widely used by the REEF CHECK /Global Coral Reef Monitoring Network (GCRMN) etc.)*

THE POINT TRANSECT

This system uses a 20m tape with markings at each ½ meter; laid randomly over a reef area. A diver would then follow ‘the transect’ and make notes on the organisms that would lie directly beneath the marked points under the tape according to identified categories. At the end of each transect 40 points of data are collected and the transect is repeated at a different location within the reef. For most purposes at least 3 transects must be carried out to sample a reef adequately. You need to carry out as many transects as is possibe to get better accuracy of the data . Once all the data is collected the points under each category is totaled, averaged and compared to give the percentage of points related to the total number of data points collected. The percentage of ground occupied by each type of organisms and material composing the reef floor can be calculated this way easily.

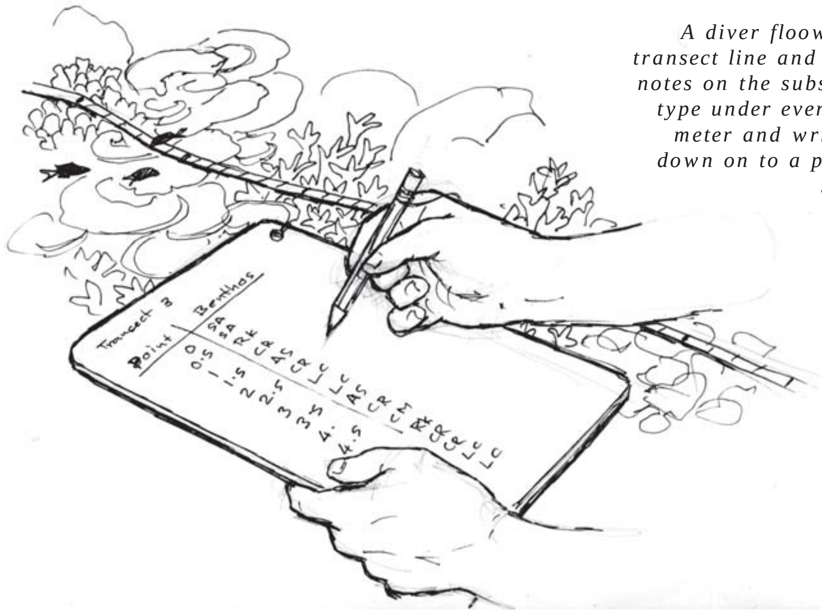
The categories used could be modified according to the site and the way a team would work. It is always good to collect more information than immediately needed while carrying out the transect (species involved etc.) and use the broader categories in assessment as there is no way of getting additional information for later use if it is not collected at the time of doing the transect. A general list of categories that are important is found on page 34.

Additional categories can be created depending on specific organisms or requirements that you need to monitor for management of your site.

Live coral (LC) will give you the amount of living coral present on the reef as a percentage. Dead coral (DC) indicates corals that had died recently, Dead coral would after some time transform in to inert substrates on which other animals would settle where they would be classified along with Rocks in general (RK), more fragile types of coral would break up and fall to the sea floor after some time when dead and are referred to as Coral rubble (CR), Differentiating between sand (SA) and silt (SI) is important as silt if stirred up could pose a threat to corals by smothering them. The presence of any other organism that occurs in significant quantities on the reef should be taken in to account and recorded to assess their impact on the reef (other organisms)

A reef that contains a higher amount of live coral (LC) is in a better state than a reef with less live coral, A reef

**The system has been modified to suit local conditions.*



A diver floows the transect line and takes notes on the substrate type under every 1/2 meter and writes it down on to a plastic slate.

where the larger amounts of recent dead coral (DC) is recorded is in danger; as the reef is dying due to some cause. Monitoring the trends in Invasive reef species and other parameters may give clues to what is causing the coral death. Some times a lowering of the live coral cover may not result in an increase in dead coral if it is caused by an invasive species; in which case the lost coral area will be occupied by that organism. Storms can break coral and pulverize them in to rubble directly and cause an increase in coral rubble on a reef.

KEEPING A REEF HEALTHY

Most of the shallow coastal coral reefs are at the mercy of both man and nature. The accessibility of these reefs make them open to exploitation by anyone; even people who can not swim; through the effects of fishing, tourism, boat anchorages, coastal pollution and construction etc. The shallow coastal reefs also suffer greatly from the impact of storms and thermal events. In the event of increased sea

Sample Substrate type categories for transects

LC	Living coral	Corals that are alive.
DC	Dead coral	Corals that had died recently and still standing in place. Where the shape of the old coral is clearly identifiable.
CR	Coral Rubble	Dead corals that have become fragmented and has fallen on to the sea floor, including un-attached coral pieces from the smallest to moderate sizes.
RK	Rock	underwater Rocks or very old dead coral areas where the substrate is still solid.
SS	Sand stone	Sand-stone or beach-rock areas.
SA	Sand	Sand, generally of a heavier grain size that will immediately fall to the bottom if lifted and dropped from the hand.
SI	Silt	Fine sand that would form a cloud of dust and fall down slowly if lifted and dropped from the hand.

Other organisms

AS	Ascidians	Any species of Ascidian, important in assessing invasive species.
CM	Corallimorph	Any species of corallimorphs
SP	Sponges	Any species of sponge
SC	Soft coral	Any leather or soft coral species
AL	Algae	Fleshy Algae
CA	Coralline algae	Coralline algae forming stone like surfaces

Note: These categories are indicated as a sample only and would often need to be modified to suit local survey needs.

tempreature the warmer sea water 'float' nearer the surface over the cooler water beneath protecting the deeper corals.

The most convenient dumping ground for coastal garbage is the sea. Most city garbage flows into the sea along canals and enters the sea and often end up getting washed up back on the beaches and on reefs. Garbage gets entangles on coral and kill them through rubbing on the coral and shading them from sun light; preventing them from photosynthesizing. Polluted water causes lowered oxygen levels in the water and is believed to be responsible for causing disease and population blooms of reef organism which could become invasive on coral.

The first step in helping a reef is to regularly clean the reef of the debris that entangles on coral, the polypropylene gunny bags and cast off fishing nets are among the worst offenders in this regard. Even the removal of these entangling debris must be undertaken with much care as a diver need to be careful not to break the corals in the process. A small scissor can assist much in this regard. Corals do not like being touched and too much handling can dam-

Cleaning the debris entangled on corals with a small scissor.

Garbage getting entangled on coral can kill the corals if not removed

age their delicate tissue and cause them to catch infections and die.

The shallow coastal coral reefs suffer much through physical impact which causes corals to break or dislodge; these coral pieces would fall to the bottom and roll with the waves. Few pieces would manage to re-settle on to the reef, most would eventually die. If these corals can be rescued and re-settled on to the reef a significant improvement can be made to the reef.

