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Remote sensing and zonation of seagrasses and algae along the Kenyan coast

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Abstract

Little information has been published on space-borne remote sensing of seagrasses, and no information is available about the distribution of seagrasses and algae in East Africa. Through satellite remote sensing this study investigates the distribution of these plants along a southern section of the Kenyan coast. The visible bands (red, green and blue) and the near infra-red band of a Landsat Thematic Mapper image acquired in 1992 were combined in order to detect seagrasses and algae in 10 sectors along the section of the coast. Ground truthing was done at three locations along the same section. Results indicate that two distinct zones of vegetation can be recognised, and ground truthing reveals their identity is rocky substrate with mostly algae and seagrasses, respectively. The extent of the vegetation in the two zones has been quantified in square kilometres for the 10 sectors. However, care is needed in the interpretation of the satellite images when dealing with artefacts such as clouds. The zonation of the algal vegetation is discussed for one of the study sites.

Introduction

Seagrass ecosystems are one of the most widespread coastal vegetation types in the world. They protect shorelines against erosion in the middle and lower intertidal and subtidal zones, because of their gregarious growth and dense root systems. Mangroves, which are often associated to seagrass meadows (Hemminga et al., 1994; Slim et al., 1996; Marguillier et al., 1997), have a similar function in the upper intertidal zone. One of the most significant roles of seagrass ecosystems is their contribution to detrital or energy pathways, involving a diversity of organisms with complicated food interrelationships (Burell & Schubel, 1977). Seagrasses are efficient in removing nutrients from marine waters and surface sediments and are, therefore, critical plants important in the control of water quality of coastal waters (Patriquin, 1972). They are also known to accumulate and stabilize sediments from the surrounding environment (Ginsberg & Lowenstam, 1958; Fry et al., 1983). Seagrass meadows are among the most productive biological systems, producing between 500 and 1000 g C m^{-2} yr^{-1} (Fenchel, 1977) with known peaks up to 1606 g C m^{-2} yr^{-1} (4400 mg C m^{-2} d^{-1}) in Sulawesi (Erftemeijer et al., 1993). Fresh seagrasses are a direct food resource to sea urchins, fishes, dugongs, geese and ducks, and when decomposing, insect larvae and amphipods can feed on them (den Hartog, 1977; Pinto & Punchihewa, 1996). Often epiphytic algae growing on seagrasses are important as a food resource for seagrass macro-invertebrates. Seagrass

ecosystems offer a supply of food for both grazers of these epiphytic algae (Leber, 1985) and larger herbivores that graze directly on living seagrasses (Thayer et al., 1984). Some organisms also benefit from the shelter and nursery functions of seagrass beds (den Hartog, 1977; Perkins-Visser, 1996; Irlandi, 1997). It is clear that the importance of the seagrass ecosystem cannot be neglected, and the need for mapping their distributions is evident.

Since Ascherson (1871) published the first seagrass distribution map, numerous scientists have investigated the global distribution of seagrasses (among others Ostenfeld, 1915, 1918, 1927a,b; Setchell, 1920; Moldenke, 1940, Den Hartog, 1964, 1967, 1970). Yet, scientific literature on country-wide distribution and zonation of seagrasses is rather limited. Only recently, as a result of the improvement of remote sensing techniques, aspects of distribution and dynamics of the seagrass ecosystem have been documented (among others Ferguson et al., 1993; Sargent et al., 1995; Ferguson & Korfmacher, 1997; Robbins, 1997; Ward et al., 1997). The majority of remote sensing investigations are conducted using optical images, which can be subdivided into satellite images, mostly used for macro-scale studies (e.g. world-wide or country-wide distribution), and aerial photographs, which are more suitable for investigations on micro-scale (e.g. zonation at a certain location).

Of the 12 seagrass genera presently recognised world-wide, seven are characteristic of tropical seas, namely *Cymodocea*, *Enhalus*, *Halodule*, *Halophila*, *Syringodium*, *Thalassia* and *Thalassodendron* (Phillips & Meñez, 1988), including the Kenyan coast (Coppejans et al., 1992). In Kenya the seagrass zonation of a single bay (Gazi Bay) has been described, but on country-scale no data seem to be available on their distribution. As is also true for other coastal vegetation such as mangroves, it is necessary to recognize the importance of getting seagrass distributional data published from some of the less studied areas in the world such as Kenya. The aim of the present study is to preliminarily determine the distribution and zonation of seagrasses and algae along a section of the Kenyan coast, through remote sensing.

Description of the sites studied

Our study area reaches from just south of Mtwapa Creek in the north to Funzi Bay in the south of Kenya (Figure 1). This area has been subdivided into 10 overlapping sectors (and 3 creeks) with the specific area of interest located between the beach and the coral reef, i.e. the main habitat for tropical seagrasses. On three locations field work was carried out to ground-truth the remotely sensed data, namely Diani Beach, Shelly Beach and the specific part of Kenyatta Beach called Iwatine Bay. Data from earlier studies conducted in Gazi Bay by Coppejans et al. (1992) complemented our ground-truth data.

