



Estimation of the Aerial Cover of Seagrasses of Lakshadweep Islands (India) Using Indian Remote Sensing Satellite (IRS P6 LISS IV)

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Abstract Seagrasses ecosystems are fragile yet highly productive ecosystems of the world showing declining trend throughout the world due to natural and anthropogenic pressures. Effective conservation and management plan is thus required to protect these resources, to aid with conservation need mapping and monitoring of seagrasses using high resolution remote sensing data is very much required. Hence, the present study was made to record the seagrass aerial cover in the Lakshadweep islands using IRS P6 LISS IV satellite data. The suitability of LISS IV sensor for seagrass mapping was tested for the first time with an overall accuracy of 73.16%. The study found an area of 2590.2 ha of seagrasses in Lakshadweep islands with 1310.8 ha and 1279.4 ha dense and sparse seagrass cover respectively. The study recommends the use of LISS IV data for mapping the shallow water seagrasses, as mapping efficiency increases nearly 4 times more than the LISS III data, as the former (LISS IV) picks up the small patches of seagrasses and delineates the coral and reef vegetation patches from seagrass class.

Keywords Remote sensing · IRS P6 LISS IV · Spatial resolution · Seagrass · Lagoon · Lakshadweep

Introduction

Seagrasses represent one of the important and highly productive ecosystems of the world, which supports a variety of life forms ranging from microbes to marine mammals like dugongs (Thangaradjou et al. 2008). Seagrass habitats have valuable roles as they function as nursery grounds and repositories of natural resources, in addition to giving biodiversity and coastal protection (Waycott et al. 2005). This ecosystem is facing severe threats from natural and anthropogenic stresses all over the world and considerable decrease in the seagrass areas has also been reported (Waycott et al. 2009). Effective management plan is therefore required to conserve these ecosystems and the major part of the management would be the appropriate monitoring of seagrass biophysical characters, species composition, seagrass area cover and biomass (Armstrong 1993; Short et al. 2001; Larkum et al. 2006).

Remote sensing and GIS techniques have been widely used in mapping and monitoring the coral reefs and mangroves but only little importance has been given for assessing the equally important seagrass resources, though higher resolution data products are now available to delineate seagrasses from coral reefs (Thangaradjou et al. 2008). Though, a wide range of methods can be used to map the seagrasses (Kirkman 1996; McKenzie et al. 2003), selection of tools for the study depends on the areas under observation, depth limit of the seagrass

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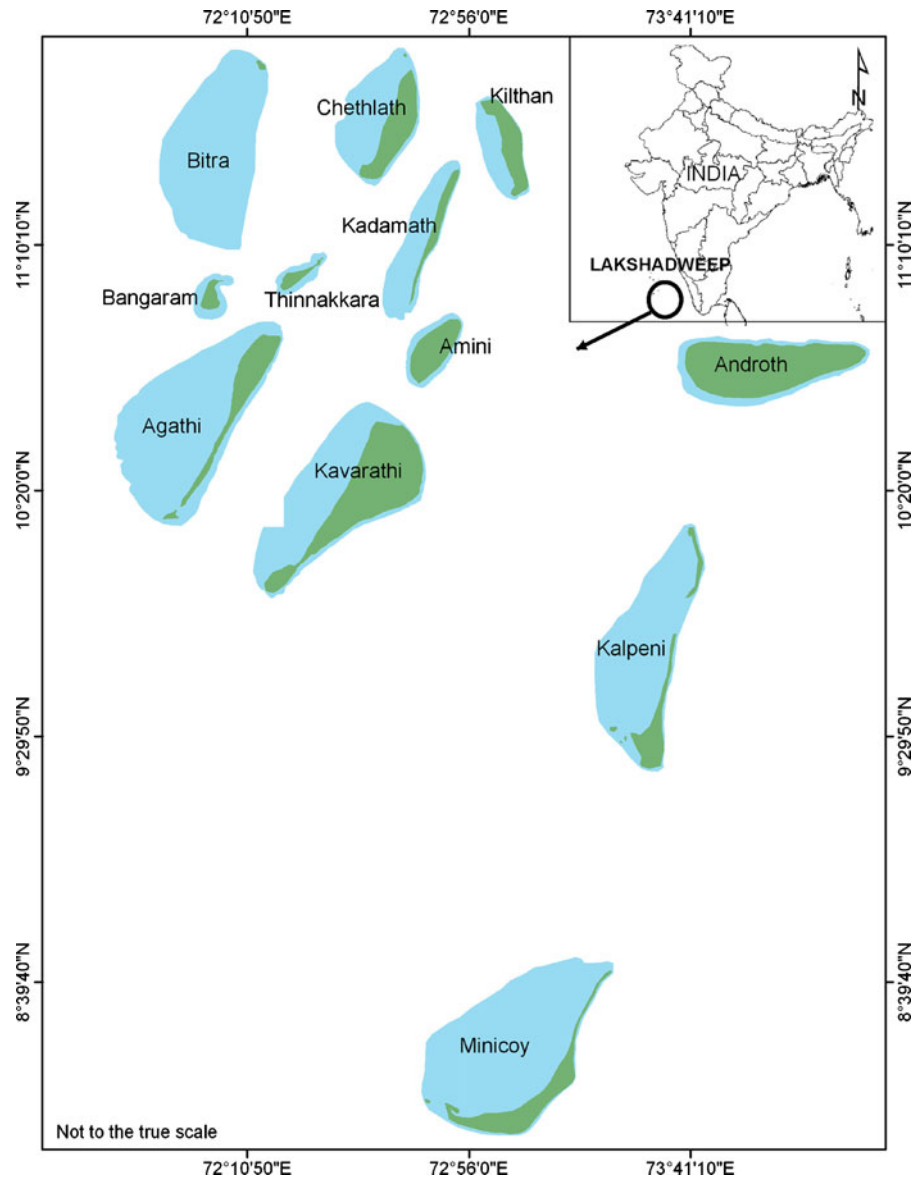
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species, degree of precision and cost effectiveness in relation to time spent (Green et al. 1996; Pasqualini et al. 2005). Now, satellite remote sensing is widely used for large scale mapping in almost all parts of the world with high resolution satellite imageries (Mumby and Edwards 2002). In India, attention and efforts towards seagrass mapping using satellite imagery are scanty (ICMAM PD 2001; Thangaradjou et al. 2008; Umamaheswari et al. 2009). Though the medium pixel size of 20–30 m is good in mapping the seagrass patches of similar size, still it is insufficient in mapping the smaller patches. In this context, the

Indian Remote Sensing satellite sensor IRS P6 LISS IV having a spatial resolution of 5.8 m would be better for seagrass mapping. LISS IV has three spectral bands (B2: 0.52–0.59; B3: 0.62–0.68; B4: 0.77–0.86 nm) being the plant system green, red and near infra red band are the best options for mapping the seagrasses. Short wave infrared band available in LISS III sensors is not helpful, as it is largely absorbed by the water.

