Extracting ocean colour and sea-grass information from remote sensing data : opportunities and limitations

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Abstract. The opportunities and limitations of extracting ocean colour and sea-grass information based on studies carried out at UTM Centre for Remote Sensing were identified in this study. The Landsat-5 Thematic Mapper (TM) data were used in two selected test sites : (i) off Kuala Terengganu including all islands gazetted as Marine Park, and (ii) off Kuala Kedah including Pulau Langkawi and nearby small islands. Phytoplankton information were extracted based on regressing samples of phytoplankton density collected at the time of satellite over-pass of the corresponding test areas with the reflectance values recorded by the satellite's sensor while information on sea-grass were determined using substrate indices computed from the measured reflectance of the sea area.

1. Introduction

Ocean colour and sea-grass are two important elements in both fishery environment and marine ecology. Within the context of this paper, ocean colour refers to spatial distribution and concentration of micro-phytoplankton (58μm). Micro-phytoplankton is a unicell organism that floats near the sea surface and plays a vital role in the fish food-chain cycle that influences fish breeding and growth (Yusof and Said 1993). Sea-grass on the other hand, refers to all categories of grassy-type salt marshes found in shallow sea areas. Sea-grass ecosystem provides habitats for a wide variety of marine organisms, both flora and fauna including plankton and fish (Keulen 1995).

Phytoplankton and sea-grass are important because they are related to the fish breeding grounds, hence, information of these two elements can assist in identifying both fish breeding and fishing grounds. However, to map phytoplankton and sea-grass over large sea area is very costly and time-consuming except by using satellite remote sensing techniques which offer synoptic view and repeatability of data capture. The opportunities and limitations of extracting both ocean colour and sea-grass information are analysed in this study.

2. Materials and methodology

2.1. Study area

The Landsat-5 Thematic Mapper (TM) data were used in two selected test sites : (i) off Kuala Terengganu including all islands gazetted as Marine Park, and (ii) off Kuala Kedah including Pulau Langkawi and nearby small islands (Figure 1). The two sites were selected to represent the two typical coastal areas of Malaysian environment : sheltered Malacca Straits and open South China Sea. The specification of Landsat-5 TM data used is tabulated in Table 1.

2.2. Sea-truthing and sampling

Sea-truth information for phytoplankton was collected at the time of satellite over-pass in the study area. A total of 17 and 19 phytoplankton samples were collected within time period of 30 minutes prior and after satellite over-pass for Terengganu and Kedah, respectively (Figure 2, Table 2).

The allowance of 30 minutes was used as basis to ensure minimum variations representative of ocean conditions at time of sampling. The 58 μm mesh-size plankton net was used in the sampling where the net was towed vertically from a depth of about 5 meters to the surface at a constant speed of 0.5 m/s. Sampling points were located through GPS observations. Other measurements made during phytoplankton sampling are wind speed and direction, turbidity, skin temperature, air temperature and suspended sediment concentrations.