Diani Beach (04° 20′ S, 39° 33′ E) is characterised by a large white sandy beach, followed by two zones of marine flora. One of the zones is exposed to the air at low tide and is composed of dead coral which once formed the natural reef barrier, while the other zone is almost permanently flooded by the water and mainly consists of seagrass beds. Shelly Beach (04° 06′ S, 39° 40′ E) is an intertidal platform of which only the high mid-littoral is emergent at neap low tide. The lower part is then flooded by approximately 30 cm water, so that one can walk to the coral reef located at about 900 m from the mainland. Iwatine Bay is the subhorizontal area of Kenyatta Beach extending over about 880 m × 550 m north-west of Ras Iwatine (04° 01′ S, 39° 44′ E). Finally, Gazi Bay (04° 25′ S, 39° 30′ E) is a semi-open bay fed by two small seasonal rivers. The intertidal flat, especially at spring low tide when most of the infralittoral fringe is emergent, slightly slopes towards the tide channel and the large shallow lagoon (−0.5–−3 m at spring low tide).

Materials and methods

Remote sensing

A TM satellite image of 26 June 1992 was obtained from the EAF/14 Project, founded within the framework of the 1985 UNEP-brokered Eastern African Action Plan for the Protection, Management and Development of the Marine and Coastal Environment of the East African Region (EAF), under the title of Eastern African Coastal and Marine Environment Resources Database and Atlas.

It is known that water penetration and chlorophyll detection in remote sensing could all be done using TM bands 1, 2 and 3 (Khan et al., 1992; Bierwirth et al., 1993; Zainal et al., 1993; Ahmad & Neil, 1994). Therefore, Diani Beach (hereafter called ‘identification site’), where a permanent seagrass-zone occurs, was sought on the satellite image using clearly recognisable anthropogenic features. Two homogeneous

