

Restoration Scaling of Seagrass Habitats in the Oceanic Islands of Lakshadweep, India using geospatial technology

E.P. Nobi^{†§*}, E. Dilipan[§], T. Thangaradjou[§], and P.K. Dinesh Kumar[†]

[†]CSIR-National Institute of Oceanography

Regional Centre, Dr. Salim Ali Road

Kochi-682018, India

nobi2007@gmail.com

[§]Faculty of Marine Sciences

Annamalai University, Parangipettai

Cudallore – 608 502, Tamilnadu, India

Present address

*Ministry of Environment and Forests

Paryavaran Bhavan

CGO Complex, Lodhi Road

New Delhi, India-110 003

Abstract

Small, isolated oceanic islands are renowned for endemic species and biological wealth. Many small islands administrations all over the world face complex challenges in protecting their natural resources. Restoration of degraded ecosystems is the best way to bring the coastal habitats to its previous forms. In the present study, seagrass restoration sites in six islands of Lakshadweep were selected using satellite map, GIS tools and field observations. Seagrass denuded areas were identified integrating the classified seagrass maps of the year 2000 and 2008. Specific criteria and buffer zones were generated to delineate the restoration sites. A total area of 156.21 ha is identified for seagrass restoration, distributed in the six islands. These areas can be given priority for the seagrass restoration as it will avoid the conflict of rising transplants in newer areas where seagrasses not exists.

Keywords: Island, Conservation, seagrass mapping, IRS P6, restoration.

Introduction

Seagrass meadows though cover a relatively small portion of the ocean (approx 1%), play an important role in the coastal zone and provide ecosystem goods and services that have been estimated to be of high value compared with other marine and terrestrial habitats (Costanza et al. 1997; Duarte et al. 2005). Furthermore, recent studies have demonstrated that seagrasses can reduce the impact of ocean acidification (Bjork and Beer 2009) and act as an important carbon sequester in the marine environment (McKenzie and Unsworth 2009) but globally they are threatened by human impacts related to coastal development and increased pressures from artisanal fisheries (Duarte 2002; Thangaradjou et al. 2009; Waycott et al. 2009).

Seagrass ecosystem in the tropics, particularly in India has been given a low priority by the scientific community and environmentalists (Jagtap 1996). The expanse and density of seagrasses have significantly declined in most of these regions in India (Space Application Centre 2006; Thangaradjou et al. 2008; Sridhar et al. 2010). The global distribution and abundance of seagrasses have changed over evolutionary time in response to sea-level change, physical modification of coastlines and global climate changes (Crowley 1990; Short and Echeverria 1996; Berner and Kothavala 2001). Multiple stresses, including sediment and nutrient runoff, physical disturbance, invasive species, disease, commercial fishing practices, aquaculture, overgrazing, algal blooms and global warming, cause the seagrass decline at scales ranging from a few square meters to hundreds of square kilometers (Orth et al. 2006).

In order to address the issues of sustainable management and conservation of seagrass ecosystems, systematic mapping and monitoring of their distribution at different periods is imperative (Wabnitz et al. 2008). However, mapping the distribution and monitoring the changes on temporal and spatial scales particularly in remotely located scattered small islands, is laborious. Recently, satellite imageries from remote sensing coupled with GIS techniques has become one of the important tools for understanding the changes in seagrass coverage (Wabnitz et al. 2008; Nobu 2010). Satellite imageries, along with field survey, have already proven to be useful in assessing the coastal resource and identifying suitable areas for bioshielding in the island groups (Nobi et al. 2010). Ecological restoration of degraded aquatic ecosystems has been done in many parts of the world and the re-establishment of submerged aquatic vegetation has been recognized as a key measure for restoring eutrophic environments (Yuan and Zhang 2007). Likewise, loss of seagrass habitats and its impact on the marine ecosystem can be slowed down or even reversed by means of planned and effective seagrass restoration (Thangaradjou and Kannan 2008).

Different site selection models (Kopp et al. 1994; Short et al. 2002) have been attempted worldwide as mitigation projects for seagrass losses. Of the possible factors that can directly influence the survival of transplanted seagrasses, poor site selection has been identified as the major cause (Harrison 1990; Fonseca 1992). So, it is better to opt for the areas for seagrass restoration, where the seagrasses were present in the past and are denuded due to various reasons, as it will avoid conflicts of site selection, habitat requirement and invasion in other habitats (Calumpong and Fonseca 2001; Campbell 2002; Katwijk et al. 2009). Remote

sensing combined with GIS tools can be very well used for seagrass restoration site detection (Short et al. 2002; Bos et al. 2005; Cunha et al. 2009; Sohma et al. 2009; Yang et al. 2010) as these are cost effective and reliable.

The overall objective of the present study is to delineate the seagrass restoration sites through integration of remote sensing data, GIS and field observations in small scattered oceanic islands in Lakshadweep Sea. The results of the study would help in sustainable management of ecologically important seagrasses.

Materials and Methods

Study Area

The Lakshadweep group of islands are scattered in the Arabian Sea about 200 to 400 km off the Kerala coast, situated between the latitude 8⁰- 12⁰ N and longitude 71⁰-74⁰ E (Fig. 1). The group consists of 36 islands, 12 atolls, 3 reefs and 5 submerged coral banks. Of the 36 islands on the atolls, only 10 (Minicoy, Kalpeni, Androth, Kavarathi, Agathi, Amini, Kadamath, Kilthan, Chethlath and Bitra) are inhabited. The general topography of the islands is hummocky to flat with steeper shore on the east. The coralline islands are fringed by beach materials all around the islands. They are largely composed of coarse sand, disintegrated corals, shell fragments and uncemented pebbles. The western side of most of the islands is fringed with coralline reef enclosing the lagoon. Erosion is more pronounced towards the eastern side. Considering the availability of repetitive satellite data and loss of seagrasses, six islands (Kavarathi, Agathi, Bangaram, Thinnakkara, Amini, and Kadamath) were considered and selected for the site identification using the modern satellite remote sensing and GIS technology.