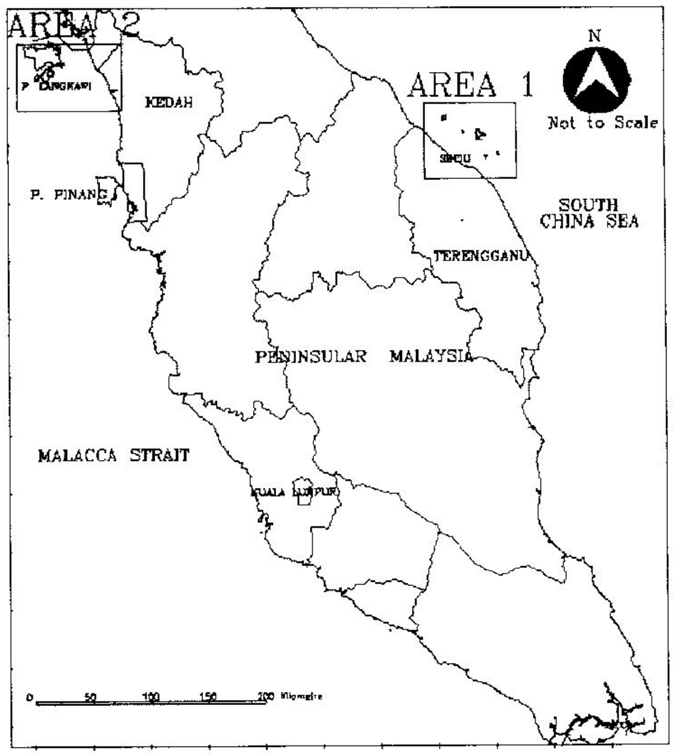
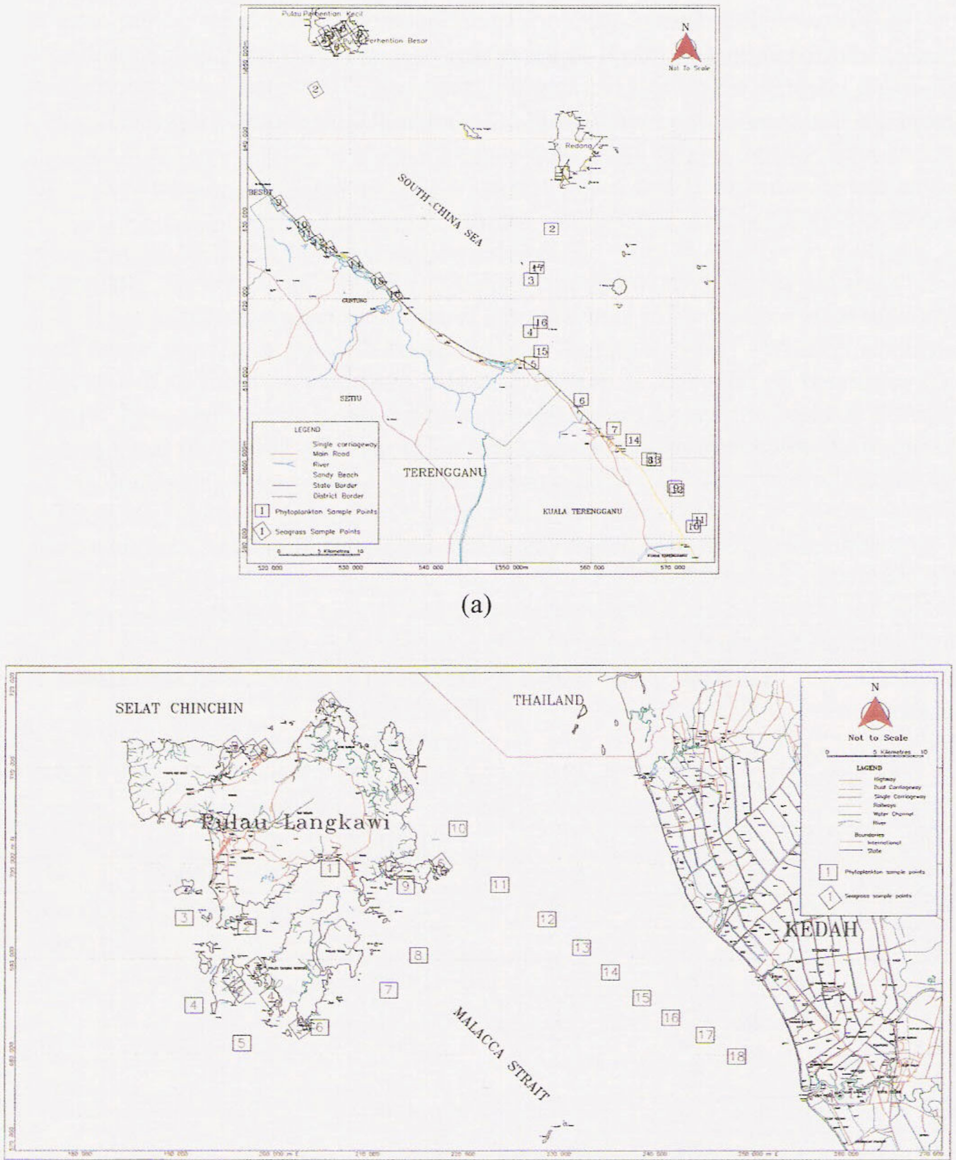


Figure 1. Location of the study areas.

Table 1. Specification of Landsat TM data used in the study.