RESTORING CORAL COVER

The first step in thinking about restoration of a damaged coral environment is to assess the site, an understanding of the current status of the reef (site) in consideration as well as collecting as much data as possible about the condition of the reef before the degradation event should be key factors in deciding what action is appropriate. It is important to understand the cause of the degradation and if the factors that lead to the destruction is still active or if it has passed away, If the cause is not removed little will probably be gained by attempted restoration efforts.

It must be important to a sensible reef restoration crew to attempt to bring a reef as close as practically possible to its former condition as bio-diversity, community composition, structure and function both physical and economical. Setting up an arbitrary plan as the restoration target may lead to less than desirable results.

A reef restoration plan needs to look at:

1. Reducing further mortality of available coral
2. Controlling reef degradation factors.
3. Stabilization of dead reef surfaces and preventing further decay
4. Fast Restoration of living coral cover of the reef. (using fast growing species)
5. Restoration of coral diversity (Species and Genetic)
6. Restoration of the physical structure and surface relief of the reef (creating micro habitats.)
7. Restoration of non-coral diversity of the reef.
8. Restoration of socio-economic functions of the reef.

Remaining reef surface area covered by living coral need to be identified and steps should be taken to reduce any threats to them, diversity of species available currently on the reef must be identified and rarer species and species under threat must be identified, and if needed some may need to be relocated on to a coral nursery for propagation. Species that was lost can sometimes be identified through dead coral material available this would form the basis on which any restoration attempt is to be undertaken. The composition of species used in restoration should ideally reflect the species present on the reef previous to the degradation event. It is often not wise to introduce species from other reefs indiscriminately. Though some times it would necessitate substituting different species to restore the physical structure of the reef (Shape of corals massive, foliaceus etc.) when original species is not available.

A small coral nubin replanted on to a reef. the fresh cement base seen as gray will soon be over-grown with algae and will blend in with the reef

ASSESSING THE PHYSICAL CHARACTERS OF THE REEF

The reefs may contain outer reef crests, enclosing lagoons within (e.g. Hikkaduwa, Ahangama), be open without an outer wave barrier (e.g., Rumassala) or form off-shore bars (e.g., Kalpitiya, Basses)

The reefs contain different sub-zones with different environmental conditions from Reef fronts/slopes regularly pounded by sea waves, reef crests prone to heating and periodic exposure to the sun etc. The sub-zones of the reefs contain different aggregations of animals and plants and restoration need to follow this pattern. The flow of currents, depth, human use patterns, effects of sedimentation, presence of invasive organisms and other factors need to be taken in to account in planning restoration.

The idea behind reef restoration activities is primarily to re-build a reef to a state that existed on that reef prior to some event that degraded it. Restoration activities are not primarily artificial reef building activities (though they could be used as supplementary techniques.)

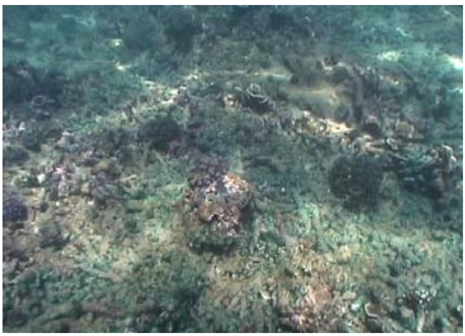
The first step in planning an activity is to identify the character of the reef prior to the degradation and set up a "target situation" to which the restoration effort would try to restore the reef to. Any reports or data available on "before situation" would be the first source in understanding this objective. The restoration workers next responsibility is to look at the reef as a detective would look at a crime scene. The reef would yield an un-ending stream of evidence of what was there, when and how they were destroyed, to a skilled observer.

Reef Environments

An open high relief reef with gully formations

Large poritis domes

Shallow reef crest



Coral rubble area

The second step is to identify priority areas where attention needs to be given; these follow the list of items given below as the Restoration Plan.

- Identify areas of **surviving** coral under threat
- Identify reef degradation factors still active and further degrading the reef.
- Identify dead reef surfaces prone to breaking up that need intervention to prevent further decay. (preserv ing available hard reef substrates)
- Formulate a plan to restore/ rebuild live coral cover of the reef.
- Assess coral biodiversity of reef prior and post to damage and identify threatened species for restora tion and need for propagation in nurseries if needed.
- Restoration of the physical structure and surface re lief of the reef (creating micro habitats. Rebuilding reef structure by biological and/or physical means)
- Restoration of non-coral diversity of the reef. (creating habitat diversity)
- Restoration of socio-economic functions of the reef. (habitats for fishery species)

Restoring live coral cover through replanting

Degraded reefs contain many corals vulnerable to damage or death. A coral that is broken would often roll around until the surface is abraded resulting in its death. Small coral patches are vulnerable to invasion by invasive reef organisms; On a degraded reef the dead coral surface will soon be overgrown with other organisms and would often begin to deteriorate and crumble within one to two years.

Damaged or destroyed coral areas can usually be restored by replanting the area with live coral material rescued from among the broken coral or from areas where their survival is at risk. A third source is through selective ‘pruning’ fully grown coral clumps where the coral had reached a dense mass that does not allow fast growth any further.

Corals should be re-introduced to habitats where the same species of coral would occur naturally, transferring coral into different type of reef area should be avoided unless it is certain that the coral would survive in the new habitat.

Handling coral

All corals are sensitive animals and dislike being handled, Care must be taken to minimize handling the coral and to touch them delicately when you must pick up and handle coral. In most instances the bottom end of the coral would be used as a attachment point for cementing back onto the reef and it is likely that a small area of live tissue could get smothered in the process, as such it is wise to handle the coral from the area that will be affected by cementing.

Healthy corals are usually brightly colored and look “clean”. If a coral looks pale, grayish, furry, swollen or covered in thick mucous the coral is stressed and should be allowed to recover in a calm area for a few days before handling.

Coral Nurseries

When coral units are small they are easily overrun by other invasive reef organisms. It is often necessary to raise small coral colonies and rare coral species on a safer area before they could be re-settled on the reef. This can be achieved through transferring them onto constructed coral nurseries for a while; where the corals would be safe from attacks by invasive organisms. Coral nurseries could be constructed as elevated racks made out of steel rods and mesh.

Coral nurseries provide a temporary safe area to hold coral before re-settlement

The structures should stand 8"- 12" off the substrate on legs that are difficult to be climbed by invasive organisms. The structures need to be firmly anchored into the substrate and should be resistant to being washed off with the waves. The nurseries should be regularly tended and any unwanted organisms settling on them weeded. Once the coral colonies have grown to about the size of a fist they are usally ready for replanting back on the reef.

Replanting coral

When suitable coral material is available, a site must be selected for replanting. Or conversely when a site has been identified suitable coral material must be collected for replanting to begin.