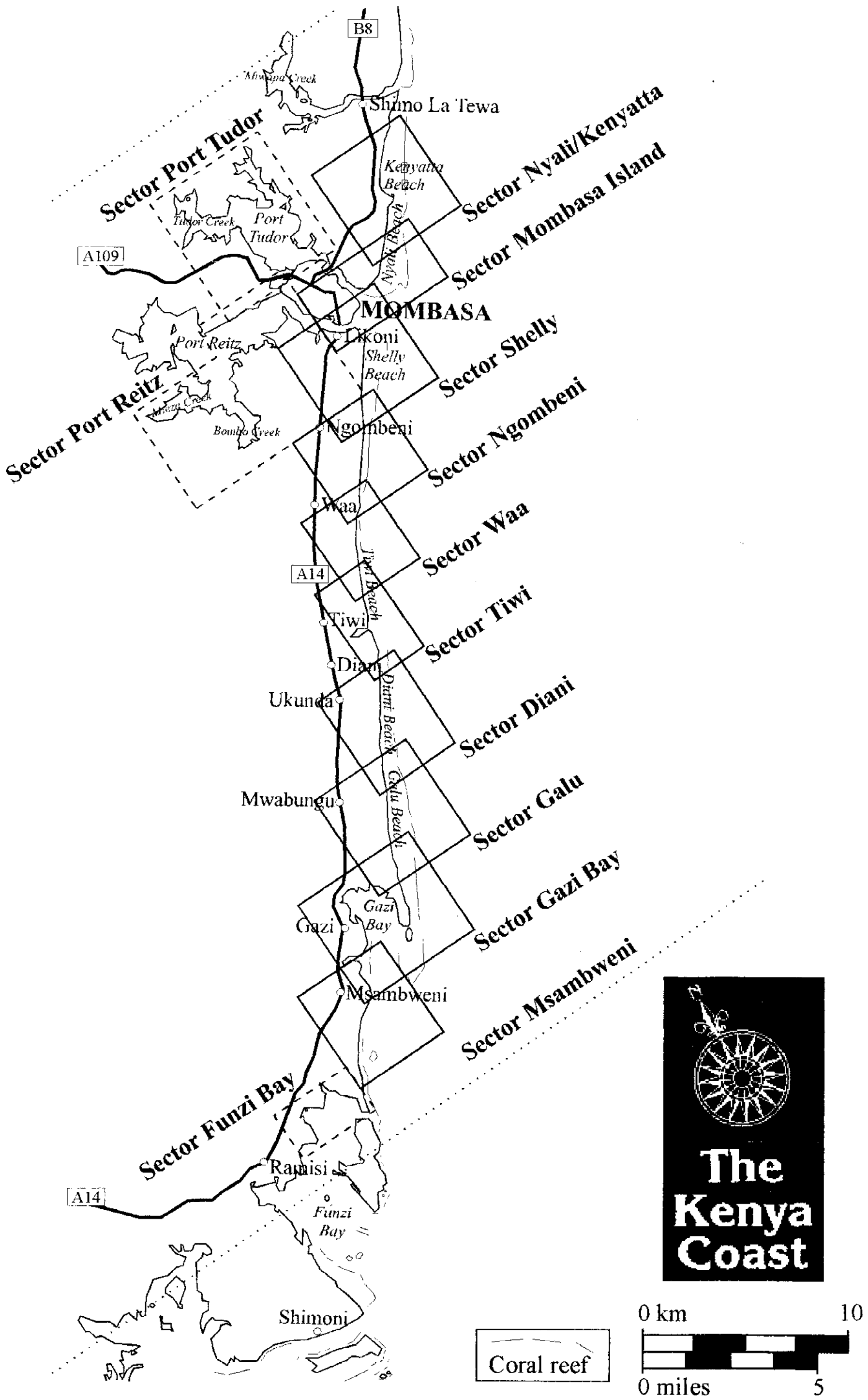

Figure 1. Part of the Kenya coast approximately showing the edge of the original satellite image (spotted line) and its division in 10 overlapping sectors. The separately chosen creeks are surrounded by a dashed line.

zones could clearly be distinguished on TM band 1, 2 and 3 at the identification site and both of them were outlined by manual construction of a polygon following the distinct zones as closely as possible. The polygon outlining the most landward zone (hereafter called ‘Zone 1’) comprised 234 image pixels, which correspond with an area of 0.15 km^2, while the most seaward zone (hereafter called ‘Zone 2’) comprised 439 pixels, equalling 0.27 km^2. The pixel values were recorded in TM band 1, 2 and 3 for each zone; their total range is between 0 (=black) and 255 (=white). The minimum and maximum pixel values detected in Zone 1 were 73 and 119 (mean value = 79.4 $\pm$ 7.5), 27 and 60 (mean value = 33.0 $\pm$ 5.0) and 22 and 72 (mean value = 28.6 $\pm$ 6.4) for TM band 1, 2 and 3 respectively. For Zone 2 they were 68 and 86 (mean value = 74.6 $\pm$ 2.7), 25 and 36 (mean value = 27.8 $\pm$ 1.6) and 19 and 28 (mean value = 22.4 $\pm$ 1.3). Using the process of density slicing (in the public domain program *NIH Image 1.52*), pixels falling within these confidence intervals for each TM-band were screened on the rest of the satellite image for the different sectors (Figure 1). Of the resulting three maps a final overlay map was made selecting only those pixels highlighted throughout the TM bands.

Whereas in common distribution maps, image pixels show presence and absence of a certain characteristic, here, the aim is to produce distribution maps with pixels also showing different probabilities of equal identification (relative to the pixels in the identification site). Therefore, as described and applied by Hoaglin et al. (1983), the trimmed mean (denoted T(α), α being the percent discarded from the tails of the distribution) was applied to the original confidence intervals for four values: T(5), T(2.5), T(0.5) and T(0). Each of the resulting confidence intervals were then adopted to redo the density slicing in each of the TM bands for both Zone 1 and Zone 2. The resulting four distribution maps (for each zone) were then coloured in grey values, ranging from dark grey for the map resulting from the T(5) confidence interval up to light grey for the map resulting from the T(0) confidence interval and white for the non-selected areas. Finally, the distribution maps were superimposed to produce one map for each zone, and this map was combined with the TM band 4 (near infrared) in order to clearly discriminate between land (coloured in black) and water bodies (coloured in white and grey-values as described above). To avoid interference between vegetation and clouds, the latter have also been coloured black. Clouds can be identified effectively from TM band 4.

In order to quantify the amount of vegetation present the areas covered by the distribution polygons have been calculated for each coastline sector and for each zone.

Ground-truth

Field work was carried out in September 1991 (Iwatine Bay) and July 1997 (Diani Beach and Shelly Beach), in the same season in which the satellite image was taken. During these ground truthing efforts, the emphasis was on the floristic composition and zonation in specific areas which were traced on the remote sensing maps.

Iwatine Bay

The seagrass and associated macroalgal vegetation at Iwatine Bay were investigated along five transects, perpendicular to the water front. At 10 m intervals along the transects small quadrats of 25 $\times$ 25 cm were established and the vegetation described using the Londo-scale (Londo, 1975). The dimensions of the quadrats were based on the concepts of minimal area and species-area curves (Cain, 1938; Coppejans & Boudouresque, 1975). Through additional use of a theodolite, which allowed accurate measurements of the height above datum, a vegetation map could be constructed.

