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Remote Sensing of Mangrove Change Along the Tanzania Coast

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This article contributes to the understanding of the changes in distribution and total area of mangrove forests along the mainland Tanzania coast over the past decade. Mangroves are recognized as critical coastal habitat requiring protection and special attention. The Tanzania coastline forms a suitable habitat for establishment of mangrove forests. Mangrove forests are distributed from Tanga in the north to Mtwara in the south covering

approximately 109,593 hectares from 1988–1990 and about 108,138 hectares in 2000. The largest continuous mangrove stands are found in the districts of Rufiji, Kilwa, Tanga-Muheza, and Mtwara. Comparison of data between these two time periods shows that the geographic coverage of mangroves has no dramatic change in the past decade. The Tanzania Mangrove Management Project and other closely related programs and efforts pertaining to mangrove conservation contribute to direct restoration and natural regeneration of mangroves. This study documents the changes of mangroves and demonstrates that remote sensing and GIS offer important data and tools in the advancement of coastal resource management and ecosystem monitoring. Application of geographic information technologies is critical for improved coastal resources management and decision making for sustainable development in Tanzania.

Mangroves are salt-tolerant forests or swamp ecosystems that occur along tropical and subtropical coastlines, usually in sheltered bays and around river mouths. Globally, about 75% of low-lying tropical coastlines receiving freshwater drainage support mangrove systems. Through the action of its roots, a mangrove forest recycles nutrients and traps land-based debris, sediments, and suspended particulate matter carried to the coast by rivers. Mangrove forests function as irreplaceable feeding and nursery grounds for many ecologically and economically valuable fish, shellfish, prawn, and crab species. The forests and the roots secure the land, preventing shoreline erosion. Mangroves are also important for the health and water quality of near-shore ecosystems such as seagrass beds and coral reefs that develop best in clear waters.

The Tanzania coastline extends over 800 kilometers from the border with Kenya in the north to Mozambique in the south. Mangroves along the Tanzania coast occur on gently sloping shores, and around river estuaries, creeks, and bays (Figure 1, sites 1, 4, 5, and 6). The Rufiji River delta has about 50,000 hectares of mangroves and is the largest single mangrove forest in the eastern Africa (Figure 1, sites 2 and 3).

Tree biodiversity in mangrove sites is low because few tree species can withstand high salinity, anaerobic sediments, acidic soils, and unstable substrates. Nine mangrove tree species are found in Tanzania (Table 1). Of these, *Avicennia marina, Rhizophora mucronata*, and *Ceriops tagal* are predominant, while *Xylocarpus mulleccensis* is rare (Semesi and Adelaida 2000). All mangrove forests in Tanzania are gazetted as forest reserves. Conservation and management of these forests are guided by forest policy and ordinances of the Tanzania government.

