Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data

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The impact of restoration of the degraded areas of Pichavaram mangrove wetland was analysed by comparing TM digital data of 1986 (before restoration) and LISS III digital data of 2002 (after restoration). The analysis indicates that the area of the mangrove forest cover has increased by about 90%. A science-based, community-centred and process-oriented approach followed for the restoration of the Pichavaram mangrove wetland in collaboration with the Forest Department, Government of Tamil Nadu and participation of local mangrove user-communities is mainly responsible for success of the effort. This study indicates that remote sensing data can be used as a monitoring tool to assess the effectiveness of restoration and conservation programmes of the mangrove wetland, where direct and regular physical monitoring is difficult due to marshy nature of the soil and presence of numerous tidal creeks and canals.

MANGROVE wetland is a multiple-use ecosystem, covering 8% of the world's coast and 25% of the tropical coastline[1]. It performs a number of protective and productive functions. It acts as a barrier against cyclonic storms and avoids coastal erosion. It provides nursery grounds for a number of commercially important species of fish, prawn and crab. It is a habitat for a number of large wildlife and a reservoir of biodiversity for smaller organisms. Recently, mangrove flora has been identified as donor of salt-tolerant genes that can be utilized for the development of salinity-resistant crop varieties through recombinant DNA technology[2]. However, till early 1980s, mangrove wetlands were considered as wasteland both by the policy makers and planners throughout the world, which resulted in large-scale degradation due to over exploitation and conversion of mangrove wetlands for other purposes. The mangrove wetlands of India are also no exception to this uncontrolled exploitation. Under such circumstances, M. S. Swaminathan Research Foundation (MSSRF), Chennai launched a major programme in 1996 on the restoration of the mangrove wetlands of the east coast of India, in collaboration with the Ministry of Environment and Forests and State Forest Departments of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. Work carried out by us in the Pichavaram mangrove wetland, located on the southeast coast of India in Tamil Nadu, on restoration and community-participation since 1992, provided necessary information and replicable models for launching a major mangrove restoration and conservation programme. The objective of this communication is to examine the effectiveness of the community-based restoration programme implemented in the Pichavaram mangrove wetland with reference to increase in mangrove forest cover using remote sensing technique as a monitoring tool.

The study area, Pichavaram mangrove wetland (lat 11°22′N to 11°30′N and long 79°45′E to 79°52′E), is located in the northernmost end of the Cauvery delta. The total area of this mangrove wetland is about 1470 ha, consisting of about 50 small islands which are colonized by mangrove vegetation. The climate is sub-humid with very warm summer (< 30°C). The annual average rainfall (70 years) is 1310 mm and annual average number of rainy days is 56. Most of the rainfall occurs during the northeast monsoon season (October to December) and nearly 70% of the rainfall occurs between November and December. The tide is micro and diurnal, and amplitude during the spring and the neap tide is about 42 and 20 cm, respectively. Recent survey indicates the presence of a total number of 13 mangrove species in the Pichavaram mangrove wetlands[3,4]. The community-structure studies show that *Avicennia marina* (Forsk.) Vierh is monospecifically dominant. Other species are represented by limited number of individuals. Regarding distribution pattern of the flora, two distinct zones, namely Rhizophora zone and Avicennia zone are identified. The Rhizophora zone is found along the fringes of the tidal creeks and channels and is about 5 to 12 m in breadth. Distribution of 11 species is restricted to this narrow zone. Avicennia zone starts just behind the Rhizophora zone and *A. marina* forms pure stands in this zone[3]. According to Chandrasekaran and Natarajan[5], a total quantity of 245 tons of fish, prawn and crab is harvested annually from the Pichavaram mangrove wetland, which gives livelihood security to about 3000 traditional poor fishers living in 14 hamlets.