The site selection

The selected site for replanting must be relatively free from potential invasive organisms, sufficiently sheltered from heavy wave action, pollution, heavy siltation and any other active destructive forces and should provide a stable and firm substrate. Coral rubble areas, murky waters and wave crests do not provide good homes to most corals. Some times it may be necessary to prepare the site and clean up the substrate and stabilize any loose substrates before replanting corals on to them.

Finding the right corals

Coral pieces used for replanting should not be too small if it is to be settled on to an uncontrolled environment. The environmental needs of the species selected should match the conditions available at the settlement site (depth, wave energy, siltation, presence of Invasive species etc.) Usually most of the required coral material can be picked up from broken coral, from areas where destructive fishing practices are in operation (common on most reefs) but any coral piece that has a chance of naturally settling on to the location it is found should be left alone. It is better justifiedto translocate a coral piece in a position where its survival is threatened. If a fixed piece must be removed it should always be extracted from the center of a colony and not at the periphery as the removed coral would re-grow faster than a piece removed from the periphery as it would slow down the natural regeneration of coral.

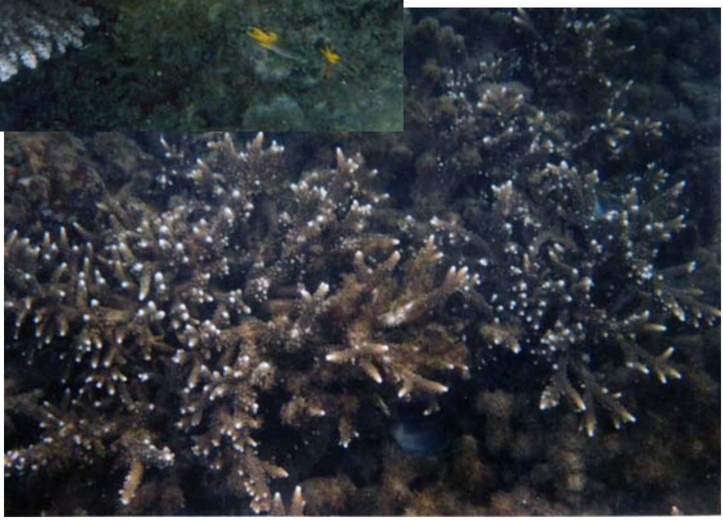
Low growing wave resistant forms should survive better in heavier surf areas, and species resistant to invasive species could be settled as a barrier line if a restoration site is threatened by an Invasive organism (eg. *Pocillopora damicornis*). If the substrate is a dead coral area that may be prone to breaking up, faster growing coral species could be used to stabilize the area before diversity could be restored. Care should be exercised when introducing a fast growing species in to an already coral populated area where that species is not a natural part of a given reef. As the introduced species may out-compete coral species natural to the reef.

The section on coral species would provide an over view of the more important species available on the Southern coastal area.

A selection of Coral Species usefull in reef restoration.

There are over 180 species of corals recorded from Sri Lankan seas. These corals show diverse ecological and biological adaptations, requirements, preferences, capabilities, strengths and weaknesses. Some species are true to the proverbial coral ideal; slow growing and vulnerable; but others could grow as fast as a weed would; with several species capable of growing over a centimeter per month. Some species are easily attacked by invasive species while others show considerable resistance. Some corals prefer the brightly lit highly oxygenated waters of the reef crest and the surf zone where they are resistant to high wave energy

Acropora cytheria



Acropora yongei

and periodic exposure to air during low tide, while others prefer the relatively mild but safer waters further below.

Any attempt to restore a coral reef must begin with a good background as to the needs of each species of coral and where each would be suitable. Most of these can be learnt easily by just looking around to see the natural occurrence of corals on the reef. If you spend enough time observing corals you would soon see the corals engage in many interactions with other life on the reef. Wars for space on the reef floor is common and in close proximity most organisms would compete or attack each other through physical or chemical war fare. If one organism wins it will spread over the loser, or if a stale mate is reached they would reinforce the marginal area and co-exist. Observing these interactions would give a good understanding in to the abilities of each species of coral against other organisms on the reef and allow for a planned approach that improves survivability of replanted coral. In addition to these basic guide lines it is always wise to re-settle a coral to an environment that is similar to the place where it came from. The decision to transplant to a different environment must be with good reason, as the chances of the coral not-surviving at that site could be higher.

With most species of coral it is best to re-plant clusters of the same species together so as to be able to form larger confluent colonies when the re-plants grow and join together. The spacing of ‘colonies’ about 20-30 cm. apart would often lead to the colony growing together in about 1-2 years with the faster growing species.

It is not possible to give details of all the coral species that would be encountered in restoration, but the following pages offers an introduction to a selection of species useful for the beginner.

Acropora formosa Staghorn coral

This coral dominated the Southwestern coastal reefs prior to the 1998 Coral Bleaching /Mass mortality event. This is an ideal candidate for coral restoration as it is a very fast growing species of coral that can usually survive fragmentation and actually uses fragmentation as a means of fast colonization of sand substrates. The open branching form of this coral also provides ideal habitat for the young of many reef fish species. The main set back is that this species had become almost extinct on many South-western reefs post to the 1998 bleaching event. When a translocation is attempted from the few reef sites it is currently surviving in large enough quantities, the *Acropora formosa* seem to go into an extended acclimatization period lasting usually over a year before the coral will begin to grow normally. If translocation is attempted it is important to translocate to a transit site on the destination reef that closely match the conditions of the donor site (temperature, salinity, turbidity etc.) and carry out the integration to the final site in stages, giving the corals enough time to adjest to the new conditions without causing too much stress.

Other larger branching *Acropora* species

Several other Acropora species form thickets of branches like *A.formosa* though most of these do not form the massive meadows that *A. formosa* formed before the 1998 bleaching event. Some species like *A. yongei* *(see page 44)* form excellent substitutes for *A. formosa*

Small branching *Acropora* species

Many other Acropora species found on the reefs are all good candidates for reef restoration. As each species has its preference of depth and distance from shore look at the site the corals are collected and try to match the conditions when selecting a site for replanting.

Acropora species do better as large singular mass colonies and it is usually a good idea to put a large group of the same species of Acropora colonies together and about 20-30 cm. apart so that in about 2 years the colonies can become one unified colony.