Remote sensing, GIS and field observations

Satellite data of the years 2000 (IRS ID LISS III) and 2008 (IRS P6 LISS III) were used for estimating the seagrass spatial changes over a time period for the six islands following the methodology of Mumby and Green (2000). Digital image processing is done with a band combination of 3, 2, 1 for digital analysis and 1, 2, 3 for on screen visual interpretation. Seagrass cover during 2000 and 2008 is estimated for six islands (Table 1). The classified seagrass maps of the two different years were converted into coverage files for further GIS analysis. The coverage data of the seagrasses of each island were converted to shape files with the help of ArcGIS software. Seagrass denuded area were identified overlaying seagrass map of 2000 and 2008. *In situ* observations were made by skin diving with GPS to verify the map produced for the seagrass denuded area and if seagrasses are found regenerated in those areas, necessary corrections were carried out in the map; incorporating the field census. Buffer zones (100 m) were generated for the island shore line, boat jetty and coral reef areas; as the seagrass restoration should not get affected by the human/coastal processes and should not interfere with the normal functioning of the other coastal ecosystems particularly coral reefs. For the identification of seagrass restoration sites, coverage files of seagrass degraded area (rectified with *in situ* data),

island and island shore line buffer, boat jetty buffer and coral reef buffer were overlaid and the seagrass denuded areas falling inside the lagoon were selected.

Results and Discussion

The present study was aimed to identify the seagrass restoration sites by delineating seagrass degraded areas and specifying the criteria. Seagrass denuded areas falling outside the 100 m buffer areas of the island boundary, boat jetty, coral reef edge and within the lagoon area were identified as the sites for seagrass restoration (Table 2). Though the other site detection models (Short et al. 2002; Yang et al. 2010) have used tidal amplitude, sediment character, presence of boring organisms etc. as other criteria, these were not included in the present study. This is because; even water and sediment characteristics were noted within the lagoon area of the Lakshadweep islands and did not show any drastic changes, except intra-seasonal (Nobi 2010). The identified seagrass restoration sites were plotted for different islands (Figs 2 A-D). A total area of 156.21 ha is identified for seagrass restoration, distributed in the six islands (Table 2).

Severe loss of seagrass is found in the north-west, south-east and the areas adjacent to shores of Kavarathi. It can be seen that most of the north-western and middle part of Kavarathi suitable for restoration (Fig. 2A) with restoration area of 21.48 ha. Katwijk et al. (2009) reported that habitat selection and donor seagrass species are the key factors for the success of the transplantation programmes. Seagrass transplantation success varies considerably (Fonseca 1992; Davis and Short 1997; Fonseca et al. 1998) for species and with site for the same species and hence there is a need for identifying suitable species for restoration. As a preliminary effort *Cymodocea serrulata* (R.Br) Asch. and Magnus which covers most part of the lagoon and the dominant species in the Lakshadweep island (Nobi 2010) can be considered as a key species for restoration.

Lakshadweep islands have been experiencing a number of developmental activities in the past ten years besides the increasing human population which raise concern about the adverse environmental impacts on the coastal ecosystems. Increasing tourism activities in the major islands and the resultant organic pollution is posing serious threats to the fragile ecosystems. As these islands are small and linear in structure, any subtle change within the island will immediately affect the coast, causing threats to the coastal ecosystems. Thus, in order to conserve the islands and their coastal habitats, there is an urgent need for continuous monitoring of the habitats at regular intervals and development of models based on environmental criteria, as suggested by Space Application Centre (2006). In Agathi, degradation is found mainly in the south-west part of the lagoon and overlaying all the parameters for the site selection, seagrass restoration site is identified for this island (Fig. 2B). Most of the sites identified in the present study are in the southern part of the lagoon near small islet Kalpitti, whereas sites outside the reef area have not been recommended for restoration as the transplants will be exposed to higher tidal and wave action which would wash ashore the transplanting units. Total area found suitable for seagrass restoration in Agathi island is 121.38 ha (Table 2).

Seagrass restoration in the seagrass degraded areas has been generally accepted and recommended as this will avoid the conflicts of raising transplantation in a newer area (Paling et al. 2009) and there is no need to worry about the ecological factors. Lots of work on developing restoration techniques and management activities are going on throughout the world, and many authors have also emphasised that seagrass conservation is the best management practice (Fonseca et al. 1998; Kelly et al. 2001; Beck et al. 2001). In the case of Bangaram and Thinnakkara islands, seagrass beds were denuded in the south-west and middle-east part of Bangaram and in the reef inner edge of Thinnakkara. Seagrass restoration site identified for this island group is less and it fell in the south-west part of Bangaram (Fig. 2C). Some sites identified in Thinnakkara island were outside the reef and thus not been considered as seagrass restoration site (Fig. 2C). Only 1.25 ha is found suitable for seagrass restoration (Table 2).

