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# Geospatial Framework For Connecting Tropical Seascapes: A Landscape Ecology Approach

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## Summary

Marine protected areas (MPAs)/Important Coastal and Marine Biodiversity Areas (ICMBAs) are recognized as key areas for conservation and act as natural laboratories for research. Connected networks of MPAs/ICMBAs lead to resilient marine ecosystems ready to face pressures such as climate change and increased anthropogenic pressures. Corridors between MPAs/ICMBAs can serve as a crucial biodiversity management tool, promoting genetic exchange that will improve the health of the entire ecosystem. Connecting seascapes enable adaptive approaches, moving away from 'static' nature conservation to a dynamic implementation that can respond to ecosystem shifts or protect marine habitats such as corals and sea grasses (blue carbon).

When used in isolation, small MPAs/ICMBAs may not support fish and invertebrate populations that are large enough to sustain themselves. To ensure that young marine organisms are available to replenish and sustain populations within MPAs/ICMBAs, the area of protection must be fairly large. However, in India, economic, social, political and ecological constraints make it impractical to create large MPAs/ICMBAs of sufficient size to support viable, self-sustaining populations of all species.

Geospatial tools can be used for modelling corridors between MPAs/ICMBAs. These approaches can facilitate selection and comparison of multiple candidate protected areas, allowing resource managers to prioritize areas on the basis of their ecological connectivity (Mumby 2006). As landscape ecology approaches using geo-informatics are applied to tropical marine ecosystems, our understanding of ecological connectivity and using results to make more informed decisions for conservation planning will be realized.

**Keywords:** Connectivity; geospatial data; ICMBA; MPA; scale; seascape.

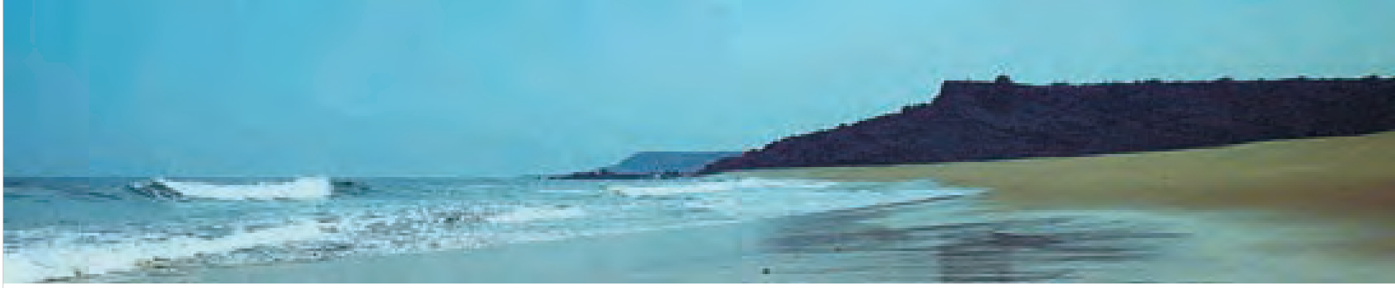
## Introduction

Coastal and marine ecosystems are declining all over the world. Habitat degradation, overfishing, pollutants and the impacts of climate change are leading to ecosystem collapses in all the major seascapes of the world including India that has a vast coastline of 7517 km and supports a huge human population that is dependent on the rich coastal and marine resources. It is estimated that nearly 250 million people live within a 50 km swathe along the coastline of India. Therefore, the ecological services of the marine and coastal ecosystems of India play a vital role in India's economic growth.

Despite the tremendous ecological and economic importance and the existence of a policy and regulatory framework, India's coastal and marine ecosystems are under threat from the increasing human population, the demand for resources and development (Durate et al 2009; Layman et al 2011). As these pressures intensify, marine protected areas (MPAs) and important costal marine biodiversity areas (ICMBAs) are increasingly being accepted as important tools to protect, maintain and restore natural and cultural resources in coastal and marine waters.

There are practical constraints in creating large MPAs. Hence, establishing many small- to moderately-sized MPAs may help reduce socio-economic impacts without compromising conservation and fisheries benefits (PISCO 2007). A well planned network between these protected areas provides important spatial connectivity essential for maintaining ecosystem processes and resilience (Andrello et al 2013; Kough et al 2013).

