Coral Reefs

Coastal Ecosystems Series (Volume 1)

Sriyanie Miththapala

Ecosystems and Livelihoods Group Asia, IUCN

Bundesministerium
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What are corals/types of coral?

Corals are two-layered invertebrates that live in groups (i.e. they are *colonial*) and are related to jellyfish and sea anemones.

Corals are made up of tiny individuals called *polyps*. Each polyp is like a fluid-filled bag with a ring of tentacles surrounding its mouth, and looks like a tiny anemone. Polyps within a colony are linked by living tissues and can share their food (Allen & Steene, 1994). In some corals, the polyp extracts calcium carbonate from the sea and secretes it as a cup of calcium carbonate from the bottom half of its body. These cups provide anchorage for the polyps but when threatened, the polyp can retreat into the safety of the hard cup. When the calcium carbonate cups of many billions of these polyps fuse together, they form coral reefs (Veron, 2000).

There are two main types of corals 1) Stony Corals and 2) Soft Corals.

1) Stony (Hard) Corals:

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

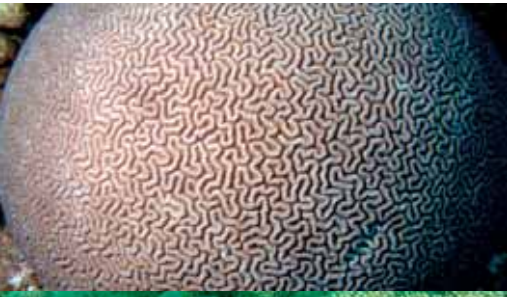
   Because of this association with zooxanthellae that need sunlight to produce food, hermatypic corals are dependent on sunlight and only grow in clear shallow waters less than 60m deep, which have a temperature range between 25° and 30°C. Hermatypic corals prefer narrow salinity and low turbidity ranges. Therefore, hermatypic corals need

   a) a particular range of temperature;
   b) sunlight;
   c) generally clear water (low turbidity); and
   d) a narrow range of salinity (Allen & Steene, 1994).

   There are about 845 species of reef-building corals (Global Marine Species Assessment, 2008).

There also are some stony corals which do not have zooxanthellae and do not build reefs. These are called *ahermatypic* corals and can live in both shallow and deep water (some up to 6,000m deep).

Stony corals have different shapes and forms. Some selected shapes are shown on these facing pages.



Massive

Columnar

Encrusting

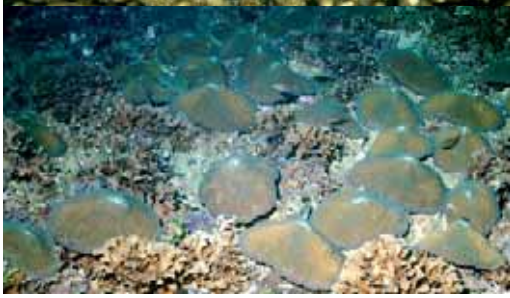
Tabular

Foliaceous (forming a whorl)

Branching

Digitate (like fingers)

Mushroom



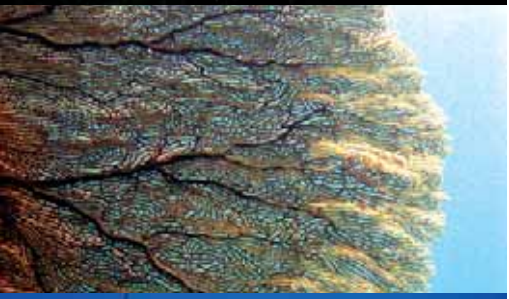
2) Soft corals:

Soft corals lack a calcium carbonate skeleton, hence their common name. However, in their bodies are tiny hardened calcium particles called *spicules* that provide support.

Some selected soft corals are shown below.

Fire and Lace Corals

Black or Thorny corals



Sea fans

Sea whips

What are coral reefs?

Coral reefs are the skeletons of stony coral polyps cemented together. Corals grow very slowly - some grow only about 3-20mm per year. Therefore, some reefs form over several million years (Veron, 2000).

As these corals grow and die, they leave behind their calcium carbonate skeletons. On these skeletons, other corals grow. As the years pass, walls of coral begin to form: massive walls of rock. As the waves and currents beat upon these reefs, nooks, crannies, ledges and caverns form in these walls.

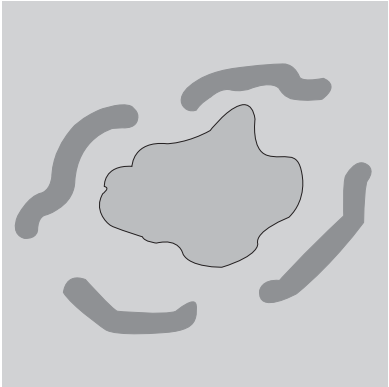
Just as there are different types of corals, there are different types of coral reefs. The three main types of reefs are fringing reefs, barrier reefs and atolls (Veron, 2000).

Fringing reefs

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

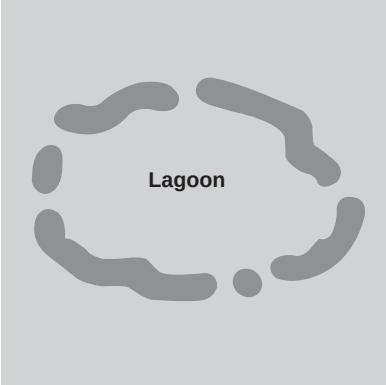
Barrier reefs

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



Atolls

Atolls grow surrounding (or partly surrounding) an island which then sinks relative to sea level (usually because volcanic activity forming the island stops), or was flooded as sea level rose after the last ice age. Atolls surround (or partly surround) a central lagoon. The Maldives consists of 26 atolls.

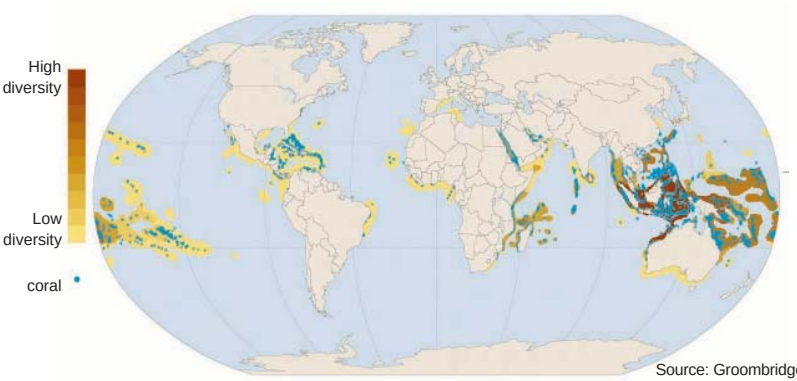


Although these are the three main types of reefs, there are many reefs that do not fit these models.

Where are coral reefs found in the world?