The following materials were used for the present study: Landsat 5 TM digital data of 23 May 1986 and IRS 1D LISS III digital data of 27 June 2002, and Survey of India toposheet No. 58 M/15. As the digital data did not have any real earth co-ordinates, both data were geometrically corrected using ground control points such as road–road intersection, road–rail intersection, canal–road intersection, etc. taken from the toposheet using ERDAS IMAGINE 8.4 image-processing package. Since the present study is restricted only to the Pichavaram reserve forest, reserve forest boundaries were traced from the toposheet, digitized and transformed to the coordinates of TM and LISS III digital data using ARC/INFO 3.5-GIS package. The remote sensing data inside the reserve forest were extracted for the present analysis. Following the transfer of reserve forest boundaries, False Colour Com-

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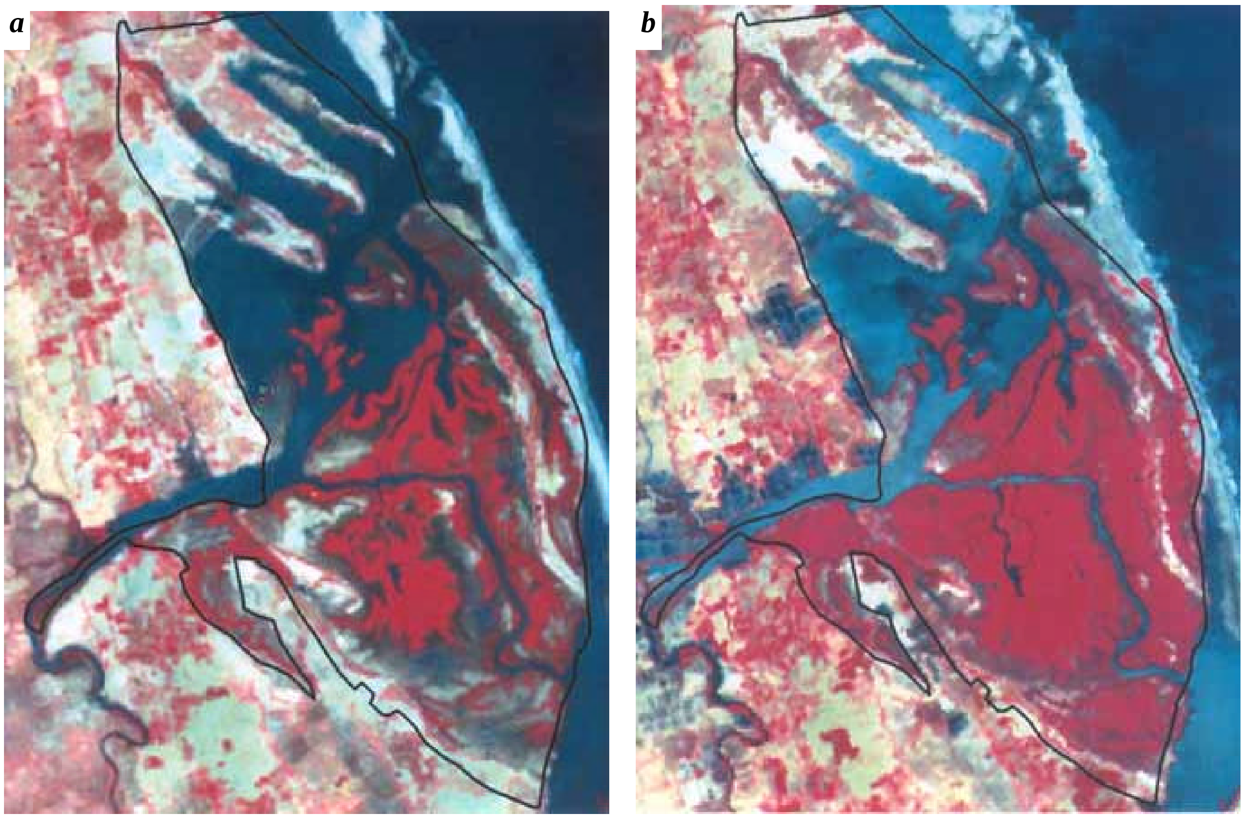

