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FOREST AND WOODLAND COVER AND CHANGE IN COASTAL TANZANIA AND KENYA, 1990 TO 2000

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ABSTRACT

Forest and woodland cover and change were calculated for the Zanzibar-Inhambane biogeographical region of Tanzania and Kenya from ~1990 to ~2000. A cover and change map was derived from high-resolution satellite imagery from Landsat and supplemental data from aerial overflights, field surveys, and local knowledge. Analyses showed that around 6820 km^2 of coastal forest habitat remained in ~2000 (2260 km^2 in Kenya and 4560 km^2 in Tanzania). In terms of change, a total of 424 km^2 (6%) of forest was cleared between ~1990 and ~2000; 53 km^2 in Kenya and 371 km^2 in Tanzania. Rates of forest loss were 8 times higher in unprotected areas than in protected sites such as Forest Reserves and National Parks. Key Biodiversity Areas had forest loss rates 2.5 times faster than protected areas while Alliance for Zero Extinction sites had the slowest rates of forest loss for the region. These baseline forest cover and change estimates along with future updates can contribute to national and sub-national carbon emission baselines and assessments of species threat within the global Red List.

Keywords: East Africa, KBAs, Landsat ETM+, habitat monitoring, protected areas

INTRODUCTION

The coastal region of East Africa contains highly fragmented habitats that are of global importance in terms of biodiversity (Burgess & Muir, 1994; Burgess & Clarke, 2000; Myers *et al.*, 2000; Brooks *et al.*, 2002; Mittermeier *et al.*, 2004). Brooks *et al.* (2002) estimated that the coastal forests and the adjacent Eastern Arc forests contained the smallest remaining area of habitat of any of the 25 hotspots of global biodiversity recognized at that time, and were therefore likely to suffer a high risk of species extinction if there was significant further habitat loss.

Natural 'forest' habitats within the coastal forest region consist of various forms of closed-canopy forest vegetation such as dry forest, scrub forest, *Brachystegia* forest, riverine forest, groundwater forest, swamp forest, and coastal/afromontane transition forest (Clarke, 2000; Schipper & Burgess, 2003). These forest habitat patches are typically small and embedded within a matrix of Miombo (*Brachystegia)* woodland, dense shrub, thicket and expanding areas of agriculture, plantations and human settlement (Burgess & Muir, 1994; Burgess *et al.*, 1998; CEPF, 2003). The varied nature of habitats leads to the region being termed the Zanzibar-Inhambane coastal forest mosaic (Schipper & Burgess, 2003).

In terms of biodiversity, all natural habitat types in the Zanzibar-Inhambane coastal forest mosaic region have high biological importance, with the forest habitats being of particular significance. Overall, the region supports more than 4500 plant species and 1050 plant genera (Clarke *et al.*, 2000); of these more than 1300 are endemic plant species and 33 are endemic plant genera. More than 500 of these endemic species are confined to the coastal forest habitats (Clarke *et al.*, 2000). The region is also biodiversity rich with the following irreplaceable, endemic fauna: 14 bird, 9 mammal, 51 reptile, and 5 amphibian species. The coastal forest region supports a large number of forest-obligate endemics or threatened species with narrow geographic ranges that are often endemic to a single site or forest patch (Burgess, 2000).

Natural habitat within the coastal mosaic is under considerable threat. This comes from habitat conversion for farmland, timber cutting and charcoal (Burgess *et al.* 2000a). Recent improvements in road infrastructure are exacerbating this pressure in South East Tanzania by opening up areas that were previously remote and relatively inaccessible (Prins & Clarke, 2006; Milledge *et al.*, 2007). Forests that remain are mostly in isolated patches of less than 5 km^2 and cover perhaps as little as five percent of original forest extent during the Holocene (Burgess *et al.*, 2000c).

Previous estimates of the extent of the remaining coastal forests used two different approaches. The first approach was based on site-specific field surveys of accessible sites and is thus a minimum conservative estimate. The Frontier-Tanzania Coastal Forest Research Programme compiled field surveys for 27 coastal forests in Tanzania and documented biological values, forest extent, conservation issues, recent history and current management status of the forests (Clarke 1995; Clarke & Dickenson, 1995; Clarke & Stubblefield, 1995). In addition, Burgess *et al.* (2000c) estimated that there was about 660 km^2 and 700 km^2 of forest habitat in the coastal areas of Kenya and Tanzania respectively, based on a compilation of all survey data from Kenya and Tanzania. The addition of further ground survey data revised the estimates of forest cover to 787 km^2 in Kenya and 692 km^2 in Tanzania (Burgess *et al.*, 2003).

The second set of forest estimates were based on analysis of satellite images, but none of the existing published regional assessments of forest extent cover the entire coastal forest region. Some focus on Tanzania and use older remote sensing data (Rodgers *et al.*, 1985; Sayer *et al.*, 1992), while others tackle a smaller region using new data; for example the Lindi and Kilwa Districts of South East Tanzania (Prins & Clarke, 2006). A variety of larger scale remote sensing datasets of land cover have also been developed for East Africa. High resolution, 30 m^2 per pixel, global land cover products include GeoCover LC Global Land Cover Classification (Anderson *et al.*, 1976; Dykstra, 2001) and MacDonald Dettwiler and Associates (MDA) Federal (MDA Federal Inc., 2006). Both products used global land cover classes that are regarded as too generic for site scale studies. One high resolution regional product, Africover (Kalensky, 1998), was created from ~1997 Landsat ETM+ data as part of a larger initiative to create a georeferenced database of natural resources for Africa. This product, while based on high-resolution data, was created by digitizing polygons with detailed land use classes that are too difficult to replicate and update to serve as a tool for monitoring change. In addition to these regional studies, forest cover and change estimates can be calculated from global vegetation maps derived from coarser-resolution satellite data (*e.g.* Anderson *et al.*, 1976; Dykstra, 2001; Friedl *et al.*, 2002; Mayaux *et al.*, 2002; Defourny *et al.*, 2006; Hansen *et al.*, 2008). However, the resolution of these products, from 250 m^2 to 1 km^2 per pixel, is generally too coarse to reliably estimate change rates for the highly fragmented and diverse forest vegetation of East Africa.

Various studies have demonstrated the utility of Landsat for monitoring habitat cover, including the detection of tropical forest clearing and regrowth (*e.g.* Skole & Tucker, 1993; Steininger, 1996, Steininger *et al.*, 2001; Christie *et al.*, 2007; Harper *et al.*, 2007; Oliveira *et al.*, 2007). Changes in tropical dry forest, although more difficult to detect because of varying deciduousness and understorey, have also been estimated using Landsat for the Cerrado in Brazil (Brannstrom *et al.*, 2008), the Atlantic forest in Paraguay (Huang *et al.*, 2009), and the Chaco in Bolivia (Killeen *et al.*, 2007).

We used Landsat ETM+ imagery with supplemental field surveys and aerial imagery to produce a detailed baseline of forest and woodland cover in the coastal forest region of Tanzania and Kenya and assess changes in habitat cover between ~1990 and ~2000. These habitat baseline and change estimates enable impact assessments of habitat loss for endemic and threatened species, and sites of consequential biodiversity such as Key Biodiversity Areas (KBAs) which are areas determined by the global conservation community as globally important sites for conservation. KBAs are identified using universal standards and quantitative criteria based on species vulnerability and irreplacebility (Eken *et al.*, 2004; Langhammer *et al.*, 2007). Vulnerability in the context of KBA assessments is defined as the presence of globally threatened species in significant numbers. Irreplacebility, or uniqueness, pertains to the presence of a significant proportion of restricted-range, congregatory, and biome-restricted species (Eken *et al.*, 2004). The KBA approach is based on that used to identify Important Bird Areas, which has already been done for Kenya and Tanzania (Bennun & Njoroge, 1999; Baker & Baker, 2002). A similar approach, although with stricter criteria, is applied to identify Alliance for Zero Extinction sites (AZEs). These sites are of highest priority for conservation because they support populations of endangered or critically endangered species threatened by imminent extinction (Eken *et al.*, 2004).

To assess the threat of habitat change to biodiversity in this region, we examined forest loss in KBAs, AZEs, and both protected and unprotected areas. We focused on forested habitat because the majority of the endemic species in this region are confined to forest, and not to other habitat types (Burgess & Clarke, 2000). We summarized results of forest cover and change within KBAs, AZEs, protected areas, and administrative districts in the coastal zones of Kenya and Tanzania.