Acropora lianae

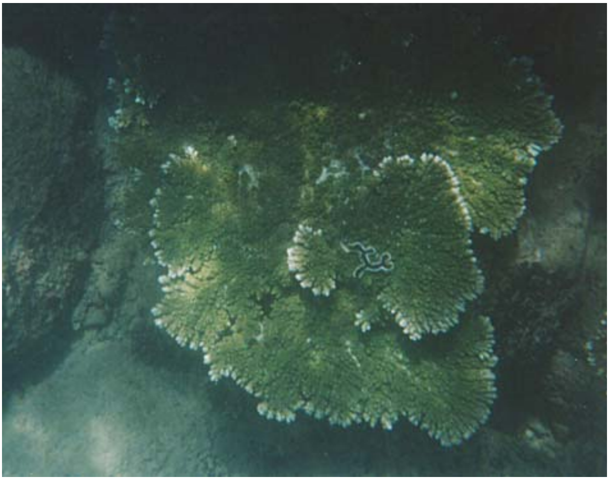


Table forming *Acropora* species

Several species of Acropora grow as table corals and some species can grow to over a meter across . They form a specialized reef habitat and is essential for some reef species such as the Chevroned Butterflyfish *(Chaetodon trifascialis)* The larger pieces if available should be mounted on sides of rocks horizontally or in some occasions they could be mounted vertically on inclined surfaces where they would take a longer time to grow vertically and then form the horizontal table form.

Montipora aequituberculata **Rose /cabbage coral**

This species was the only species that did not succumb to the 1998 Bleaching event mostly surviving without bleaching; The species is one one the dominant species of coral in Southern reefs and is also capable of fast growth and fast colonization from fragmentation. This species is specially usefull for restoration of dead coral areas.

Porites rus.

This species of Porites forms clumps of small pencil sized frond-lets growing over an encrusting base; as the colony grow of age the frontlets become more numerous and make a dense and tightly packed mass of fronds. The colonies are usually dark brown to yellow ocher in color with pale or white tips to fronds. a single clump usually grows to about 2ft in diameter but as the clumps grow in aggregations this species can quickly cover large continuous sections of the reef.

P. rus is a very fast growing species capable of spreading through fragmentation. When naturally fragmented (by waves etc.) a high percentage of fragments survive and are capable of fast reattachment to substrate and shows a good capacity in recolonizing reef environments. This species is highly competitive and is capable of settling on to reef areas already covered by turf algae sponges etc. The coral is resistant to low density aggregations of ascidians but would

be smothered by aggressive large Ascidian or corallimorph aggregations. it is also prone to attacks by a fine-branched mat forming algae *Hypnea sp*., which would settle among the base of the frontlets of the coral and grow upwards till the coral is shaded, smothered and eventually killed. These algae in infestation stage can spread fast and do considerable damage, but usually the invasive stage does not last for long periods and manual weeding with a small hook or siphon devise could minimize damage. If algal removal is attempted it is important to ensure the removed material is cleanly taken out of the reef as floating fragments can re-settle and kill more coral. *Hypnea* does not seem to attack other coral species.

The species prefers shallow to medium depths (from 4ft to 15ft depth) with periodic moderate wave action. In the proper environment the speed at which *Porites rus* can colonize a dead substrate make it an ideal candidate as a pioneer species to re-stabilize substrates before other slower growing species could be introduced.

Dome forming *Porites* species.

These are the real giants of the reef forming structures as big as a small room that would date thousands of years old as these are among the slowest growing coral species. These species are of not much use to the reef restorer except; that the slow pace of growth and the importance of these to the physical structure of reef make them important elements in the reef preservation and demand attention from the restorer to monitor and nurse them. These large domes though resistant to ascidians are highly susceptible to coral diseases like the Pink-band disease and the pale-spot disease. They do sometimes lose to spreading invasive colonies of corallimorphs but usually not without a fight.

Pocillopora damicornius* and *P. verrucosa

These brightly colored small clump forming species prefer the shallower environments and can tolerate extreme conditions of the reef crest. Though not as fast growing as *P. rus or M. aequituberculata* they can grow fast and show considerable resistance to environmental conditions and good survival, these species are among the most resistant to infestation of ascidians and corallimorphs and is useful in creating a live barrier to stop spreading colonies of invasive species.

***Pocillopora eydouxi* (group) Elk-horn corals**

This species of *Pocillopora* forms thick heavy branches and thickets that are good fish habitats. This species prefers the somewhat deeper zones of the reef, when occurring in shallow reefs it is always located in areas where there is exposure to

N.B.: This collection of species is only provided as a guide. Observation and experimentation may reveal many more suitable coral species for reef restoration.

Favid corals

open sea water and is located at the outer reaches of a reef. Care should be exercised in using this species in shallow water. The growth speed of the species is moderate and is a "moody species" that may not be a good species for initial reef substrate recovery.

Favia and_related species

These common reef species show moderate growth speeds and are moderately hardy. They can be overrun by Ascidians and corallimorphs. The colonies are usually well cemented to substrate and fragmentation is difficult without damage unless broken pieces are found for replanting.

Leptoria and _Platygyra_ species

These meandroid corals are usually hardy and *Leptoria* can be a reasonably fast growing species. These corals like the favids are difficult to break for new planting material but when broken pieces are found are good candidates.

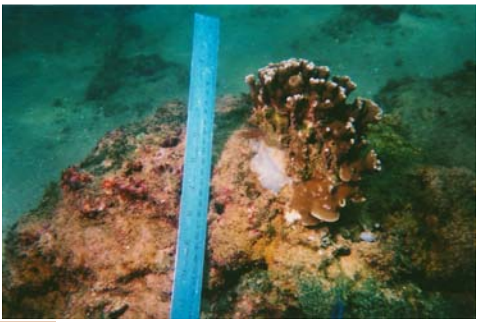
THE TECHNIQUE

The key to restoring a coral area is the success with which a coral can be re-attached to the substrate. There are many ways in which this could be achieved; coral pieces can be settled on to slotted artificial substrates, wire-tied on to reef surfaces or cemented/glued on to the reef base. The wire ties are the least effective system as this system relies on the coral unit growing and self attaching it self on to the reef. If the binding is firm this could be achieved in about two weeks. But any slack that allows the minutest movement of the coral could prolong this time to months. The system also depends on finding locations on the reef that allow a wire tie (preferably a plastic one) to find a good grip on the reef. The slotted artificial base is successful as a coral nursery, it fails as a final reef restoration technique in itself as the structure can be easily seen and does not homogenize with the reef and may disturb the aesthetics of the reef. Cementing corals on to reef substrates with cement or glue is possibly the best technique as the replanted coral becomes part of the reef almost immediately post to the replanting. Cementing corals underwater using fast setting low cost mixes of Portland cement is efficient when carried out by a trained crew. The side effects of these are insignificant when the process is carried out properly with no adverse effects observed on replanted coral or the surrounding. Several glues both Epoxy and Cyanoacylates can be used to fix very small coral units on to rocks that can be settled back on to reefs, but the higher cost of material, greater side effects, a more complex procedure and having to expose the coral out of water for even brief time while fixing the coral make these techniques less attractive than basic cement techniques.