TABLE 1 Mangrove Tree Species in Tanzania

No.	Tree species	Family	Local name
1	*Avicennia marina*	*Verbenaceae*	Mchu
2	*Bruguiera gymnorrhiza*	*Rhizophoraceae*	Msinzi or muia
3	*Ceriops tagal*	*Rhizophoraceae*	Mkandaa
4	*Heritiera littoralis*	*Sterculiaceae*	Msikundazi or mkungu
5	*Lumnitzera racemosa*	*Combretaceae*	Kikandaa or mkandaa dume
6	*Rhizophora mucronata*	*Rhizophoraceae*	Mkoko
7	*Sonneratia alba*	*Sonneratiaceae*	Mililana
8	*Xylocarpus granatum*	*Meliaceae*	Mkomafi
9	*Xylocarpus molluccensis*	*Meliaceae*	(none)
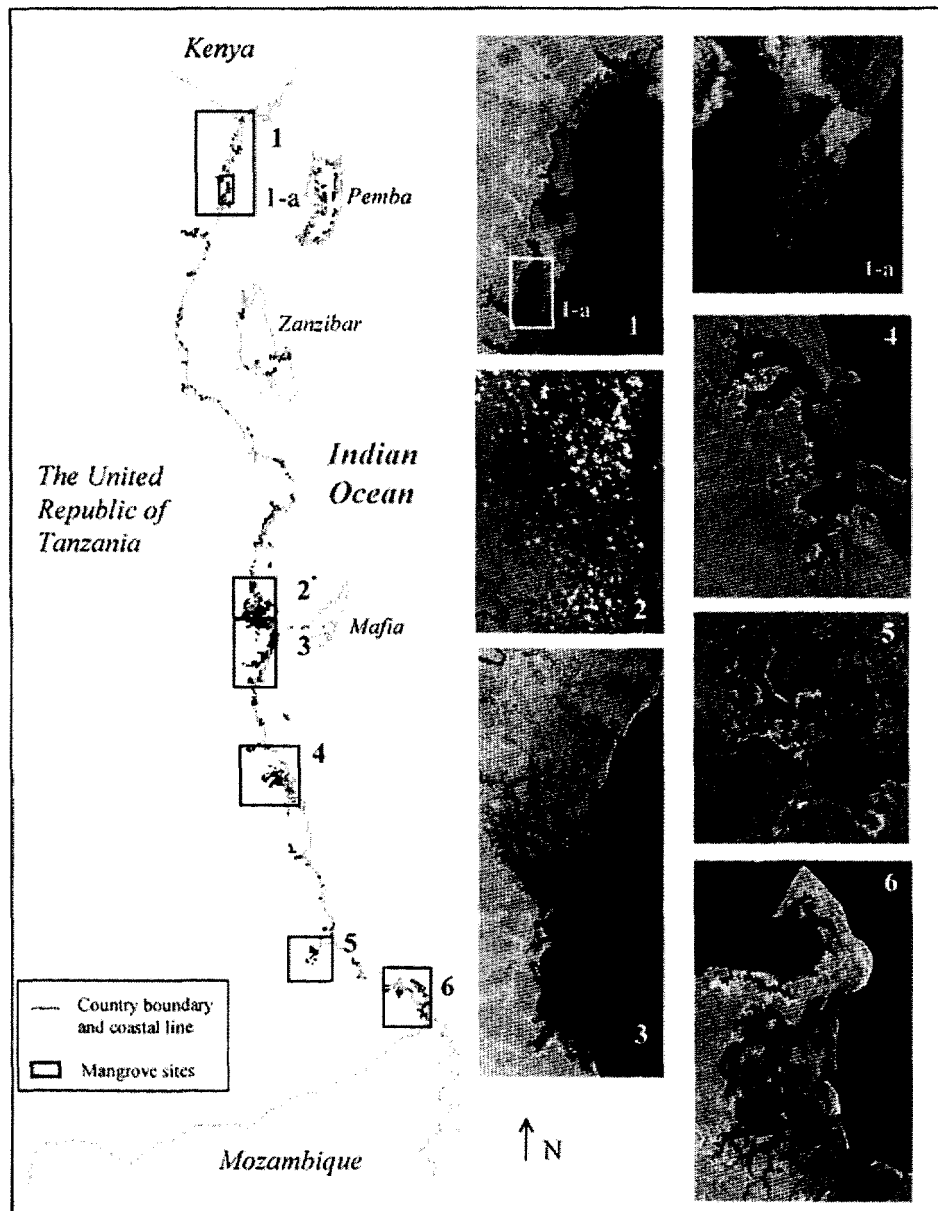
FIGURE 1 Study area and selected mangrove sites along the Tanzania coast. Landsat TM images of the sites are displayed as bands 4 (Red), 5 (Green), and 3 (Blue). The red-colored areas on the TM images along the coast and around the river mouths represent the distribution of mangrove vegetation.

Mangrove forests are an important economic and ecological resource in Tanzania. They are principal providers of useful products such as firewood, charcoal, poles, tannin, and traditional medicines. It is estimated that over 150,000 people make their living directly from mangrove resources in Tanzania (TCMP 2001).

Recognizing their value, the government of Tanzania initiated a Mangrove Management Project (MMP) in 1988. The actual implementation of the MMP started in 1994.

MMP is designed to benefit coastal communities that directly rely on mangroves for their livelihood. The project emphasizes mangrove conservation and sustainable utilization. Accessible spatial information is critical for the support of management planning, monitoring, and implementation of zoning and other management actions for mangrove conservation and sustainable use.

For coastal managers and scientists, the most important information regarding mangrove ecosystems is location boundaries, area of clearance, and mangrove density (Green et al. 2000). Previous studies have assessed Tanzania's mangrove area coverage, species composition, factors causing species zonation, physical and chemical composition of sediments, litter composition, microbial activities in sediments, and the human use of mangroves (Semesi and Adelaida 2000). Studies about the structure, ecology, coverage, and extent of Tanzanian mangroves have been conducted by analysis of field photographs and ground surveys (Semesi 1991). A previous study acknowledged that a survey of satellite imagery showed that many mangrove forests along the Tanzanian coast of various sizes have yet to be assessed (Semesi 1986).

Remote sensing has been identified as an effective tool to study otherwise difficult-to-reach and difficult-to-penetrate mangroves along coastal areas. Landsat and SPOT imageries have been applied to mangrove studies through visual interpretation (Gang and Agatsiva 1992), vegetation index (Blasco et al. 1986; Chaudhury 1990; Jensen et al. 1991), classification (Aschbacher et al. 1995; Dutrieux et al. 1990), and band ratioing (Kay et al. 1991; Long and Skewes 1994; Ranganath et al. 1989). Remote sensing applications have been applied mainly for mangrove inventory and mapping, change detection, and for management purposes. Landsat and SPOT data, as well as high spatial resolution airborne multispectral and SIR-C radar data, were recently applied in mangrove management in a number of countries (Gao 1998; Green et al. 1998; Pasqualini et al. 1999; Ramirez-Garcia et al. 1998; Rasolofoharinoro et al. 1998). Nevertheless, remote sensing techniques applied to mangrove vegetation are still not as common as other terrestrial applications, particularly along the east coast of Africa (Blasco et al. 1994; Dale et al. 1996).