MATERIAL & METHODS

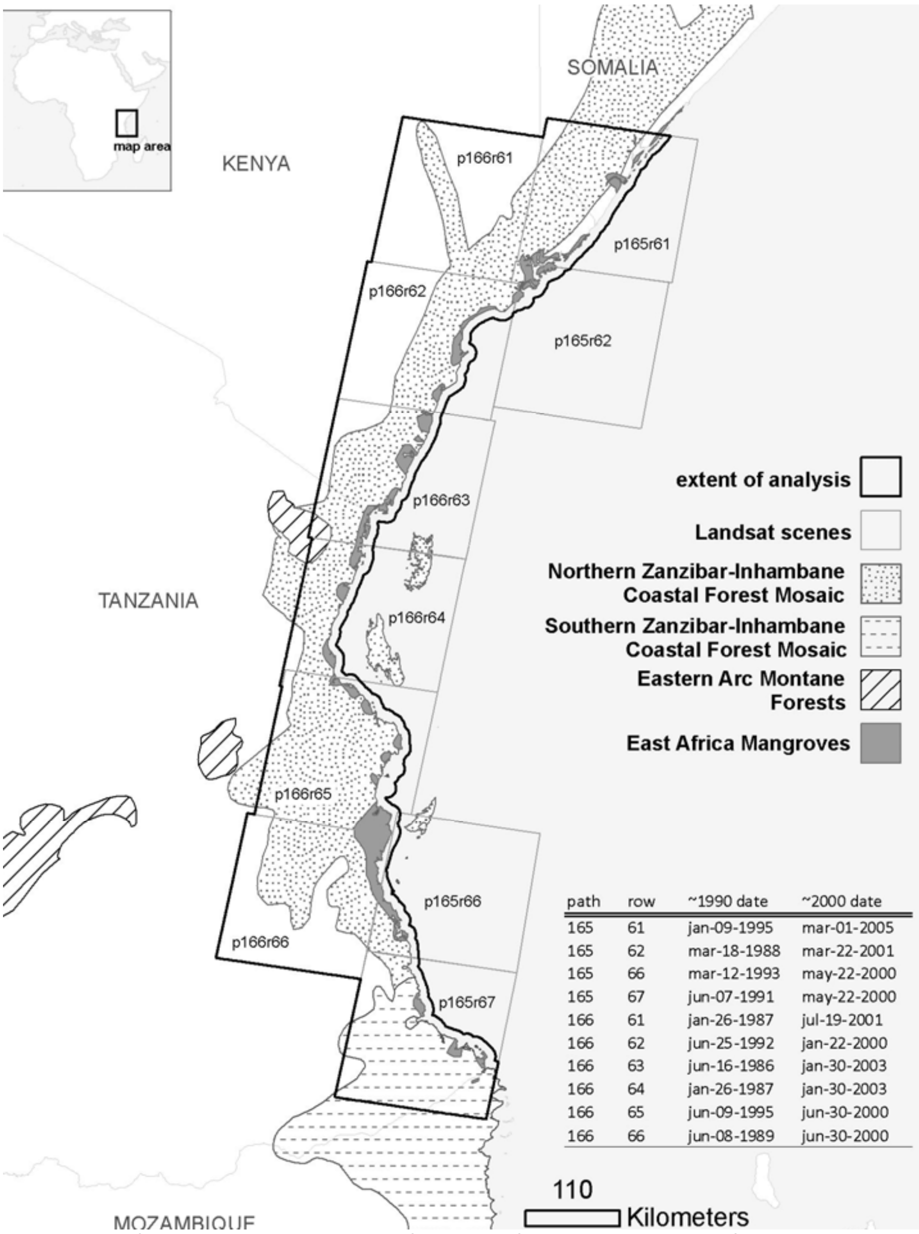
The region of analysis (figure 1) included the Tanzania and Kenya portions of the Northern Zanzibar-Inhambane coastal forest mosaic ecoregion, the northern part of the Southern Zanzibar-Inhambane coastal forest mosaic ecoregion that stretches into Tanzania, a small part of the Eastern Arc montane forests, and the East Africa Mangroves ecoregion in Tanzania and Kenya (Olson *et al.*, 2001; Burgess *et al.*, 2004a; 2004b). The islands of Zanzibar and Pemba were excluded because they had too much cloud cover on both dates to provide useful data for analysis. We also excluded the Selous Game Reserve since only a fraction of the reserve overlapped with the study area. We used spatial data for ecoregions (SCHIPPER & BURGESS, 2003) and country boundaries (National Imagery and Mapping Agency, 1997) to delineate the extent of analysis.

The study area extended across 10 Landsat scenes, spanning from 0°42'S to 11°S and 39°30'E to the coast. Landsat tile path/row and image acquisition dates are shown in figure 1. We used ortho-rectified Landsat images from NASA's Geocover project (Tucker *et al.*, 2004) for the ~1990 and ~2000 periods, as well as additional Landsat imagery purchased to replace cloudy images in the Geocover dataset. Satellite images from ~1990 were already geo-registered as part of the Geocover project. Images from ~2000 were co-registered to the ~1990 data with a second order polynomial transformation to an error within one pixel, or 28.5 meters. Two Landsat images for each tile were stacked into a single, multi-date image pair and both the cover and change classes were mapped directly by classifying the multi-temporal, stacked image in one process with a supervised Maximum Likelihood Classification (MLC). This multi-date image classification technique reduces the misclassification errors resulting from differences in seasonality, illumination, and atmospheric conditions between dates. These errors are associated with the method of post-classification change comparison of two individually classified images dates (Harper *et al.*, 2007).

Training polygons for the supervised MLC classification were created from visual interpretation of the Landsat imagery in both dates. Interpretation of land cover from the satellite imagery was assisted by field knowledge of local partners and ground-reference data published in previous studies (*i.e.* Clarke, 1995; Clarke & Dickenson, 1995; Clarke & Stubblefield, 1995; Wang *et al.*, 2003; Prins & Clarke, 2006; Gereau, 2007; Glenday, 2008; Jackson, 2008). In areas where image interpretation was difficult (*e.g.* transitional forest and woodland areas), cross checking was undertaken by studying high resolution (0.5 to 1 m depending on altitude of image acquisition), geo-rectified, digital images from aerial over flight data of southern and central Tanzania captured in May 2006 (WCST, 2006). The supplemental aerial and ground truth data facilitated image interpretation, thereby increasing the accuracy of the training data and hence of the overall map.

We classified the following land cover types: forest, woodland, mangrove, non–forest/woodland, water, and cloud/cloud shadow from the satellite imagery. The forest class consisted of only primary, mature, closed canopy forest of the following types: semi–evergreen or evergreen coastal dry forest, coastal *Brachystegia* forest, riverine forest, coastal transitional afromontane forest of the lowland East Usambaras, and humid tropical montane forest of the higher elevation East Usambaras. The woodland class consisted of deciduous Miombo (*Brachystegia*) woodlands with adjacent, but non–overlapping crowns. *Brachystegia* woodland has a grass understorey and is considered a fire–climax vegetation type. These distinctions separate *Brachystegia* woodland from the *Brachystegia* forest that has a similar composition of tree species although with a dense shrub understorey (Clarke, 2000). These deciduous woodland areas were easiest to detect with images from different seasons given the notable difference of spectral signatures between the wet and dry seasons. Sparse woodland, shrubs, and grassland, as well as plantations and secondary formations, such as forest regeneration, were assigned to type "non–forest/woodland".

For each paired Landsat scene we mapped the areas on constant land cover between the two dates and the areas of forest or woodland that changed to non–forest/woodland from the first



path	row	~1990 date	~2000 date
165	61	jan-09-1995	mar-01-2005
165	62	mar-18-1988	mar-22-2001
165	66	mar-12-1993	may-22-2000
165	67	jun-07-1991	may-22-2000
166	61	jan-26-1987	jul-19-2001
166	62	jun-25-1992	jan-22-2000
166	63	jun-16-1986	jan-30-2003
166	64	jan-26-1987	jan-30-2003
166	65	jun-09-1995	jun-30-2000
166	66	jun-08-1989	jun-30-2000

Figure 1. Map of study area. The extent of analysis for our study was defined by the coverage of Landsat scenes over the Northern Zanzibar-Inhambane coastal forest mosaic of East Africa. The area included East Africa mangrove forest ecoregion, the Northern Zanzibar-Inhambane and Southern Zanzibar-Inhambane ecoregion, and a small part of the Eastern Arc Montane Forests ecoregion containing the East Usambaras AZE.

date to the second date. We also mapped transitions of forest and woodland to and from areas obscured by clouds to estimate how much cloud cover was interfering with the habitat cover and change estimates. After several classification iterations, each classified scene was visually inspected for errors and edge matching of adjacent scenes before combining all 10 final scene classifications into a mosaic by retaining the least cloudy data where images overlapped. This mosaic was filtered to smooth the image by clumping contiguous classified groups and then eliminating groups of pixels less than 2 ha in size by recoding these groups to the class of the majority of neighbouring pixels. Plantation forests were digitized manually, based on their geometric patterns and texture observed in the images.

We preformed a map validation using QuickBird images in Google Earth (DigitalGlobe, 2005; Google, 2007). A 0.1–degree array of points was displayed over the QuickBird images in the Google Earth viewer. Land cover in the QuickBird images was visually interpreted for the area immediately surrounding each point. If the point was surrounded by a land cover patch of 2 ha or larger we labelled the point as either forest, woodland, mangrove, non-forest/woodland, or water as interpreted from the imagery. The interpreted point array was compared with the image classification in a traditional landcover mapping accuracy assessment. We calculated the kappa statistic for overall map accuracy and producers and users accuracy for individual classes. The kappa statistic is an index that compares correctly classified sampling points against the amount of sampling points that might be correctly classified by chance alone (Foody, 1992). Producer's accuracy (error of omission) is the confidence that a sampling point from the reference dataset is classified correctly. User's accuracy (error of commission) is the confidence a sampling point from the classified map represents the correct class in the reference dataset (Story & Congalton, 1986).

In calculating the forest cover and change statistics, we defined "known cover" for ~2000 as observed forest cover plus areas that were cloudy in ~1990 but classified as forest in ~2000. However, "known cover" ~1990 does not include areas that were cloudy in ~2000 because we could not know if these areas had changed to non-forest/woodland. We defined "known change" as the area that was classified as forest in the first date and changed to non-forest/woodland in the second date, *i.e.* not cloudy in either date. The denominator for calculating change rates, called the "change base", is essentially the area of forest classified in the first date that was not cloudy in the second date. We reported change in both total km^2 over the time period and in $\% .y^{-1}$ to account for varying time periods between different image pairs. We used the equation for calculating annual rates of change from the FAO (1995) to account for the increase in percent change as a forested area shrinks in size over time. The annual rate of forest loss was calculated as

$$Q=-(A_2/A_1)^{1/(time2-time1)}-1$$

where A_1 and A_2 were forest cover at $time_1$ and $time_2$. The equation was negated to convert the rate of change to rate of loss since negative change is loss.