The basic cement technique relies on speeding up the setting time of Portland cement using additives to get a mixture that will harden within 1 -2 minutes from the time of mixing. The replanting site is pre-prepared and all the coral fragments used for replanting positioned at site. The cement would be mixed on a float or boat close to the site and a small ball of cement about the size of a tennis ball is sent down wrapped in a plastic bag to prevent washing off in transit. On the sea floor the cement ball is taken out and applied on to the reef surface in a single movement followed by the coral unit being attached and fixed onto the cement mound. Care need to be taken not to over manipulate the cement as this could cause cracks to form and allow salt water to run into the mound and prevent it curing properly. And once the cement begins to set; initially it becomes brittle and if handled break up in to a cloud of cement dust that will wash over the reef. Some species of coral especially day feeding long polyped species such as *Goniopora* can be significantly stressed and even killed by cement dust if heavily exposed to it repeatedly.

cementing coral onto a reef and recemented coral at left

Though the cement would set within minutes and not get washed off; it will take another day or two to achieve full curing and become fully hardened. The settled corals should be left alone during this time without disturbance.

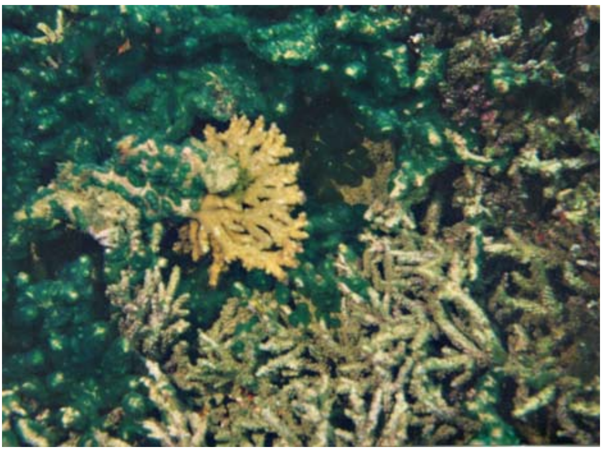


It must be remembered that this technique is an effective and efficient technique for re-planting coral IF CARRIED OUT BY SKILLED DIVERS. The advantages of the system relies mostly in the skill of the team carrying out the replanting where almost no cement wash off will be present. In the hand of careless or untrained operators the system will lose its advantages and could potentially become a danger to corals if a large amount of cement dust is allowed to get washed off in to the reef.

It must be stressed that though this book provides a basic introduction in to the techniques of coral restoration it is in no way a complete manual. A restoration worker must be a good diver fully comfortable in the water, and be extremely aware of his surroundings and how his activities affect the environment.

Reef Invasive species - an Overview

During the past few years' signs of deteriorating reef health was becoming more and more pronounced on the coral reefs of Southern Sri Lanka. These included infestations of otherwise naturally occurring reef organisms spreading out of control, attacking and killing off considerable areas of living coral. The pattern of infestations sweeping across the reef areas and on most occasions dying out naturally within a few months may or may not be natural phenomena. But due to the high levels of coral mortality caused by the organisms while the infestation is active it is no longer considered an option to allow the infestations to run its cycle and control itself naturally. Most Corals are slow growing with a growth of a few millimeters up to 15 cm recorded per year. (Veron,1986) The problem is further aggravated as the substratum lost to the infestation is soon covered by a myriad of competing reef organisms including turf algae, sponges, Corallimorphs, tubeworms, etc. reducing suitable ground for new coral recruits to settle and re-colonize lost ground.



A small coral unit in-situ on the reef; under threat from an advancing infestation of Green Ascidians.

The question should we interfere in reef ecology through managing infestations is open to debate, Ideally in a pristine environment man has no role to modify the processes. But the reality is far from this ideal and man interferes with the reef ecology every day at many levels causing significant threats to the reefs. In addition the live coral cover on the reefs have dropped to a level that is hardly able to sustain the basic functions of a reef and any further loss of live coral cover is not an acceptable situation . On the terrestrial environments physical interference in managing invasive species is practiced in wide scale as an accepted management practice.

Competition for ground among reef benthic (bottom living) communities is naturally high. Coral polyps are usually well capable of fighting off attacking organisms and on most occasions will overgrow other reef organisms when building reefs. The recent spate of corals being killed by these infestations indicate that the corals have been weakened and are no longer capable of keeping invading organisms at bay. The weakening of coral is believed to be the result of high environmental stress caused by direct human activities, pollution and natural disasters. The changes in the reef species composition due to selective fishing is also a possible cause as the loss of a controlling predatory species either as adult or larvae could lead to a bloom in a pray species.

CHRONOLOGY OF MAJOR REEF INFESTATIONS IN SRI LANKA.

The earliest records of reef organisms attacking coral reefs in Sri Lanka involved the highly publicized phenomenon of the Crown of thorns Seastar (*Acanthaster planci*) the coral eating starfish explosions devastated reefs from the Great Barrier Reef to Malaysia and Maldives. In Sri Lanka infestations were reported in 1970's and 80's from the East coast and also on a few instances from the North-west reefs. The Seastar is common around Trincomale and is considered a pest in the east coast and in the north-west; though infestations at the same scale is rarer in the Southern coast.

- The Polhena coral reef was destroyed by a population explosion of fleshy algae (*Ulva spp.)* overgrowing the coral areas in mid 1980's the event was though to have been triggered by localized organic pollution of the area. (De Silva,1997) causing eutrophication.

- In September 1996 the Rumassala Coral reef was overrun by an infestation of a colonial Ascidian belonging to the family Didemnidae. Triggered by an unknown environmental signal the green Ascidians spread across the reef overgrowing the living coral and even the fast growing calcareous algae *Halimeda*. By February 1997 the infestation began to recede but not before killing an estimated 20% of the living coral cover of the reef within the short time span of 5 months. The damage was not significant as most of the damage was caused to areas of Acroporid corals; these corals are among the fastest growing corals in the reef and showed significant re-colonization of damaged areas within a year. Similar but less intensive Ascidian infestations were documented in some other reefs Including Hikkaduwa. The Ascidians have become one of the most persistent invasive species over time and is now a regular species on most Southern reefs, causing periodic invasions followed by natural recession cycles.

- In 1997-98 Infestations of the calcareous algae *Halimeda opuntia* began to spread out of control on many Southern reefs and within months overgrew and killed significant areas of living coral. Hikkaduwa reef (De Silva, 1997) and Unawatuna was among the worst hit by this infestation though strangely the Rumassala escaped with only minor damage. Some scientists are of the opinion that this may be linked to petrochemical pollutants in the water, though unproven; there may be correlation to the possible trigger, as Hikkaduwa reef regularly receives significant amount of petrochemical pollutants from the many boats within the lagoon. And the grounding of the ship *M.V. Lord Nelson* on Unawatuna reef and its break up saw significant quantities of bilge oil entering the reef in the same year

- An unidentified species of Black encrusting sponge species claimed significant sections of the Rumassala reef in 1998 just prior to the bleaching event. The species though still active from time to time has not spread at the same rate since 1998.