Diani Beach

The two zones recognised on the satellite image were studied in a 30 m wide belt transect, by foot for the intertidal (Zone 1) and by snorkelling for the submerged zone (Zone 2), recording the species present in each zone.

Shelly Beach

Shelly Beach was investigated by drawing and delineating the vegetation patches and sand banks on a 250 $\times$ 500 m area in the field. Then a belt transect of 100 $\times$ 540 m was covered by wading, and the vegetation patches were analysed on their species composition.

Results

Remote sensing

Figure 2 shows the distribution maps of the vegetation of Zone 1 (a) and Zone 2 (b) for the most northern sectors, the sectors between Shelly Beach and Galu and

the most southern sectors respectively. Several general features were recognised:

1. About 40% of the maps show artefacts under the form of ribbons, the latter defined as the regular pattern of lines in the image which are obviously not of natural origin;
2. Clouds provide artefacts, i.e. they display the same pixel values as seagrasses;
3. The distribution polygons almost never extend beyond the coral reef;
4. The closed creeks hardly contain any distribution polygons;
5. The distribution polygons are dominated by those resulting from the T(5) trimmed mean for the vegetation of both Zone 1 and Zone 2;
6. The distribution polygons for Zone 2 are much larger than the distribution polygons for Zone 1;
7. With a few exceptions distribution polygons for Zone 1 appear in a narrow strip (about 3 image pixels wide) near the mainland and distribution polygons for Zone 2 do not appear in that area.

The quantification of the distribution polygons is shown in Table 1. A distinction was made between gross area and net area, which equal quantification with and without the artefacts respectively (see above and caption Table 1).

Ground-truth

Iwatine Bay

The results for the occurrence of the different seagrasses and associated macroalgae are given by analysis of four zones:

First, upper intertidal between 270 and 200 cm above datum. This zone is exposed to strong water currents resulting in sand-free rock substratum covered by macro-algae. *Monostroma* sp. exclusively occurs in this zone. *Cladophoropsis sundanensis* Reinbold, *Laurencia perforata* (Bory) Montagne and *Valonia aegagrophila* C. Agardh are found in this zone but occasionally also grow slightly lower. *Enteromorpha kylinii* Bliding *sensu* Dawson, which can be found as far as the infralittoral, reaches its upper limit in the high intertidal zone. Less common species in this zone are the epilithic algae *Acrocystis nana* Zanardini, *Centroceras clavulatum* (C. Agardh) Montagne (also an epipsammic species; pers. obs.), *Cladophora mauritiana* Kützing, *Caulacanthus ustulatus* (Mertens) Kützing and *Lophosiphonia reptabunda* (Suhr) Jaasund.

Second, mid intertidal between 200 and 140 cm above datum. The substratum in this zone consists of fossil coral which is locally covered by a sand layer of less than 15 cm. The fossil coral as well as the hard substratum covered by a thin (<1 cm) sand layer, is largely covered by epilithic algae such as *Acanthophora spicifera* (Vahl) Børgesen, *Boergesenia forbesii* (Harvey) Feldmann, *Cladophora mauritiana*, *Cystoseira myrica* (Gmelin) C. Agardh, *Gracilaria salicornia* (J. Agardh) Dawson, *Laurencia obtusa* (Hudson) Lamouroux, *L. papillosa* (Forsskål) Greville and *Padina boryana* Thivy. The epilithic algae *Amphiroa fragilissima* (Linnaeus) Lamouroux, *Dictyosphaeria cavernosa* (Forsskål) Børgesen, *Jania adhaerens* Lamouroux, *Sarconema filiforme* (Sonder) Kylin *sensu* Pepenfuss & Edelstein and *Turbinaria conoides* (J. Agardh) Kützing, together with the intertwined *Chaetomorpha crassa* (Agardh) Kützing and the sand fixating *Lyngbya majuscula* (Dillwyn) Harvey can be found in this zone and also in the lower zone. Where the sand layer reaches a minimal thickness of 1 cm, seagrasses such as *Halodule wrightii* Ascherson and *Thalassia hemprichii* (Ehrenberg) Ascherson can establish; this is their upper limit. *H. wrightii* typically forms a dense fringe around small sand-covered rock pools whereas the bottom of the pools can be covered by *Cymodocea rotundata* Ascherson & Schweinfurt. *Ulva pertusa* Kjellman is very well developed in this zone, particularly in the small run-off channels of the steeper lower part of this zone. *Cladophora mauritiana*, *Boodlea composita* (Harvey) Brand, *Ceramium taylorii* Dawson, *Polysiphonia coacta* Tseng and *Lophosiphonia reptabunda* also occur in this zone, although being less frequent.

