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Discovery and enumeration of Swahilian Coastal Forests in Lindi region, Tanzania, using Landsat TM data analysis

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Abstract The Swahilian Coastal Forests in eastern Africa are recognised to be a globally important habitat containing large numbers of endemic species, yet are still poorly known over much of their extent. Floristic diversity and endemism in these forests appears to peak in SE Tanzania, where only a few forests have hitherto been surveyed. We carried out a digital analysis of Landsat Thematic Mapper (TM) data to identify other potential areas of Coastal Forest in Lindi and Kilwa Districts, SE Tanzania, followed by a field survey to ground truth and fine-tune our analysis. Our analysis has identified, mapped and sub-classified all remaining areas of Coastal Forest in Lindi and Kilwa Districts, and includes the discovery of a large and hitherto undescribed area of Coastal Forest at Namatimbili, which would make it one of the largest known blocks of contiguous Coastal Forest in eastern Africa. This forest furthermore appears to be minimally impacted by human disturbance. Given the rapidly increasing threats to forested vegetation in this area, urgent efforts are required by the conservation community to ensure the immediate and continued protection of Namatimbili forest.

Keywords Swahilian Coastal Forests · Landsat TM · Tanzania · Satellite analysis · Remote sensing · Namatimbili

Background

The Coastal Forests of eastern Africa can be characterised as an archipelago of highly fragmented lowland forest habitat, occurring up to 300 km inland from southern Somalia to southern Mozambique. These forests are surrounded by

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synanthropic cultivation, fallow and scrub, or fire-maintained sub-climax (and biologically depauperate) woodland and wooded grassland. Located within the Swahilian regional centre of endemism and neighbouring Swahilian—Maputaland regional transition zone (*sensu* Clarke 1998), the Coastal Forests were until recently overlooked by the conservation community (Sheil 1992), but are currently recognised to be one of the top ten priority ecosystems in Africa (Burgess 2000). Together with the neighbouring Eastern Arc montane forests, they are jointly regarded as one of the 25 most important global centres of endemism and ranked as the most important for the conservation of endemic species in the whole of tropical Africa (Mittermeir et al. 1998).

Most (82%) of the known patches of Coastal Forest are less than 15 km^2 in area, and only 19 forests exceed 30 km^2 in extent. Between 1380 km^2 and 3170 km^2 of Coastal Forest is thought to remain throughout eastern Africa, much of which is already severely modified and degraded (Burgess et al. 2000a). This area represents perhaps 5% of the original (holocene) extent of eastern African Coastal Forest. Pressure for fresh farmland, together with an ever-increasing demand for charcoal, as well as uncontrolled bush fires, currently threaten most of the remaining areas of Coastal Forest (Burgess et al. 2000b). Recent improvements in road infrastructure are exacerbating this pressure in SE Tanzania, by opening up areas that were previously remote and relatively inaccessible.

Biological surveys in the area containing Coastal Forest have been highly uneven, focussing mainly on the forest patches occurring in Coastal Kenya and the northern Tanzania coast (cf. Burgess and Clarke 2000, Section 4). With the exception of the Rondo and Litipo Forest Reserves in coastal southern Tanzania (hereafter SE Tanzania), the remaining area that contains Coastal Forest (i.e. from the Rufiji River in Tanzania to southern Mozambique) remains virtually unsurveyed. In spite of this, an analysis of all available botanical data suggests that floristic endemism for the Coastal Forests peaks in SE Tanzania (Bidgood and Vollesen 1992; Burgess 2000; Clarke 1998, 2000).

The scant knowledge of the distribution and status of forest in SE Tanzania (see Clarke 1995 for summary) as well as the logistical difficulties of accessing this remote and isolated area, have meant that biological surveys to date have essentially been limited to (1) the vicinity of the major transport axes, i.e. the Dar es Salaam to Lindi, and Lindi to Songea highways, (2) the relatively well-known Rondo and Litipo Forest Reserves, and (3) areas surrounding sisal plantations (Clarke 2001). Beyond these zones, the vegetation and flora of SE Tanzania have remained virtually unexplored.

The location of most of the forest reserves in SE Tanzania is also rather imprecisely known, and many are incorrectly marked on the relatively new 1:50.000 ordinance survey maps of Tanzania. Botanical and vegetation descriptions are only available for the Rondo, Litipo, Chitoa and Tong'omba Forest Reserves (Vollesen 1994; Clarke 1995).