Of the possible factors that can directly influence the survival of transplanted eelgrass, poor site-selection (Harrison 1990; Fonseca 1992) has been identified as the major limitation. So, when sufficient information is available, a habitat suitability and ecosystem model can be helpful for large-scale site selection (Katwijk et al. 2009; Sohma et al. 2009). In this respect, the present result is well suited in Lakshadweep islands for a large scale seagrass transplantation programme and these low cost steps for site identification can be considered in a global scale for restoration particularly in the remote islands. Though there was an increase in seagrass cover in Kadamath, loss of seagrass was also seen in the western and middle part of the lagoon. Seagrass restoration site map for Kadamath is shown in Fig. 2D and the sites are falling in the middle part of the lagoon. Area inside the lagoon (12.1 ha) is suitable for seagrass restoration in Kadamath. Seagrass loss in the Amini is seen in the southern part of the island. As this degraded area is falling inside the buffer zones (Fig. 3), and considering the exposure of the lagoon during low tide regime, no area in this island is recommended for seagrass restoration programme.

Identified threats to the seagrass resources of this region

Natural disturbances such as storms and cyclones cause adverse effects on the seagrasses of this region. Potential threats from climate change include, rising sea levels, changing tidal regimes, increase in UV radiation, sediment hypoxia and anoxia and increases in sea water irrespective of the region (Pallewatta 2010). In the Lakshadweep islands the major pressure to seagrasses are natural processes like sea erosion, siltation, construction activities, mechanised fishing, dredging for cargo transport and oil pollution. The Lakshadweep group of atolls is situated along the main oil tanker route in the Indian Ocean, which could pollute these islands with petroleum hydrocarbons and in turn affect the seagrasses. There has been sand mining in some lagoons which could hold back the growth of the seagrasses and may cause a drift in seagrass meadows. Water currents around Lakshadweep are part of the global ocean conveyor belt, and are uniquely known to change directions of flow seasonally. For instance, the monsoon drift of the Arabian Sea and Indian Ocean have profound effects on the biological productivity of the marine ecosystems (Apte et al. 2010). The 1997-1998 El Nino Southern Oscillation (ENSO) event which elevated sea surface temperatures (SSTs) of tropical oceans to more than 38⁰C, is one of the most extreme ENSO events in recent history, resulting in extensive

bleaching of reefs (82%) in Lakshadweep and bleaching related mortality of about 26% within lagoons of Kavarathi and Kadmath (Arthur 2000). It appears that the devastation of the seagrass might have happened probably due the ENSO event.

Though the water quality remains pristine in Lakshadweep islands, the disposal of tuna and other fish waste and untreated solid waste have caused localized eutrophication and degradation of seagrasses (Thangaradjou et al. 2009). Tourism developments along the coast have significantly altered the seagrass meadows. Ecosystem modifiers also have the ability to drastically alter the ecosystem they inhabit sometimes with serious consequences for their own populations. Lal et al. (2010) reported that green turtles (*Chelonia mydas*) significantly modified seagrass ecosystems of Agathi island by their foraging activity. Thus, seagrass ecosystem is susceptible by a multitude of environmental factors that are currently changing.

Conclusion

The present study has identified suitable seagrass restoration sites in different islands of Lakshadweep Sea using satellite remote sensing and GIS. These sites can be given priority when conservation activities are initiated in the Lakshadweep islands, as the seagrass ecosystem have more importance in reducing the impact of ocean acidification. Initiatives can also be taken in remote islands of the world compiling remote sensing, GIS and field observations for seagrass transplantation without looking into much of the percentage of success of the transplantation. Even 50 % success of restoration of a degraded ecosystem has its own value and can render high value ecological and biodiversity services.

Acknowledgments

The authors thank Director and Dean, Faculty of Marine Sciences, Annamalai University for the support and help provided. We also thank Director, National Institute of Oceanography (NIO), Goa and Scientist- In charge, NIO RC Cochin, for the facilities provided. We are grateful to the Director, Department of Science and Technology, Lakshadweep Administration for their support during the field work.

LITERATURE CITED

- Apte D, Dutta S, Babu I (2010) Monitoring densities of the giant clam *Tridacna maxima* in the Lakshadweep Archipelago. Mar Biod Rec 3:1-9
- Arthur R (2000) Coral bleaching and mortality in three Indian reef regions during an El Niño southern oscillation event. Curr Sci 79: 1723-1729
- Beck MW, Heck KL, Able KW et al (2001) The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51: 633-641
- Berner RA, Kothavala Z (2001) GEOCARB III: A revised model of atmospheric CO₂ over Phanerozoic time. Am J Sc 301:182-204
- Bjork M, Beer S (2009) Ocean acidification, Could dense seagrass meadows resist. Seagrass watch 37: 2-5
- Bos AR, Dankers N, Groeneweg AH, Hermus DCR, Jager Z, de Jong DJ, Smit T, de Vlas J, van Wieringen M, van Katwijk MM (2005) Eelgrass (*Zostera marina* L.) in the western Wadden Sea: Monitoring, habitat suitability