Resilient systems are adaptable, flexible and prepared for change and uncertainty (Hughes et al 2005). Non-resilient systems, in contrast, are prone to irreversible change, often to an undesirable state (Marshall & Marshall 2007). If an MPA/ICMBA is resilient, it can recover from or endure sudden environmental changes or natural catastrophes and support populations that can potentially replenish other depleted populations (West & Salm 2003). An isolated MPA/ICMBA/seascape is less resilient as opposed to a network of MPAs/ICMBAs seascapes connected through corridors. Thus a connected network of MPAs/ICMBAs/seascapes connected through corridors across latitudinal gradients can help protect species as their ranges change. As the importance of biological connectivity has been



recognized with respect to climate change, natural disasters and economic, political and social fluxes; networks of MPAs/ICMBA are rapidly accepted as valuable management tools (IUCN-WCPA 2008) for long-term conservation of natural marine resources.

## Conceptual Framework for Linking Seascapes (MPAs/ICMBA)

Tropical marine ecosystems such as India are dynamic and spatially heterogeneous seascapes connecting varied habitat types through biological, physical, and chemical processes (Grober-Dunsmore et al 2009a, 2009b). The exchange of nutrients, pollutants, pathogens, sediments and organisms is facilitated by the water currents among the connected ecosystems. The active movement of organisms between habitat patches across the seascape (Sale 2002; Gillanders et al 2003) maintains the necessary genetic diversity in the seascape.

**Definitions related to the major concepts of landscape ecology, with reference to marine habitats, are given in Table 1.**

**Table 1 :** Definitions of concepts of landscape ecology with reference to marine habitats (adapted from Forman (1995))

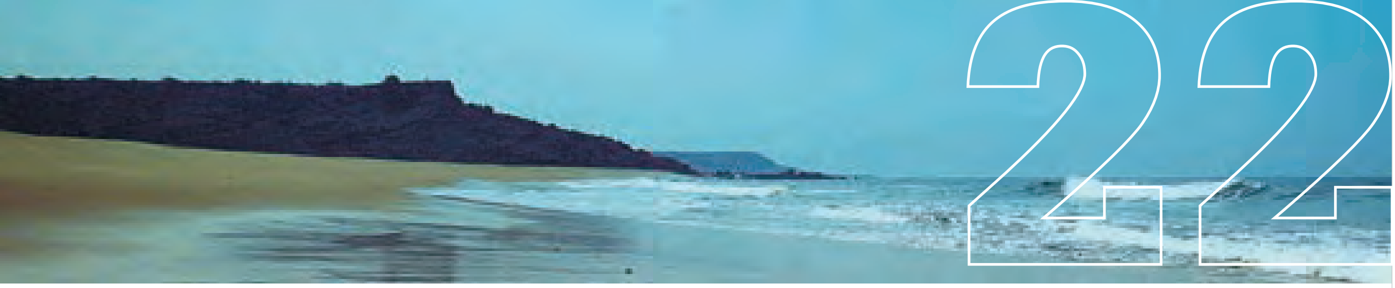
| Sl.No. | Concept | Definition |
|---|---|---|
| 1 | Seascape | A heterogeneous marine area that can exist at a wide range of scales and may be described as a mosaic pattern or spatial gradient |
| 2 | Matrix | The dominant element in a seascape |
| 3 | Patches | Patches are the basic spatial elements in the seascape. |
| 4 | Mosaic | A combination of different patch types that are usually interspersed amongst one another |
| 5 | Seascape structure | The composition and spatial arrangement of patches, but may also include bathymetric complexity or structure in the water column |
| 6 | Patch context | The position of a patch relative to surrounding seascape elements |
| 7 | Heterogeneity | The uneven, non-random distribution of objects |
| 8 | Seascape connectivity | The degree to which the seascape facilitates or impedes movement among resource patches |
| 9 | Structural connectivity | Physical linkages within a seascape |
| 10 | Potential connectivity | Measure of connectivity that incorporates indirect and limited information on mobility of organism |
| 11 | Actual connectivity | Measure of connectivity that quantifies the movement of individuals through a habitat or landscape |
| 12 | Functional connectivity | How the structure of the seascape interacts with the properties of the organisms, disturbances or materials to influence how they move |
| 13 | Stepping stone | A row of small patches (stepping stones) can connect an otherwise disconnected connectivityset of patches. |
| 14 | Spatial scale/ | A measure of the resolution or extent perceived or considered temporal scale |
| 15 | Extent | The size of the study area or the duration of time under consideration |
| 16 | Grain | The finest level of spatial or temporal resolution possible within a given data set |