Despite of growing awareness about seagrasses and their importance lesser efforts have been made to document the aerial cover of this fragile resource. So,

Fig. 1 Map showing the islands in the Lakshadweep



considering its biodiversity wealth and the ecological role it plays, it becomes necessary to document the extent of the seagrass resources of the Lakshadweep group of islands for effective conservation and management. As of date LISS IV data has not been tested for mapping seagrasses or any other under water vegetation and hence the same is used for mapping the spatial extent of the seagrasses of the Lakshadweep group of islands.

Material and Methods

Study Area

The Lakshadweep group of islands are scattered in the Arabian Sea about 200 to 400 km off the west of Kerala coast, situated between the latitude 8° – 12° N

and longitude 71° – 74° E (Fig. 1). It 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 islands have a humid, warm and generally pleasant climate. The temperature varies from 27° to 33° C. South-west monsoon is the rainy season from May to early October with an average rainfall of 1,640 mm (Bijumon 2005). Winds are light to moderate during October to March. The present study was carried out in 12 different islands of the

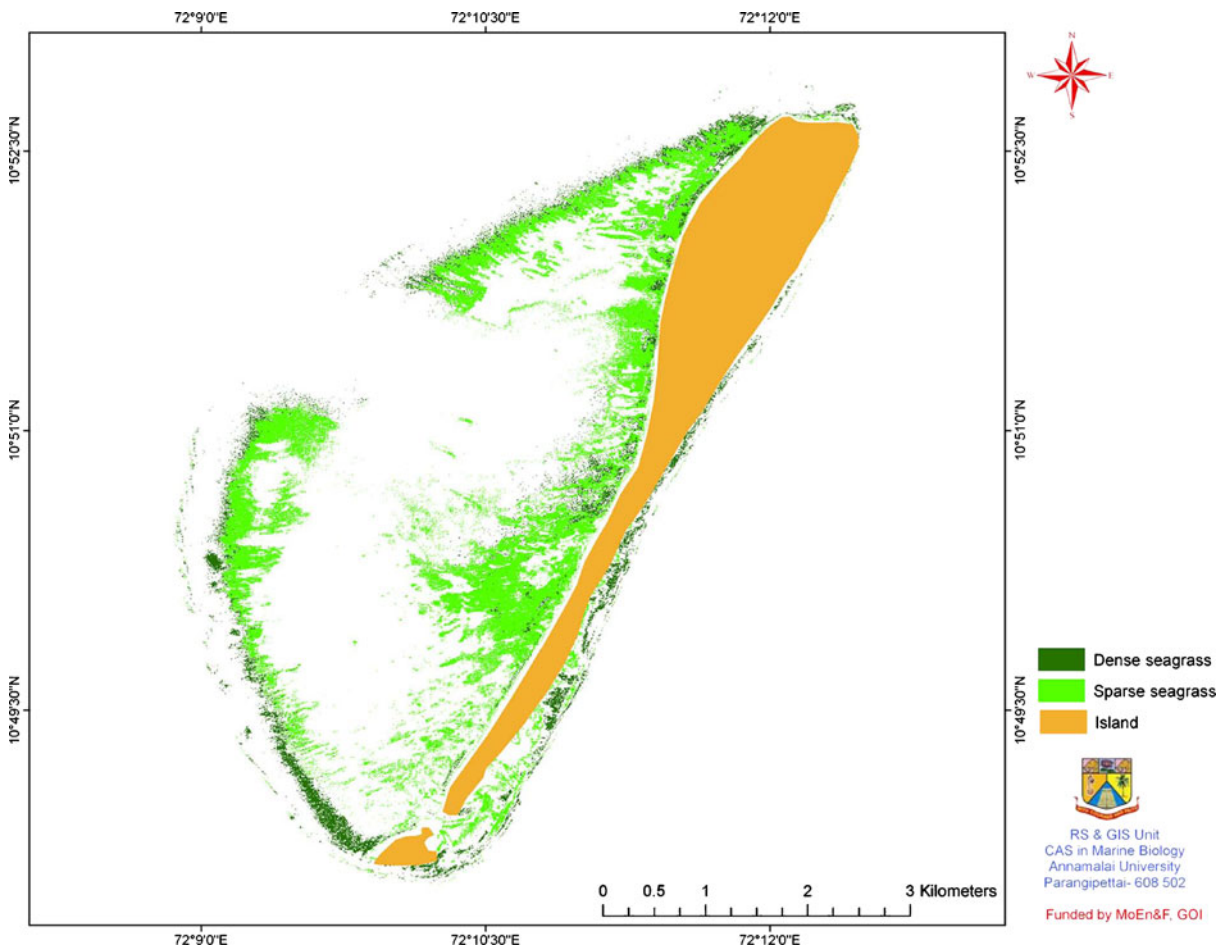


Fig. 2 Classified seagrass map of Agathi island (49 B/1) using IRS LISS IV data of 9th January 2007

Lakshadweep. Among them, 10 (Minicoy, Kalpeni, Androth, Kavarathi, Agathi, Amini, Kadamath, Kilthan, Chethlath and Bitra) are inhabited and 2 (Bangaram and Thinnakkara) are uninhabited.

Image Processing

Satellite data are geocoded using standard geometric correction algorithm of ERDAS Imagine 9.2 software using Survey of India topo sheets (1:50,000 scale) supported with ground control points (minimum 4 per scene) collected by means of a handheld GPS. Sufficient care was taken to keep the RMS errors less than the pixel value, so as to keep the accuracy of the area calculations. Digital image analysis technique following the methodology of SAC (2006) and Mumby and Green (2000)

was used for interpreting the remote sensing data and ground truth information was largely used to reduce the errors in the image. Making use of various band combinations, FCC's for IRS P6 LISS IV data were generated. To all band combinations obtained, a linear contrast stretch was applied so as to get a full range of device display. The band combinations were then assessed for their suitability in distinguishing seagrasses from other coastal features.

By using the modeler module of the ERDAS imagine software the integer DN values for each band of all images were transformed into real numbers using the spectral calibration data for which the 'gain' and 'bias' information of the sensor in each band are obtained from the header file of the digital data. Spectral reflectance of individual classes (sparse