Figure 1. False Colour Composite image of Pichavaram mangrove wetland: ***a***, Landsat 5 TM of 1986, and ***b***, IRS 1D LISS III of 2002. Black line indicates reserve forest boundary and red to pinkish-red indicates healthy mangroves.

posite print of the Pichavaram mangrove wetland was generated with the band combinations of 5, 4, 3 and 3, 2, 1 in Red Green Blue in TM and LISS III data, respectively (Figure 1 *a* and *b*). The displayed image with the above classes was spectrally enhanced by histogram equalization method[6].

Mangrove wetland maps of 1986 and 2002 were then prepared by on-screen visual interpretation method using ERDAS IMAGINE 8.4. Different classes of mangrove wetland such as dense mangroves, degraded mangroves, young mangrove stands, barren sand dune associated with mangrove wetlands, vegetation associated with sand dunes, water body and dry land were then identified using visual interpretation keys such as colour, tone, texture, pattern, size and shape. Mangrove wetland map with the above classes was then transferred to base map of 1 : 50,000 scale, which was used for ground-truth collection.

Ground-truth data were collected in 60 check points which were randomly selected and distributed all over the mangrove wetland. The number of check points and their location for ground-truth were decided based on the visual separability between classes. More number of degraded areas was verified since in some places these degraded areas appeared similar to young mangrove plantations. Since sandy area and sand dune vegetation are distinctly interpretable from other classes of the wetland, these were not checked in the ground. During ground-truth data collection, it was observed that young mangrove plantation could be classified into two types, namely (i) young mangroves plantation more than three years old and (ii) young mangrove plantations less than three years old. The age of these plantations was derived from the records of the Tamil Nadu Forest Department and village mangrove councils that undertook restoration along with the Forest Department and MSSRF. In accuracy assessment, the overall accuracy has reduced to 82% due to the introduction of the new class, i.e. young mangrove less than three years old, after ground-truth collection. The geographic coordinates of these points were noted from the classified digital image and checked in the field with Megellan GPS 2000 XL. Data collected from the checkpoints were used for accuracy assessment following the method described by Congalton[7]. The confusion matrix for accuracy of different classes identified through visual interpretation is given in Table 1. The overall accuracy of the mapping is 82%. Based on the ground-truth data, maps of 1986 and 2002 were corrected and finalized. The two finalized maps were overlaid in ARC INFO (3.5) GIS package by UNION command to

Table 1. Confusion matrix for accuracy assessment of different classes identified through visual interpretation

Class	Dense mangrove	Young mangrove 1*	Young mangrove 2**	Degraded mangrove	Other vegetation	Total
Dense mangrove	18 (100%)	0	0	0	0	18
Young mangrove 1*	0	15 (100%)	0	0	0	15
Young mangrove 2**	0	0	0 (0%)	11	0	11
Degraded mangrove	0	0	0	8 (42%)	0	8
Other vegetation	0	0	0	0	8 (100%)	8
Total	18	15	0	19	8	60

*Above three-year-old plantation; **Below three-year-old plantation.
Values in parentheses indicate accuracy level of individual classes; overall accuracy 82%.

Table 2. Changes in wetland classes in Pichavaram mangrove before and after restoration

Class	Area in 1986 (ha)	Area in 2002 (ha)	Change (ha)
Dense mangroves	325	411	+86
Young mangroves more than three years old	0	117	+117
Young mangroves less than three years old	0	90	+90
Degraded areas	375	65	–310
Sand dune	83	54	–29
Sand dune vegetation	24	47	+23
Upland (not suitable for mangrove plantation)	287	280	–7
Water-spread	380	408	+28

find the area of newly formed mangroves and other classes between 1986 and 2002.

