Nature Watch

Coral Reefs and their Fauna: An Underwater Fantasyland

Anuradha Bhat

Coral reefs, sometimes called the "the rainforests of the sea" for their extraordinary biological diversity, are one of the most beautiful ecosystems of our planet. These shallow-water ecosystems are distributed in tropical and subtropical oceanic regions and harbour a multitude of life forms with sometimes very complex interactions. Recent threats to the coral reefs as a result of human induced disturbances (leading to large as well as small scale effects), their consequences to reef ecology and possible conservation measures are discussed.

Anuradha Bhat completed her PhD at the Centre for Ecological Sciences, Indian Institute of Science, Bangalore, in 2002. She is interested in studying distribution patterns, species associations and interactions and conservation issues in aquatic ecosystems. She is currently developing conservation models for Indian riverine communities at the University of St Andrews, Scotland.

The thought of coral reefs usually conjures an image filled with colour and beauty. Isn't it fascinating that these giant walls across the oceans, which look like an artist's creation of an underwater fantasyland, are actually huge colonies of very tiny living creatures called polyps! Found throughout the warm, clear, shallow waters of tropical and subtropical oceans such as the Indo-Pacific and Atlantic (regions normally between the Tropic of Capricorn and Tropic of Cancer i.e., 30°S, 30°N latitude), coral reefs are one of the most diverse and productive communities on Earth. They are even referred to as "the rainforests of the sea"! In fact, they support over twenty five percent of all known marine species. Coral reefs are also among the most ancient of ecosystem types, dating back to the Mesozoic era some 225 million years ago. Most present day coral reefs are between 5,000 and 10,000 years old. Although size sometimes indicates the age of a coral reef, this is not always true. Different species of coral grow at different rates, depending on water temperature, oxygen level, amount of turbulence, and availability of food.

Keywords
Coral, ecology, biodiversity, marine, animal behaviour.

Worldwide, coral reefs cover an estimated 284,300 square kilometers (110,000 square miles) – less than one tenth of one per cent of the oceans. Indonesia has most reefs, followed by Australia and the Philippines. The Great Barrier Reef, considered one of the natural wonders of the world, consists of more than 3,000 individual reefs and covers an area of about 300,000 square kilometers off Australia's east coast (*Box* 1).

Worldwide, coral reefs cover an estimated 284,300 square kilometers (110,000 square miles) The Great Barrier Reef, considered one of the natural wonders of the world, consists of more than 3,000 individual reefs and covers an area of about 300,000 square kilometers off Australia's east coast.

What are Coral Reefs Made of?

Often mistaken for a rock or a plant, corals are actually composed of tiny, fragile animals called coral polyps (*Box* 2). A coral polyp is a spineless animal belonging to the phylum Cnidaria, best known for their possession of stinging organelles known as nematocysts. They are invertebrates and are cousins of anemones and jellyfish. Coral polyps can be the size of a pinhead while others are larger, sometimes a foot in diameter. Aggregates of thousands of these tiny polyps form a coral branch and are referred to as coral colonies. The polyps use calcium carbonate from seawater to build themselves a hard, cup-shaped skeleton. This limestone skeleton protects the soft, delicate body of the polyp. Coral polyps are usually nocturnal, staying inside their skeletons during the day and extending their tentacles out to feed at night.

Although there are hundreds of different species of corals, they are generally classified as either 'hard coral' or 'soft coral'. Hard corals (Order Scleractinia; Class Anthozoa) are hermatypes or reef-building corals and need tiny algae called zooxanthellae to survive. They grow in colonies and are the architects of coral reefs. Hard corals (which include species like the brain and elkhorn coral) build by secreting calcium carbonate skeletons responsible for much of the structure of reefs. Soft corals, referred to as ahermatypes (non-reefbuilding), are soft and bendable and often resemble plants or trees (e.g. sea fingers and sea whips). They do not possess stony skeletons, but instead grow wood-like cores for support and fleshy rinds for protection and

Types of Coral Reefs

The widely accepted theory of coral formation first proposed by Charles Darwin recognizes three types of reefs: the fringing reef, the barrier reef, and the atoll (*Figure* 1).