Coral reefs are found

- where the sea is shallow (less than 100m);
- where the sea is warm (usually between 25° and 29°C);
- and therefore, are located within the latitude of 30°N to 30°S i.e., only in tropical seas.



Source: Groombridge and Jenkins (2002)

What is the importance of coral reefs?

Coral reefs are extremely productive ecosystems and provide humans with many services.

Provisioning Services:

Coral reefs support human life and livelihoods and are important economically. Nearly 500 million people depend - directly and indirectly – on coral reefs for their livelihoods, food and other resources (Wilkinson, 2004). Further, it is estimated that nearly 30 million of the poorest human populations in the world depend entirely on coral reefs for their food (Wilkinson, 2004).

- A km^2 of well-managed coral reef can yield an average of 15 tonnes of fish and other seafood every year (http://www.panda.org/ about _wwf/ what_we_do/marine/blue_planet/ coasts/coral_reefs/coral_importance/).
- In 1985, the world export value of the marine aquarium trade was estimated at 25-40 million USD per year. In 1996, the world export value was about 200 million USD. The annual export of marine aquarium fish from Southeast Asia alone is estimated to be between 10-30 million fish, with a retail value of up to 750 million USD (Bruckner, 2006).

Many coral species and species associated with coral reefs have medicinal values. Several species are used in Traditional Chinese Medicine (TCM) and many are now providing novel resources for allopathic medicine.

- In TCM, 394 marine species are collected globally for their medicinal value. The majority of these species are used in Asia (Hunt & Vincent, 2006).
- Some hard coral species are used in bone grafts. Others contain chemicals which might be used as natural sunscreen products (Demers et al., 2002; http://www.coralfilm.com/about.html).
- The Caribbean sea squirt (*Ecteinascidia turbinata)* has a chemical that is being used to treat difficult cancers (http://www.ehponline.org).
- There are some 500 species of cone snails that live in and around coral reefs. These species have a range of venoms which are being investigated currently for use as non-addictive pain killers (Chivian, 2006).

Regulating Services:

Coral reefs protect the shoreline and reduce flooding.

Very importantly, coral reefs protect the shoreline, providing a physical barrier – a wall – against tidal surges, extreme weather events, ocean currents, tides and winds. In doing so, they prevent coastal erosion, flooding and loss of infrastructure. Because of this, they serve to reduce huge costs involved with destruction and displacement due to extreme weather events.

The value of this protective service of coral reefs is estimated at 314 million USD in Indonesia (Burke *et al.,* 2002).

Supporting Services:

Coral reefs are an essential part of land accretion.

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

Coral reefs are very diverse.

Corals do not even cover 1% of the Earth's surface, but they are extremely diverse. In fact they are dubbed the rain forests of the sea because of this immense diversity. The nooks and crannies formed within reefs by constant beating of waves provide shelter to many species.

- They are the home (they provide shelter and nursery grounds) of 25% of marine fish (Burke *et al.,* 2002).
- Thirty two out of the 34 described groups of organisms are found in coral reefs. (As a comparison, only nine groups are found in tropical rain forests.) (Wilkinson, 2002).
- Coral reefs support a complex and interdependent community of photosynthesising organisms and animals. There is an incredible diversity of life on coral reefs such as algae, corals (there may be as many as 750 species on one coral reef), sponges, marine worms, echinoderms (sea stars and their relatives), molluscs (snails, mussels and their relatives), crustaceans (crabs, shrimps and their relatives) and fish (http://assets.panda.org/).

Coral reefs have high primary productivity.

Zooxanthellae photosynthesise and produce their own food (like green plants do on land) and corals benefit from this association. Because of the immense diversity of coral reefs, there is a great deal of exchange of nutrients and primary productivity (food production) is very high.

Primary productivity of coral reefs is estimated at 5-10g C/m^2/day (Sorokin, 1995). This productivity is derived mainly from algae.

Southeast Asia is the area of highest coral diversity in the world, with Indonesia, Malaysia and the Philippines along with Papua New Guinea – known as the Indo-Malayan triangle - forming the centre of global coral diversity. This region has 100,000km^2 of coral reefs (34% of the world's total), which are home to over 600 of the 800 reef-building coral species in the world. (Tun, 2004; Burke et al., 2002).

Cultural services:

Coral reefs have intrinsic, aesthetic and recreational values.

The beauty of coral reefs and their diversity are essential parts of many cultures in different parts of the world. Because of their easy access, visiting coral reefs is an important recreation for snorkelers, scuba divers, recreational fishermen and beach lovers.

- In Seychelles, tourism was estimated to have generated one fifth of GDP and over 60% of foreign exchange earnings in 1995 (Mathieu *et al.,* 2000).
- In the Maldives, 'tourism contributes more than 60% of foreign exchange receipts, over 90% of government tax revenue comes from import duties and tourism-related taxes, and almost 40% of the workforce is employed in the industry' (Emerton, 1997, 2006).

What are the threats to coral reefs?

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

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

- In South Asia, 45% of 19,210 km^2 of coral reefs have been destroyed, another 10% are critically threatened and 25% are threatened. Only 20% are at low risk from human activities (Tun *et al.,* 2004).
- In Southeast Asia, 38% of 91,700 km^2 of coral reefs have been destroyed, another 28% are critically threatened and 29% are threatened. Only 5% are at low risk from human activities (Tun *et al.,* 2004).

Overexploitation (Over-fishing):

For food

A recent report states that 'centuries of over-fishing by man have emptied the world's oceans of giant fish, whales and other large sea creatures, destroying coastal environments' (Jackson *et al.,* 2001).

The human global population is expected to double in the next 50 years, and with it, an ever increasing demand for life essentials such as food. Fish is the primary source of protein for one fifth of the world's population. The demand for fish has doubled in the last 50 years, and fish production would have to double again in the next 25 years to keep up with the demand and population growth.

Because coral reefs are within the reach of small boats, they are especially vulnerable to over-fishing. Particular groups of coral reef fish such as groupers, snappers and large wrasses have been overexploited. In Southeast Asia, the live fish trade (both as food fish and as ornamentals) is estimated to be over a billion USD per year in (mostly) illegal trade.

- The average wholesale price for reef fish is 20 USD/kg. The estimated total annual value of live reef fish imported into Hong Kong for food is, therefore, more than 500 million USD (Sham, 1997 in litt. TRAFFIC, 1999).
- In the 1990s, 60% of the fish caught for the live fish food trade were from the Indonesian archipelago (Bentley, 1999).
- Hong Kong and other Asian markets are the primary buyers of live reef fish for food (Donaldson et al., 2003)
- The Giant grouper (*Epinephelus lanceolatus*) and Humphead wrasse (*Cheilinus undulates*) are listed in the 2007 IUCN Red List as Vulnerable and Endangered, respectively, as a direct consequence of over-fishing (Baillie & Groombridge, 2007).