Earlier satellite analysis (Rodgers et al. 1985) and more recent studies (FAO 1999, 2002) for the region have managed to separate open vegetation types (grassland, wooded grassland, cultivation etc. from closed canopy vegetation formations (forest, thicket, degraded scrub, orchard, etc.) but have been too crude to clearly distinguish the Coastal Forest types. We therefore conducted a detailed vegetation mapping based upon a combination of digital Landsat ETM satellite data and observations from fieldwork, with the aim of identifying and classifying all patches of

Coastal Forest in SE Tanzania. This method has already proved useful for studying tropical forest vegetation elsewhere (e.g. Foody and Hill 1996; Prins and Friis 2005; Tuomisto et al. 1994).

Method

Our study area covered Kilwa and Lindi Districts in Lindi Region, SE Tanzania. This area includes about 280 km of the southern Tanzanian coast line, extending approximately 100 km inland.

An overview of the area was established by Landsat Enhanced Thematic Mapper (ETM) satellite images which were initially interpreted against geo-registered field observations from literature (Eriksen et al. 1994; Faldborg et al. 1991) as well as first-hand knowledge of local vegetation from a number of visits to the area (G.P. Clarke). The digital Landsat TM data consisted of six spectral bands, three of which are visible, one near infrared and two middle infrared with a spatial resolution of 28.5 m. Digital image processing was carried out by the use of ERDAS Imagine 8.6 software (ERDAS 1994). The area required four full Landsat scenes, each covering 185×173 km. Two sets of cloud free scans from the same season, recorded along the same path and day were used; the 30th of June 2000 and the 25th of May 2001.

Already known Coastal Forest segments were identified and categorised according to the latest classification system for these forests (Clarke 2000; Clarke and Robertson 2000). Image enhancement of the satellite data was conducted by using these selected Coastal Forest areas for calculating statistics for histogram equalization contrast settings, which revealed the wide variance of Coastal Forest image contrast/spectral groupings. Subsequently, field maps in 15 m spatial resolution were prepared for ground-truthing and to categorise the areas indicating possible Coastal Forest.

The digital satellite data was geo-rectified to national Universe Transverse Mercator (UTM) maps and later corrected on the ground by the use of a Global Positioning System (GPS) to an overall accuracy of 20 m. Where possible, boundaries of forest reserves and other background information were derived from 1:250.000 digital map layers produced by the University of Dar es Salaam's Institute of Resource Assessment. The position of the forest reserves on these maps, as well as on the national 1:50.000 maps, often proved to be incorrect. Later adjustments were therefore applied to the GIS layers where necessary, primarily from GPS recordings from the field.

The satellite images recorded on the same day were merged using maximum values for overlapping areas (ERDAS 1994). A colour composite image of bands 4, 5 and 3 (red: near infrared band 4; green: middle infrared band 5; and blue: red visible band 3) showed the largest spectral variance.

Two sets of Landsat multispectral data were produced, a 15 m spatial resolution dataset using the 15 m pan-chromatic image, merged with the 28.5 m TM bands and a set of 25 m resolution TM images. The high resolution dataset was used for vegetation interpretation and for generating field maps, while the low resolution was used for digital classification. A supervised digital image algorithm (Jensen 1996) was chosen to classify the satellite data. This method was chosen considering the relatively small variance in spectral reflectance from Coastal Forest vegetation

compared to the surrounding land, and has already been recommended for separating out tropical forest in another study (Moran et al. 1994).

Fieldwork was divided into three phases; (1) an initial three week identification phase to analyse the variance of Coastal Forest identified from the images and not mentioned or only briefly mentioned in literature, (2) a four week phase of detailed botanical collections from four sites not visited during the first phase, and (3) a final four weeks for verifying image classes and collecting additional botanical material from interesting sites identified during the first phase.