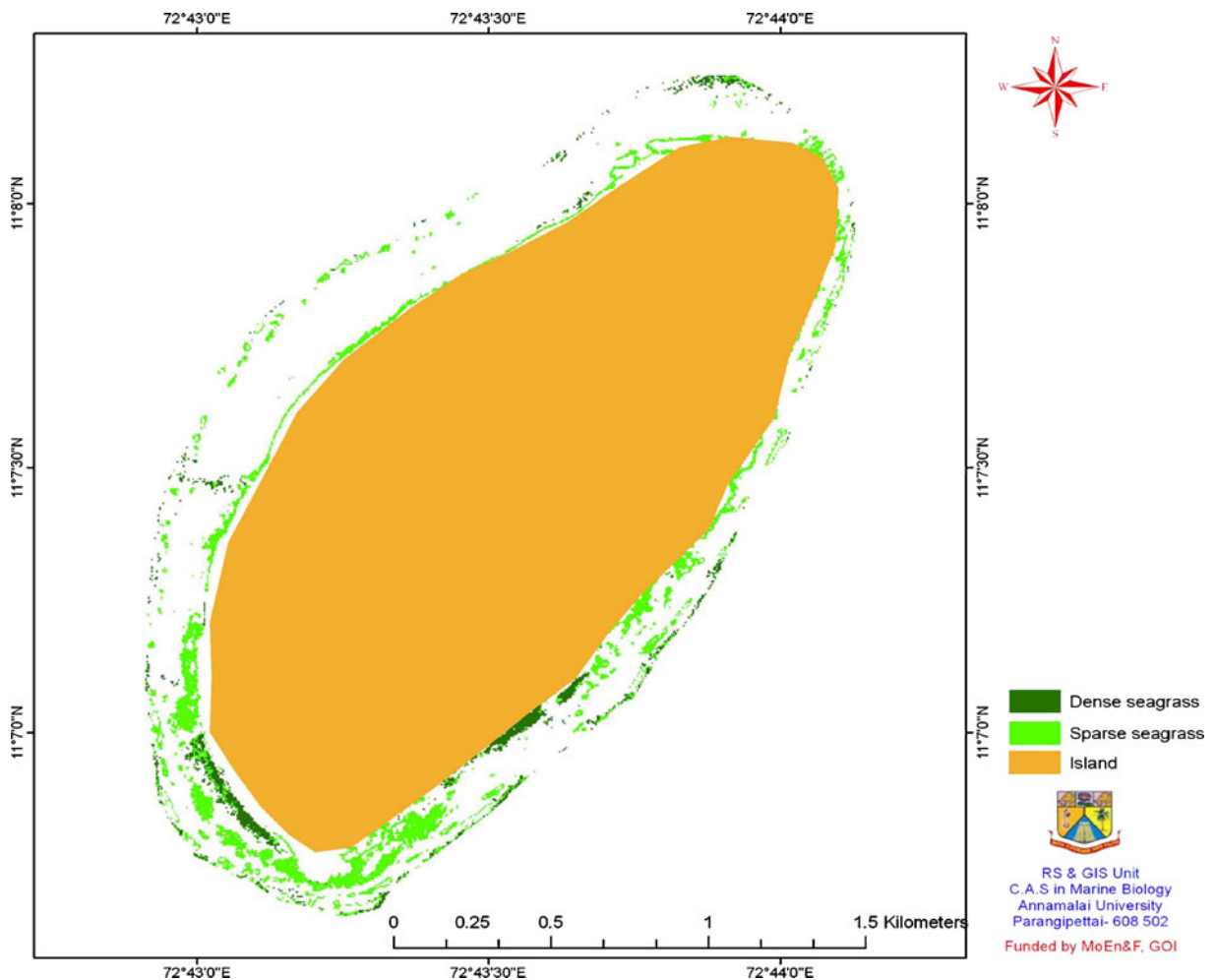


Fig. 3 Classified seagrass map of Amini island (49 A/12) using IRS LISS IV data of 6th January 2004

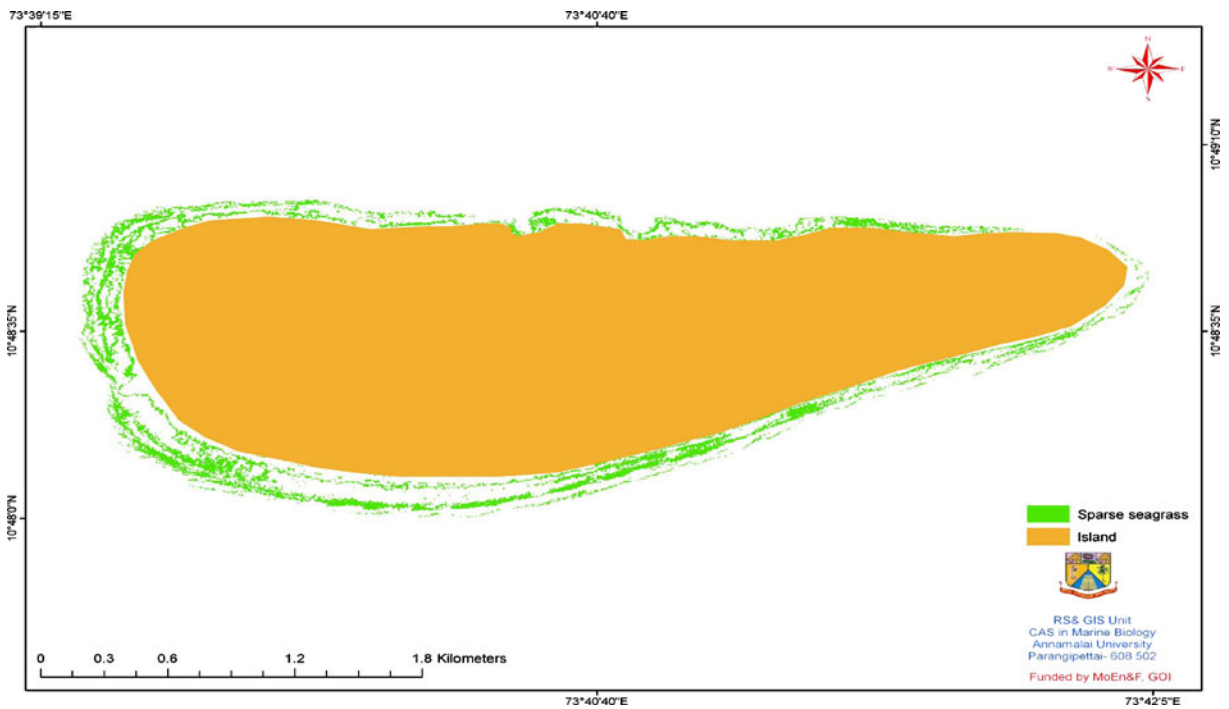


Fig. 4 Classified seagrass map of Androth island (49 F/9) using IRS LISS IV data of 14th January 2008

seagrass, dense seagrass, coral reefs, deepwater, shallow water, island vegetation and sandy area) was extracted from the radiometrically corrected images

from the identified training sites based in GPS points. Reflectance data archived for individual bands from the spectral curves of specific resources are pooled