Third, low intertidal between 140 and 20 cm above datum. Only small patches of rocky substratum occur, covered with common algae such as *Enteromorpha kylinii*, *Ulva pertusa* and *U. reticulata* Forsskål, or with species reaching their lower intertidal limit, such as *Chaetomorpha crassa*, *Jania adhaerens*, *Padina gymnospora* (Kützing) Vickers, *Hypnea cornuta* (Lamouroux) J. Agardh, *Sarconema filiforme* and *Turbinaria conoides*. *Jania adhaerens*, *Hypnea cornuta* and *Amphiroa fragilissima* also grow as epiphytes on the base of larger seagrasses which develop in pools of this zone, especially *Cymodocea serrulata* (R. Brown) Ascherson & Magnus and small specimen of *Thalassodendron ciliatum* (Forsskål) den Hartog.

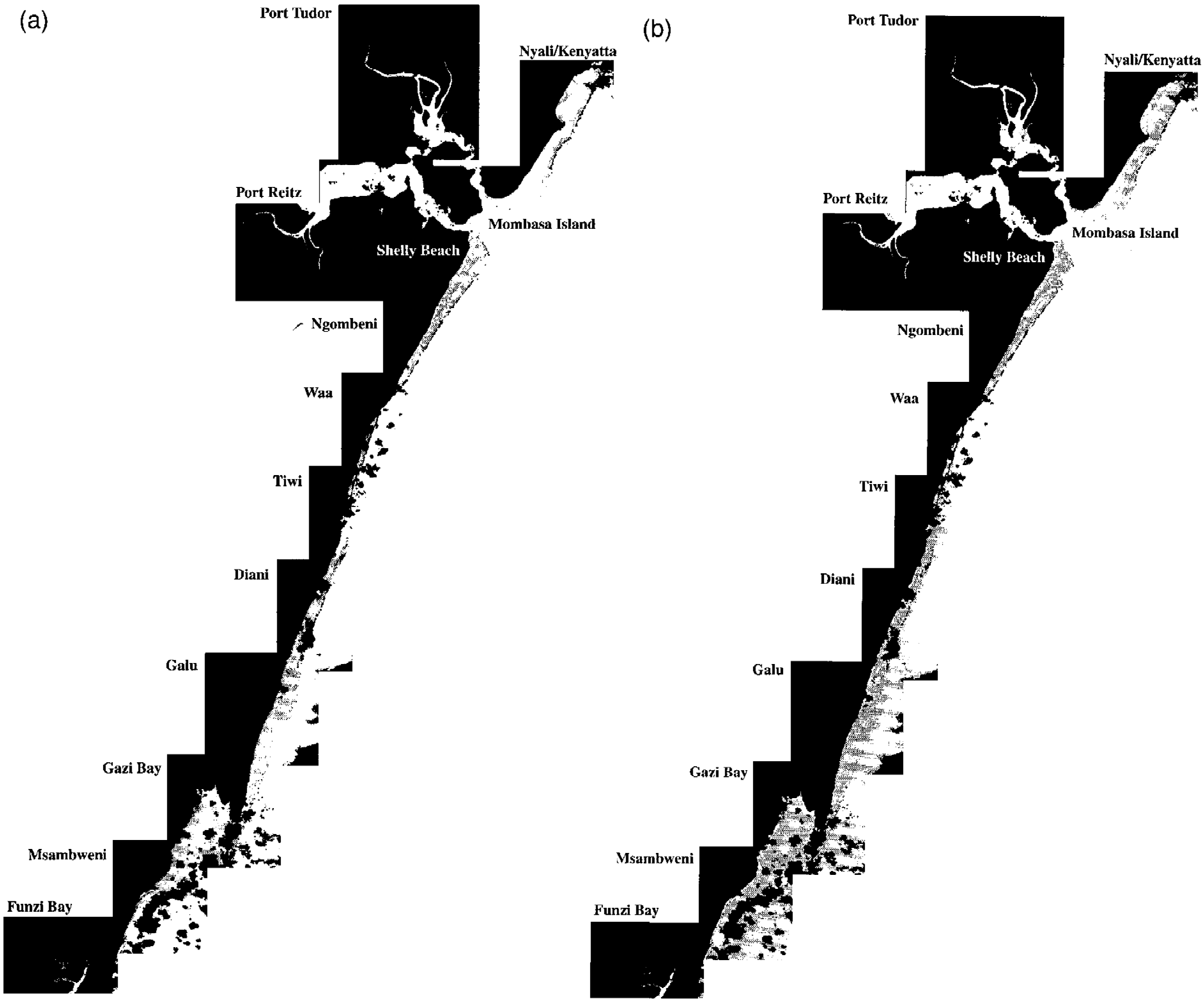

Figure 2. Distribution maps of the vegetation of Zone 1 (Figure 2a), mainly rocky substratum with algae and seagrasses, and Zone 2 (Figure 2b), mainly *Thalassodendron ciliatum*, for all the sectors (*cf.* Figure 1). Consult 'Material and Methods' for the explanation of the origin of the four different grey values and 'Results' for a detailed identification of the zones. (Close-up for each sector available from the corresponding author.)