Qualitative botanical surveys were conducted at each study site to classify the general vegetation types, and to identify the major tree species present. Sample plots of 60 m × 5 m were constructed at randomised sites identified from satellite images, to determine the structure of the different vegetation types. The exact position of each plot was registered by GPS. Other sample plots were established according to the uniqueness of the vegetation types in the areas. In all 81 plots were constructed where all trees with a Diameter at Breast Height (DBH) of more than 10 cm were registered, and height and crown cover were measured. Most of the trees were identified in the field; samples from unknown species were sent for later identification at a herbarium. All specimens were collected in triplicate. Specimens were sent to the herbaria at the University of Dar es Salaam, Tanzania, the Royal Botanic Garden, Kew, UK, and the Botanical Museum, Copenhagen, Denmark for final identification and future reference.

Sufficient ground-truthed data was obtained from the first two phases of field work to establish representative image segments of the variations in Coastal Forest and the surrounding land cover/use, and to thereby perform a digital supervised classification of the two sets of Landsat scenes. Minimum distance classification (Schowengerdt 1983) was chosen, since not all segments could be established at the same size, and because the spectral variance between some Coastal Forest types was relatively low.

Our field observations documented a large variation in the spectral properties of the satellite data for the mixed scrub forest and mixed dry forest classes already identified by Clarke and Robertson (2000), indicating that these vegetation classes could be sub-divided into several sub-groups according to the differences in their vegetation structure (Hill and Foody 1994). As a result, the Coastal Forest formation sub-types of Clarke and Robertson (2000) could be further separated by our analysis into two variants of legume dominated dry forest, four variants of mixed dry forest and eight variants of scrub forest. The variants proved to differ in terms of their spectral properties as well as their species composition, although the overall field sampling was too small to make any direct and conclusive links between image classes and dominant tree species. However, we found that the image data could clearly separate Coastal Forest into the dry forest, scrub forest, *Brachystegia* forest and maritime scrub forest formation sub-types identified by Clarke and Robertson (2000).

Eventually, the two merged eastern scenes were classified into 49 vegetation and land use classes and the western scenes into 44 classes. Recoding the two sets of scenes into one map containing 36 classes was done partly by merging classes in each image with same output label (e.g. various grass/soil classes) and partly by adjusting classes from the overlap between the two sets of scenes.

Riverine forest was identified in the satellite images by visual interpretation of closed forest along the main water courses, although no statistical separation could

be derived from other closed Coastal Forest types in the digital image classification. Selected areas of riverine forest were therefore digitized to estimate their area.

A final field visit was made to ground-truth the different vegetation classes developed through the analysis. A three pronged approach was adopted by investigating (1) 32 Coastal Forest sites determined through stratified random samling of the recorded areas of Coastal Forest, (2) pre-selected areas/transects where sudden changes in vegetation classes were noted in the analysis, and (3) independent check point sites selected by stratified random sampling from the whole region.

Findings

Our satellite image analysis indicates that much of the vegetation of Lindi and Kilwa Districts has already been transformed by human activity. Large areas of cashew nut orchard and various stages of secondary vegetation are present in these districts, particularly near the coast. Inland areas, which are drier, less accessible, and with a lower human population density, are much less heavily impacted by human activity.