Satellite remote sensing has been applied in Tanzania for general vegetation and land cover mapping since the 1980s. A 1984 map of Tanzania vegetation types was compiled from the interpretation of 1974 Landsat Multispectral Scanner (MSS) images. At a scale of 1:2,000,000, this map does not identify mangrove forests as an individual category. Two recent efforts in the application of satellite remote sensing for general land cover mapping in Tanzania include the Africover project by the United Nations and the natural resource mapping project executed by Hunting Technical Services (HTS) of the United Kingdom. The HTS land cover map product was published at 1:250,000 scale, which corresponds with existing topographic maps. The thematic maps were generated from interpretation of scale-controlled images. These were derived from mosaics of Landsat Thematic Mapper (TM) and SPOT image scenes acquired during the time period between May 1994 and July 1996, then edited to match topographic series. The HTS classification scheme has 34 land cover categories including mangrove. With the given scale, this data's physical limit is the aerial extent of discrete land cover units. A mapped area of about 4 mm square is equivalent to a ground area of 100 ha. Units smaller than this are unlikely to apear on the HTS maps as individual units and therefore aggregated into the matrix unit with an appropriate qualification.

The United Nations Food and Agricultural Organization (FAO) hosts the Africover project. A goal of the Africover project is to establish a digital, georeferenced database of land cover for African countries. The Africover project reinforces national and subregional capacities for the establishment, updating, and operational use of geographic referential and land cover maps (Alinovi et al. 2001). Africover's product for Tanzania was produced

by visual interpretation of Landsat and SPOT images acquired between February 1995 and June 1998. Land cover categories were complied using an internationally adopted Land Cover Classification System (Di Gregorio and Jensen 2000). The final map product is at 1:200,000 scale. Mangrove trees and mangrove shrubs are two of the 30 generalized land cover categories. These maps can be used as references in mangrove mapping but are not appropriate for change analysis for our study because they were developed under different classification schemes, in different map scales, and the time frame of these data does not match our study needs.

In this article, we developed mangrove cover maps for Tanzania coastal districts using Landsat TM images acquired between 1988–1990 and Landsat-7 ETM+ images acquired in 2000. We focused on mangrove change detection for the 10 years between 1990 and 2000. Given that the Tanzania Mangrove Management Project started in 1994, this change detection provides information necessary for evaluating the result of the project's implementation to date.

Methodology

### Study Areas and Data Sources

This study focused on the Tanzania mainland coast including the districts of Muheza, Tanga, Pangani, Bagamoyo, Kisarawe, Rufiji, Kilwa, Lindi, Mtwara, and Dar es Salaam (Figure 2a). The Tanzania mangrove management project divides these districts into three zones: the Northern, Central, and Southern zones. The Northern zone includes Tanga, Muheza, and Pangani districts. The Central zone includes Bagamoyo, Dar es Salaam, and Rufiji districts, and other areas. The Southern zone includes Lindi and Mtwara districts.

To extract the mangrove areas, we used Landsat TM scenes acquired between 1988 and 1990, with path/row numbers of P165/R66–67 and P166/R63–66, and 2000 Landsat-7 ETM+ scenes, with path/row numbers of P165/R66–67 and P166/R64–66. We georeferenced the images to the Universal Transverse Mercator (UTM) map coordinates and then mosaicked the scenes. Since mangroves are exclusively distributed along coastal lines and around river mouths, we delineated the areas that have identifiable mangroves. We subsequently subsetted the mosaicked images. We also referenced the Africover and HTS data to verify the mangrove area.

Field Observation and Ground Verification

We conducted a GPS-guided field investigation during January and February 2002. The fieldwork supported interpretation of TM and ETM+ images and delineation of the general land cover types and mangrove areas. The field observations provided independent reference data for the accuracy assessment. In addition, essential ecological and botanical features of mangroves and coastal landscape were observed and documented. The field observation extended to all of the Tanzania coastal districts. Since the ground truth data are mainly used for interpretation of both 1988–1990 TM and 2000 ETM+ images, we paid special attention to locations where the landscape had been altered and land use had been changed over the past years.