The major part of this low intertidal zone is covered by a thick sand layer, and thus suited for epipsammic algae such as *Lyngbya majuscula*, but mainly characterized by the seagrasses *Halodule uninervis* (Forsskål) Ascherson and *Halophila ovalis* (R. Brown) Hooker f. (colonizing species on recently sand covered substratum) and dense *Thalassia hemprichii* stands on stabilized soft substratum, with *Cymodocea rotundata* in shallow pools. At the lower fringe of this zone *Halophila stipulacea* (Forsskål) Ascherson appears as a colonizer, whereas *Cymodocea serrulata* and *Syringodium isoetifolium* (Ascherson) Dandy appear as isolated patches between which the green alga *Halimeda opuntia* (Linnaeus) Lamouroux grows as extended cushions. *H. macroloba* Decaisne grows in isolated, open populations. *Dictyota humifusa* Hörnig, Schnetter & Coppejans, *Dictyota ceylanica* Kützing and *Dictyota cervicornis* Kützing f. *pseudohamata* (Cribb) De Clerck & Coppejans have their upper intertidal level in this zone. *Hydroclathrus clathratus* (C. Agardh) Howe can locally be abundant.

Fourth, midlittoral below 20 cm above datum (= infralittoral fringe) and infralittoral. *Gracilaria corticata* J. Agardh and *Dictyosphaeria cavernosa* have both their upper and lower limit in this zone, rendering them a height indicator. The former is frequently observed as an epiphyte on the seagrass *Thalassodendron ciliatum*. Between medium and spring low water (infralittoral fringe) *Syringodium isoetifolium* and

Table 1. Quantification of the vegetation present in the respective sectors and zones, with their overlap. The gross area corresponds with the T(5) interval and the net area equals the gross area without the artefacts (see results). The overlap (in%) between the distribution polygons of Zone 1 and Zone 2 are the areas that are highlighted by the image pixels of the distribution polygons resulting from the T(5) trimmed mean in Zone 1 as well as in Zone 2. Note that there also exists an overlap between the sectors and, therefore, the total area covered for each zone is different from the sum of the areas of all sectors

Sector	Vegetation of Zone 1		Vegetation of Zone 2		Overlap
	gross area (km^2)	net area (km^2)	gross area (km^2)	net area (km^2)	percentage
Nyali / Kenyatta	1.43	1.13	4.09	2.97	8%
Mombasa Island	0.21	0.20	1.33	1.24	6%
Shelly	2.23	2.22	3.90	3.80	16%
Ngombeni	2.23	2.21	3.05	2.99	21%
Waa	0.51	0.31	1.08	0.37	7%
Tiwi	0.87	0.53	2.85	1.34	9%
Diani	1.95	1.07	4.05	1.81	14%
Galu	2.47	0.96	9.33	4.44	11%
Gazi Bay	3.05	1.65	4.22	2.67	22%
Msambweni	2.64	1.00	10.77	3.99	8%
Total	14.39	9.94	35.58	23.69	12%

Cymodocea serrulata form extensive seagrass meadows. Lower down (subtidal) *Thalassodendron ciliatum* becomes dominant and extends for hundreds of meters beyond the low water line in the lagoon. *Syringodium* and *Cymodocea serrulata* are still present as well as the colonizing seagrass species *Halophila stipulacea* and the algae *Halimeda opuntia* and several *Caulerpa* species.

Diani Beach

Both zones recognised on the satellite image correspond with two distinct zones in the field. The upper zone is characterised by rocky substratum (dead corals) provided with crevices, filled with sand or not, forming small pools at low tide. The seagrasses in this zone were mainly represented by *Thalassia hemprichii* on the inundated areas at low tide and *Thalassodendron ciliatum* in the pools, but also species belonging to the genera *Halodule* and *Cymodocea* were present. The algal community here was dominated by *Ulva pertusa*.

The lowermost zone is permanently flooded by the ocean and the vegetation consists of seagrass vegetation exclusively composed of *Thalassodendron ciliatum*, occasionally interrupted by a local, bare sand bank.

The genera *Halophila*, *Syringodium* and *Enhalus* were not observed at this site.

Shelly Beach

Shelly Beach conspicuously displays a mosaic of light and dark patches (Figure 2a,b). Ground-truthing confirmed that light patches generally correspond with sand banks, locally covered by *Halodule wrightii* or by sparsely spread *Thalassia hemprichii*. Also patches covered with the bigger growth form of *T. hemprichii* could appear relatively light. The dark patches of the upper 540 m of this site were dominated by small *T. hemprichii* specimens. Visual observation revealed that there was a trend for *T. hemprichii* to be larger when submerged in pools.

At 500 m from the beach, the first *Thalassodendron ciliatum* specimens were found. Further towards the coral reef sand banks are more numerous.