a. Fringing reefs border shorelines of continents and islands in tropical seas; such reefs are commonly found in the South Pacific Hawaiian Islands and parts of the Caribbean. They grow in shallow waters and border the coast closely or are separated from it by a narrow stretch of water. These reefs consist of several zones that are characterized by their depth, the structure of the reef and its plant and animal communities – the reef crest (the part of the reef the waves break over), the fore reef (the region of medium energy) and the spur and groove or buttress zone (the region of coral growth which includes rows of corals with sandy canyons or passages between each row).

b. Barrier reefs, which occur farther offshore, form when land masses sink (as a result of erosion and shifting crust plates of the earth) and fringing reefs become separated from shorelines by wide channels. Barrier reefs are common in the Caribbean and Indo-Pacific. The Great Barrier Reef off northern Australia in the Indo-Pacific is the largest barrier reef in the world. These are usually separated from land by a lagoon. These reefs grow parallel to the coast and are large and continuous. Barrier reefs also include regions of coral formation that include the zones found in fringing reefs.

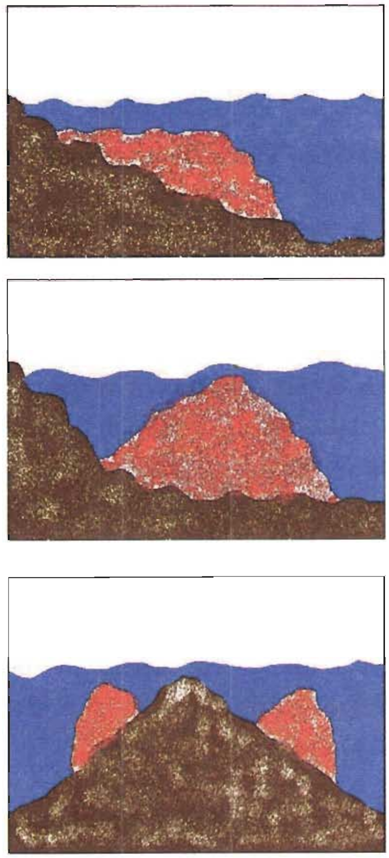


Figure 1. The three types of coral reefs – a) Fringing reefs, b) Barrier reefs and c) Atolls.

c. Atolls are annular reefs that develop at or near the surface of the sea when islands that are surrounded by reefs subside. Atolls separate a central lagoon and are circular or subcircular. The result is several low coral islands around a lagoon. Atolls commonly occur in the Indo-Pacific, where they develop during slow subsidence of volcanic islands and grow on the perimeter of the island. The largest atoll, named Kwajalein, surrounds a lagoon over 60 miles (97 km) long. There are two types of atolls: deep sea atolls (i.e., those that rise from the deep sea) and those found on the continental shelf.

In the Indian subcontinent, the reefs are distributed along the east and west coasts at restricted places. Fringing reefs are found in the Gulf of Mannar and Palk Bay. Platform reefs are seen along the Gulf of Kachchh. Patchy reefs (small isolated reefs) are found near Ratnagiri and Malwan coasts. Atoll reefs are found in the Lakshadweep archipelago. Fringing and barrier reefs are found in Andaman and Nicobar islands.

Box 2. Structure and Feeding Habits of Polyps

A polyp has a sac-like body and an opening or mouth encircled by stinging tentacles called cnidae. Distinguishing characteristics of cnidarians include radially symmetrical bodies, usually a crown of tentacles encircling the mouth, and a large hollow body cavity known as a coelenteron. Other cnidarians include sea anemones, jellyfish, hydroids and sea fans. They exist as either free-swimming medusae or as sessile benthic polyps. Polyps have columnar bodies topped with a ring of tentacles, a centrally located mouth leading to a gastrovascular cavity and nematocysts. When feeding, cnidarians capture food using their nematocysts that either inject, becomes entangled, or adhere to prey (*Figure* 2).