## Spatial Data Requirements

The planning process for connecting MPAs/ICMBAs requires the development of an effective decision support system (data, maps and tools) for stakeholders, scientists and decision makers involved in the process. The objective is to develop a planning strategy using the best scientific information available readily through a transparent process involving maximum stakeholder participation (IUCN-WCPA 2008). Spatial planning requires maps of biophysical, management and socioeconomic factors.

The following are a few important categories of spatial data.

1. Base maps: study region boundary, nautical charts, shoreline features, etc.
2. Physical and bathymetric: depth contours, bathymetric imagery, submarine features, currents, sea surface temperature, coastal watersheds, etc.



3. Biological/habitats: habitats, ecologically significant areas, species occurrence or distribution, etc.
4. Cultural: towns, harbours, ports, coastal access points, etc.
5. Consumptive uses: commercial fishing areas, aquaculture, etc.
6. Recreational uses: dive sites, wildlife viewing, boating lanes, etc.
7. Existing coastal and marine managed areas and other jurisdictions: MPAs, mangrove areas, naval areas, etc.

Mapping of key habitats, areas of ecological importance and important threats to marine resources provides the scientific framework for connecting seascapes (MPAs/ICMBAs).

## Use of Spatially Referenced Faunal Distribution Data

Ecological data should be spatially explicit, having correct geographic coordinates or other information for determining an organism's location with respect to the surrounding seascape (Bostrom et al 2011). The type of data selected for study will be largely driven by what aspects of connectivity are of interest, for eg.

(1) The combinations of habitat types and, more specifically, spatial configurations that provide functional connectivity for a species or community metric.
(2) The consequences of habitat loss for functional connectivity.
(3) The actual pathways of movement across the seascape for marine organisms.

It is important to be aware of the trade-offs when choosing among data sources since certain questions can only be addressed with specific types of data and the availability of information varies, as does the cost of acquiring the information. To provide useful and durable information that assists with adaptive management of MPA networks, it is critical that consistent, long-term monitoring be carried out so that changes over time can be measured. Long-term information provides reliable feedback on the effectiveness of management based on relevant monitoring indicators (Pomeroy et al 2004).

## Scale and Seascape Connectivity

The relationship between scale and pattern is considered one of the most important issues in landscape ecology (Levin 1992; Schneider 2001). Measurement of this pattern is determined by scale selection, and species respond to patterns individualistically at a range of spatial scales (Wiens & Milne 1989). In India, connectivity is increasingly being investigated through examination of the spatial patterns of species abundance, size class and movement data (i.e., acoustic telemetry). While these approaches are useful, such studies often neglect to incorporate and quantify patterns in the seascape structure. Without spatially explicit information on seascape structure, studies will be missing a suite of potentially important explanatory variables, and results will have limited application to resource management.

Spatial (cell size or minimum mapping unit) and thematic resolution (level of detail in patch composition) affect the results and subsequent hypotheses (Kendall & Miller 2008). Practical considerations such as data availability and the type of research methods employed also affect the scale selected.

In an ecological study of connectivity, the grain size and spatial extent are first considerations, followed by the study area size (spatial extent) and the time duration (temporal extent). These attributes of scale that are to be examined define the level of detail and set the time and space limits required for the study in the early planning stages. These decisions will impact all stages of an ecological study from budgeting to data collection and interpretation of results (Kelly et al 2011).