- model, transplantations and communication. In: International Conference on Nature Restoration Practices in European Coastal Habitats, Koksijde, Belgium, pp 95-109
- Calumpong HP, Fonseca MS (2001) Seagrass transplantation and other seagrass restoration methods. In: Short FT, Coles RG (eds) Global Seagrass Research Methods, Elsevier Science, pp 425-442
- Campbell ML (2002) Getting the foundation right: a scientifically based management framework to aid in the planning and implementation of seagrass transplant efforts. Bull Mar Sci 71: 1405-1414
- Costanza R, d'Arge R, deGroot R et al (1997) The Value of the world's ecosystem services and natural capital. Nature 387(15): 253-260
- Crowley TJ (1990) Are there any satisfactory geologic analogs for a future greenhouse warming?. J Climate 3: 1282-1292
- Cunha AH, Assis J, Serrão EA (2009) Estimation of available seagrass meadow area in Portugal for transplanting purposes. J Coastal Res 156: 1100-1104
- Davis RC, Short FT (1997) Restoring eelgrass, *Zostera marina* L., habitat using a new transplanting technique: The horizontal rhizome method. Aquat Bot 59: 1-15
- Duarte CM (2002) The future of seagrass meadows. Environ Conserv 29: 192-206
- Duarte CM, Middelburg JJ, Caraco N (2005) Major role of marine vegetation on the oceanic carbon cycle. Biogeosciences 2: 1-8
- Fonseca MS (1992) Restoring seagrass systems in the United States. In: Thayer GW (ed) Restoring the Nation's Marine Environment, UM-SG-TS-92-06, Maryland Sea Grant Publication, College Park, Maryland. pp 79-110
- Fonseca MS, Kenworthy WJ, Thayer GW (1998) Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. Silver Spring (MD): NOAA Coastal Ocean Program Decision Analysis Series no. 12
- Harrison PG (1990) Variations in success of eelgrass transplants over a five-year period. Environ Conserv 17: 157-163
- Jagtap TG (1996) Some quantitative aspects of structural components of seagrass meadows from the southeast coast of India. Bot Mar 39: 39-45
- Katwijk MMV, Bos AR, de Jonge VN, Hanssen LSAM, Hermus DCR, de Jong DJ (2009) Guidelines for seagrass restoration: Importance of habitat selection and donor population, spreading of risks, and ecosystem engineering effects. Mar Pollut Bull 58(2): 179-188
- Kelly NM, Fonseca M, Whitfield P (2001) Predictive mapping for management and conservation of seagrass beds in North Carolina. Aquat Conserv 11(6): 437-451
- Kopp BS, Doherty AM, Nixon SW (1994) A guide to site selection for eelgrass restoration Projects in Narragansett Bay, Rhode Island. Technical Report, University of Rhode Island
- Lal A, Arthur R, Marba N, Lill AWT, Alcoverro T (2010) Implications of conserving an ecosystem modifier: Increasing green turtle (*Chelonia mydas*) densities substantially alters seagrass meadows. Biol Conserv 143: 2730-2738
- McKenzie L, Unsworth R (2009) Carbon carbon everywhere. Seagrass Watch 36: 2-3
- Mumby PJ, Green EP (2000) Mapping coral reefs and macroalgae. In: Green EP, Mumby PJ, Edwards AJ, Clark CD (eds) Remote Sensing Handbook for Tropical Coastal Management, UNESCO, Paris, pp 155-174
- Nobi EP (2010) Assessment and Evaluation of the seagrass resources of Lakshadweep Islands (India): A Remote Sensing and GIS approach. Ph.D. thesis, Annamalai University
- Nobi EP, Shivaprasad A, Karikalan R, Dilipan E, Thangaradjou T, Sivakumar K (2010) Microlevel Mapping of Coastal Geomorphology and Coastal Resources of Rameswaram Island, India: A Remote Sensing and GIS Perspective. J Coastal Res 26(3): 424-428

- Orth RJ, Carruthers TJB, Dennison WC et al (2006) A global crisis for seagrass ecosystems. *BioScience* 56(12): 987-996
- Paling EI, Fonseca M, Katwijk MMV, Keulen MV (2009) Seagrass restoration. In: Perillo G, Wolanski E, Cahoon D, Brinson M (eds) *Coastal wetlands: an integrated ecosystem approach*, Elsevier, Amsterdam
- Pallewatta N (2010) Impacts of Climate Change on Coastal Ecosystems in the Indian Ocean Region. In: Michel D, Pandya A (eds) *Coastal Zones and Climate Change*, Stimson, Washington, pp 3-16
- Space Application Centre (2006) National (natural) resources information system (NRIS) for Lakshadweep Island. Technical note (SAC/RESIPA/MWRG/MSCED/TR/50/2006), India
- Short FT, Echeverria SW (1996) Natural and human induced disturbance of seagrasses. *Environ Conserv* 23(1): 17-27
- Short FT, Davis RC, Kopp BS, Short CA, Burdick DM (2002) Site selection model for optimal restoration of eelgrass, *Zostera marina* L. *Mar Ecol Prog Ser* 227: 263-267
- Sohma A, Sekiguchi Y, Nakata K (2009) Application of an ecosystem model for the environmental assessment of the reclamation and mitigation plans for seagrass beds in Atsumi Bay. *Estuar Coast Shelf S* 83(2): 133-147
- Sridhar R, Thangradjou T, Kannan L, Astalakshmi S (2010) Assessment of coastal bioresources of the Palk Bay, India, using IRS-LISS-III data. *J Ind Soc Remote Sens* 38: 565-575
- Thangaradjou T, Kannan L (2008) Survival and growth of transplants of laboratory raised axenic seedlings of *Enhalus acoroides* (L.f.) Royle and field-collected plants of *Syringodium isoetifolium* (Aschers.) Dandy, *Thalassia hemprichii* (Ehrenb.) Aschers. and *Halodule pinifolia* (Miki) den Hartog. *J Coast Conserv* 12: 135-143
- Thangaradjou T, Nobi EP, Dilipan E, Sivakumar K, Kannan L (2009) Threats to the Seagrasses of India. *Seagrass Watch* 39: 20-21
- Thangaradjou T, Sridhar R, Senthilkumar S, Kannan L (2008) Seagrass resources assessment in the Mandapam coast of the Gulf of Mannar Biosphere Reserve, India. *Appl Ecol Environ Res* 6 (1): 139-146
- Wabnitz CC, Andrefouet S, Pulliza DT, Mullerkarger FE, Kramer PA (2008) Regional scale seagrass habitat mapping in the Wider Caribbean region using Landsat sensors: Applications to conservation and ecology. *Remote Sens Environ* 112(8): 3455-3467
- Waycott M, Duarte CM, Carruthers T et al (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proc Nat Acad Sci USA* 106: 12377-12381
- Yang Z, Sobocinski KL, Heatwole D, Khangaonkar T, Thom R, Fuller R (2010) Hydrodynamic and ecological assessment of nearshore restoration: A modeling study. *Ecol Model* 221 (7): 1043-1053
- Yuan L, Zhang LQ (2007) The spectral characteristics of a submerged plant *Myriophyllum spicatum* with varied coverage. *J Remote Sens* 11: 609-616