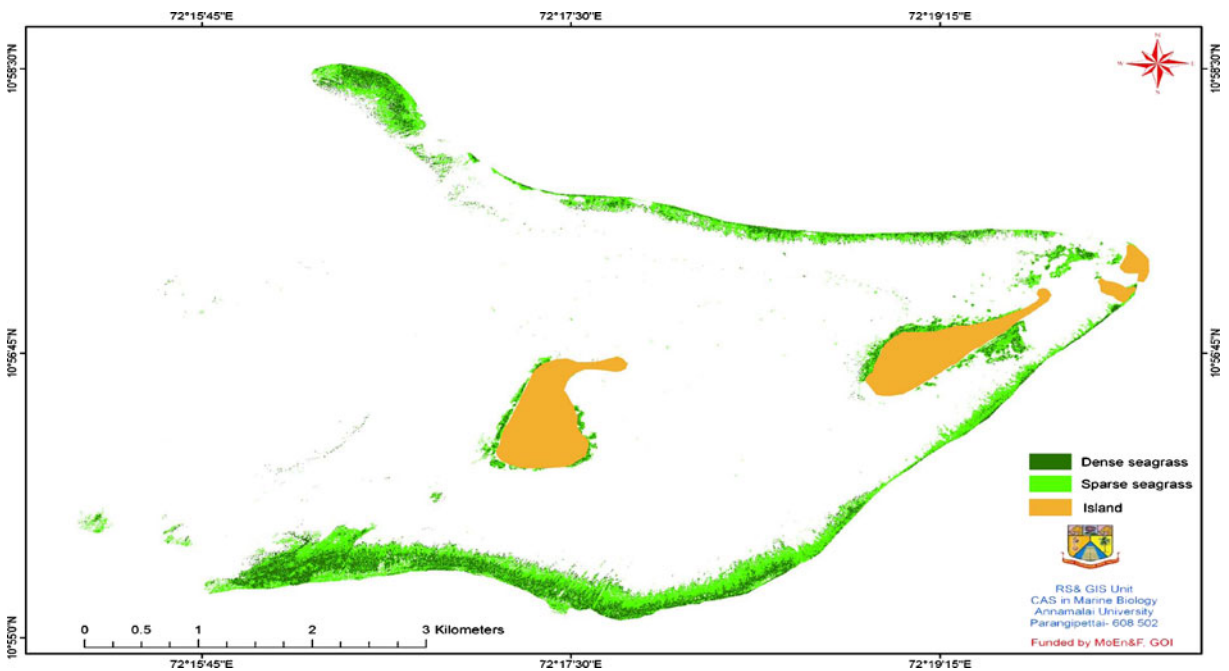


Fig. 5 Classified seagrass map of Bangaram & Thinnakkara island (49 B/5) using IRS LISS IV data of 9th January 2007

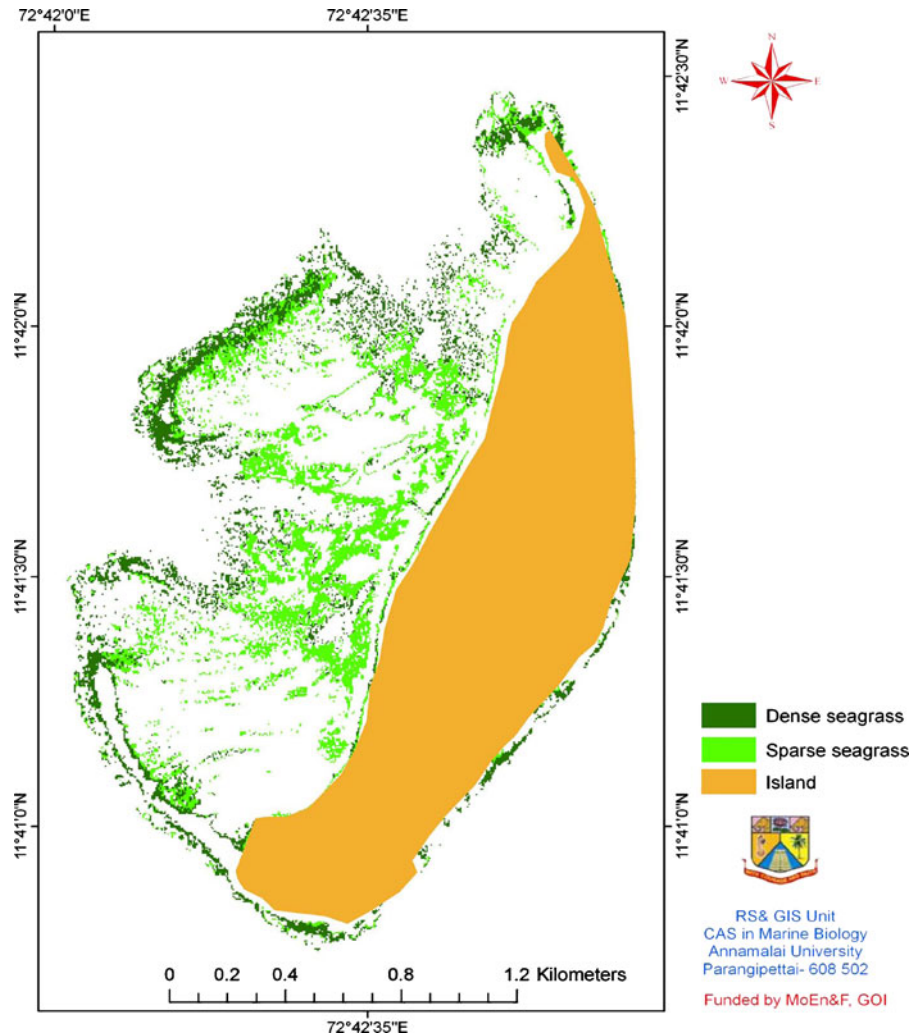
together and final graphs were drawn in excel. Hence, the spectra presented in the study are the image based reflectance of the respective class and not represents the real in situ reflectance.

The MLC algorithm was applied to perform multi spectral image classification after each site with multivariate statistical parameters. The entire sub-scene was thus classified into different classes. The classified output was presented as such at pixel level without any smothering, as it will eliminate most low frequency pixels. Contextual editing was also performed based on field experience so as to upkeep the accuracy of the measurements. The mapping accuracy was estimated on sample basis, assuming a binomial distribution for the probability of success/failure of samples tests as discussed by Nayak et al. (1991).

Results

There was no accurate information about the seagrass coverage in these islands in the recent past, and in some islands, there was no information at all. As there is no single attempt made exclusively for seagrasses using satellite data in this part, and many of the past work included seagrasses as one of the class or entire reef vegetation as one class, which includes seaweeds and seagrasses. All these raise question in using the data as pure seagrass class accurately. Hence, an attempt has been made to map the seagrass cover in the twelve islands (10 inhabited and 2 uninhabited) of the Lakshadweep using IRS P6 LISS IV (5.8 m). After carrying out mapping and ground truth surveys in these islands, only 11 islands were found to have the

Fig. 6 Classified seagrass map of Chethlath island (49 A/10) using IRS LISS IV data of 19th January 2006



seagrass cover (Figs. 2, 3, 4, 5, 6, 7, 8, 9 and 10). In Bitra, seagrasses were not found during mapping and the same was also verified by ground truth survey. Though seagrasses were present in Kilthan island, mapping was not possible, as they were found in smaller patches (<5 m²), which are less than the spatial resolution of the satellite sensor (5.8 m). Seagrass areas of the remaining 10 islands were classified and mapped as dense and sparse seagrasses with respect to their percentage of occurrence as inferred through the satellite data and ground truth validation (Table 1).