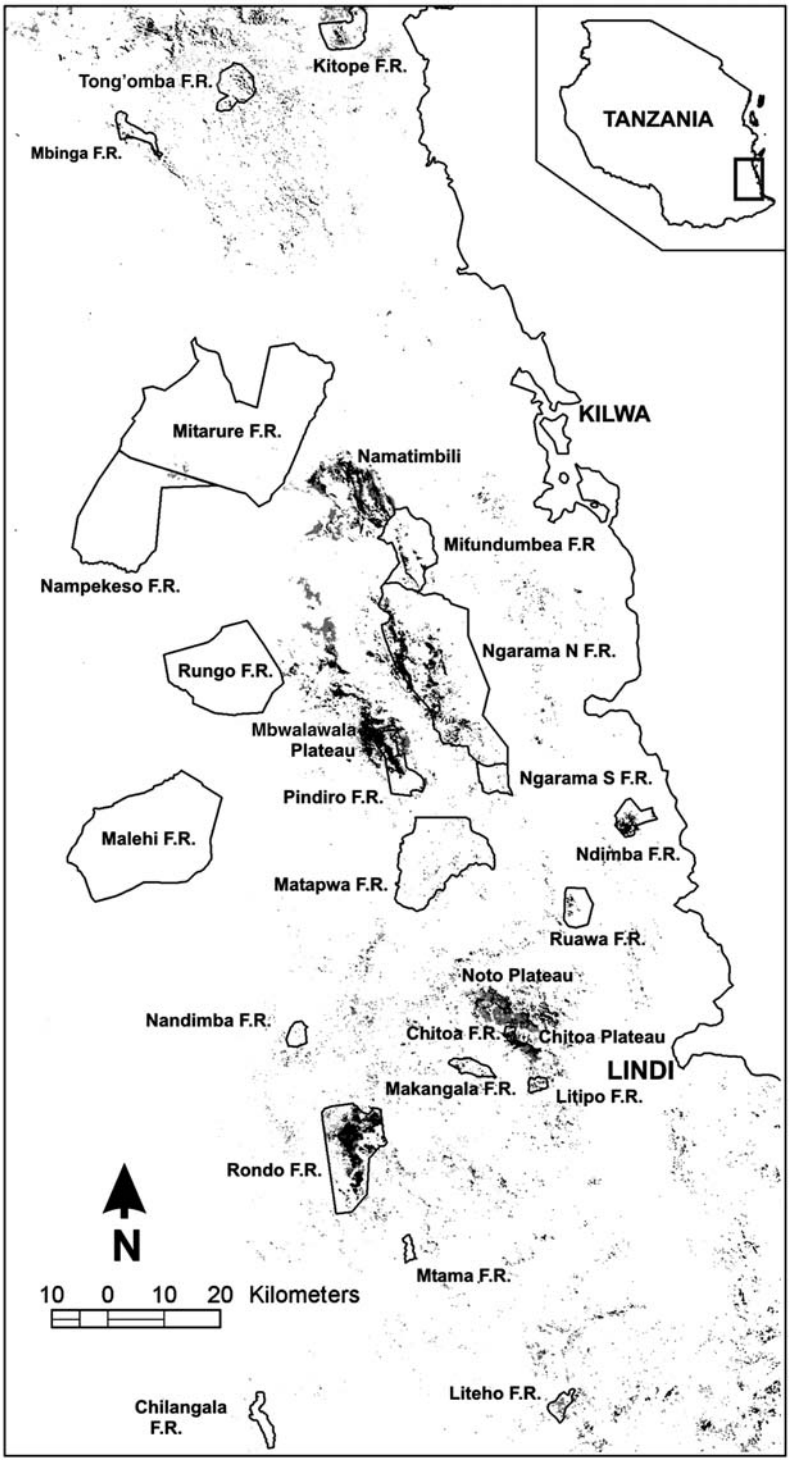
In Kilwa District it is still possible to observe a distinct series of vegetation bands running parallel with the coast. Progressing from inland towards the coast, we were able to observe a general trend towards increasing vegetation density, going from open woodland (mainly miombo), to denser miombo, *Brachystegia* forest (*sensu* Clarke 2000), scrub forest and then Coastal Forest on the series of hills that run along the coast. These hills, which are situated approximately 30 km inland of the coast, form a discontinuous chain in SE Tanzania (Clarke 2001). The moister seaward side of these hills, together with the littoral plain (which contains the main Dar es Salaam-Lindi road), are now too heavily modified by human activity to detect any recurring patterns in natural vegetation.

In Lindi District the remaining patches of Coastal Forests are primarily situated further inland, on and around a series of dissected plateaux to the east of Lindi town. It is believed that Coastal Forests previously had a much greater extent on these plateaux (Clarke 2001).

Our analysis indicates (Fig. 1 and Table 1a, b) that ca. 380 km^2 of Coastal Forest vegetation (main formation types and sub-types) still exists in Lindi and Kilwa Districts, of which just 120 km^2 consists of well developed mixed dry or legume-dominated dry forest (*sensu* Clarke and Robertson 2000). More than half of this area is contained within the Namatimbili forest, the Mbwalawala Plateau and north east of, and also within or close to the north eastern part of the Ngarama Forest Reserve.

The forest mosaic of Namatimbili has never previously been described despite its considerable size and excellent state of preservation, where our preliminary botanical survey discovered several rare species. Considerable areas of unrecorded but well-developed mixed dry forest and legume dominated forest were also located on the Ruwawa plateau, especially in the northern part of Ngarama North FR, where several rare tree species were also collected. The survey confirmed the presence of large areas of scrub forest containing smaller patches of well-developed forest on the Mbwalawala plateau N–NW of the Pindiro FR.