We visited regional and district offices with laminated hardcopy TM imagery. We consulted natural resource officers as well as the appointed mangrove officers in the coastal districts to aid in interpretation of the TM imagery. This effort helped to differentiate other types of coastal forest and shrub lands from mangrove vegetation. The districts' natural resource and mangrove officers also identified specific sites where mangrove management
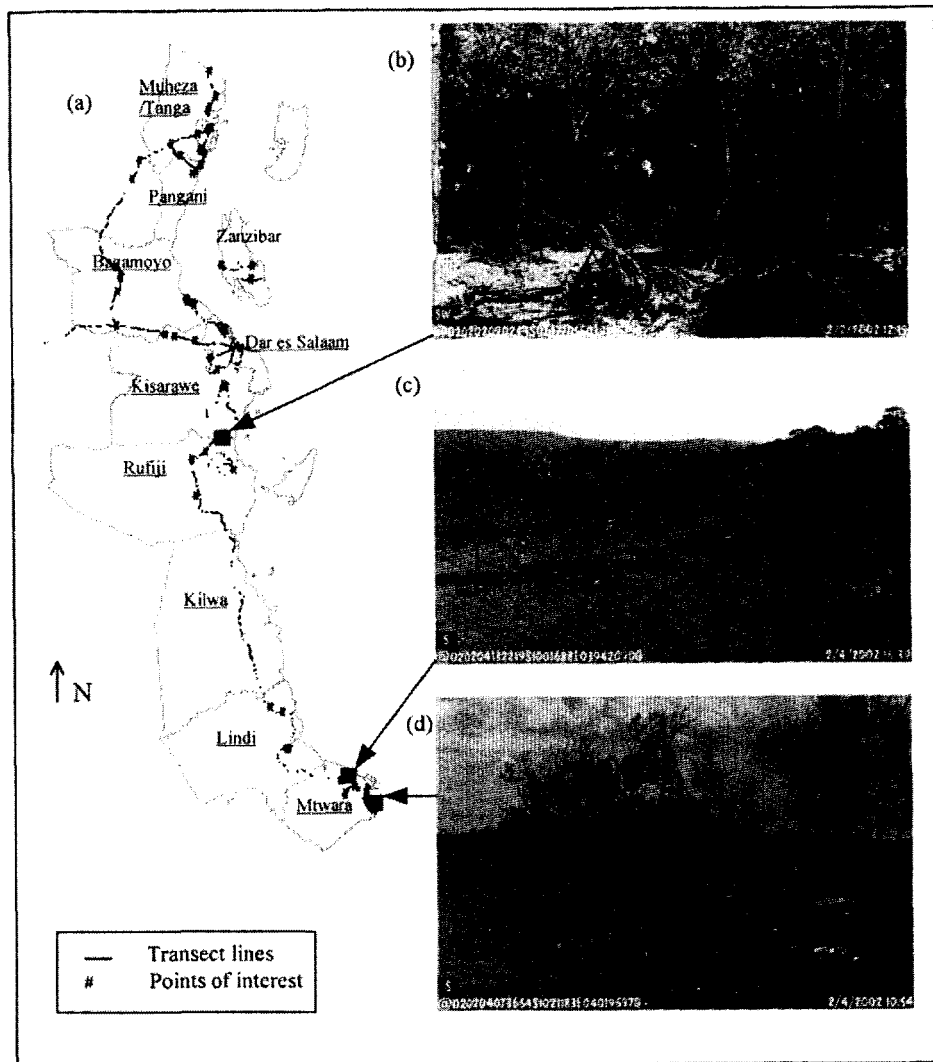
FIGURE 2 Tanzania coastal districts and the GPS ground referencing locations and GPS guided site photos within the districts: (a) GPS transect and point locations collected in the field campaign; (b) a site photo showing mangrove trees at the Rufiji River delta; (c) a site photo showing newly planted mangrove in Mtwara District; (d) a site photo identifying the location of an open mangrove site in the coast of Mtwara District. The site photos carry the information of geographical coordinates and bearing direction, which link the site to the corresponding GIS features and the pixel values in remote sensing imagery.

actions have been applied. These management practices typically include the replanting of mangroves, and conversion from coconut plantations and rice farms to mangroves. The local officers identified critical locations where land use and land cover had been changed since 1990. On several occasions local natural resources and mangrove officers, biologists and ecologists affiliated with the University of Dar es Salaam, and leaders of villages who are familiar with the mangrove conservation and management project guided us in the field to mangrove sites.

We used a Trimble GeoExplorer 3 GPS unit to record the observed locations of transects and points. A GPS data dictionary uploaded to the GeoExplorer 3 assisted us in recording the general characteristics of land cover types and the associated information as we traversed different land cover types. Items in the GPS data dictionary included site and transect identification information, date, time, description of landscape, characterization of land use, vegetation canopy and canopy density, description of understory vegetation, presence or absence of urban land use, and other site-specific comments. We also consulted the land cover types of the transection sites previously interpreted by the Africover and the HTS maps during the field investigation.

In this field campaign, we drove approximately 3,457 km across the coastal districts. Characteristics of inland coastal land cover and land use types as well as mangroves were observed and documented. We collected 726 GPS transects totaling 1063 kilometers in length as well as 87 GPS points in the coastal districts. GPS locations and the recorded attributes were imported into a GIS to facilitate integrating the data with the Landsat scenes. Figure 2(a) illustrates the locations of the ground truthing transects and points within the districts.