For the aquarium trade

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

- A total of 1,471 species of fish are traded globally, comprising 20-40 million individuals.
- One hundred and forty species of stony corals and 61 species of soft corals (comprising 11-12 million and 390,000 pieces respectively) are traded.
- The Banggai cardinal fish (*Pterapogon kauderni*) is only found in the Banggai Archipelago, near Sulawesi, Indonesia. It is very valued in the aquarium industry, with approximately 900,000 harvested every year. It is now considered Endangered.
- Barbour's seahorse (*Hippocampus barbouri)* is now listed as Vulnerable, mainly as a result of harvesting for the aquarium trade.

Source: Wabnitz et al., (2003); http://www.iucnredlist.org/

For the trinket trade

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

The USA is the biggest importer of such trinkets. Much of these trinkets are bought by tourists on holiday in the tropics, who do not know the damage they cause to coral reefs ecosystems in the tropics (Vincent, 2006).

- Six out of seven species of marine turtles are Red Listed as Endangered or Critically Endangered, partly as a result of overexploitation for the use of their shells in the trinket trade. The Hawksbill turtle (*Eretmochelys imbricata)*, with its ornate shell, is Critically Endangered (Baillie & Groombridge, 2007).
- *Corallium* spp. are a group of about 31 species of coral that have a global distribution, whose dominant colour ranges from white to pink, to orange and red. They are used extensively to make jewellery and curios and are now threatened with extinction due to over-harvesting (http:/www.iucn.org/).

For medicinal purposes

Species are also overexploited for medicinal purposes, mainly in traditional medicine. Many species such as sea horses and pipefish are over-harvested for Traditional Chinese Medicine (TCM) (Hunt & Vincent, 2006).

Another emerging threat is marine bioprospecting. Coral reefs are relatively easy to access and have many species of non-moving, soft-bodied organisms, who are armed with an wide of chemicals as defence weapons. These chemicals have a range of potential medical and industrial uses and because of this, reefs are targeted for bioprospecting. In order to extract enough chemicals for development of medicines and clinical trials, the quantities required are in the order of tons or thousands of tons (Meliane, undated). Therefore, the potential for overexploitation is very high.

- Thirteen species of seahorses (*Hippocampus spp.)* used in traditional medicine are Red Listed (Hunt & Vincent, 2006).
- The Smooth Tail Devil ray (*Mobula thurstoni*), Devil ray (*M. japonica*) and Giant manta (*Manta birostris*) are all Near Threatened because of the demand for their gill filaments used for medicinal purposes (Baillie & Groombridge, 2007).
- In 2001, India banned the collection of all *Bêche de mer* (Sea cucumbers) which were being exported for TCM and as a delicacy as well (Nithyanandan, 2003).

Destructive fishing practices

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

- Burke et al. (2002) estimate that more than 53% of Indonesia's coral reefs are threatened by destructive fishing practices.
- In Sulawesi, Indonesia, 15% of the fishermen are blast fishermen, with their catches making up 10-40% of the total landings (Pet-Soede & Erdmann, 1998).
- In regularly blasted reefs 50-80% of the coral could be dead. The net economic loss to Indonesia from blast fishing over the next 20 years will be at least 570 million USD (Burke et al., 2002).

The use of poison (cyanide) stuns fish so that they can be taken for the live fish trade. Such poison not only affects target species but also has an effect on all living organisms nearby.

- It is estimated that over 6,000 divers annually use about 150,000kg of cyanide on 33 million coral polyps worldwide (Briggs, 2003).
- Eighty five percent of the world's traded aquarium fish are caught using cyanide, mainly from Indonesia and the Philippines (Licuanan & Gomez, 2000).
- A large percentage of these fish caught using cyanide die – 50% for food fish species and above 80% of ornamental fish species – and even those that do survive usually die four to six weeks after capture (Briggs, 2003).

'Moxy' nets, fine-mesh nets and bottom trawlers all damage coral reefs.

Both over-fishing and destructive fishing disrupt ecological interconnections and upset the balance of coral reef ecosystems, resulting in changes in species diversity and abundance.

Coral mining (Overexploitation/ Habitat Destruction):

In South and Southeast Asia, corals are mined for limestone and construction materials. In this process, the reef is blasted and coral removed, causing immediate destruction but also resulting in indirect detrimental effects such as sand erosion and sedimentation. In 1995, it was estimated that 20,000m^3 of coral per year were collected in the Maldives for construction materials (Brown et al, 1995). Coral mining is prevalent in most South and Southeast Asian countries (Rajasuriya et al., 2004).

Sediment, nutrient and chemical pollution:

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

Direct sedimentation onto the reef increases the turbidity of the water, and this can lead to the smothering of corals, while associated increases in nutrients can lead to eutrophication[1]. Both turbidity and eutrophication result in a decrease in the amount of sunlight that reaches the coral. Reef building corals need sunlight for the zooxanthellae that live among them to photosynthesise and provide them with nutrients. Thus, if corals are unable to get enough light, they stop growing and eventually die (Nybakken, 1993). In addition to this, changes in nutrient levels may favour the growth of other organisms such as sponges and algae, causing a disruption in the balance of the coral reef ecosystem.

- Land reclamation by dumping sand and dirt directly onto coral reefs has been particularly bad in Singapore, which has lost 60% of its coral reefs to reclamation.
- It is estimated that 25% of the reefs of Southeast Asia are threatened by coastal development and 5% are under high threat. Coral reefs of Singapore, Vietnam, Taiwan, the Philippines and Japan are the most threatened from coastal development in the region, each with over 40% of their reefs under medium or high threat.
- Twenty one percent of Southeast Asia's reefs are at risk from sedimentation and inland development; Vietnam, Taiwan and the Philippines are at most risk with 35-50% of their reefs threatened by sedimentation.
- Indonesia's coral diversity has decreased 30-60% as a direct result of sedimentation.

Source Burke et al., (2002).

In addition to nutrient and sediment pollution, industrial effluents washed into waterways and agricultural runoff carry with them chemical pollutants such as petroleum products including oils and insecticides.

[1] Eutrophication is the over-enrichment of a water body with nutrients, resulting in excessive growth of organisms and depletion in the concentration of dissolved oxygen.

Marine based pollution:

Marine pollution in the form of oil (that often leaks into the seas), discharge of ballast water, dumping of solid waste from ships is also causing damage to coral reefs in the region. Anti-fouling bottom paints used on boats form toxic compounds harmful to corals and other species. Of the above forms of pollution, oil pollution is the most common. Oil damages the life cycle of corals. Although major oil spills make the news, minor spills occur all the time in the seas of the region, for example, through the discharge of ballast water, marine traffic and when ship engines are cleaned.

- Jakarta Bay, Singapore and Manila Bay are affected by oil pollution. This can affect the diversity coral reefs.
- In 2006, a 200 tonne oil spill in the Philippines caused damage to 1,100ha of mangrove forests, 58ha of seaweed farms and 200km of coastline.