- Post to the bleaching event the emerging reef dominant species of coral *Porites rus* was being attacked by a fine branched thicket forming algae (*Hypnea sp.*) which like the Halimeda settled itself at the base of the coral branchlets and spread upward and over the coral blocking the sun light (shading) and smothering the coral.This species can spread reasonably fast at infestation events.

The cause of increasing incidence of reef infestations within the past few years is not understood. The increasing levels of coastal pollution and global climate change related environmental stressors are believed to play a major role in reducing the defensive capacity of corals to fight off competing organisms and infections. The trend in reef death has reached alarming proportions within the past few years and unless serious action is initiated to control pollution of coastal seas the coral reefs of Sri Lanka may be exterminated within a short period of time.

GALLERY OF REEF INVASIVE SPECIES

ANIMALS

Green Ascidian

This small green colonial tunicate (Ascidian) belongs to the Class Ascidiacea of the Phylum Chordata under sub-phylum Urochordata. There are a wide range ofascidian species on coral reefs and usually cause no harm to corals. The Green colonial ascidian responsible for infestations; form small green elongate colonies less than a centimeter long and belongs to the primitive family Didemnidae, The identification of these ascidians beyond the level of the family is extremely difficult and the species in question is not identified.

The control of this species can take two forms.

- The colonies are somewhat loosely attached to the substrate and can be physically removed using a sharp tool. It is possible that the removed colonies if allowed to float away could re-attach and spread to other sites. Hence the dislodged colonies have to either be removed from the water or alternately the colony body must be broken open which will on most instances kill the colony. This method is best for managing small areas (e.g. an attack on an important coral colony)

- The green ascidians are photosynthetic with a symbiotic algae providing part of its nutrition like in corals. Hence they are dependant on sun-light for survival, if the light supply is blocked for about 2-3 weeks (using a sheet of black polythene or similar) the Ascidians would usually become bleached, weak and would often die. Care need to be taken in using this kind of shading technique

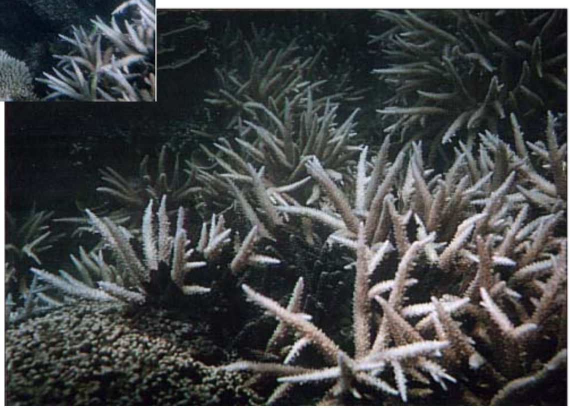
A colony of Porites rus under attack by Green ascidians. Detail of Green ascidian colonies (with a Sea slug Philidiella sp. at left)

to control ascidians as, any corals getting covered would also be affected by the loss of light. On a general note most corals are capable of surviving a two week shading better than ascidians and would recover but all possible care should be exercised to keep corals exposed. It is also important to allow some water movement under the shade as not to kill off other organisms. Shade controlled Ascidians that are not killed would recover over time but usually their growth seem to be stunted and the corals seem to be able to better defend against the weakened Ascidians.

Black 'Sponge'

This encrusting black 'sponge' species spreads as a thin film over live corals and at the peak of an infestation can cause significant damage to live corals. The identification of the organism is not certain, as the very fine layer is difficult to collect for proper identification but contain spicule types consistent with sponges, It would not be too improbable if with further investigations this organism is found to belong to a different taxonomic group. The sponge can weaken and kill corals of most species though large dome corals seem to be resistant. It is impossible to control the spread as the layer of sponge is too thin and adheres hard on to the substrate making it almost impossible to remove physically, no other control measure has been devised yet, though infestations do not last for more than one to two months and spread at a moderate pace.

Invasive "black sponge" spreading over and killing corals in Rumassala reef in 1997. the above area of coral was killed within a span of one month



A spreading colony of corallimorphs attacking a colony of Porites rus

Corallimorph

The brown Corallimorph which spread over any available hard surface on the reef is developing as a threat to reef corals. This species appear like a thick brown wooly towel. This close relative of corals shares many characters with corals but does not build limestone skeletons. Biologically they are very similar to corals and also contain symbiotic photosynthetic algae in their tissue.

Control of Corallimorphs can be achieved by physically removing them using a scraper; the colonies are easily damaged and killed, but if released without being killed there is a possibility of re-settlement and colonizing at other locations. It is therefore ideally needed to remove colonies from the water, When corallimorphs are damaged they release chemicals into the water which can cause irritation or allergies in some divers; so care must be taken in this regard. The best way to remove large colonies is with an underwater vacuum devise with a scraper attached to the inlet hose and a collecting bin at the exit. A simple underwater vacuum devise can be home- made using a 1inch PVC tube and a few accessories from a local hardware store and powered using air from a spare SCUBA tank. A more efficient method of controlling corallimorphs is to shade them for an extended period; related to corals the corallimorphs also harbour symbiotic algae in thier tissue and depend on them for survival. As such if a colony is kept covered for 2-3 weeks the colony would shrivel up and usually die off. the application of shade can be planned to leave out corals and other organisms and can be effectively applied to control large invasive colonies.

Palythoa / Zooanthids

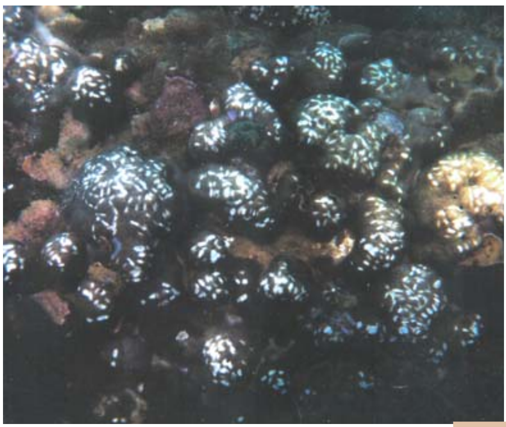
The Zooanthids are also related to corals and form rather rubbery colonies similar to true corals. Many species are found in the area and several species of Palythoa found on the reefs can at times cause minor infestations.

Crown of thorns Seastar (COT)

This large spiny Seastar can grow to over a foot in diameter and is readily identified as it contains many spiny arms usually with a bright blue/ purple band along each arm. This Seastar feeds primarily on live coral polyps and would sit over a coral head and invert its stomach out through its mouth to digest the coral tissue. Where these seastars are found usually the tell–tale circular feeding scar marks can be seen on corals. The Crown of thorn Seastar had caused major infestations in the east coast and around Kalpitiya in the North west; this species caused significant coral damage in some years. The management of an infestation of COT is usually to remove the seastars using a long spike as the spines on the Seastar is poisonous and could cause severe pain if stung. It is not advisable to cut up individuals underwater as segments of seastars can grow in to complete individuals which will aggravate the problem.