Besides the GeoExplorer 3, we also applied a Kodak DC265 Field Imaging System (FIS) to obtain georeferenced site photos along the transects and at points of interest. The DC265 FIS consists of a 12-channel Garmin GPS III unit linked to a digital camera. The FIS photographs identify the geographic locations by latitude/longitude coordinates as well as by the compass bearing directions. We recorded 1,326 georeferenced digital photos which, when augmented with GPS data from the GeoExplorer 3, were able to identify mangrove locations effectively and document coastal land cover types. Examples of the FIS site photos are displayed in Figures 2b, 2c, and 2d. The site photos helped to verify and fine-tune the image interpretation for mangrove and other land cover types.

Mangrove Interpretation

We developed a land cover classification scheme that was consistent but different from the land cover categories used by the Africover project. In this article, we focus exclusively on mangroves. The mangrove species listed in Table 1 are all regarded as a single mangrove category. In addition, we used a generalized inland type and water as the other two categories.

The Tanzania Mangrove Management Project defines the boundary of gazetted mangrove forest reserves as the area between low and high tide marks. We conducted a scale-controlled visual interpretation to delineate mangroves on the 1988–1990 TM and 2000 ETM+ images, respectively. We digitized polygons on computer screen using both the ERDAS Imagine and Environmental Systems Research Institute (ESRI) ArcInfo and ArcEditor 8.1 software programs. We chose manual interpretation instead of supervised classification for the reason that mangroves are always in mixture with surrounding water. Visual interpretation can extract more precisely the boundary of mangrove vegetation, particularly when the supporting water needs to be considered as part of the mangrove system. One skilled photo interpreter finalized the interpretation of both 1990 time-period TM and 2000 ETM+ images, which assured the consistency of our interpretations over the two time periods.

Upon finishing the interpretation, we conducted accuracy assessment. The most common way to represent the classification accuracy is in the form of error matrix. Error matrix is a comparison between sampled areas on the map generated from remote sensing data and those same areas as determined by reference data (Congalton 1991; Congalton and Green 1993). We referenced the ground truthing data that was obtained during the field investigation to select sample locations from the TM and ETM+ images. We collected 340 and 324 sample locations on the 1990 and 2000 data, respectively. Among those, 137 sample

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TABLE 2 Accuracy Assessment of Mangrove Interpretation from 1990 TM Images

1990 TM image interpretation		Reference data				
		Mangrove	Inland types	Water	Row total	User's accuracy
Interpretation result	Mangrove	135	2	1	138	97.83%
	Inland types	2	126	0	128	98.44%
	Water	0	0	74	74	100%
	Column total	137	128	75	340	—
	Producer's accuracy	98.54%	98.43%	98.67%	—	Overall accuracy 98.53%

locations were selected from the 1990 mangrove sites and 132 were selected from the 2000 mangrove sites. Tables 2 and 3 report the result of accuracy assessment. The result indicates that our overall accuracy of 1990 mangrove interpretation is 98.53%. No unbalanced interpretation error exists among the three categories. The overall accuracy of 2000 interpretation is 97.53%. The limited error resulted from the commission and omission interpretation between the mangrove forest and inland vegetation.

After the quality assurance, we used the administrative boundaries of the coastal districts on the final interpretation map to clip the result of the manual interpretation. This gave us the number of hectares of mangroves within each coastal district. The quantified mangrove areas are listed in Table 4 and the comparison of the spatial coverage of mangroves of the two time periods is illustrated in Figure 3.

Several reports and studies regarding mangroves in Tanzania have been completed (Spalding et al. 1997). The most comprehensive and extensive baseline information on the distribution, coverage, uses, and status was created by the Mangrove Management Project (Semesi 1991). This study applied 854 aerial photographs acquired between 1988 and 1989 to delineate mangrove locations in Tanzania, and subsequently quantified the area, stand density, and height of each stand. The study also delineated salt pans, water channels, clear felled, and bare-saline areas. The total estimated mangrove area, according to this study, is 111,994 hectares along the mainland Tanzania coast or 172,889 hectares if water in the creeks, clear-cut areas, and salt pans are included. This study provides valuable base information for the assessment of the change of mangroves over time. There was no

TABLE 3 Accuracy Assessment of Mangrove Interpretation from 2000 ETM+ Images

2000 ETM+ image interpretation		Reference data				
		Mangrove	Inland types	Water	Row total	User's accuracy
Interpretation result	Mangrove	128	4	0	132	97.70%
	Inland types	3	121	0	124	97.58%
	Water	1	0	67	68	98.53%
	Column total	132	125	67	324	—
	Producer's accuracy	97.70%	96.80%	100%	—	Overall accuracy 97.53%