In Agathi island, seagrasses were found to have a total area cover of 505.4 ha, in which dense seagrass cover was 105.6 ha and sparse seagrass coverage was 399.8 ha (Fig. 2). Similarly, in Amini island (Fig. 3),

dense seagrass cover was less (5.1 ha), when compared with sparse seagrass cover (21.2 ha) with a total seagrass area of 26.3 ha, whereas in Androth island (Fig. 4) sparse seagrass beds (43.8 ha) was recorded. Bangaram and Thinnakkara islands together showed a seagrass area of 324.6 ha with 112.1 ha dense and 212.5 ha sparse seagrasses (Fig. 5). Chethlath island is having dense seagrass cover of 25.1 ha and sparse seagrass area of 34.8 ha (Fig. 6). Out of all the islands mapped for the seagrass spatial extent, Kadamath island (Fig. 7) showed the maximum seagrass area with 603.4 ha with 459.1 ha dense and 144.3 ha sparse seagrasses. Kalpeni island had a dense seagrass cover of 227.7 ha and sparse seagrass area of 170.2 ha (Fig. 8). Kavarathi island had a total seagrass area of 192.2 ha, with 101.7 ha of dense and

Fig. 7 Classified seagrass map of Kadamath island (49 A/15&16) using IRS LISS IV data of 6th January 2004

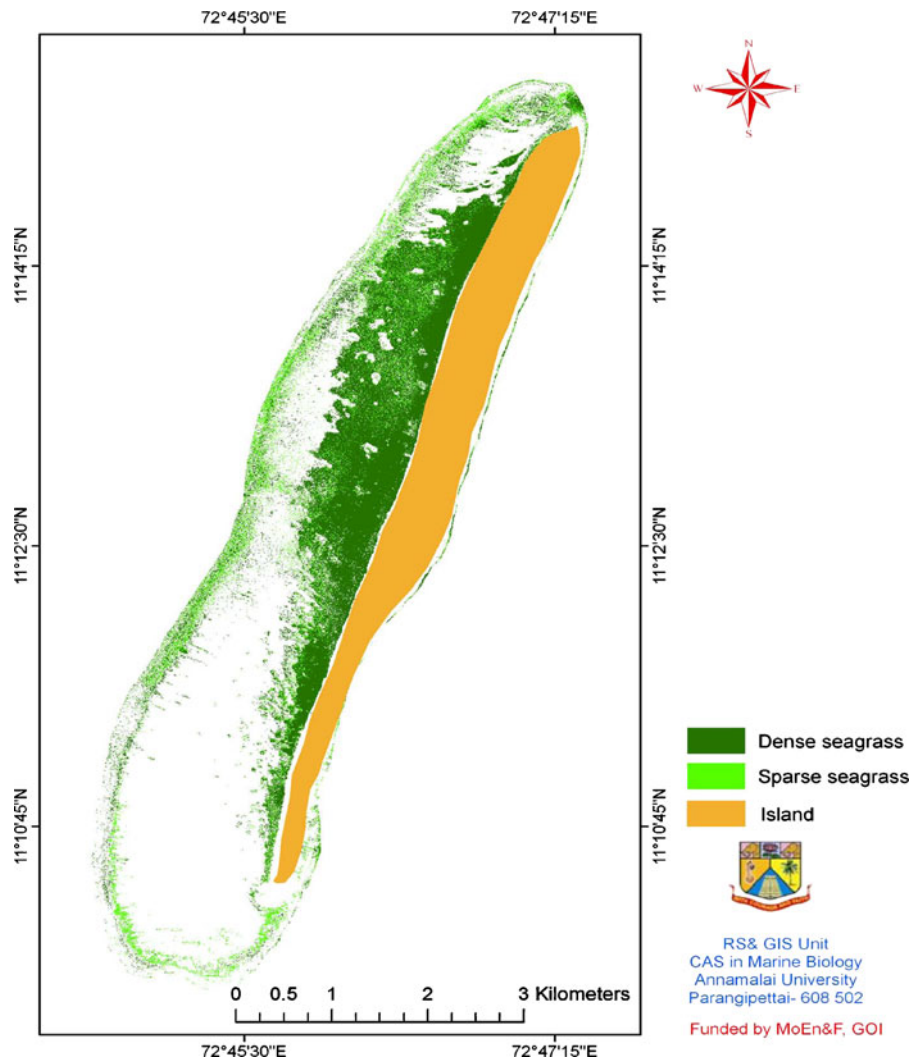
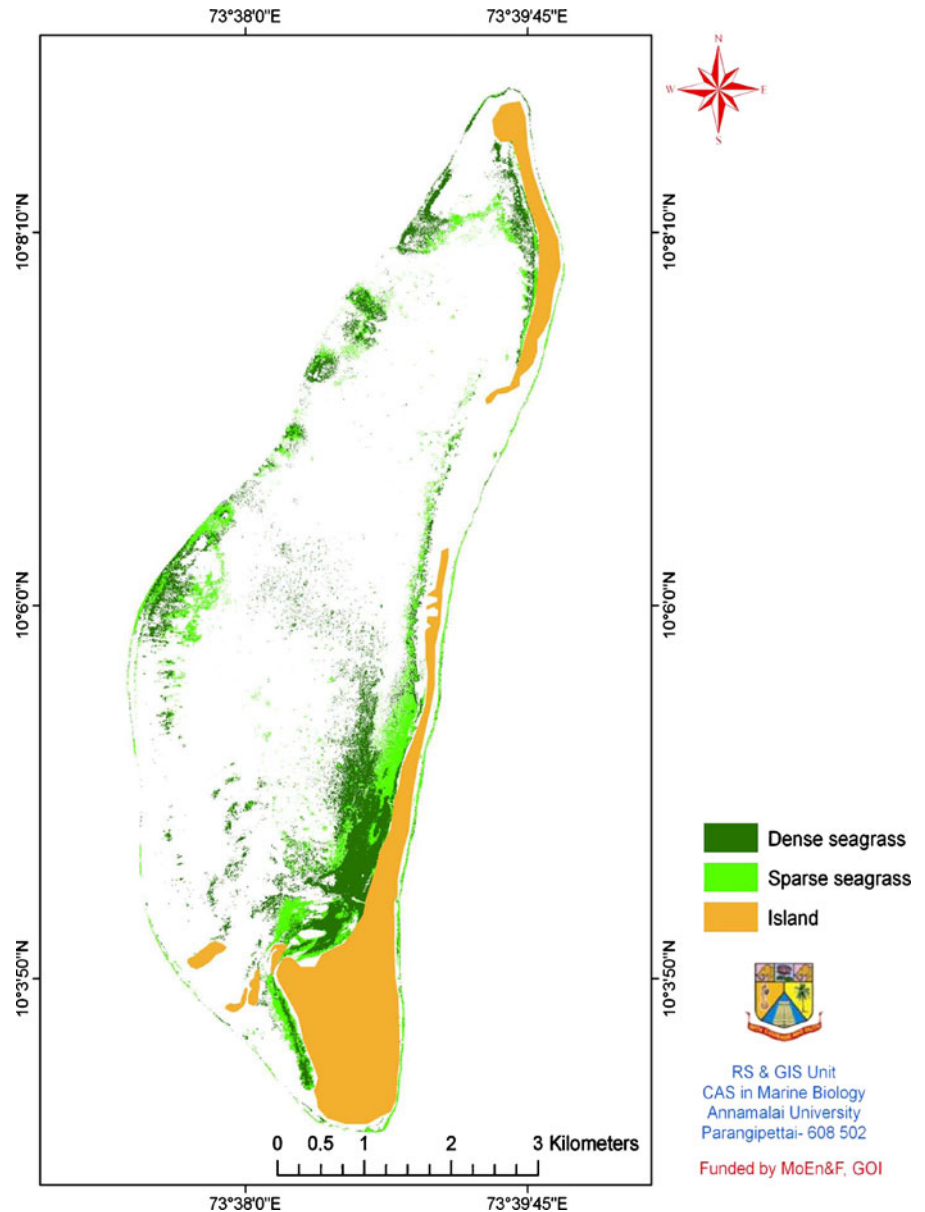


Fig. 8 Classified seagrass map of Kalpeni island (49 F/12) using IRS LISS IV data of 12th February 2007



90.5 ha sparse seagrass cover (Fig. 9). Minicoy the southernmost island in the Lakshadweep group of islands, was found to have a total seagrass area of 436.7 ha, with 274.4 ha dense and 162.3 ha sparse seagrass cover (Fig. 10).