The changes that occurred in different classes of mangrove wetland of the Pichavaram between the years 1986 and 2002 are shown in Figure 2 *a* and *b*, and Table 2. Compared to 1986, the mangrove forest cover in 2002 has increased by 293 ha (90% increase). Out of this, 86 ha can be classified as dense mangrove forest whose canopy cover is more than 40%, which is normally attained in about seven-year-old trees. Young mangrove stands in the restored area can be classified into two types, above three-year-old plantation and below three-year-old plantation, which together occupy an area of about 200 ha. In mangrove plantation which is below three years old, canopy is less and as a result it was first classified as mudflat during visual interpretation and corrected after ground-truth verification as young mangroves of less than three years old, as indicated in the confusion matrix given in Table 1. This is one of the reasons for the decrease in overall accuracy assessment to 82%. The results also show that the vegetation associated with the sand dune has increased by 23 ha (95% increase). This is mainly due to casuarina plantation undertaken in the sand dune. An increase of 28 ha has also been noticed in the water-spread area. Consequent to restoration, degraded area has reduced from 375 ha in 1986 to 65 ha in 2002.

The above results indicate that most of the degraded areas of the Pichavaram mangrove wetland have now been restored. Identification of the real causes of degradation, development and demonstration of restoration techniques and extension of the restoration activities in collaboration with the Tamil Nadu Forest Department and participation of the local user-communities are the main reasons for the success of the present efforts to restore the Pichavaram mangrove wetland. Before the present intervention, social factors such as illegal felling by local people and grazing by cattle were considered as the main causes of degradation[8–10]. But ecological studies carried out by MSSRF in collaboration with the Tamil Nadu Forest Department and in consultation with the local community indicated that changes in the biophysical condition of the Pichavaram mangrove wetland due to the past unscientific management practices followed from 1935 to 1975, were mainly responsible for the degradation[2].

From 1935 to 1975, about 500 ha of matured mangrove forest of the Pichavaram wetland was clear-felled by the government management agencies for revenue generation, with a belief that mangrove plants would regenerate naturally in the clear-felled areas[11,12]. Since nearly 80% of the mangrove soil volume is made up of water[13], clear-felling and subsequent exposure of the mangrove wetland caused evaporation of soil water, which in turn caused subsidence of sediment in the clear-felled areas. Subsidence of sediments in exposed area is a common feature of the mangrove wetlands[14,15]. Due to subsidence, topography in the clear-felled areas has become trough-shaped and tidal water entering into this trough-shaped portion becomes stagnant. Evaporation of stagnant tidal water increased both the soil and groundwater salinity to a level which is lethal to mangrove species. Thus, it was found that development of trough-shaped topography due to clear-felling and subsequent increase in salinity are the