TABLE 4 Comparison of Mangrove Areas (in Hectares) Between 1990 and 2000

Coastal districts	1990 mangroves		2000 mangroves	
	Mangrove vegetation	*If salt crust areas added*	Mangrove vegetation	*If salt crust areas added*
Tanga and Muheza	9,217	*9,221*	9,313	*9,336*
Pangani	3,799	*3,799*	3,879	*3,879*
Bagamoyo	5,039	*5,039*	5,051	*5,051*
Dar es Salaam	2,494	*2,494*	2,516	*2,516*
Kisarawe	4,159	*4,261*	4,092	*4,167*
Rufiji	49,799	*50,968*	48,030	*50,391*
Kilwa	21,826	*22,546*	21,755	*22,552*
Lindi	4,034	*4,055*	4,044	*4,065*
Mtwara	9,226	*9,409*	9,458	*9,860*
Total	**109,593**	*111,792*	**108,138**	*111,817*

Mangrove 2000
Mangrove 1990

N

1

2
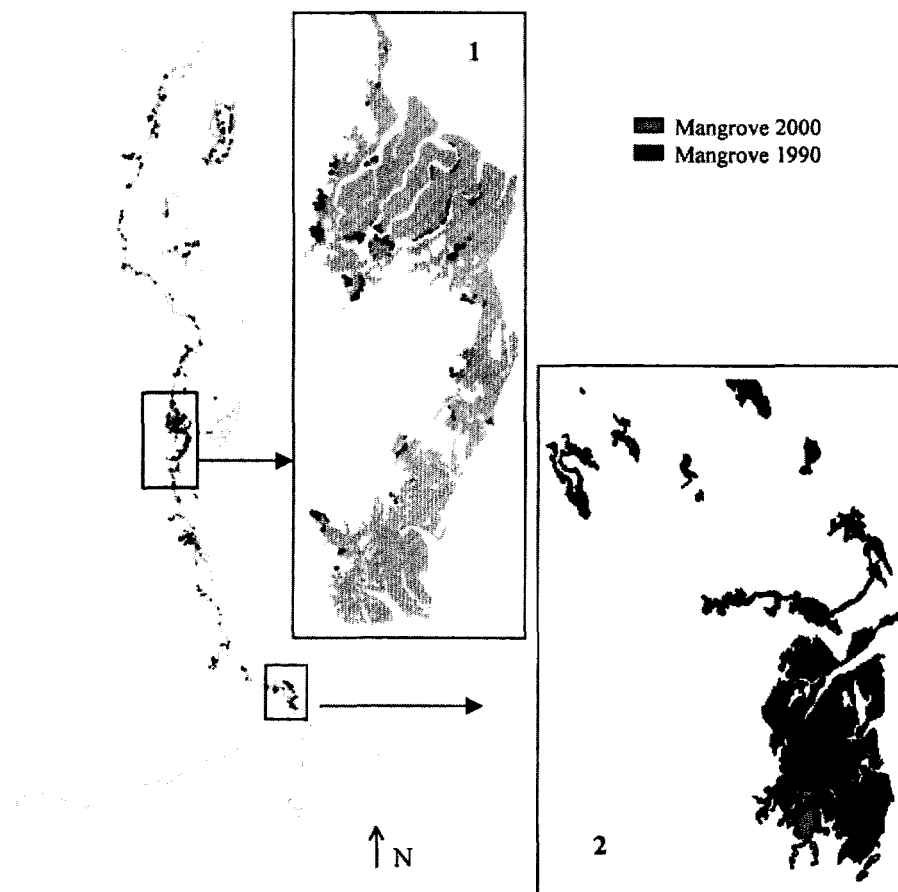
FIGURE 3 The blacked areas in subsite 1 show that the mangrove vegetation in 1990 has been either clear cut or converted into other types of land use in the past 10 years. The gray areas in subsite 2 show the increase in mangrove areas in the 10 years between 1990 and 2000 (e.g., Figure 2/Site c).

discussion, however, about the geometric rectification of the 1988–1989 aerial photographs that were applied in the mangrove interpretation. The report does not provide information about whether the interpretation was performed on individual photos or on controlled or uncontrolled mosaics of the aerial photographs. Geometric distortions caused by central projection of conventional aerial photography might have introduced unavoidable spatial errors in this study.

Results

Mangrove forests occur from Tanga in the north to Mtwara in the south covering approximately 109,593 and 108,138 hectares in the 1990 and 2000 time periods, respectively. The mangrove areas should be 111,792 and 111,817 hectares if salt crust areas are included for the two time periods. The largest continuous mangrove areas are found in the districts of Rufiji, Kilwa, Tanga-Muheza, and Mtwara. Comparison of the data between the two time periods shows that there has not been a dramatic change in mangrove area over the most recent 10 years. Mangrove areas declined in the districts of Rufiji, Kilwa, and Kisarawe and slightly increased in the other districts. However, an increase in area does not necessarily mean that the mangrove ecosystem is in a good condition. Further studies about mangrove ecosystem functions and density of the mangrove trees need to be conducted to answer biological questions in sustainable development.

The Rufiji River delta is the largest estuarine mangrove forest in Tanzania. It contains nearly half of the mangrove area in Tanzania. Several tidal channels and countless creeks dissect the mangrove swamps through which tidal-controlled water flows between mangrove swamps and the Indian Ocean. The annual floods of the Rufiji River force fresh water out into the delta, lowering the degree of salinity in the channels. The islands of the delta have been built principally by the mangroves, which via accumulating washed-in silt and their own production of detritus, raise the ground level to form dry land. The delta is a landscape with its own dynamics. Its surface changes constantly. The Rufiji delta is one of the most ecologically important areas in Tanzania. The mangrove environment in Rufiji is still quite intact. It supports a large number of other plants and animals indigenous to mangroves, thus presenting a unique ecological unit. The interpretation results indicate that approximately 49,799 and 48,030 hectares of mangroves existed in the district in 1990 and 2000, respectively. If the areas of salt crust are included, the mangrove areas of the two time periods increased to 50,968 in 1990 and 50,391 in 2000. The data in Table 4 shows that the areas of mangrove forest decreased 1,769 hectares. Most of the changes in mangrove areas in the Rufiji delta have occurred at the upper end of the river mouths and near the edge of the mangroves. The changed areas of mangrove forest are identifiable by comparison of the 1990 and 2000 mangrove maps (Figure 3c).

Kilwa is situated in the south of the Rufiji delta. It is a sparsely populated district. The area has extensive shallow water with several islands, all of which are surrounded by coral, seagrass, seaweed, and mangroves. There was no dramatic change of mangrove area within the district. Approximately 21,826 and 21,755 hectares of mangrove forest existed in the 1990 and the 2000 time periods, respectively.

Mtwara District also has extensive mangrove cover relative to other coastal districts. The Mnazi Bay and Ruvuma River estuary are located in this region, just north of the border with Mozambique. There are extensive mangrove forests in Mnazi Bay as well as around the Ruvuma estuary. This area has not been seriously exploited, and its natural resources are in relatively better condition compared with those of other areas along the Tanzania coastline. Our data shows that mangrove forests were 9,226 hectares in 1990 and 9,458 hectares in 2000. The increase in hectares could be associated with the active implementation of the

MMP. For example, newly planted mangroves were observed during the field investigation (Figure 2c) and verified on comparing the 1990 and 2000 mangrove maps (Figure 3, Site 2). Natural regeneration of mangroves has been observed and reported in the Mtwara District as well.

Pangani, Tanga, and Muheza Districts comprise the northern zone of the MMP. The status of mangrove forests has been reported in the northern zone (Mbwambo 2001). The report states that since the MMP started in 1994, there have been no documented cases of clear cutting of mangroves for agriculture and salt farming, as well as no fuel wood cutting for salt boiling or lime burning. Nearly all the large degraded mangrove sites have been replanted (Mbwambo 2001). Illegal harvesting of mangrove products has been reduced. This is attributed to increased mangrove protection efforts as well as an increase in people's awareness of the importance of the mangrove ecosystem. Data in Table 4 indicates that mangrove area in this northern zone increased slightly in the past decade.

The district around the urban center of Dar es Salaam has high demand for timber products. Clearance of mangrove forests was identified in the past. Rapid rural population migration to the city has resulted in the conversion of large areas of mangrove forest to residential, business, and agricultural use. The growth rate of the city of Dar es Salaam over the most recent decade is estimated at 4.8 percent (TCMP 2001). Mangrove forests in suburban areas surrounding the city have been particularly affected. However, our interpretation of Landsat images indicates little recent change in mangrove area between 1990 and 2000.

Discussion and Conclusion

The importance of mangroves to Tanzania has been recognized and all mangrove areas are legally protected. The key to their protection lies in the wise management and use of mangrove habitat, and in the enforcement of existing rules and regulations. Harvest restrictions, conservation areas, replanting, public education, and permits for timber harvesting are currently the principal approaches to mangrove conservation and sustainable use in Tanzania. It is believed that the MMP has resulted in the regeneration of mangrove vegetation in Tanzania over the past 5–10 years. The fact that mangrove stands in several of the districts have increased may indicate the effectiveness of the project, since the trend prior to the introduction of the project clearly showed major problems associated with the clearance of mangrove in many areas of Tanzania.

Careful use and sensible harvesting may result in an increased area of mangrove growth. Mangrove restoration has been conducted in various parts of the coastline with the support of MMP and in some cases by local coastal management projects. In the central zone of the MMP and in the Rufiji River Delta, there are several ongoing projects that focus on mangrove conservation. For example, the goal of the Rufiji Environmental Management Project is to promote the long-term conservation of mangroves through wise use of the Rufiji forests, woodlands, and wetlands. The project works through a variety of education and management practices to conserve biodiversity, maintain the critical ecological functions, promote sustainable use of renewable resources, and enhance alternative livelihood opportunities of the area's inhabitants (Njana 2001). Other projects, such as the Tanzania Mangroves Protection Association and the Rufiji Beekeeping project, all contribute to these conservation efforts.