Parrotfish

Post to the bleaching event the fish populations on reefs changed with large numbers of herbivorous species taking advantage of the predominance of algae colonizing the dead coral areas, as time passed other organisms begin recolonising areas occupied by the algae through direct competition. As the algal stock is depleted some large parrotfish herds turn their attention on to corals feeding on the symbiotic algae in coral tissue, Parrotfish grazing can some times leave significant damage on coral heads.



Coral snails

Though not a serious issue currently, localized events where high abundance of coralivourus snails feeding on corals can lead to death of coral heads. A single event was observed in 2001 when an increse of Coral snails caused some damage to corals in a localized patch in Rumassala, though no major events have been reported it is advisable to monitor large aggregations of Coral snails.

Coralliophila snails feed on coral; but in normal numbers pose no threat to reefs

Tubeworms

Tube building polychate worms are common on reefs and few species live in large colonies and some show a tendency to grow at an accelerated pace for short periods; during which they could turn invasive. Usually the fast growing species are larger. building cemented sand tube colonies which are normally brittle and easily broken. Where it becomes necessary to control a colony it is easily managed by physically breaking up a safety belt around threatened coral colonies. And as the colonies at peak infestations can grow 4-5cm per month a clearance of about 20-30 centimeters need to be made.

ALGAE

Halimeda

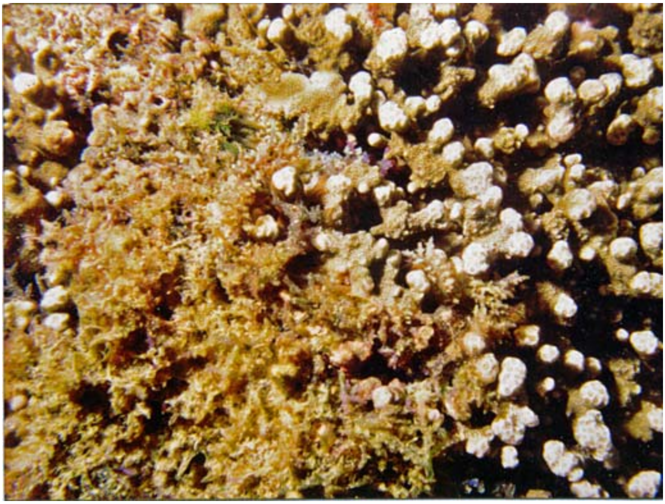
Algae of the genus Halimeda are readily identified as they secrete skeletons of calcium plates linked in multiple branching chains, among the Halimeda species the *H. opuntia* with medium sized plates is the species that is most likely to cause invasions. The first documented *Halimeda opuntia* infestation occurred in 1997 in the Hikkaduwa coral reef and at the Unawatuna coral reef. Though the algae are not resistant to coral defenses the Halimeda uses an indirect strategy to kill corals. The algae settles at the base of a coral and grows upward between coral branches and once it reaches above the coral spreads over it effectively killing the coral by shading and cutting off the sunlight to the coral. At the peak of the Infestation Halimeda can cover over a meter of surface per month. Some debates on the cause of infestations suggest that there may be a link between petrochemicals in sea water and accelarated growth in Halimeda.

Ulva

The fleshy green algae was among the primary species along with Halimeda that was responsible for the overgrowth of algae at Polhena reef around 1998 which destroyed significant areas of coral; It is believed that this bloom was caused by eutrophication of the reef lagoon through nutrients released into the water by retting coconut husks in the sea for the coir industry. Similar out-breaks of *Ulva* was seen at Bundala post to a shipwreck caused oil and phosphate pollution of the area.

Hypnea

Hypnea is a thin finely branching Brown algae that can form algal mats that may be ½ to a centimeter thick. This species sometimes attacks the coral *Porites rus* by growing among the branches after settling on a dead part of the colony and like Halimeda by growing over the coral and killing the coral by shading it. Tough the species can be physically removed using a fine hooked pick it is essential that the removed material is not allowed to float away and should be removed from the water.



The Algae; Hypnea sp. attacks only The Coral porites rus. The algae settles initially between the branchlets of the coral and grows over and smothers the coral.

Montepora silt accumulation

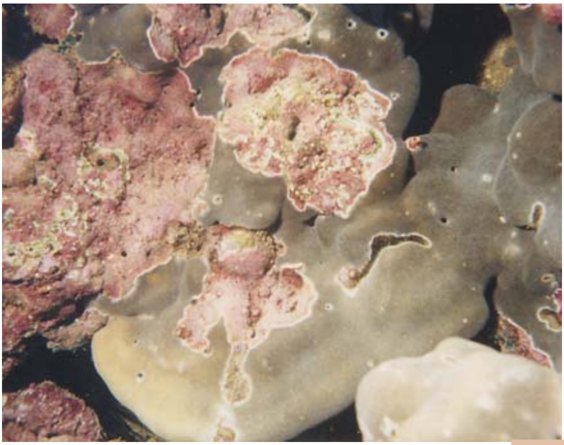
This unidentified condition was responsible for the death of many colonies of leafy *Montipora* corals especially *Montipora aequituberculata* in 1996. The otherwise healthy corals begin collecting a small patch of fine silt at the center cup of the colony, which keep spreading until the most or whole colony is killed. The cause of the condition is not fully understood, but if the silt is fanned off a very fine filamentous algal mat is found buried under the silt which may be the cause of the silt accumulation as the algal filaments seem to stabilize the silt; and help in the collection of more sand and prevent the normal process of silt removal. Though the algae does not kill the coral directly; the accumulating sand smothers and kills the coral.

CORAL DISEASES

Pink-band disease

The disease was first identified in Sri Lanka in 1997 and became a significant threat to corals post to the 1998 coral bleaching event. The disease attacks only the large dome forming *Porites* species of coral. The infection starts at a scar on the coral colony or at one of the many holes on the coral maintained by the tiny coral living hermit crabs (*Paguritta spp*.) The characteristic mark of the infection is a pink band spreading as a ring over the coral surface leaving the inside of the ring always dead and usually covered by pink coralline algae. At peak infestations the pink band can spread and kill about 2-3 cm. in diameter per month over a coral surface; if multiple infections are found on a coral head which is usually the case large coral boulders could be killed off within a short time by the pink band disease. Though it is not fully studied it is believed that the condition is caused by a bacteria or a fungus attacking the coral tissue. No cure has been identified currently and management is not possible. The condition is more likely to occur when the water is polluted.