In Lindi district, Ndimba FR was found to comprise a unique stand of dry forest strongly dominated by its endemic species *Cynometra gillmannii*, which is quite different in tree structure and spectral reflectance from other areas of forest, which


TANZANIA
Kitope F.R.
Tong'omba F.R.
Mbinga F.R.
KILWA
Mitarure F.R.
Namatimbili
Mitundumbea F.R
Nampekeso F.R.
Ngarama N F.R.
Rungo F.R.
Mbwalawala Plateau
Ngarama S F.R.
Pindiro F.R.
Malehi F.R.
Ndimba F.R.
Matapwa F.R.
Ruawa F.R.
Noto Plateau
Nandimba F.R.
Chitoa F.R.
Chitoa Plateau
LINDI
Makangala F.R.
Litipo F.R.
Rondo F.R.
N
10 0 10 20 Kilometers
Mtama F.R.
Liteho F.R.
Chilangala F.R.

◀
Fig. 1 Distribution of Swahilian Coastal Forest and Forest Reserves in Lindi region, Tanzania. Closed forest in black and scrub forest in grey

may explain why it has not been mapped as forest in earlier satellite studies (FAO 2002).

On the Noto and Chitoa plateaux there were found considerable amounts of mixed dry and mixed scrub forest. Among these, a tiny patch of mixed dry forest on the edge of the Chitoa FR contained the most well developed and species rich dry forest of all the 81 transects carried out. The two plateaux are currently threatened by selective logging and clearing for shifting cultivation. On the Ruawa plateau forest only remains within the confines of the Ruawa FR, where a species-rich dry forest on ancient coral rag is intersected by the only known stand of *Pandanus rabaiensis* swamp forest south of the Rufiji River.

Small pockets of Coastal Forest still exist in other parts of Lindi District but outside of gazetted forest reserves are all less than 2 km^2 in size. Those not occurring on steep plateau slopes will probably be cleared in the near future. This study sadly revealed that Coastal Forest no longer occurs on the Likonde and Maputwa plateaux, even though forest was reported in these areas as recently as 1995 (G.P. Clarke, pers. comm.).

We validated the satellite image classification (Table 2) by the use of an error matrix (Congalton and Green 1999). Although we could detect unique sub-classes of Coastal Forest, we did not have sufficient resources to make a stratified verification of these over a large scale. Thus, our validation was limited to the main Coastal Forest types, miombo woodland, open woodland and other types of woody vegetation. The results reveal that the main Coastal Forest classes could be derived with an accuracy of approximately 85%, which Thomlinson et al. (1999) have characterised to be within the acceptable range for satellelite image classification. A Kappa coefficient (Congalton and Oderwald 1983) of 0.84 from the error matrix indicates that the result is reliable.

Discussion

The presence of extensive areas of closed canopy vegetation in Kilwa Region was first identified by coarse scale satellite photographs by Rodgers et al. (1985), although that survey was unable to differentiate between well-developed forest and degraded thicket, which both form dense evergreen canopies. More recent studies (FAO 1999, 2002) have also identified considerable areas of forest cover in the region, but these studies have also been too coarse to demarcate different Coastal Forest types and generally overrated the extent of closed forest/tree cover compared to other types of dense woody cover.

The forests of Kilwa Region, and to a lesser extent Lindi Region, had long been obscured from the attention of biologists and conservationists, due historically to the interruption by the First World War of the exploration and gazettement of their forests by the German colonial administration, and a subsequent lack of investment in these districts. This left the area remote and isolated (until recently the journey from Dar es Salaam to Lindi involved a 16 h drive in the dry season, with roads becoming impassable during the rainy season). Ironically, these factors have

Table 1 (a) A description of major Coastal Forest areas in Lindi Region, Tanzania, including location, forest area, biological importance and conservation status and (b) Forest reserves in Lindi region, Tanzania, not mentioned in Table 1a, which contain comparably little Coastal Forest