To assess the influence of clouds obscuring forest in the satellite imagery and therefore skewing the forest cover and change statistics, we calculated a cloud factor value for each reporting unit. This value was calculated as one minus the ratio of observed forest to that of the potential forest covered with clouds. Potential forest in the 1990 imagery was all area obscured by cloud because we have no previous mapped knowledge of possible forest under the clouds. However, potential forest in 2000 excludes areas that were determined not forest in ~1990. Similarly, a cloud factor value for each change estimate was calculated as one minus the forest change base divided by that plus all other areas of possible change that were covered with clouds. Statistics of woodland cover, change, and woodland habitat cloud factor for the entire region were calculated the same as the forest cover and change statistics described above.

We calculated overall "known cover" and "known change" of forest and woodland habitats for the Zanzibar-Inhambane coastal forest mosaic of Tanzania & Kenya, whereas we calculate "known cover" and "known change" for only forest habitat within administrative boundaries, protected areas, KBAs, and AZEs. We did not present statistics for mangroves given the excessive cloudiness of the coastline and our focus on biodiversity values of lowland tropical and dry forests, not mangroves.

Forest cover and changed statistics were calculated for administrative districts, KBAs, AZE's and protected areas using the following spatial datasets. Spatial data on the administrative districts of Kenya were from Kenya Marine and Fisheries Research Institute (KEMFRI) (Ongada *et al.*, 2009). Only one Kenyan district, Mombasa, was completely contained inside the extent of analysis. We generated statistics based only on the area overlapping the study region and not the entire area of the district. We also reported the percent of the district that overlaps our study area. For the administrative districts of Tanzania we used data from the International Livestock Research Institute (ILRI, 2007) updated by Sokoine University of Agriculture (SUA) in 2008 to include the urban and rural districts of Morogoro, Lindi, and Mtwara. Of the 25 districts in the study region, only 11 were entirely contained inside the extent of analysis. Spatial data for coastal forest KBAs and AZEs used in the analysis were acquired from NatureKenya and WCST and AZEs were provided by World Wildlife Fund (WWF) (Ricketts *et al.*, 2005). Individual forest reserves, parks or game reserves can be designated as a KBA or AZE and often KBAs and AZEs include a group of forest reserves, parks, or game reserves (*e.g.* the East Usambaras, Lindi District Coastal Forests). KBAs and AZEs are not always protected areas and in some cases they have partial protection with some forested areas within the KBAs/AZEs designated as protected areas while others are not. Within our study area 18 out of 23 KBAs in Kenya are protected areas and in Tanzania 12 of 20 KBAs are protected, with an additional five that are partially protected. For KBAs with partial protection, we calculated the proportion of area that is protected within the entire site area and presented this number as "percent area protected". Within the coastal forests of Kenya and Tanzania both AZE sites are protected, the Shimba Hills in Kenya and the East Usambara Mountains in Tanzania. For forest cover and change statistics within protected-area boundaries, we used updated versions of the World Database on Protected Areas for Kenya (IUCN & UNEP, 2008) and Tanzania (IUCN & UNEP, 2009). The Kenya dataset was edited by Conservation International and Nature Kenya since the 2008 release of the WDPA 2008 and the Tanzania dataset was updated by United Nations Environmental Programme-World Conservation Monitoring Centre (UNEP-WCMC) and Cambridge University since the February 2009 release of the WDPA 2009. In total, there are more that 120 protected areas within the study area, covering up to 12 000 km2 of land.

RESULTS

Forested habitat in ~2000 covered 7% (6800 km^2) of the Zanzibar-Inhambane coastal forest mosaic region in Tanzania and Kenya, with 28% of the potential forested area obscured by cloud cover (table 1). Woodland habitat in ~2000 covered 15% (14 645 km^2) of the region with 96% of the mapped woodland habitat located in Tanzania. The accuracy assessment preformed for the entire study region for ~2000 resulted in an overall map accuracy of 88% with a kappa statistic of 65%. The producer's accuracy (indicating errors of commission) and user's accuracy (indicating errors of omission) for all mapped land cover classes in ~2000 are shown in table 2.

We estimated only 2250 km^2 of forested habitat in Kenya in ~2000 and these remaining forest habitats were small, isolated patches of forest along the Tana River and areas within 80 km of the coast. Kenya lost 53 km^2 (2.6%) of forest cover at a rate of 0.2%.y^{-1} over the study period. One area in Kenya that experienced significant forest loss was the North Malindi *Brachystegia* woodlands, part of the Dakatcha woodlands. This region had 141 km^2 of forest

Table 1. Forest and woodland cover in circa 2000, total and percent change from ~1990 to ~2000 and cloud factor statistics for habitat contained within the Tanzania and Kenya portion of the Zanzibar-Inhambane coastal forest mosaic. The yearly change rate was based on an average of 10 years difference between the image dates for ~1990 and ~2000.

Habitat type	cover ~2000 (km^2)	cloud factor cover ~2000 (km^2)	habitat change base (km^2)	Rate of loss ~1990-~2000 (km^2)	Rate of loss ~1990-~2000 (fractional %.y^{-1})	cloud factor rate of loss (%)
Forest	6824	28	6949	424	0.6	53
Woodland	14 645	15	14 935	585	0.4	34

Table 2. Overall map accuracy and producers and user's accuracy for each mapped land cover class in ~2000.

map \ QuickBird	forest	non-forest/ woodland	mangrove	woodland	total	user's accuracy
forest	146	42	2	33	223	65%
non-forest/ woodland	18	1688	2	56	1764	96%
mangrove	0	23	18	0	41	44%
woodland	15	86	1	144	246	59%
total	179	1839	23	233	1996	
producer's accuracy	82%	92%	78%	62%		88% overall map accuracy

remaining in 2000 after losing forest habitat at the rate of 1.1%.y^{-1} during the 1990s. The then unprotected Madunguni Forest, adjacent to the Arabuko-Sokoke Forest Reserve's northern border, also had a high rate of forest loss, 2.5%.y^{-1} during the 1990s, leaving only 3 km^2 forest in 2000. The Kenyan districts with high rates of forest loss included Malindi (0.9%.y^{-1}) and Kilifi (0.9%.y^{-1}); however Kilifi had 90% of forest loss obscured by clouds as indicated by the cloud factor value (table 3a). For all of Kenya, clouds obscured 65% of the imagery for 1990, 50% of potential forested area in 2000, and 75% of potential areas for forest loss between those two dates. Clouds were less of a problem for estimating forest cover in Tanzania, however, clouds still obscured 24% of potential forest in 1990, 10% of potential forested area in 2000, and 28% of the potential areas for forest loss between 1990 and 2000. Tanzania had 4565 km^2 of forest habitat remaining in ~2000 after losing 372 km^2 (7.5%) at a rate of 0.8%.y^{-1} since 1990. The largest loss of forested area in the entire study region happened in the Pwani and Mtwara regions of Tanzania**.** Forest loss rates of Tanzanian districts with greater than 100 km^2 of forest in 1990, high rates of forest loss, and low cloud factor values were Mtwara Rural (3.8%.y^{-1}), Lindi Rural (1.8%.y^{-1}), Mkulanga (1.6%.y^{-1}), and Kisarawe (1.2%.y^{-1}) (table 3b).

Protected areas covered 23% of known forested habitat for the entire coastal forest region in ~2000 with 30% of Kenya's forest habitat protected and 23% of Tanzania's forest habitat protected. Forest loss inside protected areas in the Zanzibar-Inhambane coastal forest mosaic region was 8 times slower than the rate outside protected areas. The forest loss within all protected areas was 1.1 % (16 km^2) at a rate of 0.1%.y^{-1} over the study period. This is in contrast to forest loss of 7.5% (408 km^2) at a rate of 0.8%.y^{-1} for all forest outside these protected lands. Fortunately, protected areas in Kenya experienced little to no observed loss of forest cover between ~1990 and ~2000 (table 4a). In Kenya, the rate of forest loss within protected areas was 0.01%.y^{-1}, a rate 19 times slower than the rate for unprotected areas. The rate of forest loss for protected areas in Tanzania was higher than in Kenya at a rate of 0.2%.y^{-1}. This rate was 5.5 times slower than forest loss in Tanzania's unprotected areas. Forest cover and loss within Tanzania's protected areas were reported for those sites with greater than 1 km^2 of forest habitat in 1990 in table 4b. Estimates of forest loss in Tanzania were significant for Ruvu North Forest Reserve. This reserve lost 1.8 km^2 of forest in ~1990 at a rate of 0.5%.y^{-1}. The Bombo Forest Reserves in the East Usambaras had also been severely impacted by deforestation. Bombo West lost 20% of forested area at a high rate of 1.3%.y^{-1}, Bombo East 1 also lost 20% of forest at the rate of 1.3%.y^{-1}, and Bombo East 2 lost 28% of forest at the rate of 1.9%.y^{-1} from ~1990 to ~2000.

The average rate of forest loss among all KBAs was 0.3%.y^{-1} during the study period while AZEs was 0.1%.y^{-1}. Forest loss within protected KBAs averaged 0.3%.y^{-1} whereas forest loss in unprotected KBAs averaged 0.4%.y^{-1}. Protected status of Kenya's KBAs showed little difference in forest change rates as protected KBAs had a change rate of 0.2%.y^{-1} and unprotected had a rate of 0.2%.y^{-1}. The AZE, Shimba Hills, experienced no forest loss over the study period. Table 5a shows there was very little forest loss observed in many of Kenya's coastal forest KBAs (i.e. the Arabuko-Sokoke Forest, Dodori, Marenji Forest, and Witu Forest Reserve). Unfortunately, the Tana River Forests, Chivara, Mwache Forest Reserve, Lunghi, and Diani Forest KBAs had unreliable results due to excessive cloud cover in both image dates. Results showed high deforestation rates within the protected Mangea Hill KBA at 5.0%.y^{-1}, and the unprotected Marafa KBA at 2.4%.y^{-1} with a cloud factor value for both sites around 50%. It should be noted that these are all small sites where even small amounts of forest loss will result in a large percent rate of change. The Kenyan KBA that experienced the most significant forest loss was the Dakatcha woodlands with an estimated loss of 2.1%.y^{-1} based on 66% of paired forest observation between the two dates. The Dakatcha woodland KBA boundary does not include forested regions to the north where there was significant deforestation occurring at a rate of 0.8%.y^{-1} just outside the KBA.

Within the Tanzania coastal forest region, unprotected KBAs had about the same rate of forest loss compared to protected KBAs, 0.4%.y^{-1}. The most forested KBAs included Kilwa District Coastal Forests, Kisarawe District Coastal Forests, Lindi District Coastal Forests, Rufiji Delta; and one AZE site – the East Usambara Mountains (table 5b). KBAs that showed significant rates of forest loss between 1990 and 2000 were two unprotected KBAs, the Lindi District Coastal Forests at 0.8%.y^{-1} and Rufiji Delta at 0.2%.y^{-1}. The AZE site, East Usambara Mountains, experienced a forest loss rate of 0.1%.y^{-1}. The East Usambara Mountains contain a conglomeration of 25 Forest Reserves and one Nature Reserve and unprotected forest lands outside these reserves. The forested area of the East Usamabara Mountains AZE was reduced by 4.8 km^2 between 1990 and 2000, with the highest forest loss rates occurring in the Bombo West Forest Reserve. The Pande Game Reserve and Dondwe Coastal Forests KBA in Tanzania experienced severe reduction of forested area at a rate of 3.9%.y^{-1}. The Pande Game Reserve alone lost 15% of its entire forested area from 1990–2000.

Table 3a. Forest cover in circa 2000, rate of change from ~1990 to ~2000, and cloud factor statistics for the portion of Kenya's administrative districts inside the extent of analysis. Total area does not represent the total area of the administrative district, but the total area included within the coastal forests study region The percent of the district included in the study region in listed in the last column. The total percent of coverage in analysis is the percent ratio of the extent of analysis in Kenya and the total area of the 8 districts.

Kenya district	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	percent coverage of analysis (%)
Garissa	7422	801	40	689	1.2	0.0	63	17
Kilifi	3586	144	57	144	10.2	0.9	90	79
Kwale	6660	177	1	169	0.4	0.0	71	79
Lamu	6099	561	66	425	1.5	0.0	82	90
Maldini	5178	469	24	480	31.6	0.8	38	66
Mombasa	240	0	69	0	0.0	0.4	100	100
Taita Taveta	134	1	0	1	0.0	0.0	40	1
Tana River	5040	106	71	111	7.9	0.5	87	13
TOTALS	34360	2259	50	2019	52.7	0.2	75	27

Table 3b. Forest cover in circa 2000, rate of change from ~1990 to ~2000, and cloud factor statistics for the portion of Tanzania's administrative districts inside the extent of analysis. The percent of the district included in the study region in listed in the last column. The total percent of coverage in analysis is the percent ratio of the extent of analysis in Kenya and the total area of the 25 districts.

Tanzania district	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	percent coverage of analysis (%)
Bagamoyo	4083	65	64	69	3.3	0.3	90	48
Handeni	1710	16	5	16	0.1	0.0	56	21
Ilala	333	2	81	2	0.2	1.6	98	100
Kibaha	1659	61	5	66	5.1	1.1	30	90
Kilwa	6624	840	0	875	35.5	0.4	0	49
Kinondoni	544	12	50	15	2.9	4.2	81	100

Tanzania district	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	percent coverage of analysis (%)
Kisarawe	4856	686	13	729	43.1	1.2	24	100
Korogwe	632	102	1	106	9.0	0.5	13	20
Lindi Rural	5801	250	0	299	48.2	1.9	0	92
Lindi Urban	240	1	0	2	1.1	7.9	0	100
Liwale	3992	161	1	161	0.0	0.0	1	11
Lushoto	34	1	2	1	0.0	0.3	11	1
Masasi	520	2	0	2	0.1	0.7	6	5
Mkulanga	2721	450	26	490	40.3	1.7	48	100
Morogoro Rural	1776	12	11	13	0.8	1.2	63	14
Mtwara Rural	3836	217	0	329	112.3	4.5	0	100
Mtwara Urban	191	3	0	7	4.4	9.4	0	100
Muheza	4204	352	0	364	12.7	0.2	15	100
Newala	1421	4	0	7	2.8	5.9	0	73
Pangani	1780	8	14	9	0.1	0.1	80	100
Ruangwa	750	7	0	7	0.4	0.6	0	27
Rufiji	11242	1289	5	1317	28.0	0.3	9	85
Tandahimba	1881	12	0	33	20.9	10.7	0	86
Tanga	588	2	0	2	0.0	0.0	83	100
Temeke	746	7	73	8	0.2	0.5	96	100
TOTALS	62164	4563	10	4929	371.5	0.8	28	43

Table 4a. Forest cover in circa 2000, rate of change from ~1990 to ~2000, and cloud factor statistics for Kenya's protected areas. Only protected areas with greater than 1 km^2 of observed forested area in 1990 are listed here.

Kenya Protected Area	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 (%y^{-1})	cloud factor forest loss ~1990-~2000 (%)
Arabuko Sokoke National Park	42	25	14	24	0.0	0.0	17
Arabuko Sokoke Nature Reserve	369	217	15	207	0.3	0.0	19
Boni National Reserve	1292	225	0	211	0.0	0.0	25
Buda Forest Reserve	7	4	0	4	0.0	0.0	6
Dodori National Reserve	844	21	1	18	0.0	0.0	76
Gogoni Forest Reserve	8	4	0	4	0.0	0.0	20
Gonja Forest Reserve	9	1	2	1	0.0	0.0	10
Marenji Forest Reserve	15	11	1	11	0.0	0.0	5
Mkongani North Forest Reserve	11	9	0	9	0.0	0.0	4
Mkongani West Forest Reserve	14	8	0	8	0.0	0.0	0
Mrima Forest Reserve	4	3	0	3	0.0	0.0	1
Shimba Hills National Reserve	192	96	0	89	0.1	0.0	17
Tana River Primate National Reserve	164	1	87	2	0.8	4.5	95
Witu Forest Reserve	39	21	19	21	0.0	0.0	31
Total	3009	645	92	611	1.2	0.0	71

Table 4b. Forest cover in circa 2000, rate of change from ~1990 to ~2000, and cloud factor statistics for Tanzania's protected areas. Only protected areas with greater than 1 km^2 of observed forested area in 1990 are listed here.

Tanzania Protected Area	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 (%y^{-1})	cloud factor forest loss ~1990-~2000 (%)
Amani Nature Reserve	87	59	0	59	0.4	0.0	1
Bamba Ridge Forest Reserve	11	10	0	10	0.0	0.0	1
Bombo East 1 Forest Reserve	12	4	0	5	0.9	1.3	6
Bombo East 2 Forest Reserve	5	1	0	2	0.4	1.9	10
Bombo West Forest Reserve	36	10	0	11	2.2	1.3	4
Chitoa Forest Reserve	8	4	0	4	0.0	0.0	0
Forest Reserve Name Unknown (TZA) (Mangrove) No.10	57	2	0	2	0.0	0.0	78

Tanzania Protected Area	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)
Forest Reserve Name Unknown (TZA) (Mangrove) No.27	1192	59	16	60	0.9	0.4	20
Kambai Forest Reserve	10	8	0	8	0.0	0.0	0
Katundu Forest Reserve	61	7	0	7	0.0	0.0	0
Kazimzumbwe Forest Reserve	50	9	59	9	0.1	0.3	69
Kichi Hills Forest Reserve	69	64	0	64	0.0	0.0	0
Kihuhwi Sigi Forest Reserve	9	2	0	2	0.0	0.0	0
Kikole 2 Village Forest Reserve	20	5	0	6	0.1	0.2	0
Kingoma Forest Reserve	14	2	0	2	0.1	1.1	2
Kiono Zaraninge Forest Reserve	170	4	20	4	0.0	0.0	92
Kisangi Village	40	20	0	21	0.3	0.1	0
Kitope Forest Reserve	41	22	0	22	0.2	0.1	0
Kiwawa Village	43	10	0	10	0.2	0.3	0
Kwamarimba Forest Reserve	9	7	0	7	0.0	0.0	0
Kwamgumi Forest Reserve	13	12	0	12	0.0	0.0	0
Litipo Forest Reserve	7	1	0	1	0.0	0.0	0
Looguza Forest Reserve	15	5	0	5	0.0	0.0	0
Magoroto Forest Reserve	11	7	0	7	0.0	0.0	0
Manga Forest Reserve	17	10	0	10	0.0	0.0	0
Masanganya Forest Reserve	23	8	48	8	0.1	0.1	49
Matapwa Forest Reserve	181	14	0	14	0.2	0.1	0
Mbwara Village Forest Reserve	23	3	0	3	0.0	0.0	0
Mchungu Forest Reserve	12	5	1	5	0.0	0.0	2
Mgambo Forest Reserve	13	7	0	7	0.1	0.1	0
Migeregere Villa	11	5	6	5	0.0	0.0	6
Mitarure Forest Reserve	618	20	0	20	0.0	0.0	0
Mitundumbea Forest Reserve	90	26	0	27	0.2	0.1	0
Mlinga Forest Reserve	8	4	0	4	0.0	0.0	0
Mlungui Forest Reserve	2	2	0	2	0.0	0.0	0
Mnazi Bay Marine Park	488	3	0	5	2.2	6.3	0
Mohoro Forest Reserve	31	9	0	9	0.0	0.0	0
Mtai Forest Reserve	32	28	0	28	0.1	0.0	0
Mtita Forest Reserve	35	5	14	5	0.0	0.0	15

Tanzania Protected Area	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)
Namakutwa Nyamulete Forest Reserve	47	28	0	28	0.1	0.0	0
Ndimba Forest Reserve	27	10	0	10	0.0	0.0	0
Ngulakula Forest Reserve	23	4	0	4	0.0	0.2	0
Nilo Forest Reserve	59	51	2	49	0.6	0.1	8
Nyumburuni Forest Reserve	45	6	5	6	0.1	0.2	6
Pande Game Reserve	12	7	3	8	1.5	3.9	5
Pugu Forest Reserve	24	9	46	9	0.2	0.4	48
Rondo Forest Reserve	145	37	0	37	0.3	0.1	0
Ruawa Forest Reserve	30	4	0	4	0.7	1.9	0
Ruhai River Forest Reserve	794	7	6	7	0.1	0.2	47
Rupiange Forest Reserve	24	1	0	1	0.0	0.0	0
Ruvu North Forest Reserve	326	69	5	71	1.8	0.5	13
Ruvu South Forest Reserve	325	89	0	89	0.4	0.1	0
Saadani Game Reserve	1009	3	53	3	0.0	0.0	97
Segoma Forest Reserve	13	12	0	12	0.0	0.0	0
Semdoe Forest Reserve	10	8	0	8	0.0	0.0	0
South Gendagenda Forest Reserve	32	2	0	2	0.0	0.0	5
Tamburu Forest Reserve	52	31	0	31	0.0	0.0	0
Tongomba Forest Reserve	30	22	0	22	0.2	0.1	0
Tongwe Forest Reserve	14	2	0	2	0.0	0.0	7
Vikindu Forest Reserve	18	3	59	3	0.0	0.0	70
Yelya Village	13	4	0	4	0.0	0.0	0
Total	6648	889	6	900	14.7	0.2	20

Table 5a. Forest cover ~2000, rate of change from ~1990 to ~2000, and cloud factor statistics for Kenya's KBAs and AZE (indicated with ""). The proportion of area that was protected for each site is noted in the last column . The total forest cover and change for all of Kenya's KBAs and AZE in the study area and the portion of protected area within Kenya's KBAs and the AZE are located at the bottom of the table.*

Kenya KBA/AZE(*)	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	area protected (%)
Arabuko-Sokoke Forest	411	242	14	231	0.3	0.0	19	100
Boni Forest Reserve	245	10	0	9	0.0	0.0	76	100
Buda Forest Reserve	7	4	0	4	0.0	0.0	7	100
Chivara	1	0	100	0	0.0	0.0	100	100
Chuna Forest	35	0	3	0	0.0	0.0	87	0
Dakatcha Woodland	352	26	23	29	4.5	2.1	34	100
Diani Forest	4	0	82	0	0.0	1.2	97	100
Dodori	844	21	1	18	0.0	0.0	76	100
Dzombo Hill Forest	6	1	0	1	0.0	0.0	15	100
Gongoni Forest Reserve	8	4	0	4	0.0	0.0	20	100
Kayas	43	4	20	4	0.0	0.0	69	100
Kiunga Marine National Reserve	242	0	0	0	0.0	0.0	9	100
Lunghi	324	17	76	12	0.0	0.0	89	100
Mangea Hill	72	4	46	6	2.1	5.0	45	100
Marafa	16	2	46	2	0.3	2.4	49	0
Marenji Forest	15	12	1	12	0.0	0.0	4	100
Mrima Hill Forest	4	3	0	3	0.0	0.0	1	100
Mwache Forest Reserve	4	0	46	0	0.0	0.0	94	100
Sabaki River Mouth	6	0	71	0	0.0	0.0	74	0
Shimba Hills	217	114	0	107	0.1	0.0	15	100
Shimoni Forests	14	6	0	6	0.0	0.0	12	0
Tana River Delta	77	8	57	8	0.0	0.0	62	0
Tana River Forests	258	2	97	3	2.5	8.9	96	100
Witu Forest Reserve	39	21	19	21	0.0	0.0	31	100
Totals	3244	501	26	482	9.9	0.2	46	95

*AZE

Table 5b. Forest cover in ~2000, rate of change from ~1990 to ~2000, and cloud factor statistics for Tanzania's KBAs and AZE (indicated with ""). The proportion of area that was protected for each site is noted in the last column. The total forest cover and change for all of Tanzania's KBAs and AZE in the study area and the portion of protected area within Tanzania's KBAs and AZE are located at the bottom of the table.*

Tanzania KBA/AZE(*)	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	area protected (%)
Bagamoyo (Kikoka Forest Reserve)	16	0.08	87.76	0	0.0	0.0	94	100
Bagamoyo District Coastal Forests	1141	7	32	7	0.0	0.0	94	100
Dar es Salaam coast	399	0	100	0	0.0	0.0	100	100
East Usambara Mountains	377	248	0	249	4.8	0.1	2	100
Handeni District Coastal Forests	32	2	0	2	0.0	0.0	5	100
Kisarawe District Coastal Forests	398	105	16	106	0.9	0.2	21	100
Kisiju	13	0	14	0	0.0	2.6	69	0
Lindi (Nyangao River)	37	2	0	2	0.1	0.6	0	0
Lindi Creek	62	0	0	0	0.0	2.0	0	0
Lindi District Coastal Forests	438	66	0	71	4.8	0.8	0	51
Mikindani	15	0	0	0	0.0	0.0	0	100
Mnazi Bay	280	3	0	6	2.7	6.2	0	0
Muheza District Coastal Forests	40	2	0	2	0.0	0.0	15	100
Newala (Kitama)	110	0	0	1	0.7	23.0	0	0
Newala District Coastal Forests	59	1	0	1	0.1	1.5	0	100

Tanzania KBA/AZE(*)	total area (km^2)	forest cover ~2000 (km^2)	cloud factor forest ~2000 (%)	forest change base (km^2)	forest loss ~1990-~2000 (km^2)	annual rate of forest loss ~1990-~2000 rate ($\%y^{-1}$)	cloud factor forest loss ~1990-~2000 (%)	area protected (%)
Pande Game Reserve and Dondwe Coastal Forests	12	7	3	8	1.5	3.9	5	100
Pangani District Coastal Forests	48	0	5	0	0.0	0.0	41	94
Rufiji Delta	1258	60	36	61	0.9	0.2	40	2
Rufiji District Coastal Forests	133	34	1	34	0.2	0.0	3	100
Tanga North - Kibo saltpans	1	0	0	0	0.0	0.0	69	0
Tanga South	23	0	0	0	0.0	0.0	21	100
Totals	4892	539	15	552	16.8	0.3	30	96

*AZE

DISCUSSION

Our results showed that the forest area in the Eastern African Coastal Forests has declined, and that the rate of decline is significant. Rates of forest loss within protected areas were lower than in unprotected forest areas, which means that protected areas will become increasingly important as areas for species conservation while habitat is lost elsewhere. Most KBA and all AZE sites are also fully protected areas, and the AZE sites combined had the lowest rate of forest loss compared to KBAs and protected areas. Tanzania's protected areas had a higher rate of forest loss compared to Kenya's protected areas, however, the excessive cloudiness in both dates of imagery for Kenya may have prevented the detection of changes in forest cover. Furthermore, Kenya has much less coastal forest remaining compared to Tanzania and might have experienced higher rates of forest loss before 1990.

As forest loss continues across the coastal forests, those species confined to forest habitats, including the majority of the endemic species (Burgess *et al.*, 1998; Burgess & Clarke, 2000), will decline in range and population over time. For endemic and near-endemic mammal species, the most important coastal forest areas for conservation in our study area are Arabuko-Sokoke, East Usambaras, South Gendagenda, Pugu Hills, Tana River, and Rondo (Burgess *et al.*, 2000b). Our results showed little degradation of forest in Arabuko Sokoke, Gendangenda, Rondo; however we did report forest loss in the East Usambaras, and high rates of forest loss in Pugu forest.

In terms of endemic birds, the Clarke's Weaver *Ploceus golandi* (Clarke, 1913) is one of the most highly threatened species in the coastal forests (IUCN, 2008). It is confined to South East Kenya, especially in Arabuko-Sokoke Forest and lowland *Brachystegia* habitats in the Dakatcha woodlands KBA (see inset, map 2 in figure 2). While our results showed little forest loss in the Abruko-Sokoko KBA, Bennun & Njoroge (1999) reported significant clearing of woodland in the Dakatcha hills for pineapple farming and nearby woodland were under threat from the collection of timber for fuel wood and carving-timber.

Another important area for biodiversity conservation is the lowland East Usambara Mountains. While overall forest loss within this AZE was low, some forested areas in the East Usambaras experienced relatively high rates of forest loss from ~1990 to ~2000. Any detected loss of forest is worrying, given the high degree of endemism for reptiles, amphibians and plant species in this area (Iversen, 1991; Johansson *et al.*, 1998; Burgess *et al.*, 2007; 2000b). Previous forest loss in the northern reserves of the East Usambara Mountains KBA resulted from both legal and illegal cultivation of tea, cardamom spice and subsistence agriculture as well as logging for timber (Rodgers & Homewood, 1982). The Bombo East reserves I & II, which had the highest rates of forest loss in the East Usambara Mountain reserves, are threatened by fire and selective logging, raising concerns over the conservation of the endemic and near endemic forest dependent species (Staddon *et al.*, 2002a; 2002b).

The KBA and AZE sites we analyzed are defined by the presence of threatened species and therefore the completeness and accuracy of the Red List has influenced the results we present and discuss here. For this region the plant Red Listing process is known to be incomplete and somewhat inaccurate. For reptiles, almost no Red Listing has been attempted for the species confined to the region, and this is also the case for other taxonomic groups. As such the list of KBA sites is likely to change in the future as further Red List assessments become available; this will change the distribution of the KBA sites in the area, and hence change the relevance of the results presented here.

The accuracy of results from this study, as in any study using optical satellite images for land cover mapping, are influenced by the cloudiness of a region, the separability of land cover types, and limitations in detecting changes in the canopy understorey or canopy thinning. Unfortunately, coastal East Africa is persistently cloudy and this was reflected in the cloud

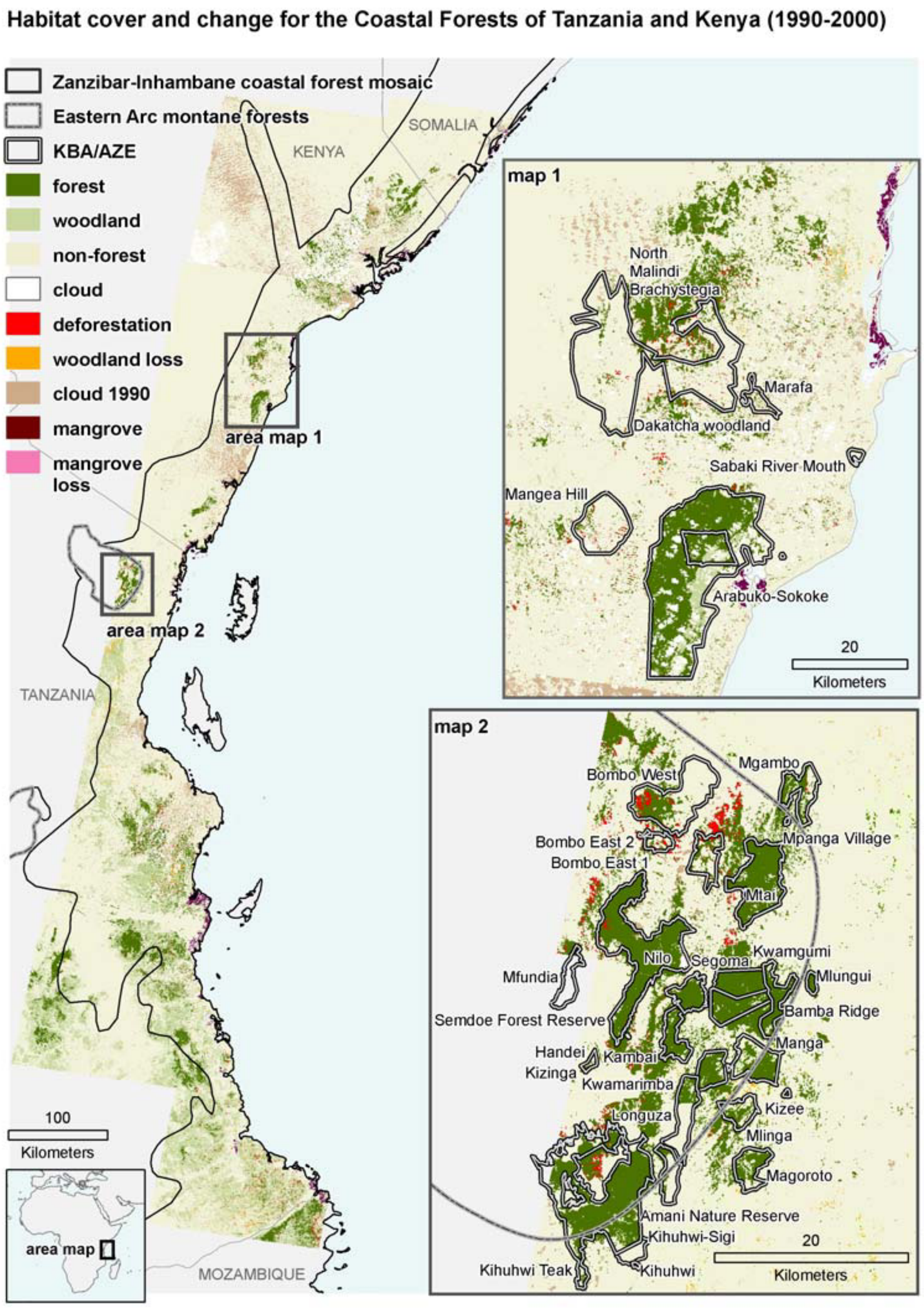


Figure 2. Map displaying forest, woodland, and mangrove cover and change for the coastal forests of Tanzania and Kenya from ~1990-~2000. Shown are forest, woodland and mangrove cover for ~2000 and forest, woodland and mangrove loss from ~1990 to ~2000. The subset, map 1, is a zoom in of the coastal forests along in Kenya near the city of Malindi. Map 2 is a zoom in of the forest reserves that make up the East Usambaras KBA.

factor values for forest observations in the satellite imagery. These values were extremely high for Kenya in general due to excessive cloudiness along the Kenya coast. Tanzania had much lower cloud factor values with the exception of the coastal Dar es Salaam region and northern Pwani Coast region. Another regional challenge in producing a classified map product from remotely sensed imagery is defining vegetation classes in a complex, transitional landscape. Map classifications of this area are difficult to produce and to compare with other map products because closed forest transitions to woodland and then bushland and grassland in a gradient. Furthermore, changes in habitat are relatively easy to monitor when there is forest clear cutting. However, selective timber logging only thins the forest canopy and is therefore more difficult to detect with optical imagery and usually requires sub-pixel analysis of images every 6 to 12 months (*e.g.* Asner *et al*., 2005). In the 1990s, timber trade emerged as a thriving export industry in Southern Tanzania, particularly in the Rufiji, Kilwa, and Liwale Districts and in the last decade there has been a substantial increase in illegal logging activity leading to unsustainable rates of timber harvesting from the forests and woodlands of southern Tanzania (Milledge *et al*., 2007). Our results of habitat change from ~1990 to ~2000 might not capture the initial canopy thinning from selective logging, however as selective logging causes further habitat degradation, these changes will be detected with our methodology. An additional update of habitat baselines would better reflect the habitat destruction now that coastal Tanzania has endured the brunt of selective and illegal logging.

Our accuracy assessment reflected the reliability of our results and revealed the confusion between classes that resulted from separating land cover classes in a transitional landscape. While our overall map accuracy was high, the kappa statistic for our accuracy assessment was relatively low. The small number of classes might attribute to this low kappa value since having fewer classes increases the likelihood of a pixel being classified purely by chance. The accuracy among classes was highest for the non-forest class, a reflection of the ease of interpreting non-forest in the imagery and because 82% of the study region is non-forest, resulting in more sampling points. The majority of omission errors occurred where non-forest was classified as forest or woodland, according to our visual interpretation of QuickBird images. Some of these errors may be due to land cover change between 2000 and 2005 since our classified map is based on ~2000 satellite imagery, whereas the QuickBird imagery is more recent, ~2005. However, this is unlikely a large factor given the estimated 0.6 $\%.y^{-1}$ forest loss rate. The woodland class had the lowest accuracy, mostly because of confusion with non-forest. Accuracy of the forest class also suffered errors of commission where woodland was miss-classified as forest. Much of the error of commission for the forest class, 42% of it, was from inclusion of woodland into the forest class.

We have compared our forest statistics with other regional studies that estimate forest area in the coastal forests to gauge the reliability of our results. Prins & Clarke (2006) used Landsat ETM satellite imagery at 28.5 m resolution to derive forest estimates for the Lindi and Kilwa districts of southern Tanzania and found that only 1159 km^2 of dry, scrub and *Brachystegia* Coastal forest remained in 2000/2001. This is close to our estimate of 1091 km^2 of forest in 2000 within the same districts, however, we only estimated forest cover for the Zanzibar-Inhambane geographic region in these districts, and this region only covers half of the Kilwa district while encompassing most of the Lindi District. For areas inside forest reserves (*i.e.* Kitope, Matapwa, Mitarure, Nampekeso, Nandimba) in the districts, our estimated forest cover was 41% less than Prins & Clarke (2006). The discrepancy between estimations could arise from different interpretations of a certain difficult-to-classify woody vegetation dominated by *Brachystegia* trees which is a prominent forest type in this area. This *Brachystegia* forest had been described with several names from transitional woodland, deciduous forest and *Brachystegia* thicket and it is even difficult to characterize in the field (Clarke, 2002). In general, transitional vegetation types make map classification of this area difficult to produce and to compare with other map products.

Our ~1990 forest cover results were only 18 km^2 lower (12% less) than the estimates derived from field research in four reserves by the Frontier-Tanzania Coastal Forest Research Programme between 1989–1994 (Clarke 1995; Clarke & Dickenson, 1995; Clarke & Stubblefield, 1995). Given the difference in study dates, this change may be due to forest loss or intense forest degradation over time. Our estimate of ~2000 Tanzania coastal forest cover in 24 reserves is somewhat different, and is 189 km^2 higher than the previous total estimate of same reserves from Burgess *et al.* (2000a). Parks and reserves with very similar estimates (within 3 km^2 or 3% of forested area) compared to Burgess *et al.* (2000a) included Kwamgumi, Manga, Mchungu, Mlungui and Semdoe.

Our estimates of the area of forest in Kenyan reserves were mostly lower than those in previous studies. This is most likely due to the heavy cloud cover in our satellite images. For example, the Lunghi KBA is reported by Burgess *et al.* (2000a) to have 80 km^2 of forest, but we estimated only 17 km^2 of forest. However, for our analysis 76% of this area was obscured by clouds in ~2000. We were unable to report results for the lower Tana River forests due to excessive cloud cover. However, a recent estimate of forest cover along the lower Tana River in Kenya by Moinde-Fockler *et al.* (2007) revealed that only 36 km^2 forest remain in 2000 with 15 km^2 of forest left inside the Tana River National Primate Reserve. For the Kenyan reserves with cloud factors less than 30%, our estimates for forest cover were within 1 km^2 of estimates from Burgess *et al.* (2000a) for nine reserves. In addition, the forest estimates for Mrima Hill Forest (KBA), Kaya Bore and Dodori (KBA) were within 3% in both studies.

We grossly overestimated forested area in the Witu Reserve (KBA), Shimba Hills NR/FR (AZE) and Boni Nature Reserve (KBA) when compared to estimates by Burgess *et al.* (2000a). Much of what we classified as forest in the Boni, Dodori, and Lunghi reserves is actually dense, semi-evergreen woodland and scrubland on the ground (Q. Luke, pers. comm.; Robertson & Luke, 1993). Therefore, most forest and any forest change analysis for this region were probably inaccurate and should have been classified as a type non-forest/woodland. We did not make any changes to the results of this study based on this discovery, and the overall forest loss results are not affected because there was almost no forest change detected in these KBAs. Recoding these areas from forest to non-forest/woodland would reduce the overall forest cover by 48 km^2, which would result in a 2% reduction of the ~2000 forest cover estimate for Kenya and a change of less than 1% for the entire region. These errors stress how discrepancies between comparative studies of forest cover classification often stem from differences in the definition of a forest cover class or from the interpretation of the satellite imagery. Therefore, monitoring forest cover over time is challenging in this region.

Our estimate of the rate of forest loss from ~1990 to ~2000 in the coastal forests of Kenya and Tanzania is 0.6 %.y^{-1}. This rate is higher than that calculated for the adjacent Eastern Arc Mountains, estimated using the same methodology, which revealed an 11% reduction in forested area between ~1970 to ~2000, from which we calculated an annual rate of loss of 0.4%.y^{-1} over the 30-year period. However, 95% of the original ~1970 forested area was lost between 1970 and 1990 and mostly for agriculture. Between ~1990 and ~2000, the remaining 5% was mostly lost for timber extraction, a practice that is less detectable by remote sensing (Forestry and Beekeeping Division, 2006; Burgess *et al.*, 2007). To compare these decadal changes to our 1990–2000 coastal forest rates, we estimated a comparable annual rate of forest loss of 0.5%.y^{-1} for the first two decades of the Eastern Arc study period and a much lower rate of 0.1 %.y^{-1} for the 1990s.

CONCLUSION

Coastal Tanzania and Kenya have a long history of forest loss and fragmentation that continued during the 1990s. The rate of loss over the study area is within the range found among many other tropical forest countries and close to the global average rate of loss for tropical forests (Hansen *et al.*, 2008). The significantly lower rate inside protected areas is in agreement with findings from studies in other countries (*e.g.* Christie *et al.,* 2007; Harper *et al.,* 2007). However, some protected areas did experience significant forest loss, and the causes of this should be explored as forest habitat supports the majority of the thousands of the species narrowly endemic to this region. In addition, several un-protected KBAs experienced significant forest loss, such as Marafa and Lindi District Coastal Forests. Whether these KBAs and protected areas have continued to experience forest loss since 2000 should be determined. The forest loss threat to these sites should be taken into account when assessing resources needed to manage protected areas and when prioritizing the creation of new protected areas.

This study forms a baseline from which regular monitoring can continue using a consistent data source. The data produced from monitoring not only provides information on the level of threat of particular sites from forest loss, but can also feed into important assessments at the national level. For example, Red List assessments of sets of species can be improved by using the more-precise data on habitat cover and change that result from such studies, *e.g.* Buchanan *et al.* (2007) and Hall *et al.* (2009), and historical forest loss trends are the main input into site-level or national-level emission baselines required for projects seeking to reduce emissions from deforestation and degradation (REDD).

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REFERENCES

Anderson, J.R., E.E. Hardy, J.T. Roach & R.E. Witmer (1976). *A land use and land cover classification system for use with remote sensor data.* U.S. Geological Survey, Professional Paper 964. Reston, VA.

Asner, G. P., D.E. Knapp, E.N. Broadbent, P.J.C. Oliveira, M. Keller & J.N. Silva (2005). Selective logging in the Brazilian Amazon. *Science* **310**(5747): 480–482.

Baker, N. & E.M. Baker (2002). *Important Bird Areas in Tanzania: a First Inventory*. Wildlife Conservation Society of Tanzania, Dar es Salaam, Tanzania.

Bennun, L. & P. Njoroge (1999). *Important Bird Areas in Kenya*. Nature Kenya, Nairobi, Kenya.

BirdLife International (2008). Threatened Birds of the World 2008. www.birdlife.org. Cambridge: BirdLife International. [accessed 30 March 2009].

Brannstrom, C., W. Jepson, A.M. Filippi, D. Redo, Z. Xu & S. Ganesh (2008). Land change in the Brazilian Savanna (Cerrado), 1986–2002: Comparative analysis and implications for land-use policy. *Land Use Policy* **25**: 579–959.

Brooks, T.M., R.A. Mittermeier, C.G. Mittermeirer, G.A.W. de Fonseca, A.B. Reynolds, W.R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin & C. Hilton-Taylor (2002). Habitat loss and extinction in the hotspots of biodiversity. *Conservation Biology* **16**: 909–923.

Buchanan, G.M., S.H.M. Butchart, G. Dutson, J.D. Pilgrim, M.K. Steininger, K.D. Bishop & P. Mayaux (2007). Using remote sensing to inform conservation status assessment: estimate of recent deforestation rates on New Britain and the impact upon endemic birds. *Biological Conservation* **141**: 56–66.

Burgess, N.D. (2000). Global importance and patterns in the distribution of Coastal Forest species. In N.D. Burgess & G.P. Clarke (eds.), *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Gland and Cambridge. Pp. 235–248.

Burgess, N.D. & C. Muir (eds.) (1994). The Coastal Forests of Eastern Africa: biodiversity and conservation. Coastal Forest Research Programme Technical Report No. 25. The Society for Environmental Exploration, Royal Society for the Protection of Birds, and the University of Dar es Salaam. London and Dar es Salaam.

Burgess, N.D., G.P. Clarke & W.A. Rodgers (1998). Coastal Forests of eastern Africa: status, species endemism and its possible causes. *Biological Journal of the Linnean Society* **64**: 337–367.

Burgess N.D. & G.P. Clarke (eds.) (2000). *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Gland and Cambridge.

Burgess, N.D., G.P. Clarke, J. Madgwick, S.A. Robertson & A. Dickinson (2000a). Status and vegetation; distribution and status. In N.D. Burgess & G.P. Clarke (eds.), *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Gland and Cambridge. Pp. 71–81.

Burgess, N.D., D. Kock, A. Cockle, C. FitzGibbon, P. Jenkins & P. Honess (2000b). Biodiversity Values; mammals. In N.D. Burgess & G.P. Clarke (eds.), *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Gland and Cambridge. Pp. 173–190.

Burgess, N.D., P. Matthews, Y. Evers & K. Woodcock (2000c). Human and forest interactions; non-timber uses, threats and local attitudes. In N.D. Burgess & G.P. Clarke (eds.), *Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme, Gland and Cambridge. Pp. 281–301.

Burgess, N.D., N. Doggart., K. Doody, G. Negussie, P. Sumbi & A. Perkin (2003). New information on the lowland coastal forests of eastern Africa. *Oryx* **37**: 280–281.

Burgess, N., J.D. Hales, E. Underwood, E. Dinerstein, D. Olson, I. Itoua, J. Schipper, T. Ricketts & K. Newman (2004a). *Terrestrial Ecoregions of Africa and Madagascar: a Continental Assessment*. Island Press, Washington DC.

Burgess, N.D., I. Gordon, J. Salehe, P. Sumbi, N. Doggart, A. Rodgers & P. Clarke (2004b). Coastal Forests of Eastern Africa. In R.A. Mittermeier, P. Robles-Gil, M. Hoffmann, J.D. Pilgrim, T.M. Brooks, C.G. Mittermeier, J.L. Lamoreux, & G Fonseca (eds.), *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions*. Second Edition. Cemex, Mexico. Pp. 231–239.

Burgess, N.D., T.M. Butynski, N.J. Cordeiro, N.H. Doggart, J. Fjeldsa, K.M. Howell, F.B. Kilahama, S.P. Loader, J.C. Lovett, B. Mbilinyi, M. Menegon, D.C. Moyer, E. Nashanda,

A. Perkin, F. Rovero, W.T. Stanley & S.N. Stuart (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation* **134**: 209–231.

CEPF (2003). Ecosystem Profile: Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya Biodiversity Hotspot. Critical Ecosystems Partnership Fund, Washington DC. www.cepf.net [Accessed on 5 May 2009].

Christie, T., M.K. Steininger, D. Juhn & A. Peal (2007). Fragmentation and clearance of Liberia's forests: 1986–2000. *Oryx* **41**: 539–543.

Clarke, G.P. (1995). Status Reports for 6 Coastal Forests in Lindi Region, Tanzania. Coastal Forest Research Programme Technical Report No. 18. The Society for Environmental Exploration, U.K and the University of Dar es Salaam, Tanzania.

Clarke, G.P. (2000). Defining the Eastern Africa Coastal Forests. In N.D. Burgess & G.P. Clarke (eds.), *The Coastal Forests of Eastern Africa.* IUCN: Cambridge and Gland. Pp. 2–26.

Clarke, G.P. & A. Dickinson (1995). Status Reports for 11 Coastal Forests in Coast Region, Tanzania. Coastal Forest Research Programme Technical Report No. 17. The Society for Environmental Exploration, U.K and the University of Dar es Salaam, Tanzania.

Clarke, G.P. & L.K. Stubblefield (1995). Status Reports for 7 Coastal Forests in Coast Region, Tanzania. Coastal Forest Research Programme Technical Report No. 16. The Society for Environmental Exploration, U.K and the University of Dar es Salaam, Tanzania.

Clarke, G.P., K. Vollesen & L.B. Mwasumbi (2000). Vascular Plants. Pp. 129–149. In N.D. Burgess & G.P. Clarke, *The Coastal Forests of Eastern Africa*. IUCN Forest Conservation Programme: IUCN, Cambridge and Gland.

Defourny, P., C. Vancutsem, P. Bicheron, C. Brockmann, F. Nino, L. Schouten, & M. Leroy (2006). GLOBCOVER: a 300 m global land cover product for 2005 using ENVISAT MERIS time series. ISPRS Commission VII Mid-term Symposium "Remote Sensing: From Pixels to Processes", Enschede, the Netherlands, 8–11 May 2006.

DigitalGlobe (2005). QuickBird imagery in GoogleEarth. DigitalGlobe, Longmont, Colorado.

Dykstra, J.D. (2001). The GeoCover-Ortho Program: Covering the Entire Earth's Landmass with 14,000 Landsat Images; *GEO INFORMATICS.* Jan/Feb: 26–29.

Eken, G.L. Bennun, T.M. Brooks, W. Darwall, L.D.C. Fishpool, M. Foster, D. Knox, P. Langhammer, P. Matiku, E. Radford, P. Salaman, W. Sechrest, M.L. Smith, S. Spector & A. Tordoff (2004). Key Biodiversity Areas as site conservation targets. *BioScience* **54**: 1110–1118.

FAO, 1995. Forest resources assessment 1990. Global Synthesis. FAO, Rome.

Foody, G.M. (1992). On the compensation for change agreement in image classification accuracy assessment. *Photogrammetric Engineering and Remote Sensing* **58**(10): 1459–1460.

Forestry and Beekeeping Division (2006). Forest Area Baseline for the Eastern Arc Mountains. Compiled by B.P. Mbilinyi, R.E. Malimbwi, D.T.K. Shemwetta, Songorwa, E. Zahabu, J.Z. Katani and J. Kashaigili for Conservation and Management of the Eastern Arc Mountain Forests, Forestry and Beekeeping Division, Dar es Salaam.

Friedl, M.A., D.K. McIver, J.C.F. Hodges, X.Y. Zhang, D. Muchoney, A.H. Strahler, C.E. Woodcock, S. Gopal, A. Schneider, A. Cooper, A. Baccini, F. Gao & C. Schaaf (2002). Global land cover mapping from MODIS: algorithms and early results. *Remote Sensing of Environment* **83**: 287–302.

Gereau, G., Q. Luke, W.J. Kindeketa, S. Bodine, L. Festo, O.A. Kibure, G.S. Laizer, G. Schatz, C. Hilton-Taylor & M. Maunder (2007). Plant Conservation Assessment in the Eastern Arc Mountains and Coastal Forests of Tanzania and Kenya. www.mobot.org/MOBOT/Research/tanzania/cepf.shtml [accessed 9 August 2010]

Glenday, J. (2008). Carbon storage and emissions offset potential in an African dry forest, the Arabuko-Sokoke Forest, Kenya. *Environmental Monitoring and Assessment* **142**(1–3): 85–95.

Google (2007). Google Earth version 4.2. Google Inc. Mountain View, CA.

Hansen, M.C., S.V. Stehman, P.V. Potapov, T.R. Loveland, J.R. Townshend, R.S. DeFries, K.W. Pittman, B. Arunarwati, F. Stolle, M.K. Steininger, M. Carroll & C. DiMiceli (2008). Humid tropical forest clearing from 2000 to 2005 quantified by using multitemporal and multiresolution remotely sensed data. *Proceedings of the National Academy of Sciences* of the USA **105**(27): 9439–9444.

Hall, J., N.D. Burgess, J.C. Lovett, B. Mbilinyi & R.E. Gereau (2009). Fifty years of deforestation in the Eastern Arc Mountains of Tanzania: impacts on the extinction risk of endemic plants. *Biological Conservation.***142**(11): 2510–2521.

Harper, G.J., M.K. Steininger, C.J. Tucker, D. Juhn & F. Hawkins (2007). Fifty years of deforestation and forest fragmentation in Madagascar. *Environmental Conservation* **34**: 325–333.

Huang, C., S. Kim, K. Song, J.R.G. Townshend, P. Davis, A. Altstatt, O. Rodas, A. Yanosky, R. Clay, C.J. Tucker & J. Musinsky (2009). Assessment of Paraguay's forest cover change using Landsat observations. *Global and Planetary Change* **67**(1–2): 1–12.

ILRI (2007). International Livestock Research Institute. Nairobi, Kenya. www.ilri.org/gis/search.asp [accessed on 29 April 2009].

IUCN (2008). *2008 IUCN Red List of Threatened Species*. www.iucnredlist.org. [accessed on 23 March 2009].

IUCN & UNEP. (2008). The World Database on Protected Areas (WDPA): Protected areas of Kenya. UNEP-WCMC, Cambridge, UK.

IUCN & UNEP. (2009). The World Database on Protected Areas (WDPA): Protected areas of Tanzania. UNEP-WCMC, Cambridge, UK.

Iversen, S.T. (1991). The Usambara mountains, NE Tanzania: phytogeography of the vascular plant flora. *Symbolae Botanicae Upsaliensis* **29**(3): 136–151.

Jackson, C. (2008). Research & Monitoring by A Rocha Kenya Activity Report for 2007. A Rocha Kenya. www.arocha.org/ke-en/5017-DSY/version/default/part/AttachmentData/data/2007%20ARK_RM_2007_summary_rpt.pdf [accessed 30 March 2009].

Johansson, S.G., P. Cunneyworth, N. Doggart & R. Botterweg (1998). Biodiversity surveys in the East Usambara Mountains: preliminary findings and management implications. *Journal of East African Natural History* **87**: 139–157.

Kalensky, Z.D. (1998). Africover—Land Cover Database and Map of Africa. *Canadian Journal of Remote Sensing* **24**(3): 292–297.

Killeen, T. J., V. Calderon, L. Doria, B. Quezada, M.K. Steininger, G. Harper, L. A. Solórzano, & C.J. Tucker (2007). Thirty years of Land-cover change in Bolivia. *AMBIO: A journal of the Human Environment* **36**(7): 600–606.

Langhammer, P.F., M.I. Bakarr, L.A. Bennun, T.M. Brooks, R.P. Clay, R.P., W. Darwall, N. De Silva, G.J. Edgar, G. Eken, L.D.C. Fishpool, G.A.B. de Fonseca, M.N. Foster, D.H. Knox, P. Matiku, E.A. Radford, A.S.L. Rodigues, P. Salaman, W. Sechrest, & A.W. Tordoff (2007). *Identification and Gap Analysis of Key Biodiversity Areas:Targets for Comprehensive Protected Area Systems.* Gland, Switzerland: IUCN.

Mayaux, P., E. Bartholomé, M. Massart & A.S. Belward (2002). The land cover of Africa for the year 2000. LUCC Newsletter **8** December.

MDA Federal Inc. (2006). EarthSat GeoCover LC Overview. www.mdafederal.com /geocover/geocoverlc/gclcoverview [accessed 12 January 2009]

Milledge, S., A.H. Ised, K. Gelvas, & A. Ahrends (2007). *Forestry, Governance and National Development: Lessons Learned from a Logging Boom in Southern Tanzania* TRAFFIC East/Southern Africa/ Tanzania Development PartnersGroup/Ministry of Natural Resources of Tourism, Dar es Salaam, Tanzania.

Milne, R. & D.C. Mobbs (eds.) (2006). UK emissions by sources and removals by sinks due to land use, land use change and forestry activities, Centre for Ecology & Hydrology-Edinburgh

& Lancaster, Aberdeen University, Rothamsted Research, Forest Research-Alice Holt, Centre for Terrestrial Carbon Dynamics (Universities of Sheffield, Edinburgh, York & University College London). Department of the Environment, Food and Rural Affairs, Global Atmosphere Division. London, UK. http://www.edinburgh.ceh.ac.uk/ukcarbon /docs/Defra_Report_2006.pdf [accessed 3 June 2009].

Mittermeier, R.A., P.R. Gil, M. Hoffman, J. Pilgrim, T. Brooks, C.G. Mittermeier, J. Lamoreux, & G.A.B. da Fonseca (2004). *Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions.* University of Chicago Press, Chicago, Illinois.

Moinde-Fockler, N.N., N.O. Oguge, G.M. Karere, D. Otina, & M.A. Suleman (2007). Human and natural impacts on forests along lower Tana river, Kenya: implicataions towards conservation and management of endemic primate species and their habitat. *Biodiversity Conservation*. **16**: 116–1173.

Myers, N., R.A. Mittermeier, C.G. Mittermeier, G.A.B. da Fonseca & J. Kent (2000). Biodiversity hotspots for conservation priorities. *Nature*. **403**: 853–858.

National Imagery and Mapping Agency (1997). World Countries (VMAP0) Fairfax, VA: National Imagery and Mapping Agency.

Oliveira, P.J.C., G. