Natl. Acad. Sci. Lett. (January–February 2013) 36(1):67–77
DOI 10.1007/s40009-012-0087-x

RESEARCH ARTICLE

Mangrove Inventory of India at Community Level

Ajai · Anjali Bahuguna · H. B. Chauhan · Kakoli Sen Sarma · Somenath Bhattacharya · Subhash Ashutosh · C. N. Pandey · T. Thangaradjou · L. Gnanppazham · V. Selvam · Shailesh R. Nayak

Received: 29 June 2012 / Revised: 17 August 2012 / Accepted: 17 October 2012 / Published online: 18 November 2012

Abstract Mangroves are salt tolerant plants that occur between 32°N and 38°S latitudes. Mangroves play an important role in stabilizing shoreline and protect the coast against storm surges and heavy tides. Though the mangrove inventory has been done earlier in India using satellite data but no systematic attempts has been made to map the mangroves at the community level for the entire country. The present paper reports the mangrove inventory at community level for India using Resourcesat-1 satellite data. State wise inventory on the mangrove area and the dominant communities are presented. Total area under mangrove based on the satellite data of 2005–2007 is 495,620 ha. West Bengal has the highest area under mangrove.

Ajai (✉) · A. Bahuguna · H. B. Chauhan
Space Applications Centre, ISRO, Ahmedabad, India
e-mail: ajai@sac.isro.gov.in

K. Sen Sarma · S. Bhattacharya
Institute of Environmental Studies & Wetland Management, Kolkata 700 064, India

S. Ashutosh
Forest Survey of India, Dehradun 248 195, India

C. N. Pandey
Gujarat Forest Department, Gandhinagar 382 007, India

T. Thangaradjou
CAS, Annamalai University, Chidambaram, Parangipettai 608 502, India

L. Gnanppazham · V. Selvam
M.S. Swaminathan Research Foundation, Chennai 600 113, India

S. R. Nayak
Ministry of Earth Sciences, New Delhi 110 003, India

Keywords Mangrove · Coastal habitats · Coastal zone · Resourcesat-1 · Community zonation

Introduction

Mangroves are salt tolerant plants that occur along intertidal zones in the form of narrow strips or as extensive patches in estuarine habitats and river deltas of tropical and sub-tropical regions. They occur between 32°N and 38°S latitudes, mostly on the eastern coasts of Africa, Australia, Asia and America [1]. Sheltered environment with brackish influx, estuarine and deltaic muddy soils, good rainfall (1,000–3,000 mm) and temperature between 26 and 35 °C are considered as ideal habitats for luxuriant growth of mangroves. Mangrove forests are usually characterized by uniform type of trees and shrubs and the species diversity decreases with increasing latitudes. According to a trend analysis conducted on available data by FAO [2], 15.2 million hectares of mangroves are estimated to exist worldwide as on 2005, down from 18.8 million hectares in 1980. The most extensive mangrove areas are found in Asia, followed by Africa and North and Central America. According to Finlayson and Moser [3] the total mangrove area of the world is about 14 million hectares: out of these, the old world tropical mangroves, i.e., the Indo-Pacific tropical zones and tropical Australia have the most dominant and important mangroves in respect of species diversity, richness, abundance and succession.

Mangroves play an important role in stabilizing shorelines and protect the coast by acting as barriers against storm surges and heavy tides. They are self-generating, self-perpetuating and highly resilient littoral formations, playing a major role in the global cycle of carbon, nitrogen and sulphur. They act as sink for sediments and detritus

draining from coastal catchments and help in the tertiary assimilation of wastes. Mangrove swamps are also source of nutrients and supports highly productive marine food chains. Mangroves serve as nursery grounds for the larvae and juveniles of marine denizens. They contribute to the livelihood of coastal folks in terms of forest produce and fishery resources. Mangrove forests are also valued as potential recreation site for fishing, boating, bird watching, sightseeing and photography. In addition, it is vastly used as fuel and fodder by local people and has many medicinal usages.

The most dominant and largest single block of mangrove formation of the world is in the Sunderbans, the Ganga–Brahmaputra deltaic regions and spreading over two countries India and Bangladesh. West Bengal has the maximum mangrove cover in India, followed by Gujarat and then Andaman and Nicobar islands.

The exact number of mangrove species is still a matter of debate and ranges from 50 to 70 according to different classification systems with the highest species diversity found in Asia, followed by eastern Africa [4, 5].

On the macro-scale, geomorphic setting of the mangrove wetlands of the east coast of India is different from those of the west coast. Steep slopes, rises, promontories and drowned estuaries characterize the west coast of India, while the east coast shows a sequence of delta formations [6]. This vast expanse of deltaic soil and mud-flats favours luxuriant growth and diversity of species. According to Jagtap et al. [7], the mangrove flora of India consists of 57 species, of which 37 species are reported from east coast and 20 from the west coast.

In spite of ecological and economical significance, mangroves are endangered ecosystems. The major threats are conversion of mangrove habitats for agriculture, industrial development, human settlement, salt extraction and shrimp farming. Reduction in freshwater flow and excessive extraction of wood for fuel also add up to the severe degradation of mangroves. This has necessitated the need for its constant surveillance. In this regard, remote sensing techniques become practical alternative to field-based surveys and are being successfully used over the years for mangrove mapping at primary level, especially in differentiating mangroves from other vegetative covers [8, 9].

In recent years, there have been new initiatives to understand the spatial relationship between mangroves and their immediate environment, viz., 'community zones' using advanced digital image processing techniques [10, 11]. These mangrove zones exhibit unique spectral signatures and earlier studies at select sites by Nayak and Bahuguna [9] revealed the potential of remote sensing data in discerning and mapping these communities effectively. Indian Remote Sensing Satellite (IRS) data has been extensively used to map mangroves and other coastal vegetation for the entire Indian coastline. Large data bases on spatial extent of mangroves for the entire Indian coast have been created on 1:25,000, 1:50,000 and 1:250,000 scale by Space Applications Centre using IRS data of 1986 and 1990–1993 timeframe. However, no systematic attempt has been made to map the mangroves at the community level for the entire country. As the mangrove inventory for the entire Indian Coast at a larger scale was done using satellite data of 1990–1993 timeframe, it was also felt necessary to carry out once again detailed mangrove inventory using recent satellite images and to find out changes that might have occurred during the last 15 years. Accordingly, the task of mapping mangroves at community level was taken up and the findings are presented in this paper.

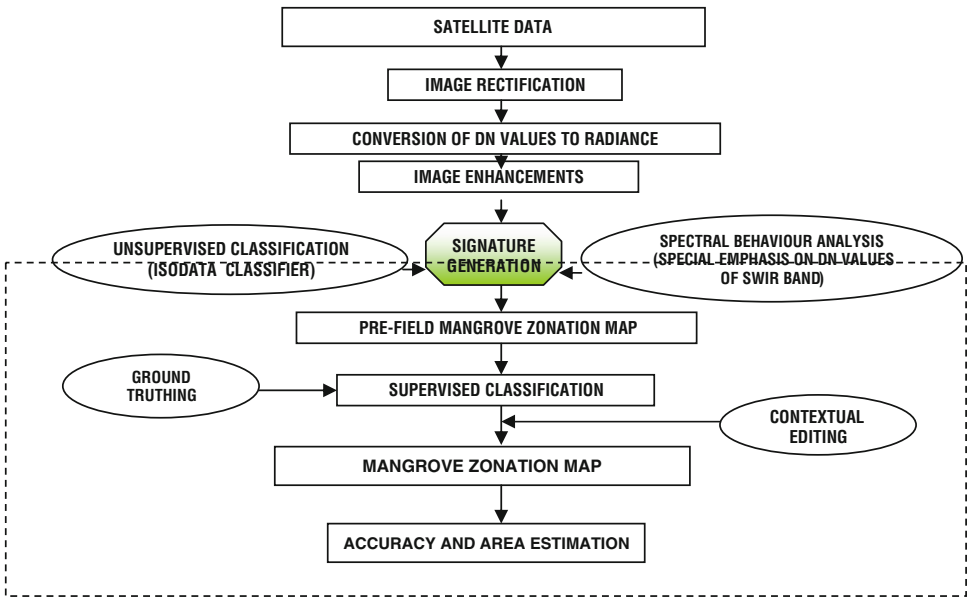

Fig. 1 Methodology for mangrove mapping at plant community level

Materials and Methods

In the present study, mangroves have been mapped at plant community level on 1:25,000 scale for the entire Indian Coast using Resourcesat-1 satellite data. The study covers all the maritime states/union territories of the country harbouring mangroves, namely, Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andaman and Nicobar Islands, Puducherry, Andhra Pradesh, Orissa and West Bengal.

Resourcesat-1, LISS-IV/LISS-III data of 2005–2007 during the period October–March have been used in this study. As mangrove forests are tide inundated, care was taken to utilise low tidal data sets of coastal regions. For delineating fringe mangroves along narrow creeks and new plantation areas, Quickbird data of above period was also used as support data.

Short wave infra red band of IRS LISS-III is effectively used for differentiating mangroves from adjacent other vegetative cover; therefore, supervised classification was performed on LISS-III imagery for generating mangrove community zonation map on 1:25,000 scale. IRS LISS IV and Quickbird imagery were used as supporting data, mainly as an aid to the analyst. These data having higher spatial resolution were used as surrogate to the ground truth, specially in cases of small patches of mangroves. The actual supervised classification was performed on LISS-III data.

The details of the methodology adopted for mangrove community zonation and mapping are given in Fig. 1. LISS IV/LISS III images were geo-referenced using survey of India (SOI) topographical sheets. Digital values from LISS IV/LISS III images were converted to spectral radiance using the following equation:

$$L_{rad} = \{[DN/\max\ grey] \times [\ L_{max} - \ L_{min}]\} + L_{min}$$

where DN = digital number of each pixel; max grey = 255. L_{max} and L_{min} are the maximum and minimum radiance values.

As there was only scanty information available regarding community zonation, so to start with, the geo-referenced spectral radiance images were subjected to unsupervised classification using the commonly used Iterative Self-Organising Data Analysis (ISODATA) classifier. The ISODATA method uses minimum spectral distance to assign a cluster for each candidate pixel. Depending upon the scene characteristics arbitrary clusters are specified with a convergence threshold of 0.99. The clusters thus obtained were colour coded for better visual discrimination and pre-field classification maps were prepared.

The basic premise on which the eco-geomorphological zonations of mangrove communities using spectral data are done is based on the fact that each of the mangrove community classes have different reflectance (or radiance/DN values) in each of the four spectral bands of LISS-III data. Thus, these classes are separable in the four dimensional spectral feature space.

From the field observations, topography, salinity and duration of tidal inundation were found to be the predominant factors influencing the species composition of plant community. The false colour composite developed from digital data using Short Wave Infrared (SWIR) band is able to discern the major communities to a considerable extent. To identify the subtle differences in species composition, classified outputs developed from ISODATA classifier were also used in ground truthing. Ground truth points were selected in such a way to sufficiently represent all the digitally discernible communities. Geographical coordinates, species composition and dominance, influence of tidal inundation and field photographs of each selected reference point were also collected. Based on the ground truth information, supervised classification was performed with sufficient training sets for each community. Ground truth information is used to identify the training sites on the image for each of mangrove community classes. The radiance/DN values and their associated statistics (mean and variance − covariance) computed for each of the training sites are used to train the classifier. After training the classifier, the entire image is classified into various community classes. Mangrove community classes thus obtained were evaluated critically with the ground truth information and expert knowledge. Contextual editing was performed wherever necessary to improve the classification accuracy [12]. Contextual editing is the use of non spectral information e.g. geography, location, association etc. to improve classification of spectrally overlapping classes. For example, the pixels which are classified as mangroves but they are located outside the highest of the high tide line (landward side) has to be recorded as the terrestrial vegetation. Contextual editing has been extensively used in coastal habitat mapping based on spectral data analysis and it helps in improving the accuracy [13]. Contextual information has to be added as a series of explicit decision rules that are applied to the entire image.

Finally the map outputs were generated on 1:25,000 scale. Area statistics is drawn based on final classification. Accuracy assessment of the mangrove community map was carried using field/ground truth data. As mentioned earlier, the ground truth data collected from a large number of sites (well distributed geographically) were used for training the classifier. Fifty percent of the total no. of the ground truth sites were used in training the classifier, the remaining fifty percent ground truth sites were used for assessing the accuracy of mangrove community maps. The mapping accuracy was computed by identifying these known sites on the classified (mangrove) map and comparing the class on the map with the actual ground information on the mangroves for that particular site.

Table 1 Geomorphological zones and ecological classes of mangrove habitat

Geomorphological zones		Ecological classes	
Onshore areas	Beach	Muddy	Fringe tidal mangroves with dominant species
		Sandy	
Deltaic complex	Estuarine mouth	Inter-tidal mudflat	*Avicennia* pure (3 species)
			Aegialitis (only in Sunderbans & Mahanadi)
	Mid estuary (creeks and canals more)	Inter-tidal mudflat	*Rhizophora*, *Bruguiera*, *Ceriops*, *Sonneratia, Aegiceras*, *Xylocarpus*
	Inner estuary	Inter-tidal mudflat	*Rhizophora*, *Bruguiera*, *Heritiera*, *Carberra*, *Cynometra*, *Excoecaria*, *Phoenix*, *Xylocarpus*
	Outer estuary	High-tidal mudflat	*Dalbergia*, *Derris*, *Excoecaria*, *Acrostichum*, *Pongania*
			Marsh vegetation
			Saline blanks
Bay complex	Mouth	Inter-tidal mudflats	*Rhizophora*, *Bruguiera*, *Ceriops*, *Sonneratia*, *Xylocarpus*
	Middle zone	High-tidal mudflats	*Avicennia*, *Phoenix*, *Lumnitzera littoralis*, *Heritiera littoralis*, *Nypa*
	Inner zone	High-tidal mudflats	*Avicennia*, *Nypa*, *Acrostichum*, *Thespesia*, *Derris*
			Marsh vegetation
			Saline blanks
Gulf complex	Seaward zone	Sub-tidal mudflat	Algae
	Inner zone	Inter-tidal mudflat	*Rhizophora*, *Sonneratia*, *Avicennia*, *Ceriops*, *Bruguiera*
	Outer zone	High-tidal mudflat	*Avicennia*,
			Salt marsh vegetation
			Grass/*Acanthus*
			Saline blanks
Offshore area	Continental shelf		Algae/seaweeds
	Islands		Mangroves
			Sand vegetation
	Coral reefs		Algae/seaweeds/seagrass

Classification System

A hybrid classification system involving both geomorphological as well as ecological characteristics of the habitat is ideal for habitat mapping as both the characteristics strongly influence the radiance recorded by a remote sensing instrument. The classification system used in the present study is given in Table 1. Though a direct geomorphological classification is not attempted in this study, mangrove community zonation is quite discernible based on definite environmental gradients. Depending on the dominance of genus present in these zones and its crown cover density, mangrove community classes were delineated and assigned class names in the order of dominance. In several cases, where it is possible and mono-community was observed, it was even possible to go up to the species level. But, in general, community zonation up to the genus level has been attempted and carried out in this paper. Mangrove communities with more than three mangrove genus are classified as mixed mangrove communities.

Zoning also included condition assessment in the form of density-wise classification of the communities. Mangroves have been classified in four density classes, viz., very dense (>70 % cover), moderately dense (40–70 % cover), dense (10–40 %) and degraded (<10 % cover). In many cases the term "Sparse" has also been used to represent the mangroves which have a density between 10 and 20 %.

Results and Discussion

As per the present spatial inventory (on 1:25,000 scale), using Resourcesat-1 data of 2005–2007 timeframe, the area under mangrove cover for Indian Coast is 495,620 ha. The accuracy of the mangrove map has been found to be 91 %. The highest mangrove area is in the state of West Bengal.

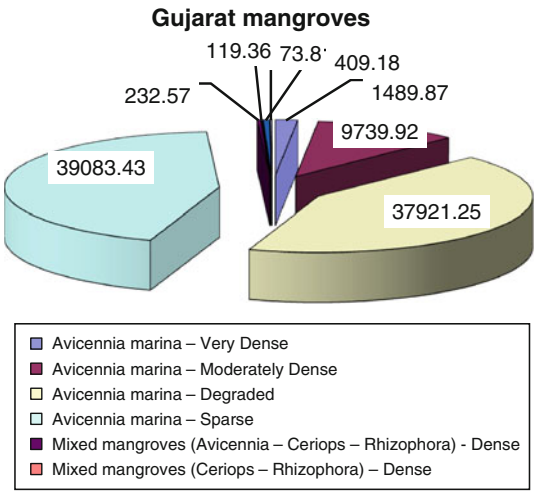

Fig. 2 Mangrove communities of Gujarat

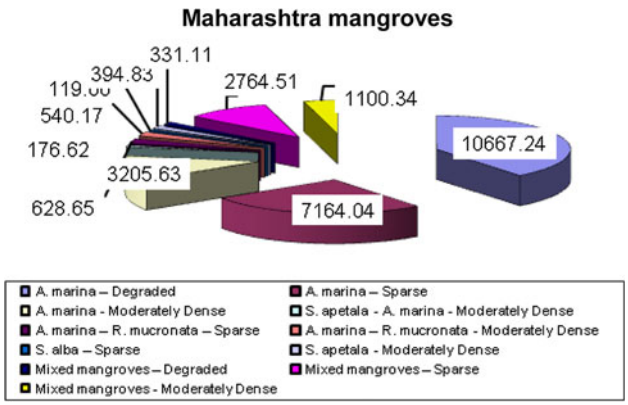

Fig. 3 Mangrove communities of Maharashtra

Gujarat and Andaman have the second and the third largest mangrove cover in the country. The state wise details of mangrove community and densities are as under:

Gujarat

Mangrove vegetation in the state of Gujarat is found in the districts of Valsad, Navsari, Surat, Anand, Bharuch, Ahmedabad, Bhavnagar, Amreli, Junagadh, Porbandar, Jamnagar, Rajkot and Kachchh. Total area under mangrove in Gujarat state is 89,069.34 ha. Figure 2 shows the distribution of mangrove and associated plant species in the state of Gujarat. *Avicennia* is the dominant species in the state of Gujarat. Small area under *Sonneratia apetala* species is found in south Gujarat.

Maharashtra

Maharashtra has a total area of 27,092.14 ha under mangrove vegetation. *Avicennia*, *Sonneratia*, *Rhizophora* are the major mangrove genus found in Maharashtra. The details of the mangrove community distributions are given in Fig. 3.

Table 2 Mangrove plant communities of Goa

Mangrove communities	Area (ha)
A. officinalis–Excoecaria agallocha—Sparse	669.31
A. alba–R. mucronata—Sparse	877.76
Sonneratia alba–A. officinalis—moderately dense	1,030.00
Mixed mangroves—Sparse	490.06
Mixed mangroves—degraded	396.23
Total	3,463.36

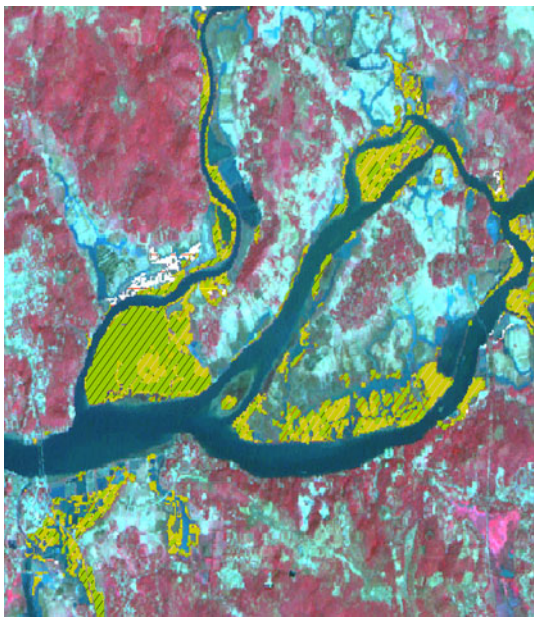

Fig. 4 Mangrove communities map of Chorao island, Goa

Goa

In Goa, mangrove forest covering an area of 3463.36 ha is classified into five classes as given in Table 2. *Avicennia*, *Sonneratia* and *Rhizophora* species along the rivers like Mapusa, Zuari and Mandovi cover the majority of area under mangrove cover.

Moderately dense patches of *Sonneratia alba–Avicennia* officinalis community are present along all the major rivers of the state viz., at Aldona, Vasvaddo and Kamarkajali along Mapusa river, at Danda, Adpal and Panchwadi along Zuari river and at Chorao Sanctuary along Mandovi river. The classified image showing major communities at Chorao island is shown in Fig. 4. The legend for community level classification is given in Fig. 5. This community covers the maximum area (1,030 ha). Sparse and small patches of *Avicennia alba–Rhizophora mucronata*

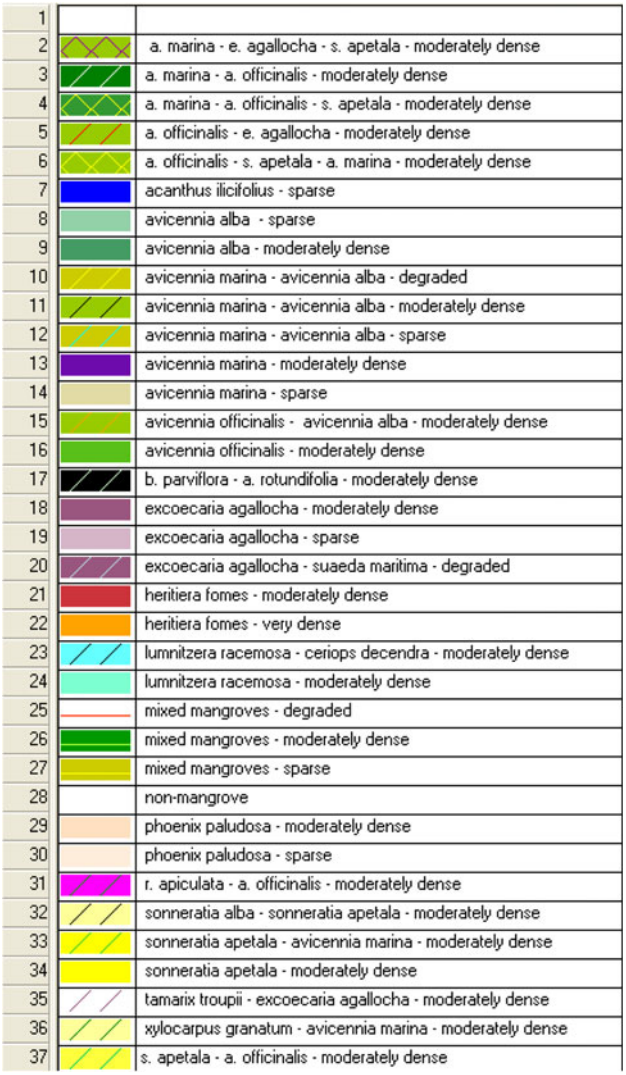

Fig. 5 Legend for mangrove community zonation of Figs. 4 and 8

community are present more towards the periphery of the islands and along the banks of the rivers like Mandovi, Zuari, Chapora and Terekhol. Total area of this class is 877.76 ha.

Avicennia officinalis–Excoecaria agallocha community covering a total area of 669.31 ha is also present as sparse patches along all the rivers but its occurrence is found more towards the landward side rather than on the banks. This community covers a significant area under mangrove forest in the Chorao sanctuary. An assemblage of mangrove species comprising mainly of *Aegiceras corniculatum*, *Ceriops decandra*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Kandelia candel*, *Derris heterophylla* is found along with the pure patches of mangrove communities mentioned above. Mixed mangroves (sparse and degraded) are mainly located in saline blanks and in elevated areas towards landward side and cover the least area (886.29 ha) (Table 2) among the five communities.

Table 3 Mangrove communities of Karnataka

Mangrove communities	Area (ha)
A. alba—degraded	50.07
A. Alba–A. Marina—Sparse	27.41
Mixed mangrove—degraded	61.35
Mixed mangrove—Sparse	283.68
Mixed mangrove—moderately dense	182.32
Total	604.83

Table 4 Mangrove communities of Kerala

Mangrove communities	Area (ha)
R. apiculata—moderately dense	97.92
K. candel–R. apiculata—moderately dense	4.67
R. apiculata—Sparse	43.03
E. agallocha–A. aureum—Sparse	20.28
Mixed mangroves—moderately dense	259.26
Mixed mangroves—Sparse	187.89
Mixed mangroves—degraded	26.90
Total	663.09

Karnataka

Coastal districts viz., Karwar, Honnavar, Kundapur, Mangalore houses luxuriant growth of mangroves. Karnataka has a mangrove cover of 604.83 ha comprising of five mangrove communities (Table 3). 'Mixed mangrove—Sparse' is found to be the most widely distributed community, covering an area of 283.68 ha. Mixed mangrove community, which are moderately dense and also degraded occupy 182.32 and 61.35 ha respectively. The lowest cover is observed for the *Sonneratia alba–Avicennia marina*—Sparse community (27.41 ha). *S. alba* degraded class covers an areas of 50.07 ha.

Kerala

Major mangrove harbouring areas in the state are in Valapattanam, Kunhimangalam, Kasargod–Nileshwar, Kavvayi and Puthuvypin and total area of mangrove is 663 ha. The community wise distribution of mangroves in Kerala is given in Table 4.

Tamil Nadu

Ecologically sensitive areas such as Pulicat bird sanctuary, Kaliveli backwaters, Pichavaram mangroves, Vedaranyam wildlife sanctuary, Muthupet mangroves, Ramanathapuram mangroves and Gulf of Mannar biosphere reserve are the important protected areas of Tamil Nadu coast. Mangroves

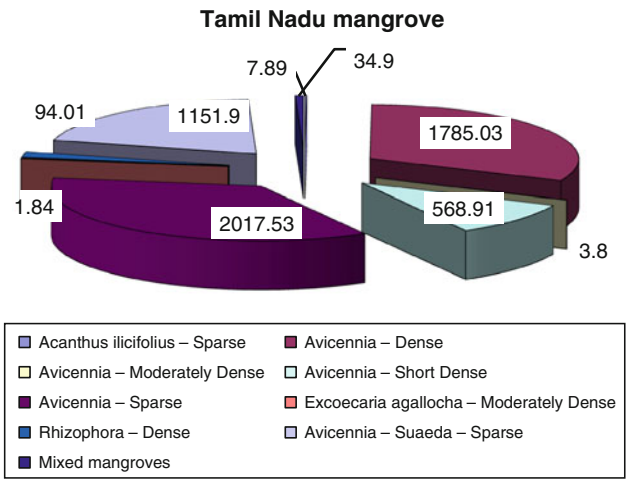

Fig. 6 Mangrove communities of Tamil Nadu

are the dominant feature of these ecosystems which stretches along the coast.

The major mangrove species found in the entire coast of Tamil Nadu is *Avicennia marina*. Other major species found are *Rhizophora*, *Excoecaria* and *Acanthus ilicifolius.* Apart from these two major mangrove distribution types, most of estuaries and backwater system along the coast have patches of mangroves. Total area under mangrove in the state is 5,565 ha. Areawise distribution of mangrove communities in Tamil Nadu is given in Fig. 6.

Andaman and Nicobar Islands

Andaman and Nicobar islands are the largest archipelago which comprises of more than 572 scattered islands, islets and rocky outcrops. The total coastline of the islands is 1,962 km, which accounts for 25 % of the country's coastline and encompasses 28 % of the total Exclusive Economic Zone. These islands harbour 34 true mangrove species belonging to 15 genera, 10 orders and 12 families [14].

Andaman Islands

The mangroves in Andaman are probably the best in India. Anchored in transition zones throughout the coasts, the total area under mangrove in Andaman is 56,658.22 ha (Table 5). The major mangrove species found here are *Scyphiphora hydrophyllacea*, *Cynometra iripa*, *Avicennia marina*, *A. officinalis*, *Excoecaria agallocha*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *B. parviflora*, *B. sexangula*, *Ceriops tagal*, *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Heritiera littoralis*, *Lumnitzera littorea*, *L. racemosa*, *Sonneratia alba*, *S. caseolaris*, *S. ovata*, *Aegiceras corniculatum*, *Xylocarpus granatum*, *Nypa fruticans* and *Phoenix paludosa*. This community of transition mangroves comprises of *Cerbera odollam*, *Scyphiphora*, *Cynometra*, *Intsia bijuga*, *Flagellaria indica*, *Fimdristylis*, *Excoecaria ebracteata*, etc.

Nicobar Islands

Degraded mangroves dominate in this island followed by dense *Rhizophora–Bruguiera*, *Avicennia–Excoecaria*, mixed dense, *Nypa* (dense) and fringe mangroves (Fig. 7). A total of 2,174.08 ha of mangroves were recorded in Nicobar (dense) and 190.7 ha of mixed mangroves. This degradation of mangroves are mainly due to the Tsunami waves in 2004.

Mangrove mapping was undertaken for Great Nicobar, Little Nicobar, Camorta, Katchal, Nancowry, Trinket, Tarasa, Tillanchong and Car Nicobar islands using IRS P6 LISS III data. Field data were collected from these islands except Little Nicobar, Tarasa and Tillanchong as these islands were inaccessible during, 2007 due to impacts of tsunami. Phytophysiological data on the mangroves of the Nicobar groups of islands are given in Fig. 7. Nicobar is classified into six mangrove communities.

Puducherry

District Yanam in Puducherry has patches of mangroves of the open category. The mangrove species found in this area are *Bruguiera cylindrica*, *Rhizophora apiculata*, *Avicennia marina* and *Acanthus ilicifolius*. Associate flora like *Suaeda maritima* and *Sesuvium portulacastrum* are also found. Puducherry and Karaikal districts have mainly patches of *Avicennia marina* from moderately dense to degraded condition, but at some places mangrove species like *Rhizophora apiculata*, *Excoecaria agallocha* and associates like *Thespesia populnea* are also present. In the Mahe river area, only some trees of *Rhizophora mucronata* is present.

Puducherry UT has a mangrove cover of 169.79 ha (Table 6) contributed by eight mangrove communities. *Avicennia marina* and *Avicennia officinalis* species are the prominent constituents of mangrove forests in Puducherry. Degraded mangroves represent the highest area of Puducherry. Moreover, 'Mixed mangroves—Degraded' is found to be the most widely distributed community accounting to about 123.31 ha. *Avicennia marina–Excoecaria agallocha*—Moderately dense (17.25 ha) ranks second in area statistics followed by *Avicennia marina*—Moderately dense (12.17 ha).

Andhra Pradesh

Andhra Pradesh has a total mangrove cover of 35,126 ha (Table 7) comprising of nine communities with varying crown densities. *Avicennia marina*—Moderately dense is

Table 5 Mangrove communities of Andaman

Mangrove communities	Area (ha)
Avicennia–Excoecaria—dense	169.93
Avicennia—Sparse	783.15
Bruguiera—dense	218.38
Bruguiera–Rhizophora—dense	1,609.18
Ceriops–Excoecaria—Sparse	283.58
Fringe mangroves	6,257.83
Mangroves—degraded	1,903.28
Mangroves—Sparse	2,080.98
Mangroves—Sparse	3,048.62
Mixed mangroves—moderately dense	959.04
Mixed mangroves (*Avicennia–Bruguiera–Ceriops–Lumnitzera*)—dense	105.95
Mixed mangroves (*Ceriops–Avicennia–Excoecaria*)—dense	699.95
Mixed mangroves (*Phoenix–Avicennia–Excoecaria*)—dense	215.94
Mixed mangroves (*Rhizophora–Bruguiera–Ceriops*)—dense	640.63
Mixed mangroves (*Xylocarpus–Phoenix–Heritiera*)—dense	87.96
Mud-flat with sparse mangroves	102.27
Nypa—dense	189.99
Phoenix–Xylocarpus—dense	594.26
Phoenix–Acrostichum—sparse	1,009.03
Phoenix–Avicennia—dense	1,942.44
Rhizophora–Avicennia—dense	927.29
Rhizophora–Bruguiera—degraded	82.93
Rhizophora–Bruguiera—dense	5,550.06
Rhizophora–Ceriops—dense	267.67
Rhizophora—dense	9,773.22
Rhizophora—moderately dense	2,536.99
Rhizophora—Sparse	12,318.98
Rhizophora–Xylocarpus—Sparse	564.54
Transition mangroves	93.82
Xylocarpus—dense	1,523.61
Xylocarpus–Heritiera—dense	116.72
Total	56,658.22

found to be the most widely distributed mangrove class constituting about 8,260.93 ha. Mangrove community zonation map for Coringa Sanctuary Andhra Pradesh is given in Fig. 8. The classification legend is given in Fig. 5. Krishna Sanctuary, south eastern part of Coringa Sanctuary (Fig. 8) and Nizampatnam of Guntur district has vast expanse of pure *Avicennia marina*. Mixed mangroves—Sparse ranks second with an area of 8,055.68 ha. It is characterized by an assemblage of mangroves forming a community and is found as patches or fringe mangroves along the rivers. Moderately lush mangrove cover of

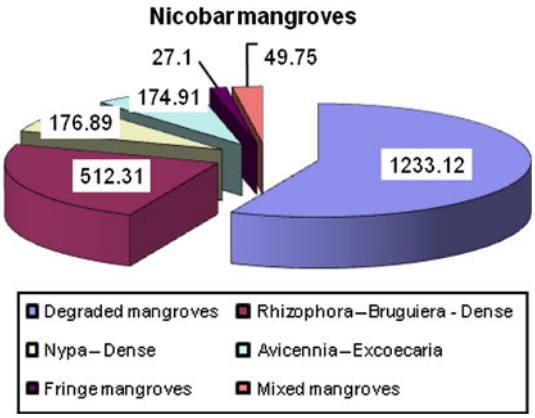

Fig. 7 Mangrove communities of Nicobar

Table 6 Mangrove communities of Puducherry

Mangrove communities	Area (ha)
Mixed mangroves—degraded	123.31
Mixed mangroves—Sparse	3.80
Mixed mangroves—moderately dense	1.28
A. marina—Sparse	1.67
A. marina—moderately dense	12.17
A. officinalis—moderately dense	9.24
E. agallocha—moderately dense	1.07
A. marina–E. agallocha—moderately dense	17.25
Total	169.79

Andhra Pradesh is mainly comprised of four communities: (a) pure patches of *Avicennia* species viz., *A. marina, A. officinalis* and *A. alba*, (b) enmesh of well grown *Excoecaria agallocha* forming almost closed canopies, (c) *Avicennia marina* along with under cover of *Excoecaria agallocha* and (d) 'mixed mangrove' community comprising of three or more mangrove species like *Sonneratia apetala*, *Rhizophora* sp., *Avicennia* sp., *Ceriops decandra*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Lumnitzera racemosa*, etc.

A total area of 4,767 ha is recorded as 'degraded' based on the canopy cover density of less than 10 %, of which 4,726 ha is 'mixed mangroves' comprising mainly of widely spaced true mangroves like *Excoecaria agallocha*, *Avicennia marina* along with associates like *Acanthus ilicifolius*, *Clerodendrum inerme*, *Ipomoea pes-caprae* or marsh vegetation like *Suaeda* sp., *Salicornia* sp. etc. The remaining 42 ha comprises of *Avicennia marina* patches mainly in the early stages of growth. The regeneration of mangrove patches can be considered as a positive trend in perceiving the well being of mangrove vegetation for the years to come.

Table 7 Mangrove communities of Andhra Pradesh

Mangrove communities	Area (ha)
Mixed mangroves—degraded	4,726.27
Mixed mangroves—Sparse	8,055.68
Mixed mangroves—moderately dense	1,798.11
A. marina–E. agallocha—moderately dense	6,475.15
A. officinalis—moderately dense	3,316.72
E. agallocha—moderately dense	1,067.70
A. marina—moderately dense	8,260.93
A. alba—moderately dense	100.09
A. marina—Sparse	745.80
A. marina–A. officinalis—Sparse	170.54
Acanthus ilicifolius—Sparse	66.15
Rhizophora mucronata—Sparse	165.02
A. marina—degraded	41.79
A. officinalis—Sparse	93.86
A. marina–E. agallocha—Sparse	42.85
Total	35,126.66

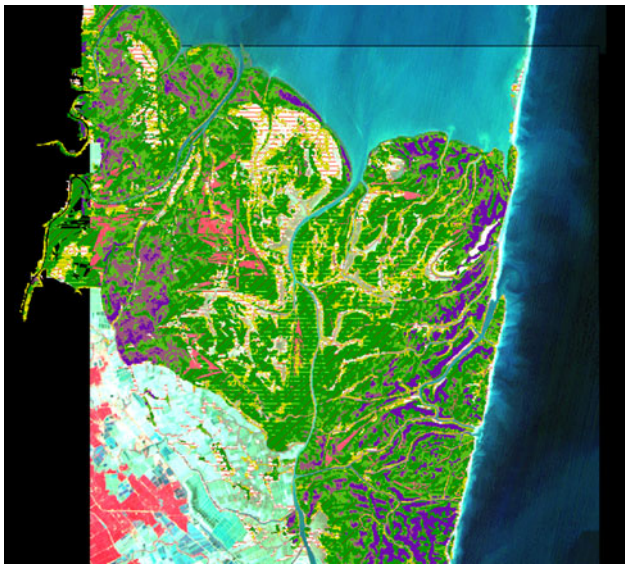

Fig. 8 Mangrove communities map of Coringa sanctuary, Andhra Pradesh

Table 8 Mangrove communities of Orissa

Mangrove communities	Area (ha)
A. officinalis—moderately dense	1.47
A. marina—moderately dense	3,144.21
A. marina—Sparse	635.77
A. alba—moderately dense	1,045.21
A. alba—Sparse	7.66
H. fomes—moderately dense	548.52
E. agallocha—moderately dense	13.42
E. agallocha—Sparse	78.91
P. paludosa—moderately dense	1,300.85
P. paludosa—Sparse	54.70
S. apetala—moderately dense	104.60
L. racemosa—moderately dense	5.01
A. ilicifolius—Sparse	140.98
A. marina–A. alba—moderately dense	417.93
A. marina–A. alba—Sparse	797.67
A. marina–A. alba—degraded	262.47
A. marina–A. officinalis—moderately dense	472.09
A. officinalis–A. alba—moderately dense	85.13
A. officinalis–E. agallocha—moderately dense	64.82
S. apetala–A. marina—moderately dense	436.36
S. apetala–A. officinalis—moderately dense	42.46
S. alba–S. apetala—moderately dense	92.13
L. racemosa–C. decendra—moderately dense	559.80
T. troupii–E. agallocha—moderately dense	780.61
R. apiculata–A. officinalis—moderately dense	1,103.49
B. parviflora–A. rotundifolia—moderately dense	99.24
X. granatum–A. marina—moderately dense	168.85
E. agallocha–S. maritima—degraded	532.32
A. marina–A. officinalis–S. apetala—moderately dense	2,119.65
A. officinalis–S. apetala–A. marina—moderately dense	225.30
A. marina–E. agallocha–S. apetala—moderately dense	37.05
Mixed mangroves—moderately dense	4,288.20
Mixed mangroves—Sparse	879.05
Mixed mangroves—degraded	663.84
H. fomes—very dense	896.90
Total	22,106.67

Orissa

Mangroves of the Orissa Coast is mainly tide dominated. Dominant features are high tidal range with strong bi-directional current, main river channels are funnel shaped with extensive tidal flats dominated by mangroves. The most luxuriant mangroves of Orissa are found in Bhitarkanika located between the latitude 20°04′N and 20°08′N and longitude between 86°45′E and 87°30′E.

As per the present study, Orissa has a mangrove cover of 22,106.67 ha comprising of 36 mangrove plant community classes (Table 8). 'Mixed mangrove—Moderately dense' is found to be the most widely distributed community accounting to about 4,288.20 ha. *Avicennia marina*—Moderately dense ranks second in area (3,144.21 ha) as pure patches of this species cover vast areas along the coast in Bhadrak and Baleshwar district, majority of mangrove cover in Udabali island and most of the parts in Mahanadi Mangrove Wetland. A total area of 1,458.62 ha is recorded as 'degraded' based on the canopy cover density (less than 10 %) of which 663.84 ha is contributed by 'mixed mangroves' and the rest is accounted by *Excoecaria agallocha–Suaeda maritima* (532.32 ha) and *Avicennia marina–*

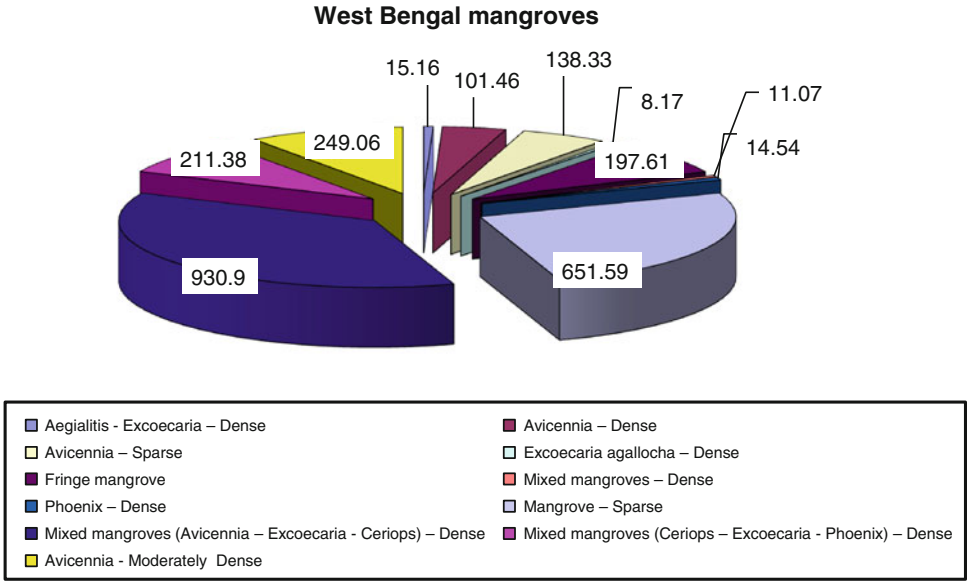

Fig. 9 Mangrove communities of West Bengal

Avicennia alba patches (262.46 ha) which are mainly in the early stages of growth (Table 8).