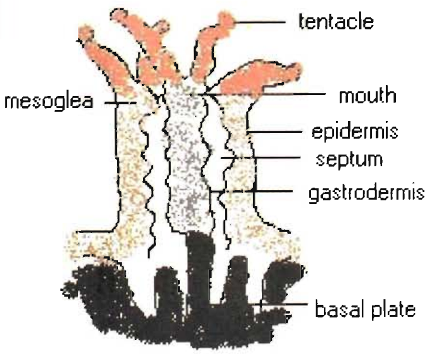


Figure 2. Simplified illustration of a coral polyp showing its basic structure.

Coral polyps feed in two different ways, depending on their species. Many coral polyps are nourished in a unique way by a tiny algae called zooxanthellae. The algae live within coral polyps, using sunlight to make sugar for energy, just like plants. Zooxanthellae process the polyp's wastes to retain important nutrients and in turn provide the polyp with oxygen. Meanwhile, the coral polyps provide the algae with carbon dioxide and a safe, protected home. Zooxanthellae living within the tissue of hard corals can supply them with up to 98 percent of their nutritional needs.

Another way that corals feed (mostly at night) is by catching tiny floating animals known as zooplankton. The polyps stretch out their long, stinging tentacles to capture the zooplankton that are floating by. The captured plankton are then put into the polyps' mouths and digested in their stomachs.

do not always have zooxanthellae. Soft corals are found both in tropical seas and in cool, dark regions (*Figure* 3).

Of the 6,000 species of anthozoans which are all marine, not all are involved in reef-building. Reef development typically begins with the settlement of reef forming organisms on a pre-existing hard foundation in shallow, warm well-illuminated water. The development of corals is influenced by such abiotic factors as light, substrate, wave forces, sediment and temperature. Corals grow in areas with sufficient light and appropriate temperatures; light is essential for the symbiotic relationship between corals and zooxanthellae, and the intensity of light affects the growth

Figure 3. Reefscape with schooling red and orange tropical fish, red soft coral, and green hard coral (in the Bligh Waters, off the coast of Viti Levu).

Photographer: Kevin Roland. Courtesy: The Coral Reef Alliance website [6].

and nutrition of the coral. Optimal coral growth occurs when water temperatures are between 25-29°C. Abundance of corals decreases with increasing depth due to the extinction of visible light. Shallow-water coral reefs typically grow to depths within 50 m. Recently, however, scientists have discovered the presence of many coral species in the deeper oceans as well – some of these form coral reefs and forests similar to those in shallow waters in appearance and species richness (e.g., *Lophelia* coral reefs in cold waters of the Northeast Atlantic with 1,300 species of invertebrates and over 850 species of fauna have been found on seamounts in the Tasman and Coral Seas). Most coral polyps have clear bodies and their skeletons are white, like human bones. Interestingly, corals get their color from the zooxanthellae inside them. Several million zooxanthellae live in just one square inch of coral and produce pigments. These pigments are visible through the clear body of the polyp and give the coral its beautiful color.

Animals Associated with Coral Reefs

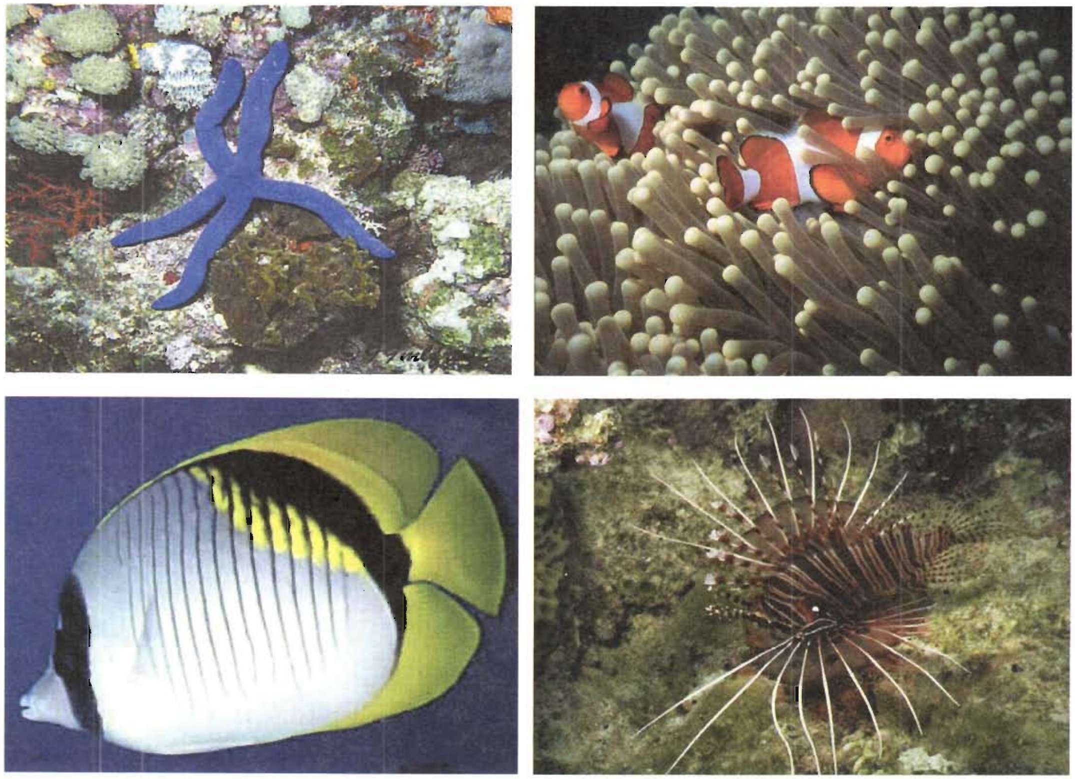
The reef ecosystem has several aspects, ranging from providing food and shelter to fish and invertebrates to protecting the shore from erosion. Being one of the most complex ecosystems on the planet, the multitude of organisms inhabiting coral reefs include sea urchins, jellyfish, oysters, clams, turtles, sea anemones and of course, fishes. They are home to over 4,000 different species of fish and thousands of other plants and animals. Through symbiosis with unicellular algae (zooxanthellae), reef-building corals are the source of primary production in reef communities. Organisms that co-inhabit corals through mutual, commensal and parasitic interactions include those within the taxonomic groups Porifera, Polychaeta, Gastropoda, Crustacea, Echinodermata and Pisces. Sponges (Porifera) are found inhabiting cavities in the reef. These sponges, such as *Cliona*, cause bioerosion in corals. Polychaetes like *Hermodice carunculata* and Gastropods in the family Trochidae depend on corals for food while Decapod crustaceans such as shrimps and crabs depend on corals for shelter. Fish (e.g. the parrot fish) also depend on corals for protection against predators as well as food. Echinoderms such as *Acanthaster planci* (crown-of-thorn starfish), on the other hand, are coral predators.

An estimated 4000 species of fish (18% of all living fishes) live on coral reefs and associated habitats of the Indo-Pacific, and this number is increasing as more surveys are being conducted!

Coral Reef Fish Ecology

The high diversity of fish species in reef ecosystems is partly due to the fact that coral reefs provide a wide variety of habitats (for shelter as well as food), each with its own set of characteristic species. The extreme diversity in habitats are determined by the abundance, shape, variety of coral, differences in the degree of exposure to wave action, currents and light intensity, availability of algae, plankton and other food, etc. An estimated 4000 species of fish (18% of all living fishes) live on coral reefs and associated habitats of the Indo-Pacific, and this number is increasing as more surveys are being conducted! This highly complex ecosystem is thus perfect for studying the factors and mechanisms regulating species diversification and distribution patterns. An ongoing debate is – what regulates the high species diversity of fishes in coral reefs?

Ecologists are divided in their opinion with regards to whether these fish assemblages are random aggregations (caused by stochastic mechanisms) or are deterministic, with a complex interplay of various mechanisms acting together to establish an



Courtesy: The Coral Reef Alliance website [6].