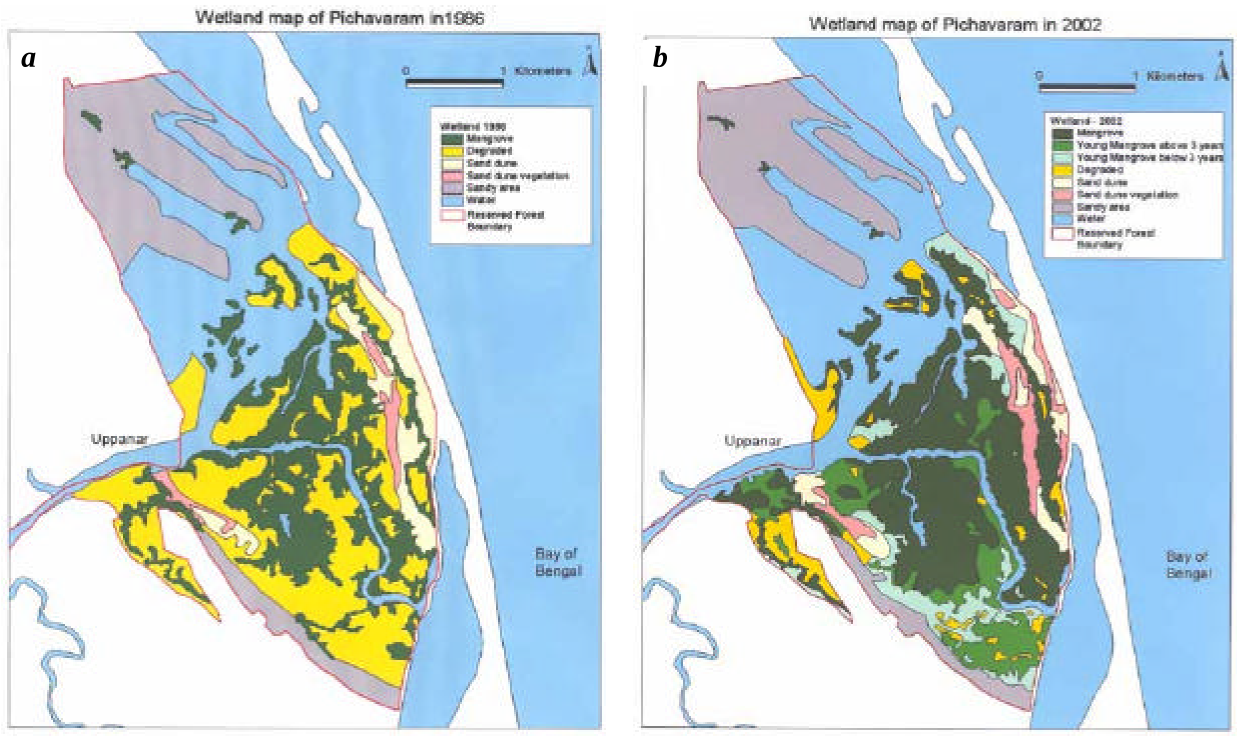

Figure 2. Classified map of Pichavaram mangrove wetland: (***a***) 1986 and (***b***) 2002 showing increase in area of dense and young mangrove forests in 2002 due to restoration.

main causes of degradation of the Pichavaram mangrove wetland. Details of the above study are provided in ref. 2.

On the basis of the above observation, it was hypothesized that degraded areas of the Pichavaram mangrove wetland could be restored easily, if facilities are provided for free flow of tidal water in and out of the degraded areas. This hypothesis was tested in about-10 ha degraded plot with the participation of the Tamil Nadu Forest Department and the local community. In this demonstration plot, a main canal was dug in the middle portion of the degraded areas from which a large number of feeder canals were dug, covering the entire degraded area. Then the main canal was connected to the nearby natural canals. This artificial canal system facilitated free flow of tidal water, which gradually decreased the soil and groundwater salinity and increased the soil moisture, making the degraded areas suitable for mangrove growth. As a result, mangrove species planted in the demonstration site showed more than 80% survival, and growth was comparable to seedlings planted in the non-degraded areas[2]. Following the success of this demonstration, a community-based joint mangrove management system was introduced in the Pichavaram mangrove wetland, by which all other degraded areas have been restored following the canal method outlined above. A large number of canals dug in the degraded areas for free flow of tidal water could be one of the reasons for 17.4% increase in the water-spread area observed in 2002 (Table 2). In the joint mangrove management system, the local community plays a dominant role in sustaining these restoration efforts by desilting the artificial canals dug in the resorted areas wherever needed and protecting young plantations against grazing, if any. Thus, a science-based, community-centred and process-oriented approach followed is mainly responsible for the restoration of the Pichavaram mangrove wetland.

It is well-known that mangrove wetlands are marshy in nature and intersected by a number of tidal creeks, channels and large canals. This makes regular and direct monitoring of the mangrove conservation and restoration activities difficult. Secondly, getting a synoptic view of the status of the resorted areas and a comparative study of the past condition of the mangrove wetland with the status after restoration are primary requirements to convince managers, decision makers and planners for further extension of restoration activities. As indicated in the present study, these problems can be overcome by using remote sensing as a monitoring tool for mangrove wetland conservation and restoration programmes.

