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**Technologies  
and their  
Applications in  
Sustainable use  
and Conservation  
of Coastal and  
Marine Protected  
Areas in India**

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## Summary

India is one among the 12 mega biodiversity countries and holds 4 of the 34 biodiversity hotspot eco-regions of the world. Much of the world's wealth of biodiversity is found in highly diverse marine and coastal habitats. The major part of the coastal marine environment of India consists of tidal mudflats, mangroves, estuaries, lagoons, beaches, marshes, vegetated wetlands and coral reefs. Delineation and demarcation are keys for management of these sensitive areas. These involve the use of remote sensing and GIS (geographic information system) tools. Sustainable use of the coastal bio-resources involves ecosystem management, bio-prospecting of coastal organisms and genetic characterization of coastal bio-resources with significant bio-activity. This paper summarizes the tools and techniques used for conservation and sustainable use of coastal and marine bio-resources in general and those in protected areas in particular.

## Introduction

The marine environment, along with the adjacent coastal area, supports productive habitats such as mangroves, coral reefs and sand dunes. India is one among the 12 mega biodiversity countries and holds 4 of the 34 biodiversity hotspot eco-regions of the world. Much of the world's wealth of biodiversity is found in highly diverse marine and coastal habitats. The major part of the coastal marine environment of India consists of tidal mudflats, mangroves, estuaries, lagoons, beaches, marshes, vegetated wetlands and coral reefs.

Several marine habitats in India have been designated as protected areas (PAs) to provide protection from indiscriminate usage and to conserve biodiversity. India has designated five major marine ecosystems as marine PAs (MPAs): the Gulf of Mannar National Park (GOMNP), Gulf of Kachchh Marine National Park, Gulf of Kachchh Marine Sanctuary, Mahatma Gandhi Marine National Park (Andaman Nicobar Islands) and Gahirmatha Sanctuary (Orissa). Many other protected areas (PAs) that have associated marine ecosystems are also considered as MPAs by many authors, but the number and classification are variable (Singh 2003; Rodger & Panwar 2004; Venkataraman et al 2012). Singh (2003) lists 31 MPAs, of which 18 are primarily in the marine environment and 13 are partly terrestrial. But according to a report of the Wildlife Institute of India, 26 PAs are MPAs. Venkataraman et al (2012) consider a rather large list by including 115 PAs under 3 broad categories. Category 1 includes those PAs where marine areas are in focus, and 12 PAs are included in it. Category 2 includes those PAs where the area of focus is terrestrial, including islands-and the boundaries are confined to land-but have important marine biodiversity areas adjoining their territories, and this category includes 92 PAs of India. Category 3 includes those PAs where the areas in focus are primarily terrestrial; however these are coastal sites and islands and have important marine areas in the fringes, and this category includes 11 PAs of India.

While various coastal habitats have been recognized as ecologically sensitive ecosystems, only coral reefs and mangrove areas have been accorded the status of PAs. These ecosystems provide a number of ecological services with economic value to the coastal communities. There are a number of *in situ* and *ex situ* approaches to the conservation of coral reefs and mangroves. Delineation and demarcation are the keys for management of these sensitive areas. These involve the



use of remote sensing and GIS (geographic information system) tools. Sustainable use of coastal bio-resources involves ecosystem management, bio-prospecting of coastal organisms and genetic characterization of coastal bio-resources with significant bio-activity.

### Remote Sensing for Management of PAs

The potential of remote sensing technologies in coastal habitat mapping is widely acknowledged, and these technologies are now being extensively used for coastal planning, conservation, management and monitoring. The aquatic coastal zone is one of the most challenging coastal environments. Unlike the terrestrial ecosystem, properties such as bottom reflectance, sun glint, suspended sediments and phytoplankton communities, diverse benthic communities and transitory events such as algal blooms and runoffs make the aquatic coastal ecosystem highly optically complex.

In optical remote sensing methods, the ability of the sensor to penetrate the water column helps examine submerged objects such as corals or sea grasses. Visible light penetrates clear water up to approximately 15-30 m. Light penetration is wavelength dependent, being greater in short wavelengths, like blue wavelengths (400 nm), compared with red wavelengths (600 nm). Also, the precise degree of penetration in a spectral band will depend upon the optical properties of the water (e.g. the concentration of coloured dissolved organic matter and suspended sediments). Furthermore, due to differential attenuation by the water column and Rayleigh scattering, the reflectance spectra measured at the top of the atmosphere are considerably different from the in situ spectra.

With the advent of sensors having high spatial resolutions of about 50 cm, with additional spectral bands in the shorter wavelengths (coastal blue, 400-450 nm; blue, 450-510 nm; yellow, 585-625 nm), underwater features can be mapped with high accuracy. For coastal applications, images require radiometric and atmospheric corrections that take care of sensor peculiarities, effects of atmospheric haze and the angle of sun at the time of image capture. Because of variable depth effects, underwater habitat mapping entails water column correction, which helps benthic features to be accurately discriminated.

Remote sensing coupled with GIS is utilized to address a wide variety of management and scientific issues in the coastal zone. The most common applications are production of coastal habitat maps and detection of change in habitat features. With increasing concern about global climate change, applications pertaining to estimation of the biomass and carbon sequestration potential of coastal ecosystems are also being explored widely.

### Mapping of Coral Reefs

Medium-resolution satellite sensors such as Landsat TM and SPOT XS and high-resolution multispectral sensors such as Quickbird and IKONOS are useful in capturing reef geomorphology and broad-scale ecological information such as locations of coral, sand, algal and sea grass habitats. Airborne multispectral instruments such as CASI (Compact Airborne Spectrographic Imager) and high-resolution satellite sensors with additional spectral bands as in Worldview2 (spatial resolution of 50 cm), QuickBird (spatial resolution of 2.44 m) or Geoeye (spatial resolution of 1.65m) can be used for mapping coral reef habitats at a finer level of discrimination. Though aerial photography offers high spatial discrimination, visual interpretation of benthic features is cumbersome and time consuming.

### Mapping Sea Grass Beds

The location and extent of sea grass of medium to high density can be effectively estimated using medium-resolution satellite sensors with water penetration bands duly compared with the direct quadrat harvest method, but accurate prediction of low-standing crops is difficult. However, airborne digital sensors and very high-resolution satellite sensors (resolution of the order of 50 cm) are capable of more accurately identifying sea grass habitats and help in monitoring changes in sea grass standing crop. For instance, the capability of these sensors to produce maps at a larger scale augments their utility in monitoring changes in sea grass beds due to thermal or industrial effluent discharges.

### Mapping of Mangroves and Biomass Estimation

Remote sensing is often considered a very cost-effective method of mapping mangrove forests as they often exist in inaccessible terrain. When coupled with GIS, remote sensing can help with surveillance of their health too. Mangrove vegetation can be distinguished from terrestrial vegetation with high accuracies (~ 90%) using the shortwave infrared (SWIR, 1.55-1.7  $\mu\text{m}$ ) band, (IRS LISS 3 data). Vegetation indices derived from spectral bands show a close correlation of leaf area index (LAI) with percentage of canopy closure. LAI and percentage canopy closure can be predicted with reasonable confidence from IRS LISS 3, Land Sat TM, SPOT XS data using the correlation between the Normalized Difference Vegetation Index (NDVI) and these parameters. Biomass can be estimated using average stand biomass and indices derived from optical data such as aerial photography or satellite images. Recent studies concentrate on deriving forest biomass using radar (JERS, SIR-C, SRTM, Airsar) and/or Lidar (ICE sat/ GLAS, LVIS) active remote sensing to

retrieve more accurate and detailed measurements. By accurately quantifying forest biomass, both above and below ground and thereby the carbon stored in mangrove forests, an estimate of carbon sequestration, emission and storage can also be derived.

### Bathymetric Charting

Active remote sensing techniques such as Airborne Lidar can produce very accurate ( $\pm 30$  cm) and detailed bathymetric charts of up to 50-60 m depth in clear waters, about 2.5 times the depth of penetration of passive optical remote sensing technologies.

### Monitoring Coastal Water Quality

Water quality and productivity are not used as independent criteria for mapping PAs. However, they are keys to the health of sensitive coastal ecosystems. Remote sensing and GIS tools are used for monitoring pollution, algal blooms, chlorophyll content and sea surface temperature. Relative concentrations of sediment in coastal waters, sediment plumes and marine oil pollution are being monitored using satellite and airborne optical, infrared (IR), ultraviolet (UV) and radar sensors. Synthetic Aperture Radar (SAR) can help with routine monitoring of oil pollution. Airborne UV sensors in combination with IR sensors can provide overlays, which are useful for generating relative thickness maps for oil spills. Toxic algal blooms of dinoflagellates and cyanobacteria, which have major economic impacts on aquaculture, can be readily detected by an array of satellite sensors. Phytoplankton in surface water is readily detectable due to the unique spectral signature of chlorophyll-a, although suspended sediments and yellow substances in coastal waters interfere with the process. The Advanced Very High Resolution Radiometer (AVHRR) provides reasonably accurate estimates of sea surface temperature, with an absolute accuracy of  $1^{\circ}\text{C}$  and relative accuracy of  $0.2^{\circ}\text{C}$ . The sea surface temperature is often correlated with widespread bleaching of corals during years when the El Nino Southern Oscillation (ENSO) is strong.

## Molecular Tools for Conservation of Coastal Bio-resources

### Molecular taxonomy

Species are the basic units of taxonomy, and the delineation of species boundaries is clearly a fundamental requirement for improving the accuracy and validity of biodiversity assessments and thus their conservation. In recent years, the development of molecular biological techniques has enabled rapid compilation of nucleotide sequence databases for a variety of animal phyla. It has long been recognized that DNA sequence diversity, whether assessed directly or indirectly through protein analysis, can be used to discriminate species. More than 40 years ago, starch gel electrophoresis of proteins was first used to identify species (Manwell & Baker 1963). Nearly 30 years ago, single gene sequence analysis of ribosomal DNA was being used to investigate evolutionary relationships at a high level (Woese & Fox 1977), and mitochondrial DNA approaches dominated molecular systematics in the late 1970s and 1980s (Avice 1994). Recently, Tautz et al (2002, 2003) made the case for a DNA-based taxonomic system. DNA sequence analysis has been used for 30 years to assist species identification, but different sequences have been used for different taxonomic groups by different laboratories. Hebert et al (2003) proposed that a single gene sequence would be sufficient to differentiate all, or at least the vast majority of, animal species and proposed the use of a new tool for animal species identification called DNA barcoding.

Several smaller pilot studies have recently been conducted independently, with various levels of resolution and success (Duran & Rützler 2006; Wörheide 2006). The standard mtDNA cytochrome oxidase subunit 1 (CO1) bar coding fragment, which is used for almost all current (eukaryotic) barcoding initiatives, spans an approximately 650 nucleotide region close to the 5' end (Erpenbeck et al 2006). In any case, a DNA sequence-based taxonomic system cannot replace conventional taxonomy based on comparative morphology but only complement it. The pitfalls and conceptual weaknesses of DNA barcoding have been discussed extensively in the literature (Moritz & Cicero 2004; Meyer & Paulay 2005; Hickerson et al 2006). For a barcoding approach to species identification to succeed, within-species DNA sequences need to be more similar to one another than to sequences in different species. Recent studies show that this is generally the case, but there are exceptions.

### Bio-prospecting and ex-situ conservation

The marine environment in general and critical habitats such as coral reefs and mangroves in particular are inhabited by a number of organisms with immense bioactive potential. With the advancement in the our capacity to identify such organisms, cultivate them in mass and discover the genes responsible for their novel functions, products of pharmaceutical significance could only be expected to grow exponentially. Genomic technologies allow them to be studied from very small samples and without the need for cultivation. The potential value of existing genetic resources cannot be determined because future environmental conditions and novel future technologies are unknown. Therefore



all genetic variation can be considered to have potential value, thus being a resource.

Modern biotechnology has various tools and techniques that can be used towards this end viz., genetic engineering, culture of recombinant microorganisms, cell culture, hybridization technology, nano-biotechnology, protein engineering, transgenesis, tissue and organ engineering, immunological assays, genomics, proteomics and bio-separation/bioreactor technologies. Sperm and embryo cryopreservation are important tools for storing the genetic material of indigenous and endangered species, thus aiding ex situ conservation.