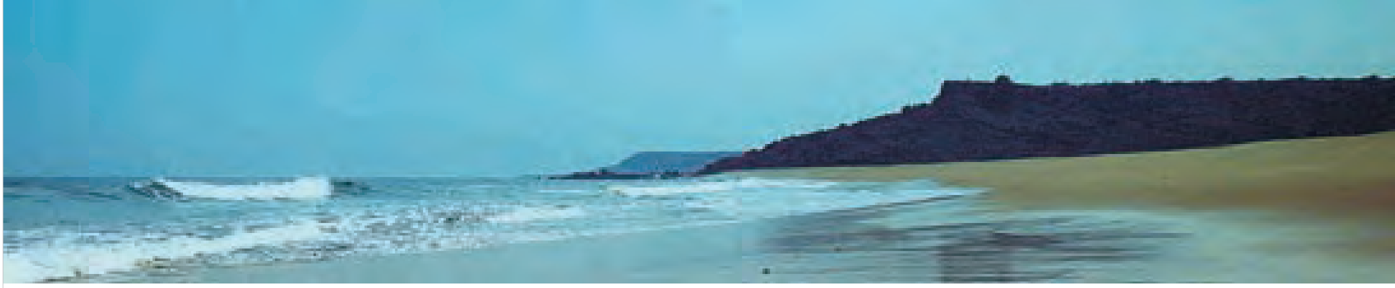
## Geospatial Tools for Examining Seascape Connectivity

Compiling spatial data into a GIS database is the most effective way to store, analyse and map relevant information (Ferretti & Pomarico 2012; IUCN-WCPA 2008). Many analytical tools are available to assist our understanding of the structural and functional connectivity of seascapes and the consequences for species distribution and behaviour (Brock & Purkis 2009). Often adapted from engineering and systems analysis, these methods have been successfully used to examine ecological connectivity in both terrestrial and marine landscapes (Bottero et al 2013). The following are three types of spatial analytical tool of particular relevance to seascape analyses:

(A) Geospatial pattern metrics.
(B) Graph theoretic approaches.
(C) Computer simulation models.

These tools address three types of connectivity:

  (i) Structural.
  (ii) Potential.
  (iii) Actual connectivity (Calabrese & Fagan 2004).



## A. Geospatial Pattern Metrics

Spatial pattern metrics measure structural connectivity and are usually algorithms designed to quantify the composition and spatial arrangement of landscapes (Grober-Dunsmore et al 2009a, 2009b). Structural metrics are measured on maps or remotely sensed images. The computer-based approach provides higher spatial accuracy and greater flexibility in data processing. Software packages such as Fragstats (McGarigal et al 2002) offer a wide selection of structural connectivity metrics such as contagion (the aggregation of patches; Li & Reynolds 1993), proximity index (the isolation of patches; Gustafson & Parker 1992), patch cohesion (area-weighted mean perimeter-area ratio divided by the area-weighted mean patch shape index; Schumaker (1996)), connectance index (number of functional joining's between all patches of the same type divided by total number of possible joining's; McGarigal et al 2002), and lacunarity (a measure of the distribution of gap sizes; Plotnick et al 1993). Several of these metrics quantify similar geometric properties of spatial pattern and therefore are often collinear (Riitters et al 1995). In addition, patch area and patch quality interact with spatial patterning to determine connectivity, such that a range of metrics and additional information may also be required to quantify ecologically meaningful structural connectivity.

Few marine examples exist where spatial pattern metrics have been applied to seascapes (Garrabou et al 1998; Turner et al 2001; Andrefouet et al 2003; Pittman et al 2004, 2007a, 2007b; Grober-Dunsmore et al 2007, 2008; Kendall & Miller 2008; Bostrom et al 2011; Wedding et al 2011;). Further studies are needed to determine the ecological relevance of seascape structure as quantified by structural connectivity metrics for marine species and marine processes. In time, such studies should also provide the needed information for evaluating the appropriateness of pattern metrics to investigate seascape connectivity. Some caution is necessary when choosing and interpreting results from patch metric studies since existing metrics are unlikely to capture all the relevant spatial information in marine environments and new metrics specific to aquatic systems may be required.