TM image	Study area	
	Terengganu	Kedah
Date of image acquired	7 August 1997	19 March 1998
Latitude	N 5° 46' 45"	N 5° 46' 42"
Longitude	E 103° 31' 43"	E 100° 26' 50"
Observed time	2h 23m 00s UT	2h 41m 00s UT
Path/Row	126/56	128/56

Sampling sea-grass information need not be carried out in real time during satellite overpass. However, sampling of sea physical parameters such as tidal height at the time of satellite overpass is of prime importance in order to carry out sea-grass sampling at other convenient period. The tidal height is needed for compensating the effect of depth to the substrate's reflectance during the computation later in sea-grass extraction from satellite data. In sea-grass sampling, measurements made were GPS observations for the location of sea-grass, depth, tidal height at sampling time and water turbidity. A total number of 16 and 12 sea-grass locations were identified (via divers) during sea-truthing for Terengganu and Kedah study area respectively.



(a)

(b)

Figure 2. Location of phytoplankton and sea-grass sample points: (a) off Terengganu and (b) off Kedah.

2.3. Data pre-processing

(a) Atmospheric correction

Atmospheric correction was applied to the TM data in order to minimise atmospheric perturbations contributed by Rayleigh and aerosol components. A "Fast Atmospheric Correction" technique based on Richter (1990) was adopted in this study due to completeness of correction functions in compensating effects of atmospheric scattering, attenuation and adjacency effect found in relatively high resolution satellite data such as Landsat TM. The atmospheric input parameters of the study area at the time of data acquisition period were derived using atmospheric models provided by LOWTRAN-7 (Kneizys et al.1989) and SENSAT-3 (Richter 1989).

(b) Geometric correction

Both satellite images were rectified to the corresponding topographic maps of the area. The second degree polynomial transformation was used in the image-to-map registration where both images were then resampled using nearest neighbour resampling scheme. To ensure good image-to-map registration of both images, a root mean square error (rms) of less than 0.5 pixel was maintained.

2.4. Data processing
(a) Extraction of ocean colour

A regression analysis using five functions namely, simple linear, power, logarithmic, exponential, and polynomial were examined for analysing the relationship between reflectance (bands 1. 2 and 3) and phytoplankton density. The chlorophyll index (ratioed difference of band 1 and band 3 normalised by band 2) suggested by Mayo et al. (1995) was also examined as input to the regression analysis. The best regression function (based on correlation coefficient, r^2) was then used further in extracting the distribution of phytoplankton from the appropriate TM band for the entire study area. The regressed density of phytoplankton in bands 1, 2, and 3 are tabulated in Table 3.

Table 2. Density of phytoplankton versus reflectance values of Landsat-5 TM bands 1, 2 and 3 off Terengganu and Kedah, respectively.

	Terengganu				Kedah			
Sample Point	Density of Phytoplankton (cell/m^3)	Landsat-5 TM Reflectance			Density of Phytoplankton (cell/m^3)	Landsat-5 TM Reflectance		
	Landsat TM bands	Band 1	Band 2	Band 3	Landsat TM bands	Band 1	Band 2	Band 3
1	7.95x10^5	50	73	1	1.50x10^7	29	39	11
2	1.33x10^5	49	69	1	1.11x10^7	29	32	9
3	2.46x10^4	52	71	1	2.17x10^7	23	31	6
4	1.78x10^5	50	71	1	4.63x10^7	23	25	6
5	1.86x10^5	53	79	3	4.93x10^7	31	36	9
6	1.16x10^5	49	74	3	1.64x10^6	29	36	8
7	9.94x10^4	50	74	3	1.61x10^5	32	38	9
8	5.58x10^4	47	75	3	1.33x10^7	28	39	12
9	6.72x10^5	49	78	3	2.46x10^7	32	46	17
10	2.00x10^5	50	74	3	1.83x10^7	31	38	9
11	4.42x10^6	50	75	3	1.74x10^7	26	32	7
12	2.32x10^6	50	77	2	2.28x10^7	27	27	6
13	6.14x10^5	52	75	3	3.54x10^7	20	25	6
14	4.14x10^5	50	74	3	2.59x10^7	19	25	6
15	1.69x10^5	48	71	1	1.42x10^7	20	27	6
16	2.24x10^5	51	75	2	1.85x10^7	21	31	6
17	8.36x10^4	48	71	1	1.83x10^7	24	31	6
18					2.31x10^7	24	32	6
19					2.47x10^7	27	38	11

(b) Extraction of sea-grass

Extraction of sea-grass information from satellite data was made based on modification of technique developed by Bierwirth et al. (1993) which was originally used for mapping shallow substrates. With known sea-grass location and water depth (treated for tidal height) during satellite overpass, the index of sea-grass (and other substrates if appropriate samples are available) can be determined. These indices are unique in nature i.e each family of substrate can be defined within a range of values, hence can be used to map substrates. Bands 1, 2 and 3 of Landsat-5 TM were the only bands used in this study due to their penetration capability.