## Field Techniques for Conservation of PAs

### Coral reef restoration

Restoration of degraded reefs is considered to be one of the major reef management strategies to help remedy the pressure due to anthropogenic forces and natural disasters on coral reef ecosystems. The worldwide deterioration of reefs, particularly in the last decades, has directed more attention to the prospects of mitigation activities, notably coral reef restoration (Edwards 1998; Edwards & Clark 1998; Pickering et al 1998; Clark & Edwards 1999; Yap 2000, 2003). Coral reef restoration techniques are at an experimental stage and in a few places have been a great success. The variety of mitigation activities ranges from species reintroduction and coral transplantation to enhancement or recruitment potential and creation of artificial reefs. Restoration is defined as the act of returning an ecosystem as closely as possible to its original condition (Edwards 1998). At present the defined goals of various restoration programs include returning the reef to a previous state, rescuing or promoting a given species, increasing live cover or biomass, increasing diversity, etc. In coral reefs, the two major restoration approaches are coral transplantation and construction of artificial reefs, which in many cases are applied regardless of the environmental conditions, causes of decline or goals.

During the last 30 years, construction of artificial reefs has become a popular management tool employed by both government and private groups (Seaman & Sprague 1991). There is tremendous popular support for the construction of reefs because fishermen visiting these habitats frequently experience high catch rates. The high catch rates are supported by relatively rapid colonization of artificial reefs by economically important species (Bohnsack et al 1991). Transplantation of corals along controlled substrata attached to an artificial structure makes them more stable and improves the aesthetic appearance of an artificial reef, thus making it appear more natural (Fitzhardinge & Bailey-Brock 1989).

### Mangrove conservation

Mangrove forests are among the most productive and taxonomically diverse wetlands on Earth. They consist of a diverse group of salt-tolerant, mainly arboreal, flowering plants that grow primarily in tropical and subtropical regions (Ellison & Stoddart 1991). Mangrove ecosystems act as buffer zones between the land and sea, protecting the coast against erosion by wind, waves and water currents. They help stabilize banks and coastlines and provide habitats for many types of animals.

One of the major problems mangroves face is ecosystem deterioration due to inappropriate management practices, hydrological and geomorphological causes and anthropogenic causes. Restoration of degraded mangroves is being carried out in tropical and subtropical estuaries throughout the world (Field 1996; Qureshi 1996; Snedaker & Biber 1996; Soemodihardjo et al 1996; Untawale 1996).

These degraded patches have to be plotted using the GPS, and a GIS database may be developed for planning restoration methods. Micro-level plans have to be prepared in the respective degraded areas for restoration of these degraded mangroves. One of the major restoration techniques is nursery plantation for raising healthy seedlings. The seedlings can be transferred to degraded areas. Fish bone-type canals have been adopted for mangrove restoration in our country, with reasonable success. These canals are designed like fish bones in order to facilitate easy inflow and outflow of tidal water.

### Monitoring fish diversity in PAs

Fish and fisheries management have been the focus of many MPA programmes. Underwater visual census (UVC) has been the predominant survey tool in studies focusing on shallower coral reefs and temperate rocky reefs. The use of single-video and stereo-video techniques will help survey fish community composition, relative abundance and fish length and weight. These techniques have potential application in initial surveys of candidate habitats for MPAs. Remote video techniques can be used in depths beyond the limits of diver-based Underwater Visual Census. Stereo-video systems can also be used to complement and enhance normal UVC by allowing very precise and accurate estimates of fish morphometrics (including weight). Some video techniques are very cost-effective and can help remove the sources of observer bias in underwater observations by allowing simultaneous collection of a much wider suite of data in a permanent record that can be analysed later.

## Conclusions

MPAs can generally be understood as areas of marine waters or seabed that are delimited within precise boundaries (including, if appropriate, buffer zones) and that are granted a special protection regime because of their significance for a number of reasons (ecological, biological, scientific, cultural, educational, recreational, etc). MPAs are instruments limited to those protection measures that are necessary to ensure the prescribed objectives without unnecessarily burdening maritime activities that can be carried out in an environmentally sustainable way. The establishment of MPAs, as a key element of marine environmental protection, is linked to the most advanced concepts of environmental policy, such as sustainable development, precautionary approaches, integrated coastal zone management, marine spatial planning, ecosystem approaches and trans-boundary cooperation.

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