Figure 4. Fauna of coral reefs – a) blue sea star (Lickia laevigata) on a rocky reef (Great Barrier Reef); b) Clownfish (Amphiron ocellaris), inside their host Magnificent Anemone (Heteractis magnifica) (Malaysia); c) Butterflyfish (Hawaii); d) Spotfin Lionfish (Pterois antennata) with fins and spines fully extended (Pacific); e) Sea Turtle (Chelonia mydas) (United States of America).

Photographer: a) Mary L. Frost, b) Steve Turek, c) Steve Turek, d) Chuck Savall, e) Steve Turek.

equilibrium. The unique life cycle of coral reef fishes plays an important role in structuring species assemblages. Almost all coral reef fishes have distinct larval and adult phases (*Box* 3). The larval phase is mostly entirely different in its behavioural, morphological, physiological and habitat preferences from the adult phase. The larval stage is pelagic (that is, life spent in the open water column of the oceans) and is subjected to wide

Box 3. Reproduction and Feeding Habits of Coral Reef Fishes

Reproduction: Reef fish vary greatly in where, when and how they reproduce. While the majority use a common method (shed sperm and eggs in midwater), some other modes are: scattering the eggs over the substratum; preparing and defending demersal nests; carrying the fertilized eggs in mouth or pouch (sea horse). Coral reef fishes are highly fecund and egg production ranges from 10,000 to over 1,000,000 per female. However, predation by a variety of organisms (corals, pelagic cnidarians, other larval fishes and both reef and coastal adult fishes) leads to mortalities approaching very near 100%!

Most coral reef fishes have a unique pelagic (oceanic) larval stage resulting in a life history with two distinct phases: the pelagic and benthic stages. Larvae eat a wide variety of microzooplankton and their distributions are controlled by physical oceanic processes (circulation patterns and currents) and topography.

After a range of 9 to over 100 days (depending on the species) in the pelagic stage, the fish find a reef to live in and undergo many modifications (morphological, behavioural and physiological). Fishes in this phase, called 'settlement', range in size from about 8 to 200 mm and from 2% to 80% of the size at sexual maturity.

Fish feeding habits: Because of the high diversity of coral reef-associated fishes, complex trophic structures (with many interactions) can be found (e.g. non-territorial herbivores, territorial herbivores, planktivores, corallivores, spongivores/octocorallivores, invertebrate or bottom feeders, sedentary predators and free swimming predators). There are five major trophic categories:

a) Planktivores (feeding on small aquatic organisms): These include diurnal planktivores, e.g. Serranidae (groupers), Chaetodontidae (butterflyfishes), Pomacentridae (damselfishes), and Balistidae (triggerfishes) and nocturnal planktivores like the Holocentridae (squirrelfishes and soldierfishes), Priacanthidae (bigeyes) and Apogonidae (cardinalfishes).

b) Herbivorous reef fishes are a diverse group and those most common are the Acanthuridae (surgeonfishes), Pomacentridae (damselfishes), Scaridae (parrotfishes) and Siganidae (rabbitfishes).

c) Invertebrate predators are considered the most diverse group and play an important role in the composition of their prey communities. They eat coral polyps, other sessile and mobile invertebrates (e.g., the Clown Triggerfish, *Balistoides conspicillum*).

d) Omnivores, which appear to be primarily carnivores, also influence the composition of their prey communities. Filefishes, as well as triggerfishes and puffers, feed on a variety of crustaceans, star-fishes and some algae.

e) The piscivores usually include larger fishes like the Serranidae (groupers), survive by feeding on other fish. Many of the piscivores become more active at dusk and dawn, when they become less visible to potential prey.

There are also some fishes that do not fall into the above groups. They feed on mucus and parasites found in the skin of other fishes. In the Atlantic, the major groups of cleaners are the gobies (Gobiidae, e.g. Neon Goby (*Gobiosoma* sp.)), while in the Pacific the wrasses (Labridae) dominate.