3. Results and discussion

3.1. Ocean colour

In analysing best relationship of reflectance and phytoplankton density, the entire sample collected were divided in two sets. The first set was used in regression analysis, and the second set was used for independent test of the best relationship identified. The root mean square error (RMSE) was computed and the best regression function was determined based on correlation coefficients. Table 3 summarises the results of the regression analysis. The relationship between TM reflectance and phytoplankton is best shown by polynomial function with TM band 1. Tests at both study sites confirm that other bands (bands 2 and 3) and Mayo index tested are relatively inferior to band 1 ($r^2 > 0.5$). Figure 3 shows the spatial distribution of phytoplankton concentration extracted from TM band 1 using polynomial function at the time of satellite overpass.

Table 3. Results of regression analysis.

Study area	Independent	r^2 of functions analysed *					RMSE #	Sample Points +	
	Variable (*x*)	1	2	3	4	5		Reg.	Ind.
Tereng-ganu	Band 1	0.201	0.328	**0.517**	0.063	0.041	2.357	1,2,3,5	4,8
	Band 2	0.138	0.131	0.328	0.141	0.149		6,7,9	10,12
	Band 3	0.140	0.129	0.172	0.152	0.142		11,13	& 15
	Mayo index (1995)	0.131	0.132	0.135	0.149	0.145		14,16 & 17	
Kedah	Band 1	0.329	0.314	**0.532**	0.305	0.292	0.470	1,2,3,4	7,9,11
	Band 2	0.305	0.322	0.381	0.275	0.290		5,6,8	13,15
	Band 3	0.147	0.191	0.449	0.125	0.166		10,12	17
	Mayo index (1995)	0.008	0.004	0.067	0.005	0.002		14,16 & 18	19

* Functions analysed : 1 = Linear , 2= Logarithm, 3= Polynomial, 4=Exponential, and 5=Power
# RMSE (root mean square error) computed using independent samples for only best relationship function + Sample points used in regression (Reg.) and independent samples (Ind.) used for computing RMSE (see figure 2 (a) and 2 (b) for locations).