## B. Graph Theory

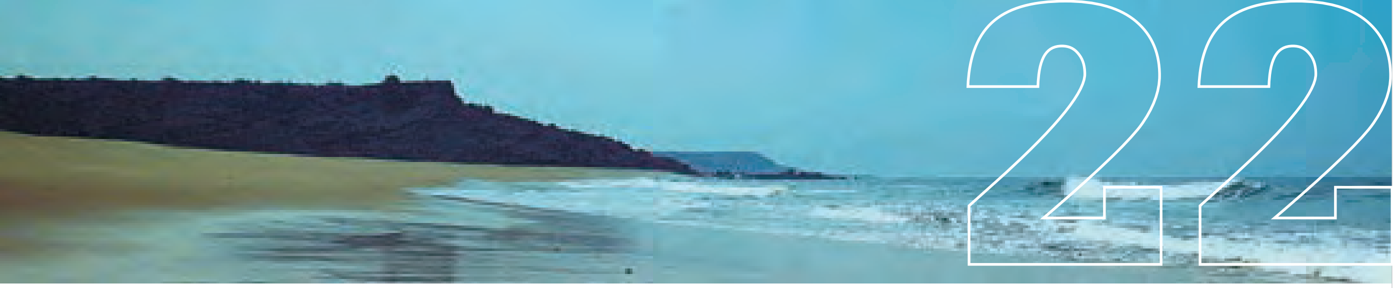
A graph includes a set of 'nodes', usually indicating the centre of a habitat patch, and lines termed 'edges' that link the nodes of two connected patches (Urban & Keitt 2001). If the distance between a given pair of patches is less than or equal to the distance the organism can move, then the patches are considered to be connected or potentially connectable.

Graph theory approaches integrate habitat maps with information on the movement and behaviour of fauna or any other mobile component of the ecosystem and offer several advantages for connectivity analyses. It is usually considered a potential connectivity technique (Calabrese & Fagan 2004) since graphs link structural seascape pattern to estimates of dispersal ability and thereby offer the ability to go beyond structural connectivity and closer to an understanding of functional connectivity. Connectivity can be weighted using variables such as patch type, size, isolation and other measures of patch quality to create least-cost movement pathways (Bunn et al 2000; Urban 2005). The pair-wise connections are then scaled up to measure connectivity across the entire seascape or area of interest, and graph theory provides a set of metrics to summarize various attributes of the connections. For species that undergo distinct ontogenetic habitat shifts, graphs could identify or rank seascapes based on their potential connectivity, and these models could then be evaluated using abundance data, fish telemetry or tag-recapture/resight data. The technique allows one to calculate the area of connected habitat that falls within and outside existing MPA/ICMBA boundaries and also provides connectivity surfaces to inform the design of MPAs/ICMBAs and MPA/ICMBA networks. While graph theory is relatively novel to marine systems, its use is well developed in terrestrial urban planning, computer science and protected area design (Urban & Keitt 2001; Rothley & Rae 2005; Treml et al 2008)

When combined with benthic habitat maps, the technique offers great promise for mapping connectivity and for identification of optimally connected seascapes to support marine protected area designation efforts and efficacy.

## C. Computer Simulation Models

Due to the constraints associated with data collection and broad-scale field manipulations, simulation models are valuable tools for examining the potential influence of seascape structure on species distributions and individual movements. When simulation models are employed as an exploratory tool, the results can be used to construct testable hypotheses to reveal ecological mechanisms underlying spatial patterns. In terrestrial systems, a special suite of spatially explicit landscape simulation models, termed neutral models, have proved to be very effective in examining connectivity (Gardner & O'Neill 1991; With 1997). Neutral models use a set of decision rules to create random structural patterns independent of ecological processes (Riitters et al 2007). In these models, landscape structure is typically binary (suitable and unsuitable patches) although more complex models can incorporate more of the natural variability in ecological systems such as hierarchical random landscapes and gradients using fractal algorithms (techniques) to generate complex clustered spatial patterns (With 1997). Patch mosaic neutral models have also been developed. These models simulate mosaic structure rather than the configuration of pixels in a raster grid and focus on incorporating aspects of composition and spatial arrangement (Gaucherel et al 2006).



Neutral models have been used to identify thresholds in connectivity particularly in relation to the loss of habitat that occurs along a fragmentation gradient (With & Crist 1995; Pearson et al 1996). Percolation theory proposes that beyond a predictable threshold, sudden changes are likely to occur in system behaviour (Plotnick et al 1993; With & Crist 1995).