Source: http://www.iucn.org/themes/wcpa/ newsbulletins/ webstories/guimarassep2006htm.htm

Irresponsible tourism

Tourism is essential for the economic development of many countries in the region. For example, marine and coastal tourism is the largest industry in the Maldives and accounts directly for 20% of GDP and its wider effects help produce 74% of national income; almost 40% of the workforce is employed in the industry (Emerton, 2006). When carried out in a controlled and sustainable manner, tourism can be a positive economic earner and should be an incentive for countries to invest in managing coral reef ecosystems to continue attracting tourist revenue.

However, when managed poorly, tourism has both direct and indirect negative effects on coral reefs. Snorkelling, diving and boating can cause direct physical damage to reefs, while overexploitation of reef species as food, for aquaria and as curios for tourist markets can threaten the survival of species. In some cases, bad tourism practices are not prevented. For example, tourists are allowed to walk on reefs, causing physical damage to the reef structure and stirring up sediment. Sometimes they even directly collect species off reefs. Boats carrying tourists can damage reefs by dropping anchors directly onto reefs, disturbing species and also causing marine pollution through excessive traffic.

Indirectly, careless and irresponsible building of infrastructure directly onto reefs or too close to beaches, river mouths and lagoons, results in increased sedimentation and leaves the infrastructure vulnerable to damage from extreme weather events.

Another indirect effect of tourism is often the irresponsible disposal of sewage and solid waste. Two decades ago, sewage and solid waste were mostly disposed directly into the sea but the current situation has improved greatly.

- It has been estimated globally that the world's cruise ships discharge 90,000 tons of raw sewage and garbage each day into the world's oceans (Mastny, 2001).
- It is reported that every year, plastic bags kill about 100,000 marine animals including endangered whales and sea turtles. Plastic bags, which resemble edible squid and jellyfish, choke marine animals that feed on them (http://www.planetark.com/ campaignspage.cfm/ newsid/52/newsDate/7/story.htm).

Global warming and climate change:

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

El Niño is Spanish for 'the little boy', referring to the Christ child, because this event is noticed usually around Christmas time. It is a fluctuation of the ocean-atmosphere system in the tropical Pacific ocean that is important for the world's climate. In normal, non-El Niño conditions, trade winds (prevailing tropical winds) blow towards the west across the tropical Pacific, piling up warm surface water in the west Pacific, so that the sea surface is about 0.5m higher in height and 8°C warmer at Indonesia than at Ecuador. The waters off South America are cool because of an upwelling from the deep and are nutrient-rich, with high marine primary productivity which supports fisheries.

During El Niño, the air pressure over the Indian Ocean, Indonesia, and Australia rises, but drops over Tahiti and the rest of the central and eastern Pacific Ocean. The trade winds in the South Pacific weaken. Warm air rises near Peru causing rain in its deserts, while warm water spreads from the West Pacific and Indian Ocean to the East Pacific Ocean. When it spreads, it takes the rain with it, causing rainfall in normally dry areas and drought in normally wet areas. El Niño also results is less upwelling, less nutrients, warmer sea surface temperatures (+0.5°C) and decreased marine primary production near South America.

La Niña, means 'the little girl' in Spanish, meant to reflect that its effects are the opposite to that of El Niño. Here, the result is a lowering of sea surface temperatures by about 0.5°C. It usually follows an El Niño event.

(Source: NOAA, 2007)

Effects of the increase in ocean temperatures: coral bleaching

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

As a result of El Niño event in 1998 and an associated rise in ocean temperatures, coral bleaching destroyed 16% of the world's coral reefs and 50% in the Indian Ocean (Wilkinson, 2004).

Effects of sea level rise

Light is essential for zooxanthellae to photosynthesise in coral reefs. Photosynthesis promotes the production of oxygen, which, in turn, stimulates coral polyp growth and increased deposition of calcium carbonate and coral reef growth. Changes in sea levels and associated water depths will change the amount of sunlight reaching coral reefs.

Although healthy reefs are likely to be able to adapt to projected sea level changes, coral reefs already stressed by other human activities - such as sedimentation and erosion - will not.

Effects of more dissolved carbon dioxide

Increased CO_2 dissolves in the oceans forming a weak acid - carbonic acid - making them more acidic and reducing calcium carbonate precipitation by coral polyps. It has been estimated that the precipitation of calcium carbonate has already fallen by an average of between six and 11% since the industrial revolution. If future atmospheric CO_2 levels reach double the level of pre-industrial times, then it is predicted that calcium precipitation will fall by a further eight to 17% (Caldeira & Wickett, 2003). This affects the availability of carbonate atoms for building exoskeletons and with it, reduces reef calcification. This, in turn, slows down a reef's ability to grow vertically to keep up with sea-level rise and affects its protective function.

Ocean acidification will likely disrupt marine food webs and affect the services that coral reefs provide to humans.

Ten Galapagos corals were added to the 2007 IUCN Red List of Threatened Species, two of which are listed as Critically Endangered, and one as Vulnerable. The main threats to these species were identified as the effects of El Niño, particularly the severe El Niño event in 1982, and climate change (IUCN, 2007).

The other seven species were listed as Data Deficient, which highlights the need for more research to be done on coral species. Data Deficient does not mean that the species are not threatened, but that there is not enough information to apply the IUCN Red List criteria. A global assessment of all 845 reef-building corals is currently underway and will be published in the 2008 Red List (Global Marine Species Assessment, 2008 http://www.sci.odu.edu/gmsa/). (Suzanne Livingstone, personal comm.)

Disease:

Studies on coral ecosystems have shown that disease outbreaks have increased since the 1990s (Wilkinson, 2004). In the Caribbean and Pacific not only has the incidence of disease increased but the number of new diseases affecting corals has also increased (Wilkinson, 2004). It is thought that increased ocean temperatures due to climate change increases the likelihood of infection. It has also been observed that closeness to human populations also increases infection.

Very little research has been carried out on the effects of disease on coral reefs in the Asian region.

Predator outbreaks:

The Crown of Thorns Starfish (COT) (*Acanthaster planci)* are predators of coral. They secrete digestive juices out of their bodies and efficiently digest coral polyps. A single COT can eat up to their body size in coral polyps every day (Forbes, 2006). Many of the starfish's natural predators such as the Humphead wrasse (*Cheilinus undulatus)* and the Giant triton (*Charonia tritonis*) have been over-fished in many reefs. When this happens, COTs can grow unchecked and destroy reefs (Forbes, 2006).