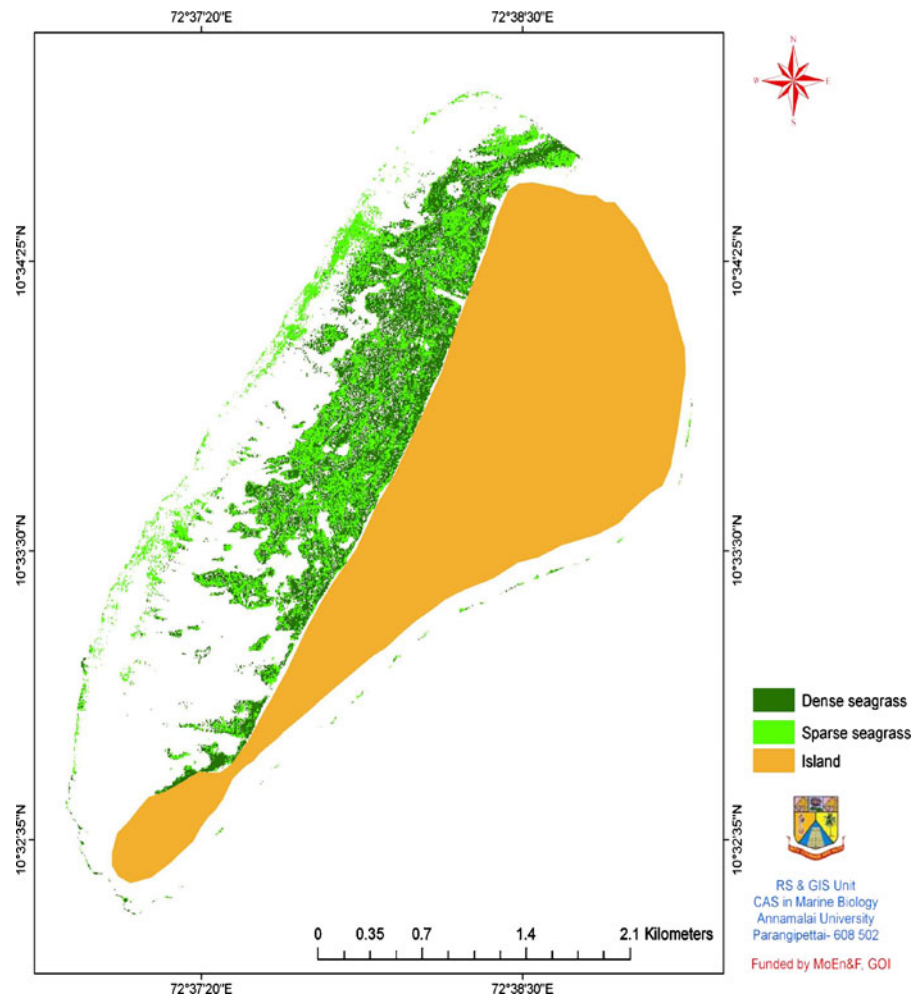
The IRS P6 LISS IV data provides more accurate details of the seagrass area in the Lakshadweep group of islands when compared with the other Indian satellite sensors. The mapping efficiency increased 4 times more than the LISS III images. Still the data generated are not exhibiting the current status of seagrass in this group of

islands, as the satellite data used for the present study are of different periods (2004–2008). So, non-availability of satellite data of current period was the main constrain and the seagrass areas worked out represent only the periods of the satellite data (Table 1).

Discussion

Conservation and management of coastal resources is a challenging job for the policy makers and for the

Fig. 9 Classified seagrass map of Kavarathi island (49 B/10) using IRS LISS IV data of 16th December 2006



conservation of natural resources, it is important to note that for developing effective management plans, distribution and health data are essential on the resources for a larger area (Thangaradjou et al. 2008). In the present study, 2590.2 ha of seagrass have been delineated from the Lakshadweep islands using IRS P6 LISS IV satellite data. Along with the seagrasses, coral reefs, lagoons, island vegetation and sandy areas were also demarcated.

Coastal habitat maps were widely recognized as the essential data for coastal management planning (Cendrero 1989; McNeill 1994). Mumby et al. (1999) suggested that remote sensing is a more cost effective technique than field surveys for coastal habitat mapping. Satellite data with high spatial resolution have been recommended for seagrass mapping in the coastal areas (Phinn et al. 2008). In the present study, the seagrass maps were produced with IRS P6 LISS

IV satellite imagery which is having a spatial resolution of 5.8 m which is far better than the LISS III, SPOT or Landsat images which are having more than 20 m spatial resolution. Though CASI, Quickbird or IKONOS have high spatial resolution they are not cost effective hence, IRS LISS IV data can be used for better seagrass mapping at least in shallow coasts up to 5 m depth. Reduced pixel size data is very much required in order to get a clear relationship between the results obtained from mapping and field observations (Pasqualini et al. 2005). The increased areal cover obtained in the present study and a comparison with that of earlier studies (Table 2) indicates the better efficiency of LISS IV data over the aerial photographs and LISS III sensors in mapping the seagrasses.

The spectral reflectance curve from LISS IV imagery has clearly brought out the variation in the spectral signature of different island features (Fig. 11).

Fig. 10 Classified seagrass map of Minicoy island (49 H/3) using IRS LISS IV data of 2nd February 2008