Location	Forest area	Description	Biological and conservation status
(a)			
Matumbi hills, (southern half located in Kilwa District)	Ca. 10 km^2 of scrub forest and less than 5 km^2 of patches of Coastal Forest.	Severely degraded forest in Tong'omba and Mbinga FR. Elsewhere, small pockets of more developed forest on steep scarp edge slopes at the southern limit of the Matumbi Hills.	Tong'omba briefly surveyed; *Baikea gesquiereana* endemic to here and nearby Namakutwa FR in Coast Region (Clarke 1995). Mbinga briefly surveyed in 2001- only scrub forest/thicket on the top of the plateau, although some forest may be present on the escarpment. Other small patches of forest still biologically unsurveyed. High population density over southern part of the Matumbi Hills; both FRs heavily exploited although boundaries appear to be respected.
Kitope hill, Kilwa District	Ca. 8 km^2 of mixed scrub forest, small areas of riverine forest.	Heavily disturbed; only small patches of scrub forest remaining.	Surveyed in 2001, dominated by woodland with mixed scrub forest (*Rothmannia urceliformis, Vitex doniana* and *Erythroxylum fischeri*) on the hill, with a small riverine forest patch emerging from the hill and into the grassland on the plain.
Ruwawa plateau (including Ngarama North and South FR), Kilwa District	Ca. 42 km^2 of scrub forest Ca. 13 km^2 of mixed dry forest and legume dominated dry forest.	Predominantly scrub forest, although many patches of Coastal Forest still occur on the plateau especially to the NW along ridges, including a formerly undescribed area of ca. 5 km^2 of well-developed mixed dry forest and legume dominated forest in the north western part of Ngarama North FR.	Preliminary survey of forest to the NW found 2 possible endemic trees (*Baphia* cf. *keniensis* and *Leptactina* cf. *oxyloba*) as well as *Pteleopsis apetala* and *Vismia pauciflora* which are otherwise only known from 1–3 locations. Forest areas currently unprotected, but surviving because of low population density in this area. However, timber poaching is taking place here.
Mbwalawala plateau (including Pindiro FR), Kilwa District	Ca.75 km^2 of scrub forest. 5 km^2 patches of mixed dry forest.	Mosaic of scrub forest with patches of dry forest, which appear to be similar to the ones in Ngarama FR, Ruwawa plateau. Scrub forest on Mbwalawala plateau similar to the scrub forest at eastern part of Namatimbili.	Briefly surveyed in 1993 (Eriksen et al. 1994) and 2001, although northern areas of the Mbwalawala plateau remain unsurveyed. Most of the scrub forest and dry forest areas are outside Pindiro FR. Forest still surviving due to low population density in this area.

Table 1 continued

Location	Forest area	Description	Biological and conservation status
Namatimbili forest, Kilwa District	Ca. 29 km^2 of scrub forest, ca. 34 km^2 of mixed dry forest and legume dominated forest and 3 km^2 riverine forest.	Mosaic of different types of dry forest in pristine condition, including an unusual (and to our knowledge unique) 3.5 ha area of cycad forest dominated by *Encephalartos hildebrandtii*. Apparently little disturbed and well developed band of riverine forest along the gorge of the Mavuji river.	Preliminary survey (September and December 2001) indicates at least one possible endemic tree (*Pterygota* sp. nov.) as well as other highly restricted species (including *Trichilia* sp. nov. aff. *lovettii*). Forest currently unprotected, but surviving because of low population density in this area.
Ndimba FR, Lindi District	Ca. 6 km^2 of scrub forest, ca. 9 km^2 of mixed dry and legume dominated dry forest.	Mixed dry and legume dominated forest covers most of the low hill in the reserve.	Surveyed in 2001. Unique stand of dry forest strongly dominated by its endemic species *Cynometra gillmannii*. FR surrounded by abandoned sisal estates. Reserve boundaries appear to be respected.
Ruawa plateau and FR, Lindi District	Ca. 9 km^2 of mixed dry and legume dominated dry forest. Small patches of groundwater forest.	Forest limited to ancient coral rag on steep plateau scarp edge, intersected by deep and narrow gullies containing groundwater forest.	Surveyed in 2001. Only known stand of *Pandanus rabaiensis* swamp forest south of the Rufiji River. Ruawa plateau intensely cultivated with a high human population density; FR heavily encroached. Remaining areas of forest highly vulnerable to over-exploitation.
Noto plateau, Lindi District	26 km^2 of scrub forest and 12 km^2 mixed dry forest in a mosaic.	Mosaic of mixed dry and mixed scrub forest.	Surveyed in 2001. Three endemic species collected in 1930s by Schlieben (1939) and never recollected since. Noto plateau exposed to extensive selective logging which has degraded most of the forest into open stands. On the northern part of the plateau larger areas have recently been cleared due to shifting cultivation. Remaining forest currently unprotected.