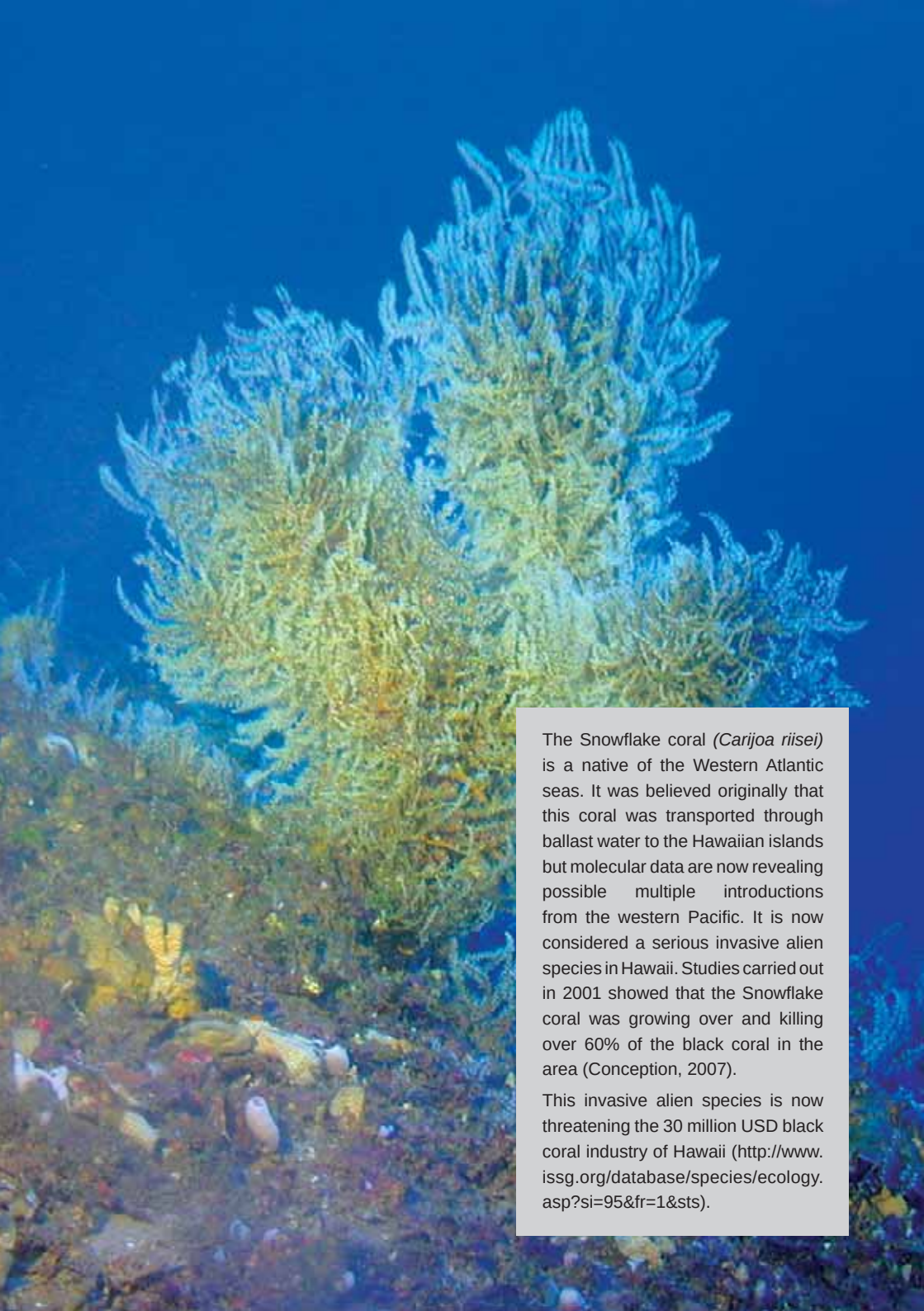
COTs infestations have increased reportedly in the recent years. It is believed that over-fishing of its natural predators is one of the main reasons for this increase, but increased nutrient runoff is also thought to help survival of its larval stage. Many reefs of South and Southeast Asia have been affected.

Invasive Alien Species (IAS):

Invasive alien species are non-native (exotic species) species that cause, or have the potential to cause damage to the environment, human health and the economy. They should not be confused with other introduced species which are also not native and have been introduced deliberately, but which are beneficial and multiply within the limits imposed on them. It is estimated that of the many introduced species transplanted and translocated from their native countries - either intentionally or accidentally - to different habitats and different climes, only about one percent pose a threat to native systems: these are invasive alien species who have the capability of growing rapidly, competing vigorously and in the absence of their natural predators, pushing out native species and generally causing ecological havoc. IUCN defines IAS as species '*which become established in natural or semi natural ecosystems or habitats, [are] agent[s] of change and threaten native biological diversity* . . . [Alien species] contribute to social instability and economic hardship, placing constraints on sustainable development, economic growth, and environmental conservation' (IUCN, 2000). In fact, the threat to global biodiversity from IAS is second only to habitat destruction.

Invasive Alien Species are as much of a threat in marine environments as they are on land. One of the main channels of spreading IAS in marine habitats is through ballast water. When ships unload their cargo at ports, they load port or coastal water to maintain the correct weight and balance for the ship. When they return to their home port they discharge this ballast water and load cargo again. With this discharge, they also release organisms that were taken in accidentally with the ballast water. Ports of intake and discharge may be located in widely different parts of the world and thus, organisms can be transported accidentally halfway across the world's oceans (ten Hallers-Tjabbes, 2004)

Species can be transported also on the outside of ships through hull fouling. Organisms such as barnacles, mussels, sponges, algae and sea squirts attach themselves to the hulls of ships, and hitch a ride form one port to the next.



The Snowflake coral *(Carijoa riisei)* is a native of the Western Atlantic seas. It was believed originally that this coral was transported through ballast water to the Hawaiian islands but molecular data are now revealing possible multiple introductions from the western Pacific. It is now considered a serious invasive alien species in Hawaii. Studies carried out in 2001 showed that the Snowflake coral was growing over and killing over 60% of the black coral in the area (Conception, 2007).

This invasive alien species is now threatening the 30 million USD black coral industry of Hawaii (http://www.issg.org/database/species/ecology.asp?si=95&fr=1&sts).

At a glance: services provided by and threats to coral reefs

(References as in text)

Ecosystem service	Description	Threats
Provisioning services (Goods)		
Lime	Lime is extracted from coral and used for construction. Largely illegal, large-scale mining of coral is ongoing in the region.	Overexploitation and damage to the entire coral reef because the reef is blasted for removal of calcium carbonate.
Fish and other species for food	Every km^2 of well-managed coral reef can yield an average of 15 tonnes of fish and other seafood every year. The demand for fish has doubled in the last 50 years, and fish production would have to double again in the next 25 years to keep up with demand and population growth. In Southeast Asia, the live food trade (both as food fish and ornamentals), estimated at over a billion USD per year is mostly illegal trade.	Overexploitation: more than 25% of the world's fisheries are overexploited, 50% are being fished to their full capacity and 75% need immediate action to ensure future supplies. The Giant grouper *(Epinephelus lanceolatus*) and Humphead wrasse (*Cheilinus undulatus*) are listed in the 2006 IUCN Red List as Vulnerable and Endangered respectively as a direct consequence of over-fishing. Spiny lobsters and sea cucumbers are over-harvested in Sri Lanka. Activities such as coral mining and destructive fishing practices such as such as purse seining, fine-mesh fishing, 'moxy' nets, cyanide fishing and blast fishing are also depleting fish stocks.
Aquarium fish	Harvest of coral, fish, and other organisms for the aquarium, is a major form of trade now.	Same as above and large-scale mortality during transport.
Medicines	Many species are collected for traditional medicine. In addition, bioprospecting is ongoing for novel remedies in allopathic medicine.	Over-harvesting of certain species (such as seahorses and some croakers) for traditional medicine, as well as other species by bioprospectors.