## Discussion and Conclusions

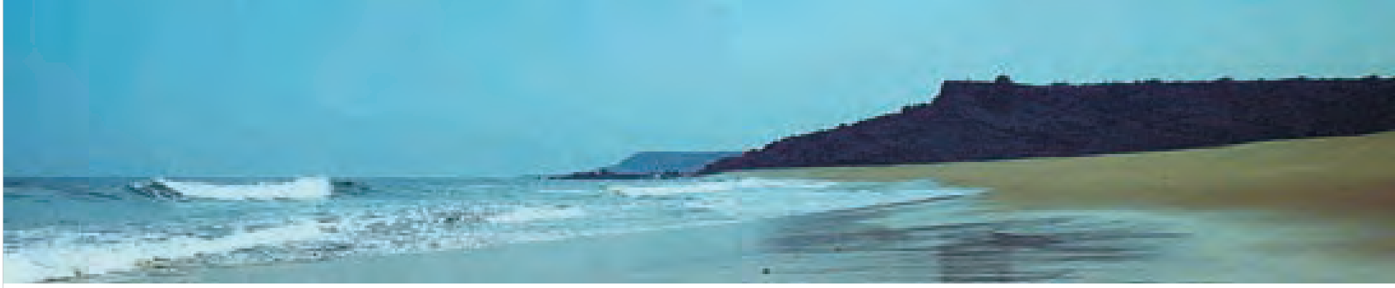
Landscape ecologists typically use a wide variety of spatial data sets, often requiring integration and additional digital processing within a GIS (e.g., vegetation maps, digital elevation models, tracking data) to study connectivity in terrestrial environments (Goodchild 2010). In marine environments, studies of connectivity in addition may also require multiple spatial data sets including the following:

1. Benthic habitat maps to capture information on the distribution of patch types that can determine connectivity in a region.
2. Oceanographic characteristics (sea surface temperature, frontal boundaries, upwelling zones, prevailing current patterns).
3. Bathymetric surfaces (linear features, canyons, continental shelf, banks, seamounts, promontories).
4. Ecological factors (distribution of predators, prey, competitors) and human uses (point or non-point source pollution, ship traffic, fishing areas) that may act as facilitators, barriers or modifiers of movement for marine organisms (Hitt et al 2011).

However, for species that are strongly linked to the benthos, a benthic habitat map alone may be sufficient environmental data to begin studies of seascape connectivity. Many of these environmental data are freely available via online data portals or digital data archives (Decker 2001); however, for many regions of the Earth, additional data may need to be collected or acquired. An important first step in any broad-scale study of connectivity is to evaluate the availability and quality of data for the study region. One of the most significant obstacles faced by marine spatial ecologists is the absence of appropriate spatial data (i.e., benthic habitat maps). Even for data-rich areas, often the available data were acquired for an entirely different purpose, and therefore may not necessarily represent the environmental reality from the organism-based perspective. Given the paucity of suitable data, researchers frequently proceed with environmental data with unknown accuracy and data that often do not match the spatial and temporal resolution of the ecological processes under investigation. The spatial data must be available at a finer scale (finer spatial grain) than the scale of the process under investigation. This then provides an opportunity to coarsen the resolution of patterning so that the linkage between organism and environment can be explored at multiple spatial scales.

Even when the necessary data are readily available or easily collected, the value of subsequent seascape analyses is compromised if researchers fail to assess the accuracy of spatial data (Turner et al 2001). Errors associated with the remote sensing and GIS data acquisition, processing, analysis, conversion and final product presentation can have a significant impact on the confidence of decisions made using the data (Lunetta et al 1991). Potential sources of error include the age of data, completeness of aerial coverage, and map scale (Burrough 1986). Those that occur with natural variation in original measurements include positional and content accuracy, while other sources of error occur during processing (i.e., numerical computation, classification) (Burrough 1986). Errors in spatial data can obscure or distort species-habitat relationships and may even result in spurious correlations (Karl et al 2000). The idiom 'garbage in, garbage out' applies to any analytical process, and typically landscape ecology analyses are highly susceptible to data quality. Therefore a validation step is essential when developing derived products such as modeled outputs to enable appropriate statements of accuracy. In addition to testing the accuracy of the original data, the use of multiple techniques to analyse relationships or create models can verify the robustness of research results by providing information on potential bias in the data, techniques and interpretation of the final model results (Treml & Halpin 2012).