List of Figures

Fig. 1. The location of study area in the south-west coast of India.

Figs. 2 A-D. Seagrass restoration sites demarcated in the study area (A-Kavarathi island, B-Agathi island, C-Bangaram & Thinnakkara island, D- Kadamath island).

Fig. 3. Seagrass restoration site analysis map of Amini island (no restoration site were identified).

Table 1. *Changes in seagrass coverage (Ha) at 6 studied islands in the Lakshadweep Sea.*

Island	Seagrass coverage (ha)		
	Year 2000 (Hectare)	Year 2007/2008 (Hectare)	Seagrass cover change (Hectare)
Kavarathi	187.06	152.81	(-) 34.25
Agathi	440.29	273.77	(-) 166.52
Bangaram & Thinnakkara	45.49	69.35	(+) 23.86
Kadamath	395.60	502.85	(+) 107.25
Amini	71.18	67.81	(-) 3.37
Total	1,139.62	1,066.59	(-)73.03

+ indicates- 'positive'; - indicates 'negative'

Table 2. *Area identified for Seagrass restoration in the six studied islands of Lakshadweep Sea.*

Island	Area identified for restoration (Hectare)
Kavarathi	21.48
Agathi	121.38
Bangaram & Thinnakkara	1.25
Kadamath	12.1
Amini	---
Total	156.21

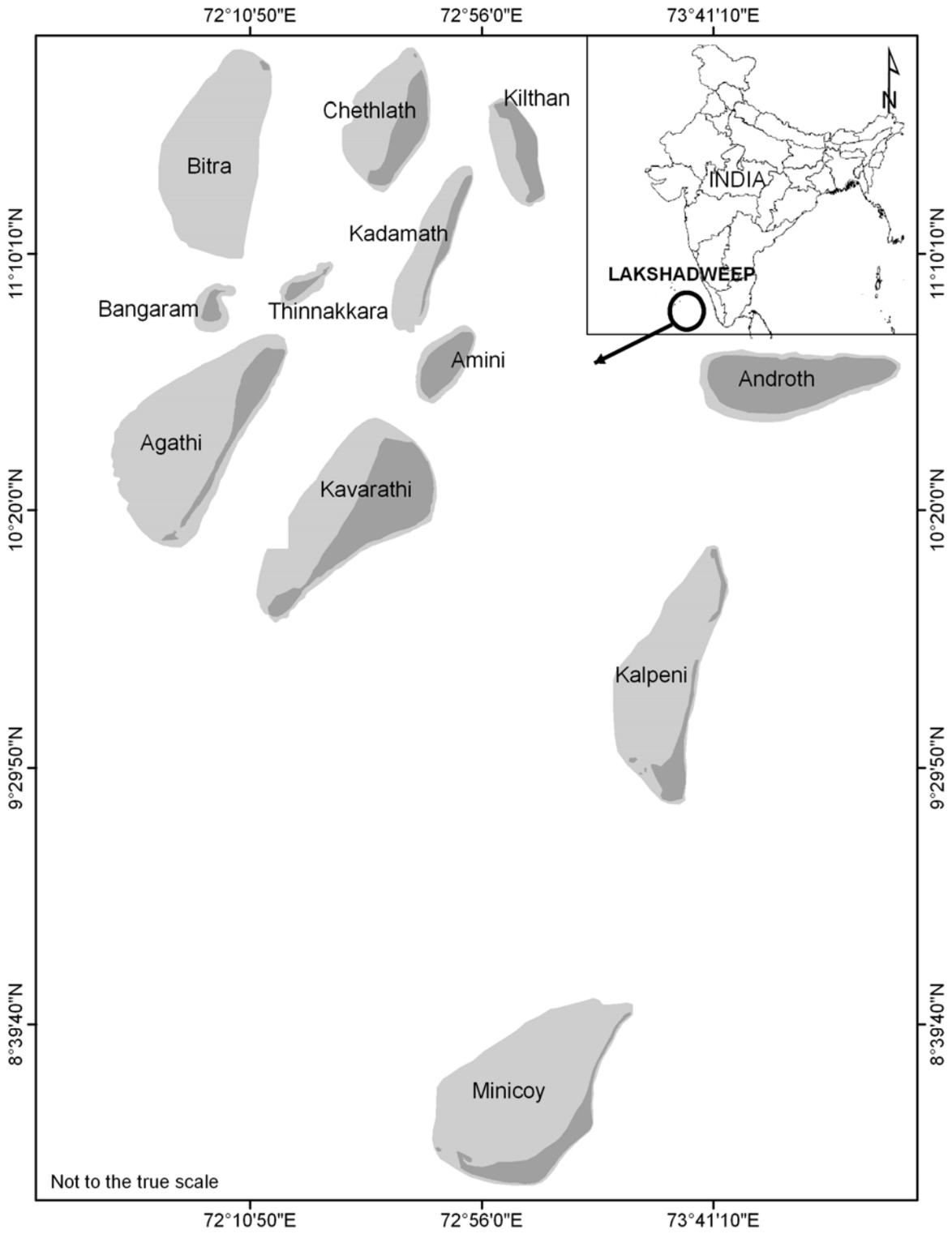


Figure 1.