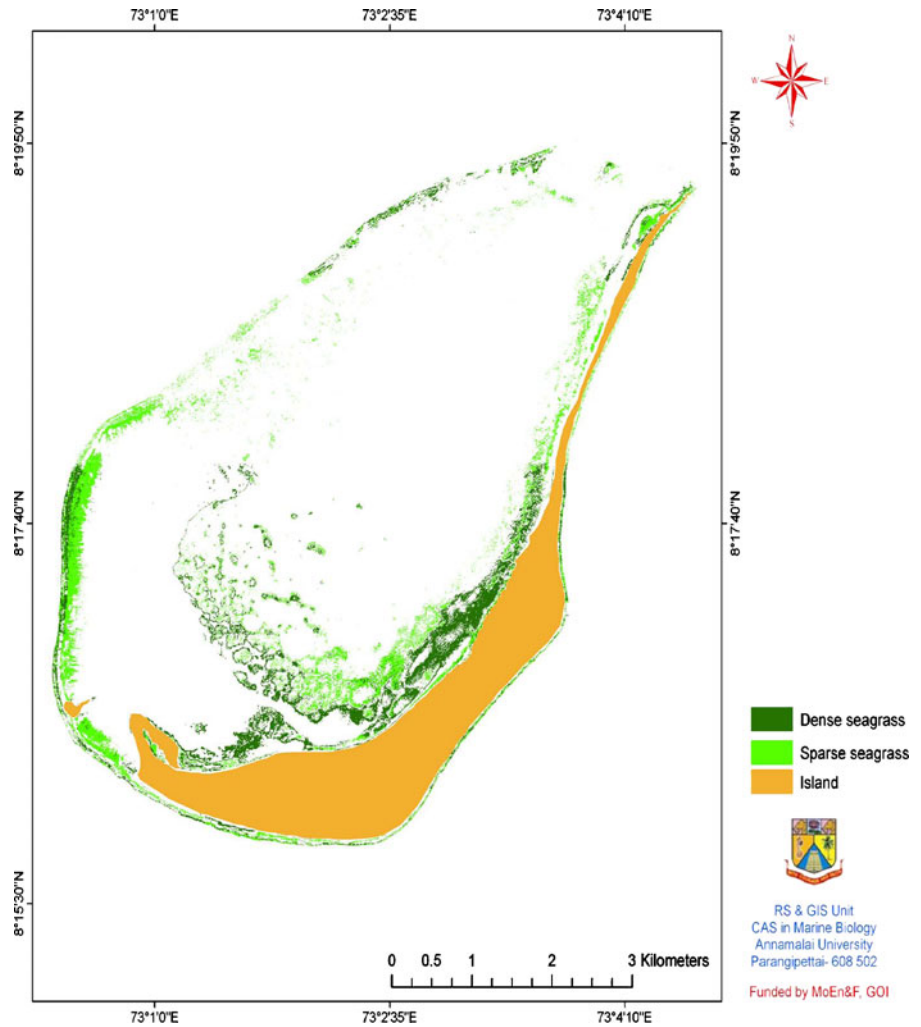


Table 1 Spatial extent of seagrasses in the Lakshadweep group of islands

S.No.	Island (Year of the satellite data)	Dense Seagrasses (Hectare)	Sparse Seagrasses (Hectare)	Total (Hectare)
1	Agathi (2007)	105.6	399.8	505.4
2	Amini (2004)	5.1	21.2	26.3
3	Androth (2008)	0	43.8	43.8
4&5	Bangaram & Thinnakkara (2007)	112.1	212.5	324.6
6	Bitra (2007)	A ^a	A ^a	A ^a
7	Chethlath (2006)	25.1	34.8	59.9
8	Kadamath (2004)	459.1	144.3	603.4
9	Kalpeni (2007)	227.7	170.2	397.9
10	Kavarathi (2006)	101.7	90.5	192.2
11	Kilthan (2005)	Neg ^b	Neg ^b	Neg ^b
12	Minicoy (2008)	274.4	162.3	436.7
	Total	1,310.8	1,279.4	2,590.2

^aA Absence of seagrass,

^bNeg. Negligible

Table 2 Seagrass area cover estimated by other workers in Lakshadweep islands

Ref./Island	Data used/date	Kavarathi	Agathi	Bangaram & Thimakkara	Kadamath	Amini	Chethlath	Androth	Kalpeni	Minicoy	Total
Jagtap and Inamdar 1991	B&W Aerial Photos February 1986	0.34 km ²	0.005 km ²	0.14 km ²	0.05 km ²	0.19 km ²	0.19 km ²	0.19 km ²	0.4 km ²	1.12 km ²	
Jagtap 1991	B&W Aerial Photos February 1986	0.34 km ²				0.19 km ²			0.4 km ²	1.12 km ²	
Jagtap 1998	B&W Aerial Photos February 1960	0.34 km ²	0.005 km ²						0.194 km ²		
Nayak and Bahuguna 2001	IRS (LISS II)			5.57 km ²						12 km ²	
ICMAM PD 2001	IRS 1 C LISS III 7th March 1997				13.8 km ²						
SAC 2003	IRS LISS III 26th March 1998				2.5 km ²						
Desai et al. 2003	IRS October 1998				0.14 km ²						
SAC 2006	IRS LISS III 30th January 2000	1.48 km ²									
Present study		1.92 km ²	5.05 km ²	3.24 km ²	6.03 km ²	0.26 km ²	0.59 km ²	0.43 km ²	3.98 km ²	4.37 km ²	25.9 km ²

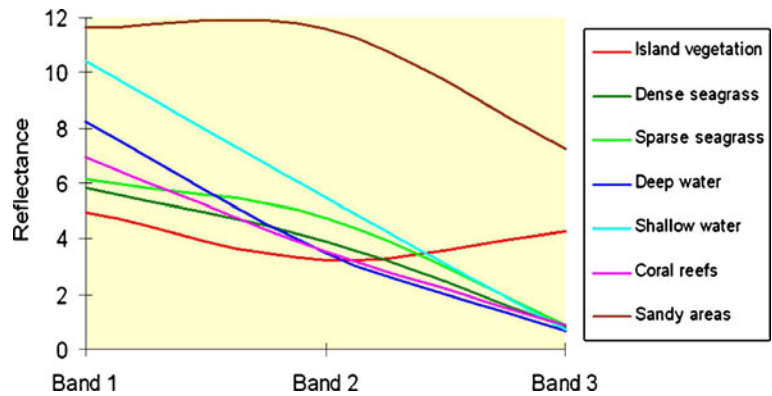
Dense seagrass, sparse seagrass and coral reef areas were spectrally differentiated; with coral reef areas showing higher reflectance value in Band 1 but gradual decrease in Band 2 and 3. In the case of sparse seagrasses, higher reflectance spectra were noticed than that of the dense seagrasses in Band 2. In Band 1, coral reef showed higher reflectance peak when compared to sparse and dense seagrasses. So, it is well understood from the Fig. 11 that sparse seagrasses, dense seagrasses and coral reefs can be delineated from the LISS IV imageries with the help of Band 2.

Present study has estimated a total seagrass area cover of 2590.2 ha, whereas previous studies conducted in the Lakshadweep islands showed consistently varied data. Jagtap and Inamdar (1991) reported a total of 1.12 km² seagrass area cover, in which Minicoy island had the maximum of 0.4 km², followed by Kavarathi (0.34 km²) and Agathi (0.005 km²). Contrary to these findings, in the present study, Minicoy island was found to have a seagrass area of 436.7 ha (4.3 km²), while Kavarathi and Agathi recorded 192.2 ha (1.92 km²) and 505.4 ha (5.05 km²) respectively.

Untawale and Jagtap (1989) reported a seagrass area of 0.765 km² in Minicoy island using black and white aerial photos. This increase in seagrass cover recorded during the present study could be attributed to the high resolution satellite imagery. This also confirms the lesser ability of black and white aerial photographs to detect the sparse seagrasses when compared to the higher resolution satellite imageries like LISS IV. Jagtap (1998) reported that 7.83% of the lagoon area of Kavarathi is occupied by seagrasses; however, the present study has indicated even more percentage of seagrass cover in this lagoon. The present investigation has also revealed a seagrass cover of 397.9 ha in the Kalpeni island while Jagtap (1998) reported 0.194 km² seagrass cover in this island.