Another project with a role in coastal resource management, including mangrove forest management, is the Tanzania Coastal Management Partnership (TCMP). The TCMP was established in 1997 as a joint effort between the National Environment Management

Council, the University of Rhode Island, and the United States Agency for International Development. The goal of TCMP is to improve national coastal planning, policy, and management, and to coordinate local and national coastal resource management. TCMP works with the existing network of integrated coastal management programs and practitioners to promote a participatory, transparent process to unite government and community, science and management, and private and public interests to conserve and develop coastal ecosystems and resources wisely.

This study shows that there has not been significant conversion and loss of mangrove area over the most recent 10 years along the Tanzania mainland coast. However, the threatening factors remain. The greatest threat to the largest mangrove stands was commercial harvesting in the southern districts and expansion for housing, salt pans, and industry in the northern districts. The MMP may have been effective in stopping development projects only and may have failed in stopping illegal commercial harvesting. Most of the mangrove cutting had already been done for the development by 1990. Because of proximity to the enforcement organizations and accessibility of these mangroves, the policing of regulations has been easy in Mtwara, Dar es Salaam, Tanga, Muheza, Pangani, and Bagamoyo. This can be one reason why MMP has been effective in these areas. On the other hand, Kisarawe was not even a district until recently. Rufiji and Kilwa are among the remotest areas of Tanzania. MMP may not be effective to operate in these areas. The decrease in mangrove forest in Rufiji, Kisarawe, and Kilwa could be due to expansion of agriculture activities. People are still breaking new grounds for farms. The dynamics of flooding and prolonged droughts along the river flood plains can be another factor leading to decreased mangroves.

While mangrove forest is protected by law, controlled harvesting of mangrove poles is permitted where mangroves are ecologically stable and have sufficient regeneration potential. Most of the mangroves in the southern districts were affected by this type of commercial harvesting. Selective harvesting of quality trees for particular purposes is a common practice, even no clear cutting is observed in these districts. Village natural resources committees and the MMP staff jointly supervise harvesting. Legal mangrove pole and fuel wood harvesting is monitored and recorded by mangrove management zonal offices (Table 5). Data in Table 5 shows that the dominant pole harvest size is between 5 and 10 cm in diameter at buttress. Over-harvesting may degrade the genetic pool of mangroves through the removal of trees with straight trunks, leaving behind only trees with badly formed stems. Illegal mangrove cutting also occurs. It is a problem that is recognized by regional officials, and a

TABLE 5 Recent Mangrove Poles and Fuel Wood Harvest in Tanzania

	Northern zone	Central zone	Southern zone	Summary
Class 1 score	—	12	23	35
Class 2 score	462	95	81	638
Class 3 score	1321	1046	227	2594
Class 4 score	—	14500	558	15058
Class 5 score	—	967	152	1119
Fuel wood (m^3)	255	32	147	434

Note: Mangrove poles are sold in scores of 20 poles each. One Score is composed of 20 poles.
Class 1: Poles over 20 cm diameter at buttress and not more than 30 cm diameter at 1.3 m above ground.
Class 2: Poles over 15 cm diameter and not more than 20 cm at buttress.
Class 3: Poles over 10 cm and not more than 15 cm diameter at buttress.
Class 4: Poles over 5 cm and not more than 10 cm diameter at buttress.
Class 5: Not more than 4 cm diameter.

strategy has been developed to address the situation (Njana 2001). Overall, however, greater awareness of the value of mangrove resources among resource managers and communities has reduced the scale of degradation of mangrove vegetation.

Some of the coastal regions of Tanzania are among the most deprived in the country in terms of infrastructure, per capita income, and well-being. The market economy is very small and income and food from natural resources, including mangrove forests, are critical to livelihood and food security. Economic well-being and the environment are intimately connected in poor coastal areas. A decline in coastal productivity of mangroves, seagrass, coral reefs, and associated near shore fisheries has a direct and significant negative impact on coastal villages. The protection of environmental resources for people who depend on them for income generation and consumption is critical to the survival of coastal villages, poverty reduction, and slowing rural to urban migration. The increase in population along the coast, as well as rapid growth of villages and towns, has increased the threat to mangroves. The population of the coastal districts has increased 23% from approximately 5.46 million in 1988 to 6.74 million in 2000 (TCMP 2001). Frequently, little consideration is given to the possible adverse effects of urban growth on mangroves.

Accurate information regarding mangrove distribution and area is critical to mangrove management. Spatial information helps obtain scientific consensus on the nature of mangrove conservation problems and increases the legitimacy and acceptability of policy options. Remote sensing and the derivatives of data from this study provide a strong foundation for integrated coastal resource planning, targeted field studies, and monitoring. The result of this study indicates that the mangrove management actions in Tanzania are very promising. With the base information that we developed, the regular monitoring and proper management decisions should be pursued for the sustainability of the mangrove resources in Tanzania.

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