Table 1 continued

Location	Forest area	Description	Biological and conservation status
Chitoa plateau and FR, Litipo FR, Lindi District	8 km^2 mixed dry forest and 12 km^2 scrub forest mosaic between the Chitoa FR and Litipo FR.	Mosaic of mixed dry and mixed scrub forest in both the Chitoa FR and Litipo FR, as well as on the plateau area.	Litipo FR well-surveyed and found to contain 12 endemic plant species. Three brief surveys indicate at least three endemic species from the tiny patch of dry forest on the southern rim of the Chitoa plateau within Chitoa FR. FR boundaries respected but forest areas elsewhere on the Chitoa Plateau threatened by shifting cultivation intruding onto the plateau from the SE.
Rondo plateau and FR, Lindi District	Ca. 10 km^2 of pine plantation, ca. 1 km^2 of mvule plantation, ca. 35 km^2 of mixed dry forest and 19 km^2 scrub forest.	Most of the forest within the FR formerly clear-felled and replaced by pine and mvule *Milicia excelsa* plantations. Natural forest still present on the steep escarpment edge slopes. Western slopes of plateau (outside FR) mainly covered with woodland.	By far the most important patch of Coastal Forest in eastern Africa, with up to 56 of its own endemic species (Clarke 1995, 2001). FR boundary well-protected by presence of forestry operations, although there are recent rumors of extensive timber poaching (A. King, e-mail, Nov. 2003). Plateau areas E of FR intensely cultivated.
(b)			
Mitarure FR, (618 km^2)	Ca. 2 km^2 of mixed scrub forest, 40 km^2 *Brachystegia* forest.	Vegetation density increases from W to E as elevation increases. Open woodland in W, grading to well developed miombo in E that in places becomes *Brachystegia* forest and eventually scrub forest.	Mitarure FR contains only limited areas of well-developed Coastal Forest, although the eastern part contains larger areas of *Brachystegia* forest
Nampekeso FR (258 km^2)	Ca. 1 km^2 of mixed scrub forest, 4 km^2 *Brachystegia* forest.	Dominated by open woodland. In the north the vegetation becomes denser miombo that in places becomes *Brachystegia* forest and eventually scrub forest.	Northern part contains similar Coastal Forest vegetation as Mitarure FR, although limited in extent.

Table 1 continued

Location	Forest area	Description	Biological and conservation status
Rungo FR (230 km^2)	Ca. 8 km^2 of *Brachystegia* forest.	Vegetation of Rungo FR has the same geographical pattern as Mitarure FR and same image properties. The western part is open woodland and eastern dominated by well developed miombo that in places becomes *Brachystegia* forest with tiny patches of scrub forest.	Similar to Mitarure FR but on a smaller scale.
Malehi FR (395 km^2)	Ca. 4 km^2 riverine forest.	Dominated by open woodland with some dense miombo. Riverine forest associated with main water courses transecting the reserve.	Never surveyed; probably limited biological values compared to other unprotected forest in the region. Riverine forest areas similar to those found along the larger watercourses of woodland vegetation in the area.
Matapwa FR (180 km^2)	Ca. 49 km^2 of scrub forest with less than 1 km^2 of mixed dry and legume dominated dry forest.	Mosaic of different types of woodland, scrub forest and tiny patches of well-developed Coastal Forest.	Surveyed in 2001 by a 7 km long transect selected from the satellite images to cover a full spectrum of variations in woody cover. Only a few Coastal Forest endemics were found (e.g. *Xylia schliebenii*).
Nandimba FR, Lindi District (12 km^2)	Ca. 2 km^2 of scrub forest and 2 km^2 *Brachystegia* forest.	Mixed dense woodland, including patches of scrub and *Brachystegia* forest.	Not surveyed; satellite classification reveals dense mixed woodland with patches of scrub and *Brachystegia* forest, similar to a transect constructed 5 km to W, which contained Coastal Forest tree species.