The high midlittoral zone is characterised by rocky substratum on which a similar algal vegetation develops as in Iwatine Bay and on the sand-covered parts seagrasses develop. In the lower zones, algae

were only found occasionally and the dark patches generally were dominated by seagrasses.

Discussion

The distributional features which can be seen from the maps in Figure 2 (see results) can be explained. The ribbon artefacts are innate to the satellite image and originate from the acquisition and processing steps of Landsat TM data to correct for satellite motion (Lillesand & Kiefer, 1994). Therefore, the areas in between two ribbons and the different grey values corresponding with the confidence intervals of the various trimmed means should be considered during interpretation. A similar caution is needed for cloudy areas, since they interfere with the pixel values identified as marine vegetation in Diani Beach (mainly seagrasses). This is illustrated by Figure 2b, where clouds far beyond the coral reef, and as a consequence far beyond the limits of seagrass distribution, apparently wrongly seem to be surrounded by seagrass vegetation. The same applies to the ribbon artefacts.

Considered the artefacts discussed above, it can be seen that the polygons actually representing the seagrass (and associated macroalgal) vegetation never extend beyond the coral reef, which is a good indication for the validity of the identification of the zones at Diani Beach, since seagrasses usually occur between the beach and the coral reef. The same is true for the apparent absence of distribution polygons in the closed creeks: seagrasses are marine plants which can hardly survive the surface freshwater running into the creeks.

Since the T(2.5), T(0.5) and T(0) polygons do not add substantial information to the dominant T(5) polygons on the distribution map, the homogeneity of the zones outlined at the identification site is confirmed. This was also visible from the low standard deviations of the pixel ranges of the three TM bands (see material and methods). The wider spread of the distribution polygons based on ‘Zone 2’, and the general appearance of ‘Zone 1’-based distribution polygons in a narrow strip along the coast (Sector Diani in Figure 2a,b), reflect the similar situation at the identification site.

Field work in Diani Beach proved that only Zone 2 (Sector Diani in Figure 2b) corresponds with a pure seagrass bed, namely one composed of *Thalassodendron ciliatum*. The huge *T. ciliatum* meadow facilitates the interpretation of the Zone 2 based distribution maps when considering the image pixel resolution of 30×30 m, because on this surface all the space is occupied by this particular species. Zone 1 leads to a slightly different situation: there a surface of 30×30 m contains rocky and sandy substrate, mostly covered with different seagrasses and algae. This must be considered when interpreting the ‘Zone 1’-based distribution maps.

Shelly Beach and Iwatine Bay test the validity of the distribution maps. The ground truth data from Shelly Beach accurately describe the very patchy distribution of the vegetation seen on the distribution map (Sector Shelly Beach in Figure 2a,b). When comparing Sector Shelly Beach in figure 2a and 2b, it can be seen that the two maps complete each other, i.e. Zone 1 vegetation is present where Zone 2 vegetation is absent and *vice versa*. However, a small contradiction exists when analysing figure 2b for this sector. On one hand, the greater part of this map shows that the vegetation, which according to the identification site corresponds with *Thalassodendron ciliatum*, is present even in the midlittoral zone. The field work on the other hand, describes that the first *T. ciliatum* specimens were found 500 m away from the beach. This discrepancy may be attributed to a possible mistracing of the transect on the distribution map, or, as will be emphasised further, be the consequence of optical interference.

From a detailed map of the Nyali/Kenyatta sector, the area of Iwatine Bay was used in an overlay with the vegetation map drawn from the results of the transects (Figure 3). It can be seen that the distribution polygons for the vegetation of Zone 1 indeed correspond with vegetation from the intertidal. Similarly, the distribution polygons for the vegetation of Zone 2, i.e. *Thalassodendron ciliatum* beds, more or less cover the infralittoral, where *T. ciliatum* indeed dominates according to the field work in Iwatine Bay. This corresponds with the observations made in Diani Beach.

It is probable that neither the gross nor the net area in Table 1 are correct, but that the true extent of the vegetation lays somewhere between these values, be it considerably closer to the net area than to the gross area for reasons outlined in the discussion of the innate image artefacts. The overlap between the distribution maps of Zone 1 and Zone 2 (Table 1) is more peculiar. According to our methodology we expect Zone 1 vegetation to be present where Zone 2 vegetation is absent and *vice versa*, or absence of all vegetation on a given location. In addition to these three situations we also find presence of both vegetation types on specific locations. This is contrary to starting from two distinct