The larval phase is mostly entirely different in its behavioural, morphological, physiological and habitat preferences from the adult phase. The larval stage is pelagic and is subjected to wide dispersion and heavy predation.

dispersion and heavy predation. This stage probably determines the geographical range of populations, as a majority of larvae move away from their natal reef into open waters. Moreover, high mortality from predation during this stage may also play a key role in the population structure of the adult reef fishes, since the surviving larval population would determine the fishes finally succeeding in finding habitats to settle on and develop into adults (stage referred to as 'recruitment'). The observation that recruitment in most coral reefs is typically low led to the belief that competition among new recruits and adults would not occur as there would not usually be a limitation for space or food ('Recruitment-limitation hypothesis').

Recent investigations, however, have revealed that fish community structure is also regulated by post recruitment processes related to inter (between species) and intra (within a species) species interactions. Interspecies interactions occur in the form of competition for food and space (habitat or territories) and predation. Competition can occur from limitation in the availability of suitable shelter sites; though such competition can be continuous, it is not believed to be a likely cause for niche diversification or competitive exclusion. This competition for territory usually does not occur among adults but rather against newly arriving recruits ('Lottery Competition' hypothesis). This theory postulates that it is the priority of the arrival of recruits that determines which species holds a territory. An optimal strategy for a fish once it finds a territory is to breed often and disperse the resulting offspring widely, so as to maximize its chances of getting them into suitable sites (before others with similar requirements do so) as and when such sites appear.

Predation on new recruits, juveniles, and adults may also have an important role in structuring assemblages. These can even sometimes reveal a negative relationship between predator and prey fish densities. Due to high levels of predation on newly recruited fish the survivorship of juveniles is quite low. Patterns of adult abundance are therefore affected by the availability of larvae and survival of juveniles. Even as specific morphological and behavioral adaptations are evidence of predators developing efficient capture techniques, the prey too develop effective defense mechanisms in response to predation.

Another theory of 'intermediate disturbance' suggests that diversity increases as a result of intermediate levels of disturbance, since more species can coexist under the conditions of reduced competition and environmental harshness. Fish communities respond to disturbance in various ways, depending on the type and degree of perturbation. Large fish kills have occurred as a result of shifts in ocean currents, abrupt changes in water temperature, outbreaks of red tide and volcanic activity. While this theory has been widely applied to patterns in coral diversity, studies of the response of reef fishes to disturbance have largely been empirical, without testing of models to predict the response of fish community to changes in habitat structure.

Thus, there seems to be evidence both for as well as against each of these processes and the significance of each effect seems to be dependent on the physical and temporal scale at which this effect is investigated. Low recruitment, predation, competition and disturbance all play major roles in structuring coral reef fish assemblages and a differing extent of each takes precedence at different times in their life histories.

AZT, used in the treatment of people with HIV infections, is based on chemicals extracted from a Caribbean reef sponge.

Threats to Coral Reefs and Conservation Issues

Coral reefs have been attractive to humans for many reasons. Biologically active compounds produced by these organisms possess antimicrobial and antiviral activity and are used in the drug making industries. The most famous of these is AZT, used in the treatment of people with HIV infections, which is based on chemicals extracted from a Caribbean reef sponge. Their natural beauty attracts many tourists from all over the world and is a source of income and revenue for local populations living near these areas. However, because many coral reef organisms can tolerate only a narrow range of environmental conditions, reefs are sensitive to damage from environmental changes.

Recent human activities responsible for rapid changes in the global environment are becoming the cause for much of the damage to coral reef ecosystems around the world. Marine species have long been considered resilient to extinction because of their large geographic range sizes. However, this is contradicted in recent investigations of geographical ranges of corals and associated species which revealed that between 7.2% and 53.6% of each taxon have highly restricted ranges, rendering them vulnerable to extinction. Less than 10% of an estimated 1-2 million reef species have been identified while an estimated 58% are under threat from human activities.

Some of the most important threats to coral reefs are sedimentation (from poor land use such as clear-cutting on steep slopes and other activities such as dredging without silt curtains), eutrophication (over-fertilization caused by excessive fertilizer use and sewage pollution) and overfishing. Other local disturbances like destructive fishing techniques (e.g. fine mesh nets, cyanide poisoning, and dynamiting) are common in coral reefs. Scuba diving and tourism can also cause physical damage. Coral pieces are sometimes removed for use as bricks or road-fill. Sand and limestone from coral reefs are made into cement for new buildings. They are also sold as souvenirs to tourists and exporters in the markets.