Table 2 Error matrix of the satellite image classification. The bold numbers represent the cases in which the labels in the ground data and image classification agree. The overall accuracy was 87.3%

Reference data									
Classified data	Dry forest	Scrub forest	*Brachystegia* forest	Miombo	Maritime scrub forest	Woodland	Other wooded	Total pixels	User's accuracy
Dry forest	283	26	0	0	0	0	30	339	83.50%
Scrub forest	31	221	10	0	0	5	14	281	78.70%
Brachystegia forest	0	5	404	41	0	35	4	489	82.60%
Miombo	0	0	30	920	0	44	12	1006	91.50%
Maritime scrub forest	0	0	0	0	80	0	15	95	84.20%
Woodland	8	0	65	23	0	635	7	738	86%
Other wooded	24	37	15	21	21	13	1130	1261	89.60%
Total pixels	346	289	524	1005	101	732	1212	4209	
Producer's accuracy	81.80%	76.50%	77.10%	91.50%	79.20%	86.80%	93.20%		87.30%

contributed to the survival of these forests, which have not been affected by the same scale of deforestation as other parts of the Tanzanian coast.

Other factors have contributed to the survival of these forests, particularly the villagisation process that commenced in 1967, where remote communities were centralised in 'ujamaa' villages, that effectively removed the human population from outlying areas. That policy was abandoned during the late 1980s, which has lead to the increasing settlement of Coastal Forest areas by subsistence farmers in search of good quality (and easy to clear) land. Our satellite image analysis has revealed the extensive scale of shifting cultivation in this area, particularly on the plateaux inland of Lindi. Unless more determined conservation efforts are implemented in these districts, the remaining patches of forest on the Chitoa and Noto plateaux will soon suffer the same fate as those formerly on the Likonde, Maputwa and Ruawa plateaux that have recently been cleared. The deforestation and exploitation of the forests of Lindi and Kilwa Districts are set to escalate further as a consequence of the recent construction of a bridge across the Rufiji River and particularly with the construction of an all year road to this region.

Until now, accurate and up to date information on the distribution and extent of Coastal Forest in Lindi and Kilwa districts has not been available, for although most of the forest reserves in the region were established almost 100 years ago, little information was hitherto available about their exact delination or about their forest resources. This study has revealed that presently only 10% of the reserve areas in these districts contain well-developed Coastal Forest (mixed dry, legume-dominated and riverine Coastal Forest) while some large forest reserves do not contain any significant patches of forest. New prioities should therefore be made for managing the remaining Coastal Forest resources in these reserves.

The discovery of particularly large tracts of well-developed Coastal Forest at Namatimbili and on the Ruwawa plateau is therefore significant, especially given the paucity of large patches of Coastal Forest elsewhere in eastern Africa. Particular conservation attention should be given to the newly identified areas of forest that are currently without any form of formal protection, i.e. those at Namatimbili and on the Chitoa, Noto, Mbwalawala and Ruwawa plateaux, while efforts to safeguard the remaining forest in the Rondo, Litipo, Ndimba and Ruawa forest reserves should be stepped up.

Future applications

Recent innovative methodology studies of remote sensing in tropical forests (Foody and Cutler 2003) have demonstrated that Landsat data contain sufficient information to determine different forest classes based upon variations in the tree species assemblages of the forest canopy. Our study suggests that this might eventually prove possible for the highly heterogenous scrub forest and dry Coastal Forest types, where we recorded relatively large spectral variances in satellite data that were to a large extent site specific. This variance mirrors the observed differences in the vegetation structure and species assemblages at these sites, as has been noted elsewhere in the literature (e.g. Lowe and Clarke 2000; Clarke and Robertson 2000). Unfortunately too few resources were available for this study to statistically document these sub-groupings over a large scale. More comprehensive remote sensing

studies involving more innovative methods should therefore be carried out to map the botanical and structural diversity of the Coastal Forests.

Our study was however able to separate out areas of forest from other surrounding vegetation classes, and to classify these into the different Coastal Forest types already identified in literature. This methodology therefore seems strong enough to be replicated in the poorly known coastal zone of northern Mozambique, where there is an urgent need to rapidly identify and quantify the remaining areas of Coastal Forest habitat before these suffer the same fate as so many other Coastal Forests in Tanzania and Kenya.

Further, considering the efficiency of this technology and relative low cost of satellite image data, these could be utilized in monitoring systems as a part of the future management of these forests.

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