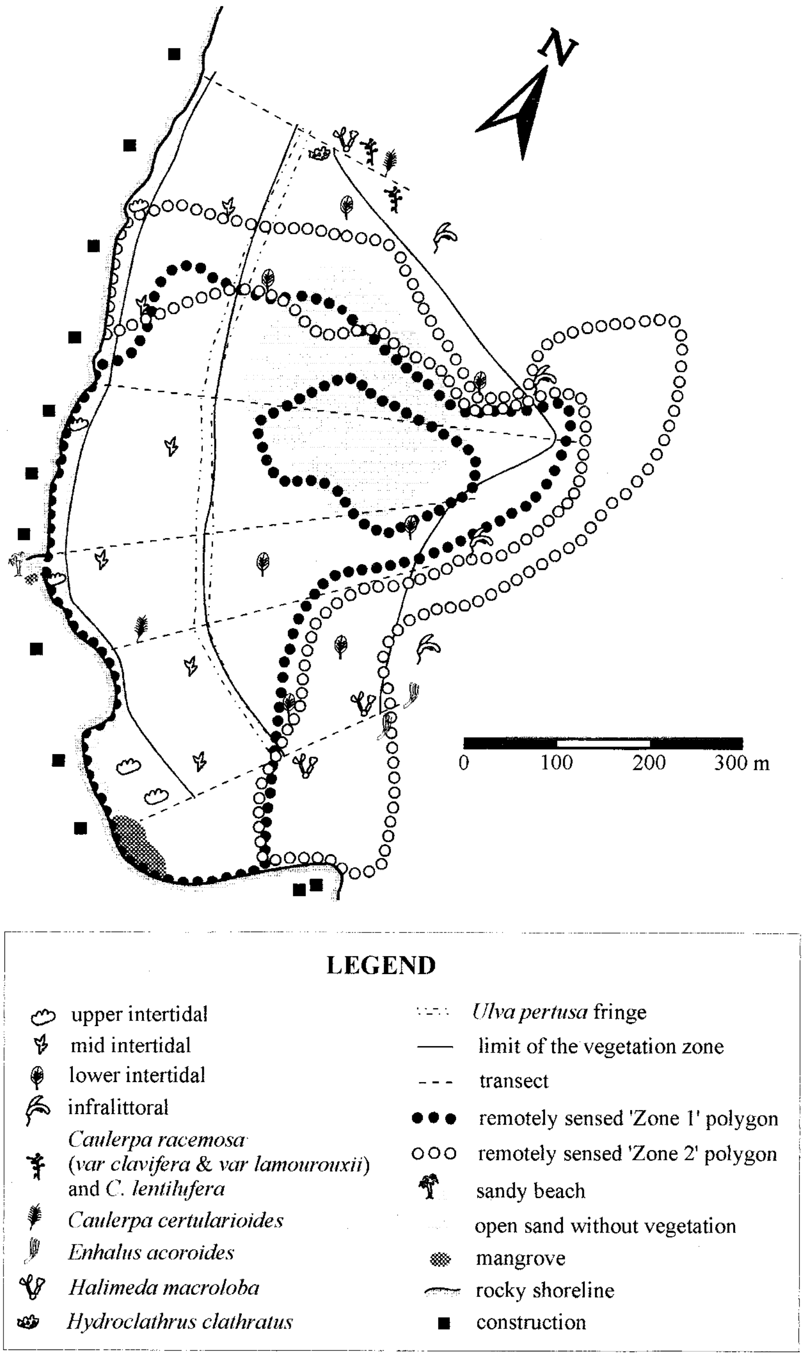

Figure 3. Overlay between a vegetation map drawn from the field work at Iwatine Bay and distribution maps of the vegetation of Zone 1 (black dots) and Zone 2 (white dots).

zones. Three different hypotheses can be put forward to explain this phenomenon:

1. On areas of 30 × 30 m (= resolution of the image) there is enough space for the vegetation of both Zone 1 and Zone 2 to occur;
2. Errors in outlining the zones at the identification site of Diani Beach may have lead to pixels inherent to both Zone 1 and Zone 2 and;
3. An extraneous presence, having the same pixel values as the vegetation of Zone 1 and/or Zone 2, is involved and causes optical interference.

Combination of the first and third hypothesis also implies that different species together, be it from Zone 1, or Zone 2 or both, may interfere with one another and cause optical interference. To give a straightforward answer on this topic of overlap, the reflectance of pure and mixed vegetation stands should be investigated in future research. At the same time special attention should be paid to the confusing effect of water depth on reflectance, which may obscure certain features in the raw data (Bierwirth et al., 1993).

The new seagrass and macro-algal distributional data from Kenya presented in this study provide a preliminary map illustrating the wide extent of these plants, but is limited by the low resolution of the TM data (30 × 30 m). The Enhanced Thematic Mapper Plus (ETM+) and the High Resolution Multispectral Stereo Imager (HRMSI)(Lillesand & Kiefer, 1994), together with the future Japanese ADEOS satellite (Ward et al., 1997) and other technological advancements will yield data with a much higher resolution, which will improve the quality of future mapping results.

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