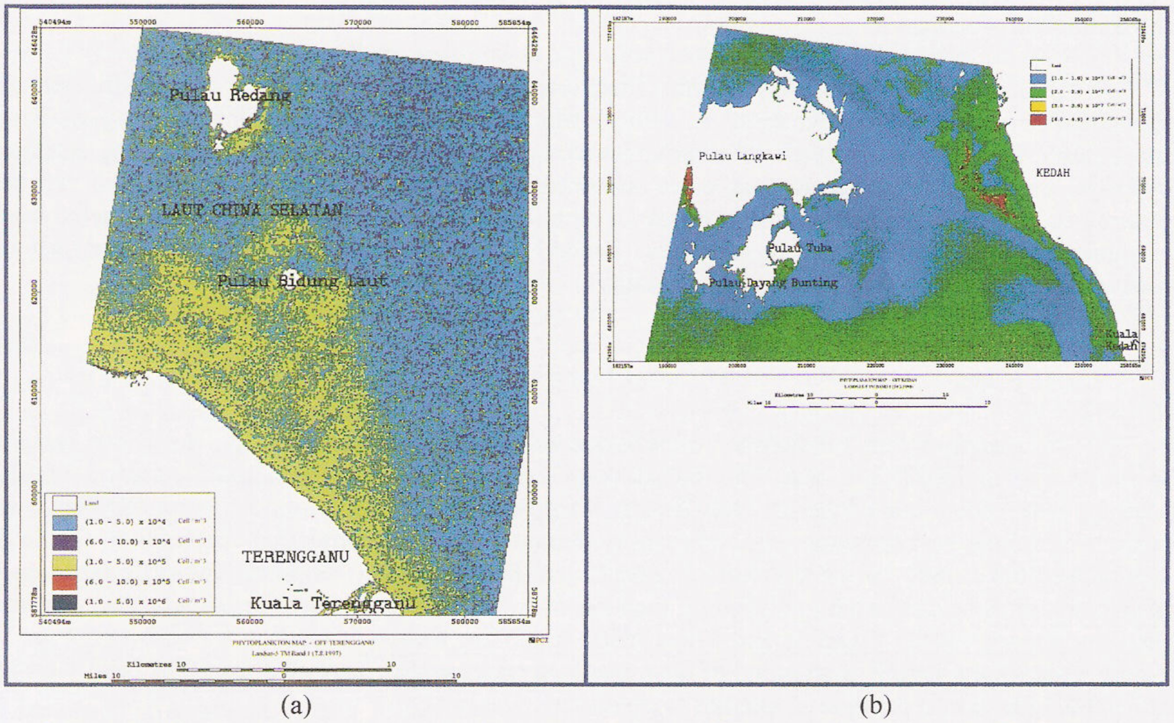


Figure 3. The distribution of phytoplankton extracted using Landsat-5 TM band 1 (a) Terengganu and (b) Kedah.

3.2. Sea-grass

Table 4 shows the accuracy of sea-grass position compared between measured sea-grass location (sampling) and location extracted from satellite data. Root Mean Square Error (RMSE) was computed to the ratioed bands which gave higher relationship based on r^2. The ratio of bands 3 and 1 was the best ratioed band to extract distribution of sea-grass compared to the ratioed band 2 and 1. Figures 4 and 5 show the distribution of sea-grass information at both study areas extracted using ratio of bands 3 and 1. The image map indicates that sea-grass information are easily found at only shore areas.

Table 4. Accuracy analysis of extracted sea-grass.

Study area	Ratioed Band	Sea-grass relationship based on r^2	Position error (RMSE in meter)
Terengganu	$\frac{Band2}{Band1}$	56 %	Not computed due to inferior r^2
	$\frac{Band3}{Band1}$	81 %	10.881
Kedah	$\frac{Band2}{Band1}$	50 %	Not computed due to inferior r^2
	$\frac{Band3}{Band1}$	75 %	13.376

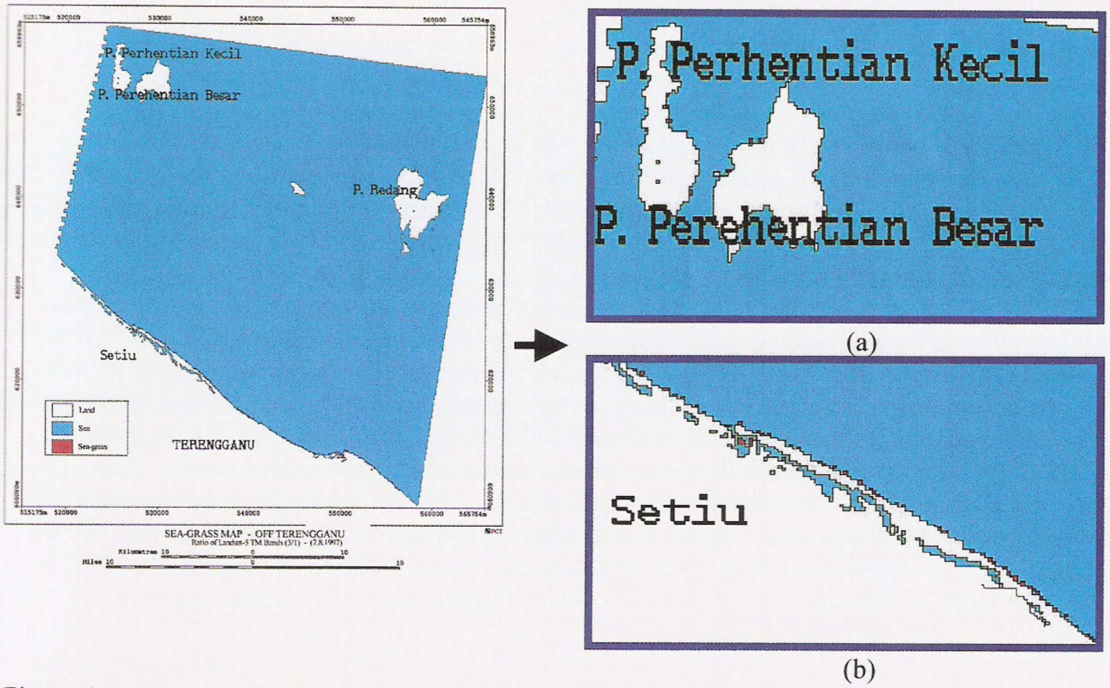


Figure 4. Sea-grass distribution computed from ratio of Landsat-5 TM bands 3 and 1 Terengganu, (a) sea-grass at Pulau Perhentian Besar, Pulau Perhentian Kecil, and (b) sea-grass at Kuala Setiu.