West Bengal

Sundarbans is considered to be one of the world's largest blocks of mangrove vegetation and lies in the delta of two rivers, the Ganges and the Brahmaputra of the Indian subcontinent. It spreads over the two southern districts of West Bengal, South 24 Parganas and North 24 Parganas. About 6,000 km^2 of mangrove forest is also present in Bangladesh spreading over two districts namely Khulna and Backharganj. The rivers Raimangal and Hooghly on the east and west, respectively, demarcate the boundary of the Indian Sundarbans.

Community wise area distribution of mangrove is given Fig. 9. Total mangrove area in west Bengal is 252,927 ha. In the present study 37 true mangrove and 32 mangrove associate species have been recorded. The category of fringe mangroves in the Sundarban is largely covered by *Avicennia* community especially *A. alba*, which constitutes 60 % of the total class and rest 40 % of this category is occupied by *Phoenix*, *Ceriops* specially where erosion is pronounced. In few places different varieties of *Sonneratia*, *Rhizophora* and *Bruguiera* genus have also been observed at the field, but it is hardly possible to map these species as separate entity in this scale. West Bengal Sundarban is classified into eleven classes of mangrove communities.

State wise distribution of mangrove forest based on the analysis of IRS data of 2005–2007 is summarized in Table 9. For comparison, the mangrove area from the mapping based on 1990–1993 satellite data, carried out by Space Applications Centre, is also given in the table. There is an overall increase in the mangrove area of the country by 51,510 ha during the above mentioned period. This may also be due to better spatial and spectral resolution of the

Table 9 State wise area statistics of mangroves in India during 1990–1993 & 2006–2007

State/Union territory	1990–1993 (Area in ha)	2005–2007 (Area in ha)	Dominating communities
Gujarat	101,460	89,069	*Avicennia* (+4)
Maharashtra	22,260	27,092	*Avicennia* (+2)
Goa	670	3,463	*Avicennia* (+3)
Karnataka	870	605	Mixed (+2)
Kerala	1,000	663	Mixed (+4)
Tamil Nadu (TN) including Puducherry (P)	2,360	5,735 (5,565 TN, 170 P)	*Avicennia* (+4)
Andhra Pradesh	38,000	35,127	*Avicennia* (+3)
Orissa	18,700	22,107	*Avicennia* (+10)
West Bengal	183,800	252,927	*Avicennia* (+5)
Andaman	67,900	56,658	*Rhizophora* (+17)
Nicobar	7,090	2,174	*Rhizophora–Bruguiera* (+2)
Total	444,110	495,620	

present LISS III/IV data, which has helped in better delineation of the mangrove coverage this time. There has been considerable decrease in mangrove vegetations of Gujarat, Karnataka, Kerala, Andhra Pradesh and Andaman and Nicobar islands (from 1990 to 1993). Significant increase in the mangrove area has been noticed for the states of Maharashtra, Goa, Tamil Nadu, Orissa and West Bengal.

Conclusions

Resourcesat-1 LISS III data of 2005–2007 timeframe has been used to map mangroves at community level on 1:25,000 scale for the entire country. This is for the first time that the mangrove inventory at community level has been made for the entire country. A hybrid classification system involving both geomorphological as well as ecological characteristics of the habitat has been used in this inventory. Total area under mangrove in the country using satellite data of 2005–2007 timeframe is 495,620 ha which is increased by 51,510 ha from the previous inventory of 444,110 ha (based on 1990–1993 satellite data). The overall accuracy of the mangrove map has been found to be 91 %. The most dominant mangrove community in most of the states of India is *Avicennia*. *Rhizophora* is the other dominant community found in Andaman and Nicobar islands. West Bengal has the highest area (252,927 ha) under mangrove. Gujarat has the second highest area under mangrove (89,069 ha). There has been substantial increase in the area under mangrove in the states of Goa, Maharashtra and Tamil Nadu.

Acknowledgments Authors are thankful to Dr. R. R. Navalgund, Director and Shri. A. S. Kiran Kumar, Associate Director, Space Applications Centre for their interest in the present work. Authors are also thankful to their scientist colleagues for providing all possible help in carrying out this study. Efforts made by Ms. Shweta Sharma in preparation of the manuscript are thankfully acknowledged.

References

1. Mark S, Blasco F, Colin F (eds) (1997) World mangrove atlas. Smith Settle, Otley, p 178
2. FAO forestry paper 153 (2007) The world's mangroves 1980–2005: a thematic study prepared in the framework of the global forest resources assessment 2005. FAO, Rome, p 77
3. Finlayson M, Moser M (eds) (1991) Wetlands: facts on file. Oxford, London, p 224
4. Aksornkoae S, Maxwell GS, Havanond S, Panichsuko S (1992) Plants in mangroves. Chalongrat Co. Ltd, Bangkok
5. Tomlinson PB (1986) The botany of mangroves. Cambridge University Press, New York
6. Ahmad E (1972) Coastal geomorphology of India. Orient Longman, New Delhi
7. Jagtap TG, Untawale AG, Inamdar SN (1994) Study of mangrove environment of Maharashtra coast using remote sensing data. Indian J Mar Sci 23:90–93
8. State of Forest Report (2001) Forest survey of India. Ministry of Environment and Forests, Dehradun
9. Nayak SR, Bahuguna A (2001) Application of remote sensing data to monitor mangroves and other coastal vegetation of India. Indian J Mar Sci 30(40):195–213
10. Bahuguna A, Nayak S (1996) Mangrove community discrimination using IRS-1C data. In: Proceedings of the national symposium on remote sensing for natural resources with special emphasis to water management, Pune, India, pp 311–319
11. Blasco F, Gauquelin T, Rasolofoharinoro MT, Denis J, Aizpuru M, Calderou V (1998) Recent advances in mangrove studies using remote sensing data. Aust J Mar Fresh Water Res 49(4):287–296
12. Groom GB, Fuller RM, Jones AR (1996) Contextual correction: techniques for improving land cover mapping from remotely sensed images. Int J Remote Sensing 17(1):69–81
13. Mumby PJ, Clark CD, Green EP, Edwards AJ (1998) Benefits of water column corrections and contextual editing for mapping coral reefs. Int J Remote Sensing 19(1):203–210
14. Dam Roy S, Krishnan P, George G, Kaliyamoorthy, Gautam Bharati MP (2009) Mangroves of Andaman and Nicobar islands. Central Agricultural Research Institute, Andaman and Nicobar islands, p 65