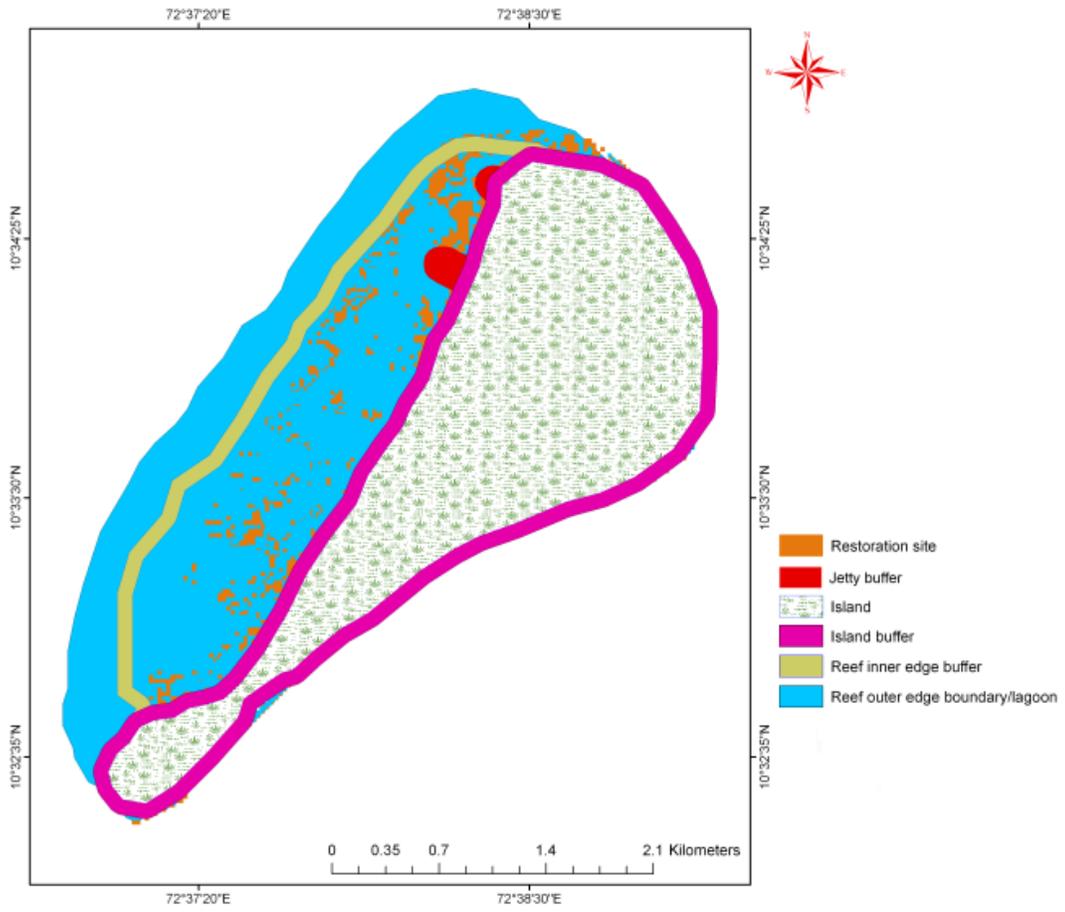


Fig 2A

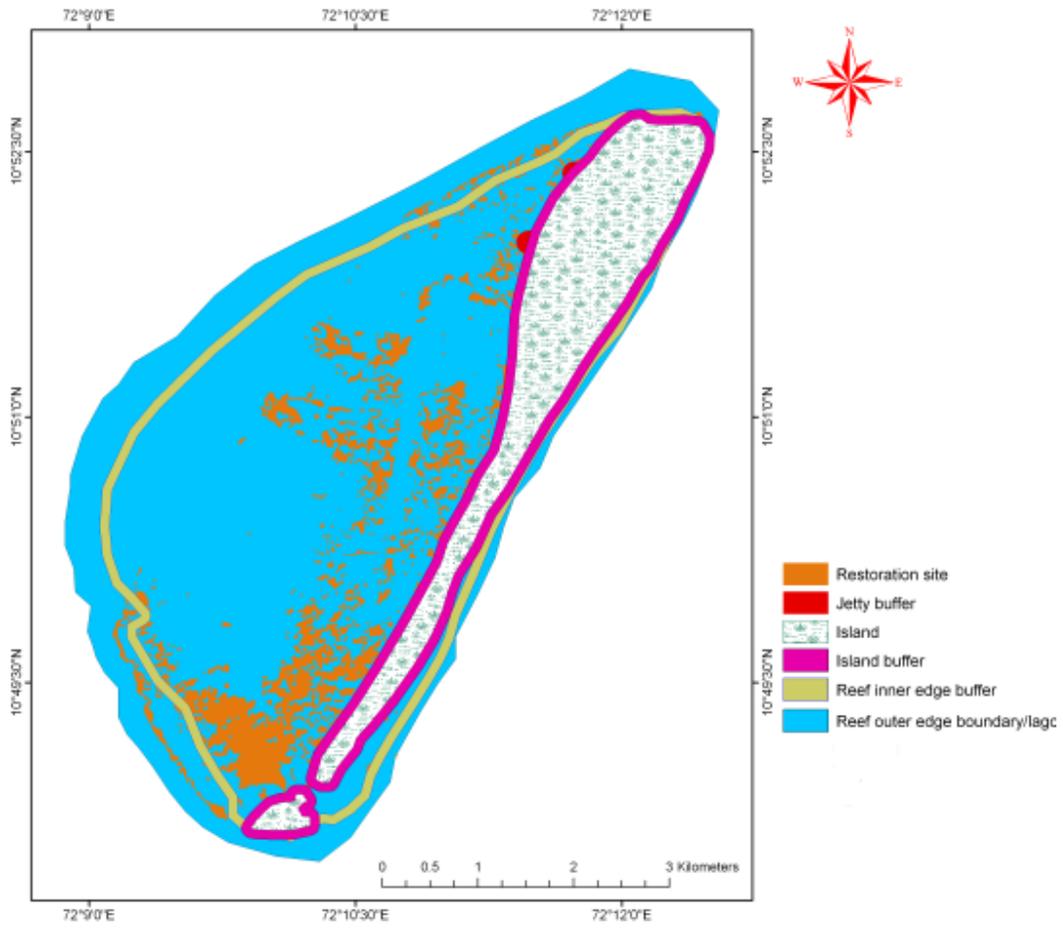