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Intraspecific variation in the internal transcribed spacer region of rDNA in black gram (*Vigna mungo* (L.) Hepper)

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rDNA internal transcribed spacer (ITS) region from *V. mungo* var *silvestris, Vigna trilobata, Vigna glabrescens* and diverse cultivars of *Vigna mungo*, were amplified and digested with twelve restriction enzymes. There was no size variation in the ITS region of the diverse cultivars and other *Vigna* species studied. The approximate length of the amplified product of the entire rDNA ITS region was found to be 650 bp. ITS1 consisted of 250 bp and ITS2 was 300 bp long. Restriction fragment length polymorphisms within species could not be detected in cultivated accessions of *V. mungo* for all the restriction enzymes tested whereas interspecific variation was found among *V. mungo* var *silvestris, V. trilobata* and *V. glabrescens*. Of the eleven restriction enzymes (*Eco*RI, *Hin*dIII, *Pst*I, *Sma*I, *Sau*3AI, *Taq*I, *Sac*I, *Msp*I, *Alu*I, *Bam*HI and *Hae*III) tested, seven endonucleases (*Sau*3AI, *Taq*I, *Sac*I, *Msp*I, *Alu*I, *Bam*HI and *Hae*III) had restriction site in the ITS region, of which five were in ITS1 and two in ITS2 of cultivated species. Presence of *Bam*HI restriction site which is unique to *Vigna* was not found to be methylated. The ITS2 of *V. glabrescens* and *V. trilobata* had restriction sites for *Sau* 3AI and *Alu*I, which are not found in *V. mungo* var *silvestris* and the cultivated varieties studied. *Msp*I enzyme had restriction site specifically present in ITS2 of *V. trilobata*. No intraspecific variation was observed among widely distributed Indian cultivars of *V. mungo* and *V. mungo* var *silvestris*.

BLACK gram belongs to the subgenus *Ceratotropis* of the genus *Vigna*. The genus *Vigna* comprises eight subgenera and seven cultivated species, two of which are of African origin (subgenus *Vigna*) and five are Asiatic (subgenus *Ceratotropis*). The African group consists of cowpea (*V. unguiculata* (L.) Walp) and Bambara groundnut (*V. subterranea* (L.) Verdc.). The Asiatic group comprises green gram/mung bean (*V. radiata* (L.) Wilczek), black gram/urdbean (*V. mungo* (L.) Hepper), moth bean (*V. aconitifolia* (Jacq.) Marechal), adzuki bean (*V. angularis* (Willd)) and rice bean (*V. umbellata* (Thunb)). Black gram is considered to have been domesticated in India from its wild ancestral form *V. mungo* var *silvestris*[1]. Recognition and exploitations of variations among genetically divergent groups of germplasm are fundamental in breeding and genetic engineering. Seed proteins have been used to find homology among the *Vigna* species from Asian and African origin[2]. Intra and interspecific variations were studied in genus *Vigna* by RFLP[3] and in subgenus *Certatropis* by RAPD[4]. Inter simple sequence repeat DNA polymorphism was used to distinguish taxa within the genus *Vigna*[5].

Internal transcribed spacers are sequences located in eukaryotic rRNA genes between the 18S and 5.8S rRNA coding regions (ITS1) and between the 5.8S and 25S rRNA coding regions (ITS2). Studies of restriction site variation in the ribosomal DNA (rDNA) in populations of animals and plants have shown that while coding regions are conserved, the spacer regions are variable[6]. These spacer sequences have a high evolution rate and are present in all known nuclear rRNA genes of eukaryotes[7,8]. They are useful for phylogenetic analysis among related species and/or among populations within a species[9].

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