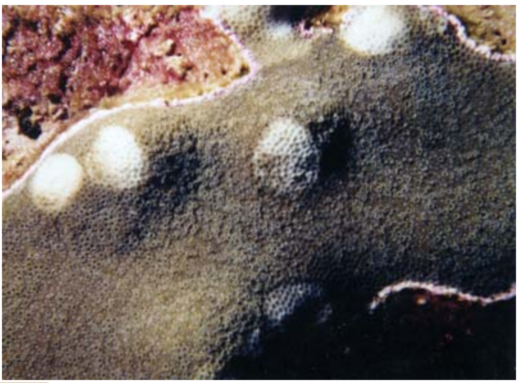
The infection spead as a thin pink band over colonies of large dome forming Poritid corals



Gray-spot disease (?)

Like the Pink-band disease the Gray spot disease is also believed to be caused by a fungus or Bacterium and attack large dome forming *Porites* corals. The disease can be identified as the coral develops pale grayish circular patches 5-12cm. across over the coral surface. The patches usually give a very fine fillamented appearance and the coral starts to secrete large amounts of mucus from these patches. This condition is periodic and can affect many coral colonies at times. Unlike the Pink band disease the Gray-spot disease does not seem to kill the coral and usually corals recover after a couple of weeks to a month

Poritid corals affected by Pale spot disease (?) the colony on the picture at left is also affected by the pink band disease



Afterword

Diving and snorkeling on the South and West coasts of Sri Lanka since early 1980's I was among the last generation of divers to witness the Coastal coral reef in Sri Lanka in its full glory, Seeing what was there before; I with my colleagues witnessed the steady degradation of most coastal coral reefs and the extinction of several in due course of time. The priority of causes blamed for the destruction changed from time to time; not because the threats lessened, but as more and more significant threats emerged. Little could we do to mitigate the threat of mans' recklessness and greed on the reef, but we found our selves far more helpless against the fury of nature going against herself.

We fell in love with the Rumassala coral reef at the beginning; as we were just wandering into the ocean as youngsters, and there was not a year where we had not explored her charms. Rumassala coral reef became our playground, school, laboratory and home away from home. She was always good to us and we were there for the reef as we fought on to save the reef from the Proposed Galle port development project and other threats that emerged.

We studied marine biology on the Rumassala reef; and the reef taught us about 'life' itself. There is much anybody can learn from a reef if you would just keep your eyes and heart open. More than anything else we saw the desire of the reef to live and the tenacity with which life clings to itself and tries to surmount the mountain of obstacles we heap on her.

We were part of the circle and had no option but to help the reef survive. Post to the greatest tragedy on the reef; the coral bleaching/mortality event of 1998 the team transformed its main activities in to saving the surviving corals and helping the reef restore itself as fast as it can. And for a decade we studied ways of restoring reefs, early failures lead us to develop more efficient and practical methods of speeding up the restoration of live coral cover. This book is the product of many years of field work and compiles a selection of techniques that had been tested successfully at Rumassala to assist in the restoration of Coral reefs.

To undertake a coral restoration activity it is essential to have a good understanding of the species and processors that shape a reef. This booklet does not provide this wider knowledge required for the task but only serves as a basic introduction to the techniques developed by Nature Conservation Group and its partners in reef restoration. We hope this would lead to a process which would eventually make replanting coral reefs as common a practice as re-planting trees to restore forests on land.

A final caution that any coral restoration activity is not stated in too much haste, Though anyone can help in keeping a reef clean and basic reef keeping, a coral restoration activity need to be undertaken with a lot more thought, the team must have a strong background in marine biology and ecology and must be good divers.

Remember! That you could end up doing more damage to a reef than good with an restoration attempt; if it is unplanned, misguided or carried out by unskilled divers.

Acknowledgments

This book owes much to the dedicated work and spirit of my friend Noyel Withanage, a man of a calibre and quality rarely encountered. It is also the result of effort of the many other team members who served at Rumassala over many years including; K. Lakmal, G. Nihal, Ajantha Palihawadana, Sajith Subhashana, Shantha Jayaweera, M.G. Dhanushka, Damith Lakshman, Kavindu, Rohana and others, support and fascilitation of the committee members of Nature Conservation Group; Chandima Kahandawala for always being available in emergencies and for editing the document, Sujeewa Jasinghe and Sanjeewani Dayananda for providing the platform on which all activities managed to continue. A special acknowledgement is made of the support received from the coastal comunity at Rumassala. A special mention must be made of the partnership of the Neo-synthesis Research Centre; Ms. Kami Melvani and staff. Who supported this work through difficult times and provided the strength to build the program in to its present strength. The support provided by the UNDP GEF/SGP (Global Environmental Facility /Small Grants Program) and its staff; Mrs. Shireen Samarasuriya, Dinali, Darshini and others who has contributed to leapfrog the program into its next stage and build up a strong base on which future activities would be carried out. I wish to extend my gratitude to all who supported our efforts in many ways through the years; among many others special mention must be made of a few; Dr. Ranjith de Silva my first Guru in diving and reef ecology for the opportunity to horn my skills at NARA coral reef unit. Dr. S.U.K. Ekarathne, and GCRMN South Asia office; for all the opportunities provided; and my dear collegue Laksiri Karunarathne, who in the initial days of Natcog was a driving force in setting up serious studies at Rumassala,

More than all I am indebted to my parents; who in my crazier days trusted me enough to let me indulge in endeavours that at the time may have looked like a lot of waste. The experiences gained in those years provided the basis of all that is achieved today.

Index

Prasanna Weerakkody

Is a keen diver, Marine naturalist and conservationist. He fell in love with the sea from his childhood and took to diving as a hobby. His short spell at NARA helped to intertwine the hobby more as a life style. Prasanna has been the drive force of the Natcog marine ecosystem program for 15 years and is involved with a highly successful experimental reef restoration activity at Rumassala reef for over a decade. In his effort to share and let others see what he has seen, Prasanna has also trained many young divers who will carry his vision to the future. He is well recognized among the marine science and conservation communities both locally and internationally.

He hails from a well known family of artists and, today an acclaimed Artist and a Natural History Illustrator who has produced technically accurate illustrations of marine life for several Sri Lankan and international posters on Reef fishes and a book on Whales and Dolphins in Sri Lanka.

Chandima Kahandawala
President,
Nature Conservation Group.

The Nature Conservation Group (Natcog)

Established in 1992 the Nature Conservation group has been actively involved and contributed to research, awareness and conservation of Wildlife and Natural resources of Sri Lanka. Marine life, Ocean and coastal ecosystems have been priority within Natcog, carrying out research on coastal Coral reefs, Reef Biodiversity, Marine mammals and Oceanic sea birds of Sri Lanka. A long term involvement with the Rumassala reef at Galle has matured into a serious and long term study of the processors that shape a reef, ways of managing reef health and restoration of degraded coral environments. Post to 1998 coral bleaching event Natcog teams has worked intensively in developing practical, efficient, low cost techniques in replanting coral in degraded reef areas and improving the health of the reef.

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