Fig 2B

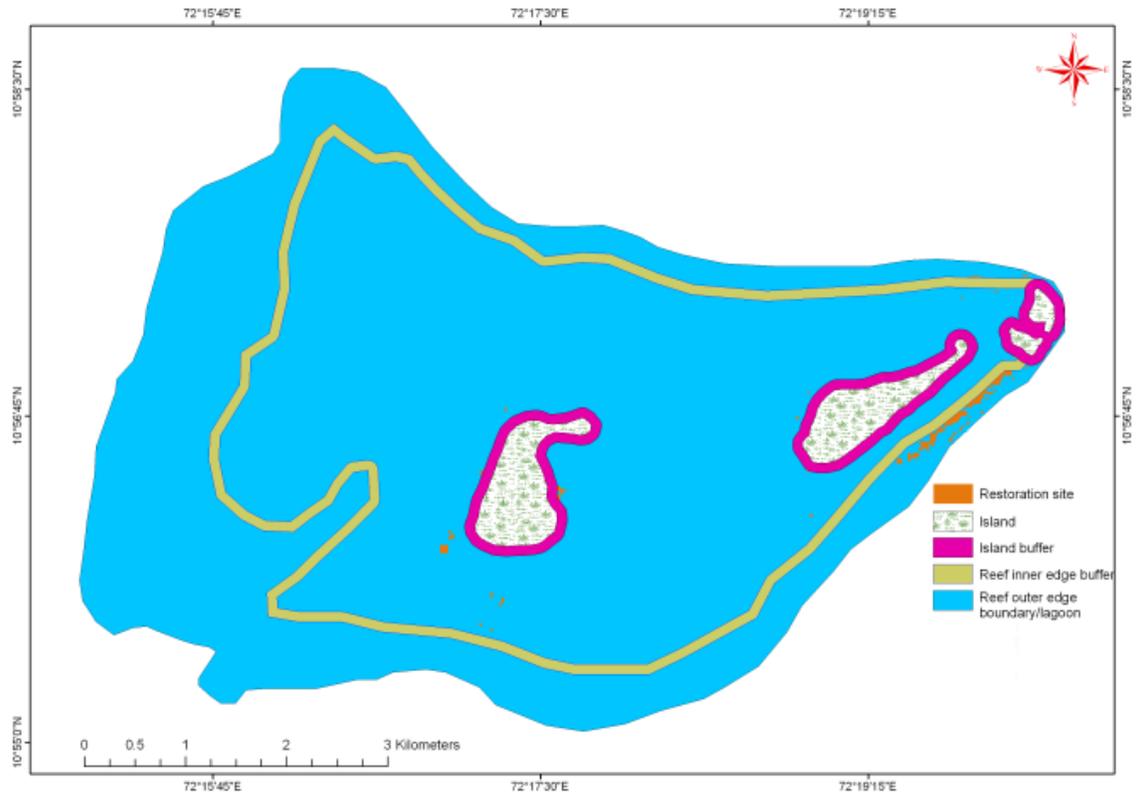


Fig 2C