By focusing specifically on the ecological connectivity of MPA's/ICMBAs and carefully scaling investigations of seascape patterns to specific ecological processes, a spatial framework using a landscape ecology approach will allow us to determine the amount, type, configuration and location of patch types required to maintain ecological connectivity (Grober-Dunsmore et al 2009a, 2009b). These are questions that must be addressed in tropical seascapes to successfully identify essential fish habitat, predict effects of habitat alteration, and prioritize among management options. Identifying optimal seascape composition and arrangement for MPAs/ICMBAs and networks of MPAs/ICMBAs requires the consideration of interactions between structural and functional connectivity across multiple spatial and temporal scales (Ward et al 1999). Increasingly, resource managers will need to manage mosaics of habitat within and among protected areas rather than focus on individual habitat types or patches. Using landscape ecology principles, concepts and geospatial tools, connectivity for various species can be identified and evaluated in relation to existing or planned jurisdictional boundaries to optimize conservation efforts across broad spatial scales.



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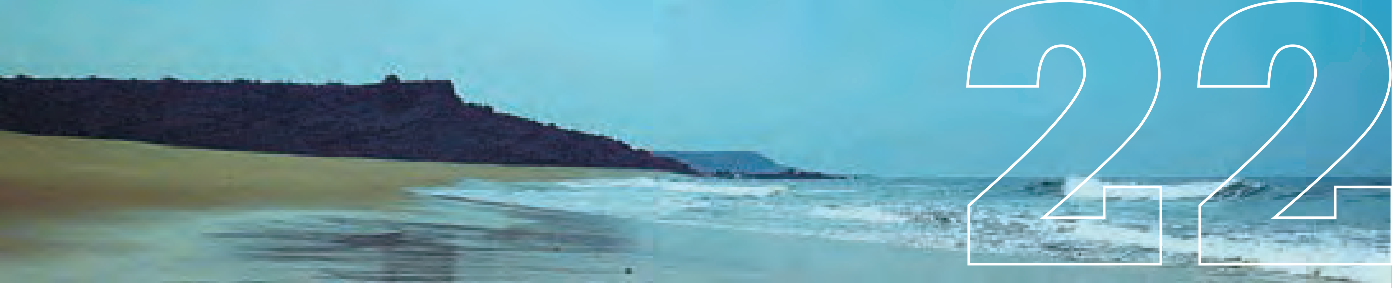

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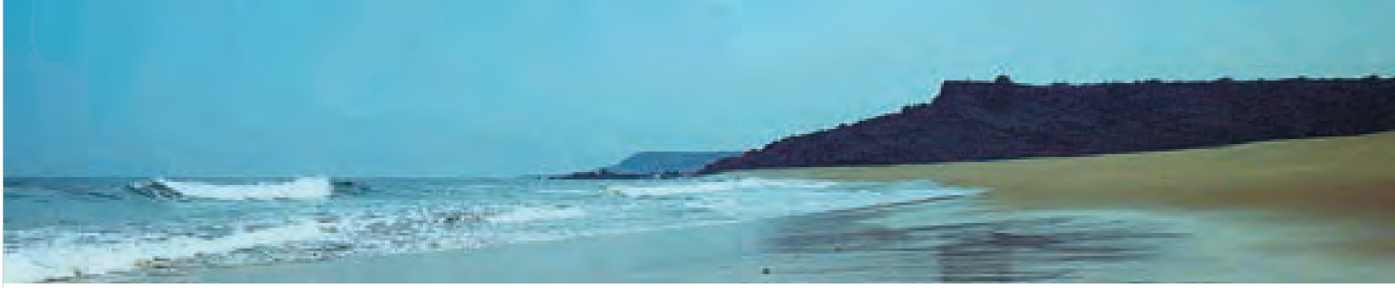

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