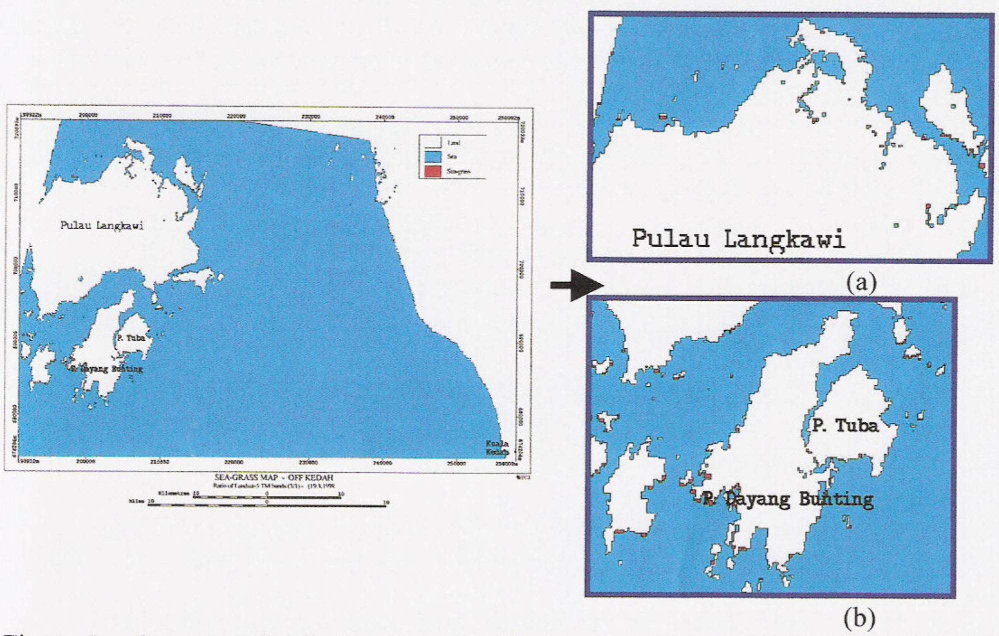


Figure 5. Sea-grass distribution computed from ratio of Landsat-5 TM bands 3 and 1, Kedah, (a) Sea-grass at northern part of Pulau Langkawi, and (b) sea-grass around Pulau Dayang Bunting and Pulau Tuba.

4. Summary

Mapping phytoplankton and sea-grass distribution using Landsat-5 TM data have been described in this study. Band 1 of Landsat-5 TM was found to be the best band to extract the distribution of phytoplankton. Lower spatial resolution satellite data such as NOAA AVHRR were also used to derive regional distribution of phytoplànkton (Rasib *et al.* 1998), and the results of the study showed that the visible band 1 produced the best output. In addition, this study also revealed that the ratioed index used by Mayo *et.al* (1995) for deriving chlorophyll concentration within sheltered lake environment are inferior for extraction of ocean colour or phytoplankton within coastal areas.

The ratio of bands 3 and 1 of Landsat-5 TM was identified as the best input for extraction of sea-grass information based on substrate reflectance model. The customization of substrate reflectance model of Bierwirth *et al.* (1993) is more sensitive to depth variations compared to previously employed depth invariant indices reported by Hashim *et al.* (1997).

This study demonstrates the opportunities for extracting macro and micro levels of ocean colour from operational remote sensing satellite systems in the short visible bands i.e NOAA AVHRR and Landsat-5 TM. However, the availability of such good quality data in short visible bands are often affected by atmospheric constituents such as clouds, water vapour, etc., hence limiting such application to only extremely good quality data. The sea-grass information can be extracted using relatively high resolution satellite data (micro level information) such as Landsat-5 TM as demonstrated in this study. This is due to the reason that the physical occurrence of sea-grass habitat was found clustering less than 50 meters (average) in both study areas, thereby limiting the use of lower resolution satellite data for sea-grass mapping.

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