Ecosystem service	Description	Threats
Provisioning services (Goods)		
Curios/ornaments	Molluscs and marine turtles are collected for making curios or trinkets. Molluscs, dried sea stars and sea urchins, dried fish (seahorses and puffer fish) and dried lobsters are collected as souvenirs.	Several species such as *Corallium* (a group of red coral) are now threatened with extinction due to over-harvesting. Molluscs (chanks) (*Turbinella pyrum*) are overexploited in Sri Lanka for export to Bangladesh. Six out of seven species of marine turtles are listed as Endangered or Critically Endangered, partly as a result of overexploitation for the use of their shells in the trinket trade.
Supporting services		
Biodiversity	Coral reefs are extremely productive ecosystems and are called 'the rainforests of the sea.' Despite this, they are extremely delicate and their balance is disrupted easily and productivity decreases when species are over-harvested.	Climate change and associated coral bleaching is a serious threat to coral reef ecosystems. Sediment, nutrient and chemical pollution from inland development, coastal development including land reclamation and irresponsible tourism are also serious threats to the biodiversity of coral reefs. Overexploitation of certain species disrupts the balance of coral reef ecosystems, often with a decrease in species diversity.
Primary production	Coral reefs have a primary productivity as high as that of tropical rain forests.	Climate change, habitat destruction, pollution, invasive alien species, predator outbreaks all affect the productivity of coral reefs.
Prevention of coastal erosion	Coral reefs dissipate the energy of waves and currents. Without the protective wall of coral reefs, the shoreline becomes more vulnerable to coastal erosion.	Habitat change in the form of coral mining (including mining of inland deposits) and blast fishing destroys reefs. Irresponsible coastal development is also a threat.
Beach accretion	Coral pieces are broken into smaller and smaller pieces and eventually become part of the beach. Reduction of the accumulation of these pieces leads eventually to coastal erosion.	Habitat change such as sand mining (both coastal and inland) and collection of corals and shells is reducing the amount of accretion, resulting in changes in beach geography and waves hydraulics.

Ecosystem service	Description	Threats
Regulating services		
Protection from storms and tidal surges	Coral reefs provide a physical barrier – a wall – against tidal surges, extreme weather events, ocean currents, tides and winds.	Coral mining (including mining of inland deposits) and blast fishing destroys reefs as does irresponsible coastal development. Mining of inland resources such as sand is also destroying coral reefs and reducing their protective service function.
Cultural services		
Recreation/tourism (snorkelling, diving etc.)	Because of their easy access, visiting coral reefs is an important recreation for snorkelers, scuba divers, recreational fishermen and beach lovers.	Snorkelling, diving and boating can cause direct physical damage to reefs and overexploitation of reef species as food, for aquaria and as curios can threaten the survival of species. Careless and irresponsible building of infrastructure sometimes directly onto reefs or too close to beaches, river mouths and lagoons results in increased sedimentation and leaves the infrastructure vulnerable to damage from extreme weather events. Another indirect effect of tourism is often the irresponsible disposal of sewage and solid waste.

The total economic value of well-managed coral reefs in Southeast Asia is estimated at 12.67 billion USD, which is 42.5% of the total economic value of coral reefs for the world (Tun *et al.,* 2004). The potential value of coral reef fisheries in the Asian region is 38.5% of a global total of 5.7 billion USD and the value of tourism, 50% of a global total of 9.6 billion USD (Tun *et al.,* 2004).

What is being done to conserve coral reefs?

Given that 20% of the world's coral reefs have already been destroyed much has to be done in the future for the conservation of coral reefs.

Establishment of marine protected areas:

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

Although more and more MPAs are being established now worldwide, the ratio between MPA and terrestrial protected areas still remains low at 1:7 (WRI, IUCN and UNEP 1992). Less than 1% of the world's oceans are protected (http://www.unep.org/wed/2004/Downloads/PDFs/Key_Facts_E.pdf.).

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

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

Prevention of over-harvesting through legislation:

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

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

- The trade of 2000 species of Stony corals, Black coral (*Leiopathes sp*.), Giant clams (*Tridacna sp.*), Queen conch (*Strombus gigas*), seahorses and sea turtles is prohibited or restricted internationally under the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).
- All hard (stony) coral species are listed on CITES Appendix II - which means trade is restricted (http://www.cites.org/).

Monitoring:

Monitoring of coral reefs is essential for the development of effective management strategies. It is only through monitoring that trends and patterns of use and the health of reefs can be assessed.

Worldwide, there are several organisations that monitor the status of coral reefs. The Global Coral Reef Monitoring Network (GCRMN) coordinates efforts to improve the management of coral reefs through knowledge sharing and capacity building, and works closely with Reef Check and ReefBase. The latter is a global database of coral reef related information. After the 1998 coral bleaching event, and with the ongoing threat of coral degradation as a consequence of other human activities, Coastal Ocean Research and Development in the Indian Ocean (CORDIO) was commenced in 1999. CORDIO funds and supports scientists and institutions in the Indian Ocean Region, to ensure that the status of coral reefs in the region is monitored, focussing both on the ecological and socio-economic effects of coral reef degradation. Many other organisations partner these major players to provide an annual status report of coral reefs across the world.

Building awareness:

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

In response to the growing threats to coral reefs around the world, 1997 was designated the International Year of the Reef (IYOR) worldwide. Year 2008 was also designated an International Year of the Reef.

- In 2001, the World Atlas of Coral Reefs was produced by the UNEP World Conservation Monitoring Centre (UNEP-WCMC). This includes data on the natural history of coral reefs, their distribution, threats and MPAs.
- In 2003, IUCN Sri Lanka produced a book on Coral Reefs, in all three national languages, as a supplemental resource book for both students and teachers of GCE Advanced Level Biology.

Reef Resilience:

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

Supporting participation and sustainable livelihoods in reef dependent communities:

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

Coral reefs provide important resources for the poor, and contribute to national economies. The current trend of increasing threats to reef resources is likely to affect poor communities, who are dependent on coral reefs. To make things worse, management of coral reefs for conservation purposes often restricts community access to these resources, leaving them even fewer livelihood options. Often, these restrictions are not followed by communities, who have little understanding of or involvement in the management process.