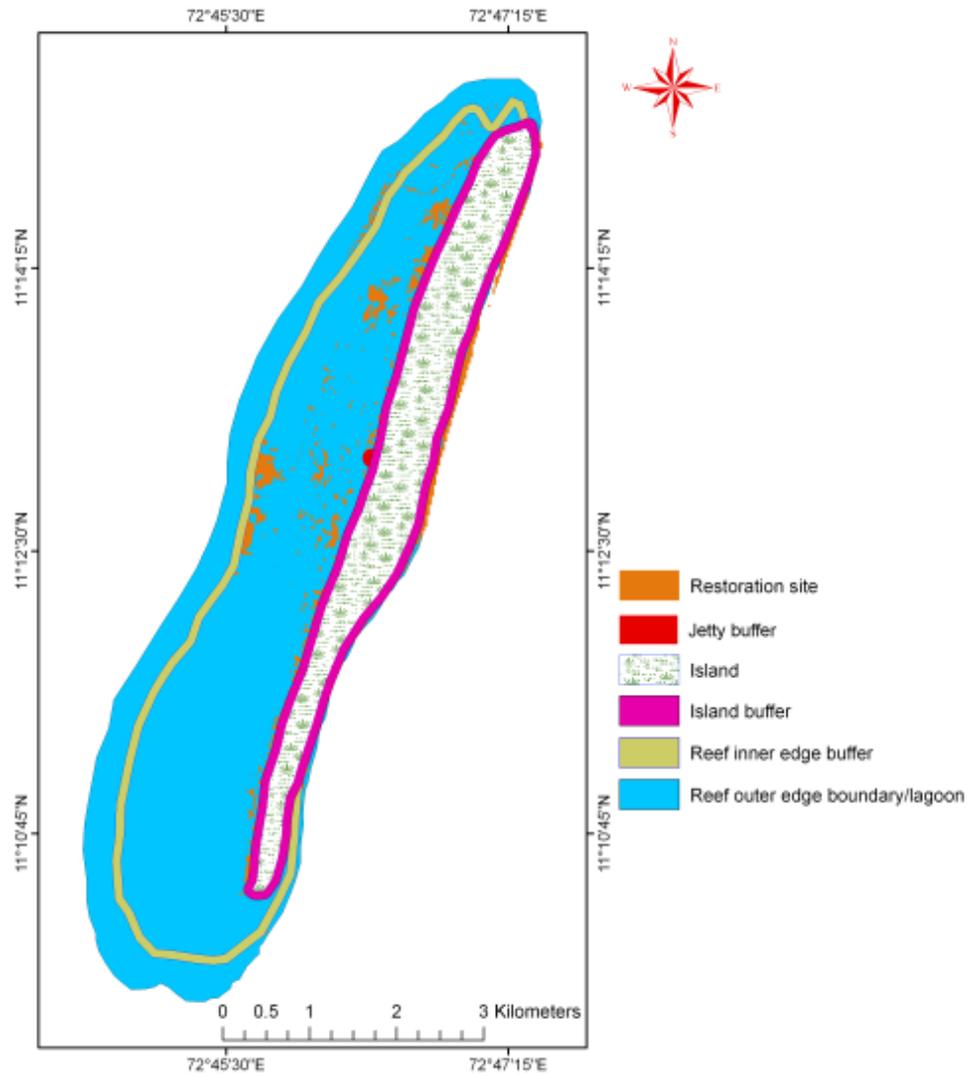


Fig 2D

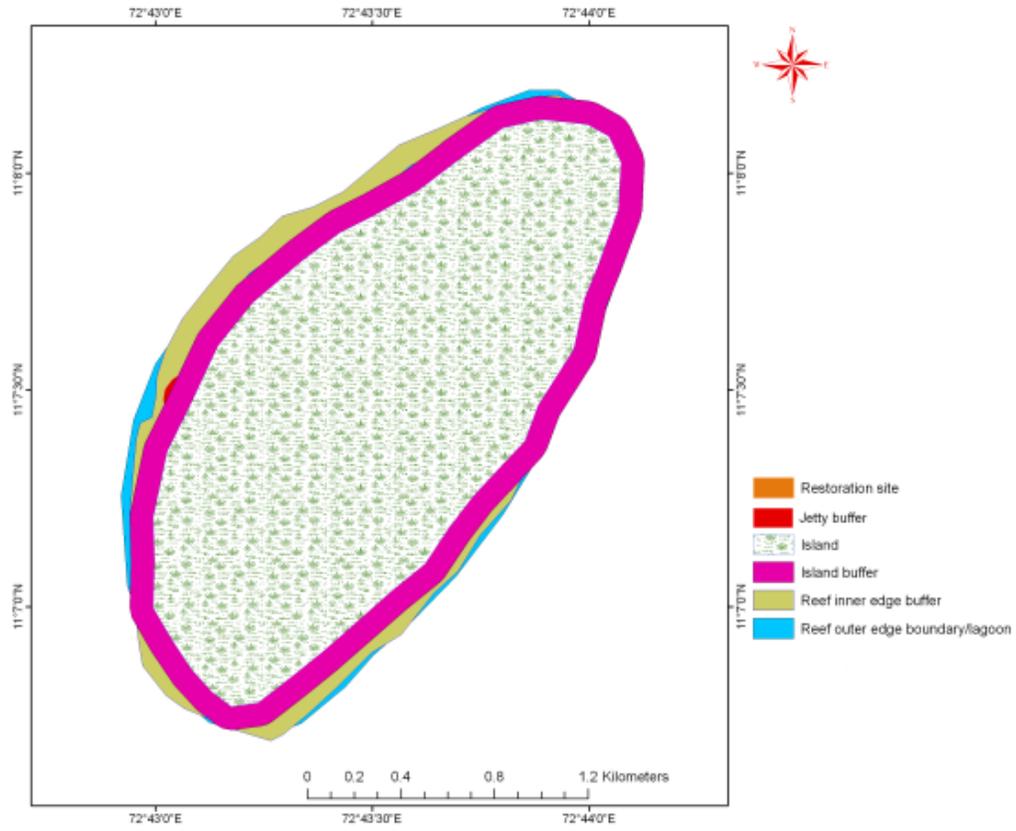


Fig 3