A major damage caused by the global rise in oceanic temperatures (linked to global warming) is bleaching. Ocean warming is extremely dangerous to coral organisms as they are very sensitive to changes in temperature. Bleaching occurs when coral polyps, stressed by heat or ultraviolet radiation, expel the algae (i.e. zooxanthellae) that live within them. The algae, responsible for most of the energy requirements and also the color of a coral, leave the coral white or 'bleached' when expelled. Recent disease outbreaks from algal invasions (e.g. the recent threat to the corals in the Great Barrier reef caused by an invasion by an algal species, *Chrysocystis fragilis*) and hurricanes (as in the Carribean region during the 1980s) are also causes for concern, while corals in the Pacific and Indian Oceans experienced heavy mortality

Suggested Reading

[1] P R Ehrlich, The population biology of coral reef fishes, *Annual Review of Ecology and Systematics*, Vol. 6, pp. 211-247, 1975.

[2] T P Hughes *et al.*, Climate Change, Human Impacts, and the Resilience of Coral Reefs, *Science*, Vol.301, pp. 929-933, 2003.

[3] C M Roberts *et al.*, Marine Biodiversity Hot-spots and Conservation Priorities for Tropical Reefs, *Science*, Vol.295, pp. 1280-1284, 2002.

[4] P Sale (ed), *The Ecology of Fishes on Coral Reefs*, Academic Press, Inc., San Diego, CA, 1991.

[5] P F Sale, Maintenance of High Diversity in Coral Reef Fish Communities, *American Naturalist*, Vol.111, pp.337-359, 1977.

[6] The Coral Reef Alliance, Internet Resource website – http://www.coralreefalliance. org/

[7] National Oceanic and Atmospheric Administration, U.S. Department of Commerce (2003), Website http://coris.noaa.gov/about/hazards/hazards.html.

due to the El Nino- Southern Oscillations in 1998 (which induced bleaching affecting an estimated 16% of the world's corals).

While reefs are resilient to an extent and can recover over time from such damages, many human activities like overfishing (which includes the overharvesting of herbivores like parrotfish and surgeonfish) can alter the dynamics of a reef and inhibit their recovery from bleaching and other disturbances leading to algae dominated reefs. Hence there is a need for the effective management of fish stocks and harvesting practices. Reef resilience is also eroded by chronic human impacts that cause persistently elevated rates of fish mortality and reduced recruitment of larvae. The creation of Marine Protected Areas (MPAs), like for the Great Barrier Reef, is an effective method for the conservation of coral reefs and other marine systems. More stringent forms of these protected areas, referred to as 'No Take Areas' (NTAs), provide protection from overfishing and offer a spatial refuge for fish larvae to disperse to neighbouring exploited areas. While NTAs may not be able to prevent damages from global effects like climate change, local conservation efforts can greatly help in maintaining and enhancing resilience as well as limiting the long-term effects of human disturbances. Their implementation, along with stronger international policy decisions to reduce the rate of global warming, is thus critical for the conservation of coral reef environments.

The creation of Marine Protected Areas (MPAs), like for the Great Barrier Reef, is an effective method for the conservation of coral reefs and other marine systems.

Eight of 10 marine biodiversity hotspots and 14 of 18 centers of endemism for coral reef species are adjacent to terrestrial biodiversity hotspots. A method of integrating terrestrial and marine conservation offers an effective and affordable strategy for protecting global biodiversity. Coral reefs are among the most endangered ecosystems on earth – human impacts may have directly or indirectly caused the death of 5-10% of the world's living reefs, and if the pace of destruction is maintained, another 60% could be lost in the next 20-40 years.

Address for Correspondence
Anuradha Bhat
Gatty Marine Laboratory
Unviersity of St. Andrews
St. Andrews, Fife KY16 8LB
Scotland, UK
Email: fishyanu@yahoo.co.in
URL: http://
www.geocities.com/fishyanu/