Earlier reports indicate the gradual decrease of seagrass cover in Agathi island 0.005 km² (Jagtap 1998). In contrast, present study revealed a dense seagrass area of 105.6 ha and sparse seagrass area of 399.8 ha based on 2007 satellite data. This is much more than the 1991 data. However, our field studies have confirmed the reduction in dense seagrass cover in this island during 2009. The seagrasses in Agathi island are facing direct threat from intensive grazing of sea turtles which are high in number in this island

Fig. 11 Spectral behaviour of different coastal classes of the Lakshadweep islands



(Thangaradjou et al. 2009). Discussion with the local people has also confirmed that the turtle population has increased in the recent years after the strict enforcement of law on hunting of turtles.

Seagrasses in the Lakshadweep islands were found largely in the shallow lagoon formed by the coral atolls. Coral reefs buffer the physical influence of the ocean resulting in the formation of lagoon and sedimentary environment suitable for seagrasses (Ogden 1988). Colonisation, distribution and abundance of seagrasses depend upon the substratum, the source, the rates of sediment transport and accumulation (Burrell and Schubel 1977). Though the lagoons support luxuriant seagrass growth, the substratums towards the reef are generally hard due to compaction or deposition of calcium carbonate, which would depress seagrass growth (Jagtap 1998). However, the coral platforms especially dead coral platforms, having coral sand, supports sporadic sparse growth of seagrasses on them. This is a very common phenomenon in Andaman and Lakshadweep islands.

Nayak and Bahuguna (2001) classified the seagrasses using IRS data with tone-orange/orangish pink and texture-smooth, and reported that they are intermingled with corals as that of the present results, where it is found that seagrasses are found in coral flats. Several other studies also reported seagrass growth in coral reef environments (Hackett 1977; Fortes 1986; Sridhar 2005; Thangaradjou et al. 2008; Susila 2009) including Lakshadweep islands (Jagtap 1991; Nayak and Bahuguna 2001) especially on reef platforms.

Umamaheswari et al. (2009) suggested that the present Indian Remote Sensing satellite sensors like IRS P6 LISS3 and LISS IV can be used for continuous monitoring of coastal resources because

of their high spatial resolution. Seagrass mapping in other parts of the Lakshadweep islands especially in Kadamath, Amini and Bangaram was attempted while dealing with geomorphological or coral reef studies (ICMAM PD 2001; Nayak and Bahuguna 2001; SAC 2003; SAC 2006). Kadamath island had the maximum seagrass cover when compared with all the other islands, with an area of 603.4 ha; but still it is less when compared with other coastal land use classes of the island. SAC (2003) reported only 2.5% of occurrence of seagrasses when compared with other categories. This might be due to the use of low resolution imagery when compared with the present satellite data or due to the misclassification of seagrass areas as sandy beach of other classes.

Present investigation has detected seagrass coverage of 324.6 ha in Bangaram and Thinnakkara islands (Fig. 5) together and dense seagrass cover of *Cymodocea* sp. But, SAC's (2003) report has not found the distribution of seagrasses in this island. This may be again due to the resolution difference or misclassification with coral reefs and also be attributed to the findings of Jagtap (1998), who reported that Lakshadweep group of islands are of emerging types and that too are not stabilized; this may be the reason for the poor seagrass growth in the past. Seagrasses have been mapped along the shores facing the lagoons and found to occupy 12 km² areas in the Lakshadweep islands (Nayak and Bahuguna 2001); they reported seagrass area of 5.57 km² in Bangaram island alone. Thus, limitation of ground truth data on seagrass areas or the difficulties faced in differentiating seagrass pixels from coral reefs are the problems in missing the seagrass cover in the coral reef areas (Thangaradjou et al. 2008). SAC (2006) reported a reduction in seagrasses from 1.48 km² to 0.31 km² from 1990–

2000 in Kavarathi island, whereas the present study has revealed the fact that seagrass cover has increased to 1.92 km² in this island.

Surveys on aquatic vegetations are commonly hindered by limited accessibility and hence remote sensing is considered as a valuable tool for the assessment of macrophytes (Silva et al. 2008). Though, the satellite data give detailed information about the coastal resources, the results are potentially limited by the disparity in dates of field surveys and image acquisition (Mumby et al. 1997) and even disparity in satellite data acquisition over larger areas, like that of the present study. Though the present study attempted to map the current seagrass cover, the satellite data availability varied widely for different islands.

From the previous studies (Table 2), it is clearly evidenced that no one has attempted to map the seagrasses of all the islands of the Lakshadweep. Most of the data are showing marked variations in aerial cover. This is because of the changes in spatial resolution of the satellite data used, less ground truth studies and differences in delineating seagrass class from other coral classes. Though seagrass presence/absence can be mapped using Indian satellites, it is difficult to do the density wise mapping, and species identification appears beyond the capability of remote sensing with a low resolution data (Nayak and Bahuguna 2001), whereas genus/species level identification can be achieved, using high resolution satellite data (Phinn et al. 2008). This has yet to be attempted in different islands of the Lakshadweep.

Maps were generated with an overall accuracy of 73.16%. Though the producer accuracy for dense and sparse seagrass was 87.5% and 75% respectively, the user accuracy of the dense seagrasses was recorded as 93.3% however the user accuracy reduced drastically for sparse seagrasses (66.6%). This is mainly because of the spectral confusion caused by the sparse seagrasses growing in the coral platforms; for the same reason coral reef class also registered only 62.5% accuracy. Lagoon and sandy area are recorded overall higher accuracy. Lagoon registered 86.6% user accuracy and 81.25% producer accuracy where as sandy area registered 100% accuracy in both the cases. This is again conforms that the sandy area can clearly be distinguished from seagrasses. But the error in lagoon area is largely because of the variations in depth due to which, the data and method cannot be

better adopted to map the seagrasses growing more than 5 m depth. The overall accuracy of 73.16% obtained in the present study is less when compared to Sridhar et al. (2010) who recorded 90.14% in Palk Bay, however it is from non coral reef area. Mapping of seagrasses in coral reef area is always considered to be difficult task. But the present accuracy was good when compared to Phinn et al. (2008) who obtained 22.69–45.64% while attempting to classify seagrass at different seagrass cover classes and Wabnitz et al. (2008) also obtained 68% of overall accuracy. Though the present study provides with information about the seagrass cover in Lakshadweep islands, data do not exactly reflect the present day seagrass cover as the maps were generated from 3 or 4 years old satellite data.

Conclusion

LISS IV data can be used for mapping the shallow water seagrasses. By using these data, the mapping efficiency increases nearly 4 times than the LISS III data, as the former (LISS IV) picks up the small patches of seagrasses and delineates the coral and reef vegetation patches from seagrass class. This increase in the mapping efficiency is achieved only because of the increased spatial resolution of the sensor. In future, if this sensor (LISS IV) is developed with blue band, then it will become the effective tool in mapping the underwater objects more precisely and seagrasses more accurately.

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