It is now well recognised that such communities need to be offered alternatives for their livelihoods in order to ensure that coral reefs are not further damaged, as well as to alleviate poverty in coastal areas. Therefore, coastal managers are shifting towards more integrated and participatory approaches to reef management and conservation. Such approaches include identifying and supporting alternative livelihoods to reduce dependence on coral reefs, as well as enhancing current livelihood activities to make them more cost and resource efficient. Limited and controlled local use of coral reefs is now advocated in certain circumstances, instead of blanket restrictions on use. Rights to reef access and resolution of conflicts over resource use, community involvement and collaborative management are now being incorporated in to reef management (Whittingham *et al.,* 2003).

New management initiatives:

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

Shifting from small, isolated management efforts to large-scale networks using collaborative management is now the trend. Increasing the area of reefs under high protection is a major thrust of this shift and 33% of the Great Barrier Reef has now been declared as high protection zones or no-take areas - where harvesting is not permitted. Collaborating to create larger networks of MPAs is yet another approach that has been favoured by major NGOs such as Conservation International, The Nature Conservancy and the World Wildlife Fund who are developing training modules to identify and develop a network of MPAs in Asia based on areas of highest biodiversity. Others are assisting managers to cope with climate change impacts. Another change is the effort to focus research on real-life problems that resource managers face (Wilkinson, 2004). There is also a definite trend towards integrated management which understands that unsuitable land use inland poses serious threats to the coastal zone. Therefore, it emphasises inland land use and watershed management. An ecosystem approach - integrating ecological, economical and social principles in a holistic manner, involving all stakeholders, is now the favoured approach.

References

Agardy, M. T (1994). Advances in marine conservation: the role of marine protected areas. *Trends in Ecology and Evolution* 9:267-270.

Allen, G. R. and R. Steene (1994). *Indo Pacific Coral Reef Field Guide*. Singapore: Tropical Reef Research, 378 pp.

Baillie, J., and B. Groombridge (Compilers and Editors) (2007). 2007 *IUCN Red List of Threatened Animals*. IUCN: Gland, Switzerland and Cambridge, UK.

Bentley, N (1999). Fishing for solutions: can the live trade in wild groupers and wrasses from Southeast Asia be managed? *TRAFFIC Report .downloaded* from http://www.trophia.com.

Briggs, M. R. P (2003). Destructive fishing practices in south Sulawesi island, east Indonesia and the role of aquaculture as a potential alternative livelihood improving coastal livelihoods through sustainable aquaculture practices. *A Report to the Collaborative APEC Grouper Research and Development Network* (FWG/01/2001).

Brown, B. E. Dunne, R. P. and T. P. Scofim (1995). Coral rock extraction in the Maldives, central Indian Ocean - limiting the damage *Coral Reefs* (14): 236.

Bruckner, A (2006). *New Threat to Coral Reefs: Trade in Coral Organisms* http://www.issues.org/17.1/bruckner.htm

Bryant, D., Burke, L., McManus, J. and M. Spalding (1998). *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs*. Washington, DC.: World Resources Institute. (<http://www.wri.org/indictrs/pdf/reefs.pdf>)

Burke, L., Selig, L. and M. Spalding (2002). *Reefs at Risk in Southeast Asia*. Washington, DC.: World Resources Institute, 72 pp.

Caldeira, K. and M. Wickett (2003). Anthropogenic carbon and ocean pH. *Nature* 425:365-365.

Cesar H. S. J (2000). Coral Reefs: Their Functions, Threats and Economic Value. Pp 14-39 in H.S.J. Cesar (ed). *Collected Essays on the Economics of Coral Reefs.* Kalmar University, Sweden: CORDIO.

Chivian, E. (2006). Medicines from natural sources: how human health depends on nature. Pp. 1-7 in S. Miththapala (ed.) *Conserving Medicinal Species: securing a healthy future*. IUCN: Colombo, Sri Lanka: Ecosystems and Livelihoods Group Asia, IUCN, 184 pp.

Concepcion, G (2007). Molecular data suggest multiple introductions of *Carijoa riisei* into the Hawaiian archipelago www.hawaiiconservation.org/_library/documents/program%20book-web.pdf

Demers, C., Hamdy, R. C., Coris, K. Chellat, F., Tabrizian, M. and L'H. Yahia (2002). Natural coral exoskeleton as a bone graft substitute. *Bio-medical Materials and Engineering* 12:15-35.

De Silva, M. E., Gately, E. M. and I. Desilvestre (1986). *A bibliographic listing of coastal and marine protected areas: A global survey*. Technical Report WHOI-86–11. Woods Hole, MA, USA: Woods Hole Oceanographic Institution.

Donaldson, T. J., Graham, T. R., McGilvray, G. J., Phillips, M. J., Rimmer, M. A., Sadovy, Y. J., Smith, A. and B. Yeeting (2003). *While Stocks Last: The Live Reef Food Fish Trade.* Asian Development Bank: http://www.adb.org/Documents/Books/ Live_Reef_Food_Fish_Trade/62289_summary.pdf

Emerton, L (1997). *Seychelles biodiversity: economic assessment*. Paper prepared for National Biodiversity Strategy and Action Plan, Conservation and National Parks Section, Division of Environment, Victoria.

Emerton, L. A (2006). *Counting coastal ecosystems as an economic part of development infrastructure*. Colombo: Ecosystems and Livelihoods Group, Asia, IUCN. 12 pp.

Fauna & Flora Protection Ordinance No. 2 of 1937 as amended 1993. Sri Lanka: Government of Sri Lanka Press.

Forbes, E (2006). *Coral Reefs and the Crown-of-Thorns Starfish*. http://jrscience.wcp.muohio.edu/fieldcourses06/PapersMarineEcologyArticles/CoralReefsandtheCrown-of-.html

Global Marine Species Assessment (2008). http://www.sci.odu.edu/gmsa/

Groombridge, B. and M. D. Jenkins (2002). *World Atlas of Biodiversity*. Berkley, USA: UNEP World Conservation Monitoring Centre, University of California Press. 360 pp.

Hunt, B. and A. Vincent (2006). The use of marine organisms in traditional and allopathic medicine pp. 64-75 in S. Miththapala (ed.) *Conserving Medicinal Species: securing a healthy future*. Colombo: Ecosystems and Livelihoods Group Asia, IUCN. 184 pp.

http://www. assets.panda.org/

http://www.cites.org

http://www.coralfilm/about/html

http://www.ehponline.org

http://www.iucn.org/en/news/archive/2007/09/12_pr_redlist.htm

http://www.iucn.org

http://www.iucn.org/ themes/wcpa/ newsbulletins/ webstories/ guimarassep2006htm.htm

http://www.issg.org/database/species/ecology.asp?si=95&fr=1&sts

http://www.mpaglobal.org

http://www.nature.org/joinanddonate/rescuereef/

http://www.panda.org/about_wwf/what_we_do/marine/blue_planet/coasts/coral_reefs/coral_importance/index.cfm

http://www.planetark.com/campaignspage.cfm/newsid/52/newsDate/7/story.htm

http://search.iucn.org/search?q=red+coral&site=All_IUCN_sites&client=default_frontend&output=xml_no_dtd&proxystylesheet=default_frontend&myAction.x=9&myAction.y=3)

http://www.unep.org/wed/2004/Downloads/PDFs/Key_Facts_E.pdf.

http://www.worldfish center.org/

Intergovernmental Panel on Climate Change (2007) Working group III Summary for policymakers. http://www.ipcc.ch/SPM040507.pdf

IUCN (2000). G*uidelines for the Prevention of Biodiversity Loss Caused by Alien Invasive Species*. Gland: Switzerland: IUCN. 21 pp.

Jackson, J. B. C and 18 others (2001). Historical over-fishing and the recent collapse of coastal ecosystems *Science* 293 (5530):629 - 637.

Jameson, S. C., Tupper, M. H and J. M Ridley (2002). The three screen doors: Can marine “protected” areas be effective? *Marine Pollution Bulletin* 44: 1177–1183.

Kelleher, G. and R. Kenchington (1992). *Guidelines for Establishing Marine Protected Areas*. A Marine Conservation and Development Report. Gland, Switzerland: IUCN. 79 pp.

Licuanan, W. Y. and E. D. Gomez (2000). *Philippine Coral Reefs, Reef Fishes, and Associated Fisheries: Status and Recommendations to Improve Their Management.* Global Coral Reef Monitoring Network. Townsville, Australia: Australian Institute of Marine Science. 44 pp.

Mastny, L (2001). *Travelling light.* www.gttp.org/docs/lisamastny.pdf

Mathieu, L., Langford, I. H. and W. Kenyon (2000) Valuing marine parks in a developing country: a case study of the Seychelles. *CSERGE Working Paper GEC 2000-27*

Meliane, I (undated) *Bioprospecting marine resources conservation concerns and management implications*. www. iucn.org/themes/marine/Word/BIOPROSPECTING %20MARINE%20RESOURCES-CBD-Info.doc

Nithyanandan, M (2003). Sea cucumbers: A resource in peril. *Samudra* Nov. 2003.

NOAA (2007) http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html

Nybakken, J. W (1993). *Marine Biology: an Ecological Approach*, 3rd ed. New York: Harper Collins. 579 pp.

Pet-Soede, L. and M. Erdmann (1998). An Overview and Comparison of Destructive Fishing Practices in Indonesia. *SPC Live Reef Fish Information Bulletin* 4: 28-36.

Rajasuriya, A., Zahri, H., Venkataraman, K., Islam, Z and J. Tamelander (2004). Status of coral reefs in South Asia: Bangladesh, Chagos, India, Maldives and Sri Lanka. Pp 213-233 in D. Souter and O. Linden (eds.) C*oral reef degradation in the Indian Ocean Status Report 2004*, Sweden: CORDIO.

Sadovy, Y. J. , Donaldson, T. J., Graham, T. R., McGilvray, F., Muldoon, G. J., Phillips, M. J., Rimmer, M. A., Smith, A., and B. Yeeting, (2003). *While Stocks Last: The Live Reef Food Fish Trade*. Manila, Philippines: ADB

Sham, 1997 in TRAFFIC (1999) The Hong Kong trade in live reef fish for food. *TRAFFIC East Asia and WWF.*

Sorokin, Y. I (1995). Ecological Studies *Coral Reef Ecology* Vol. 102. Berlin: Springer- Verlag.

ten Hallers-Tjabbes, C (2004). Marine Biodiversity threatened by ballast water transported by ships; curbing the threat. In subtheme, Coping with Aliens, in Proceedings of *Biodiversity loss and species extinctions, managing risk in a changing world.* A global synthesis workshop convened at the IUCN World Conservation Forum 18-20 November 2004, Bangkok, Thailand.

Tun, K., Chou, L. M., Cabanban, A., Tuan, V. S., Philreefs, Yeemin, T., Suharsono, Sour, K. and D. Lane (2004). Status of coral reefs, reef monitoring and management in Southeast Asia, 2004. Pp 235-275 in C. Wilkinson (ed.). *Status of Coral Reefs of the World, 2004 (Vol 1)* Townsville, Australia: Australian Institute of Marine Science.

UNDP (2002). *Human Development Report 2002.* United Nations Development Programme. http://hdr.undp.org/en/reports/global/hdr2002/

Vincent, A (2006). Live food and non-food fisheries in coral reefs and their protection management. Pp 183-236 in *Coral Reef Conservation* I. M Côté and J. D. Reynolds (eds.). Cambridge: Cambridge University Press.

Wabnitz, C., Taylor, M., Green, E., T. Razak (2003). *From Ocean to Aquarium*. Cambridge, UK. UNEP-WCMC.

Whittingham, E., Campbell, J. and P. Townsley, P (2003). *Poverty and reefs.* DFID–IMM–IOC/UNESCO, 260 pp.

Wihelmsson, D. Patterson Edward, J. K., Rayasuriya, A., Tamelander, J., and N. Perera, (2005). Assessing the status and improving management experiences of coral reef resources: experiences and achievements in South Asia. Pp 66-82 in ed. Souter, D. and O. Linden, *Coral reef degradation in the Indian Ocean Status Report 2004*, Sweden: CORDIO.

World Resources Institute (2002). *Earthtrends Environmental Database* http://earthtrends.wri.org/

Wlidlife Protection Act India (1972). http://envfor.nic.in/legis/wildlife/wildlife1.html

Wilkinson, C (2002). *Status of Coral Reefs of the World, 2002 (Vol 1)* Townsville, Australia: Australian Institute of Marine Science. x +31 pp.

Wilkinson, C (2004). *Status of Coral Reefs of the World, 2004 (Vol 1)* Townsville, Australia: Australian Institute of Marine Science. xiv + 301 pp.

Veron, J. E. N (2000). *Corals of the World.* Townsville, Australia. Australian Institute of Marine Science. 3 volumes.

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3 (3)	Digitate coral	© Nishan Perera
3 (4)	Mushroom coral	© Nishan Perera
4 (1)	Fire coral	© Jerker Tamelander
4 (2)	Black coral	© Nishan Perera
4 (3)	Sea fan	© Jerker Tamelander
4 (4)	Sea whip	© Nishan Perera
6	Aerial view of Nalandhoo Island in Shaviayani Atoll, Maldives.	© N. K. M. Nanseer
7	Coral reef, Koh Bon, Thailand	© Nishan Perera
9	Shoal of fish amid coral reef in Pulau Bagu, Indonesia	© Nishan Perera
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14	top: Hawksbill turtle *(Eretmochelys imbricata)*	© Nishan Perera
	bottom: *Corallium* necklace for sale in Hanoi, Viet Nam	© Sriyanie Miththapala
15	top: Sea horse products for sale in Hong Kong	© K. Markey
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21	Bleached coral, Maldives	© Hussein Zahir
22	Crown of Thorns Starfish (*Acanthaster planci)*	© Nishan Perera
24	Snowflake coral (*Carijoa riisei)* smothering a black coral colony in Hawaii.	© Sam Kahng

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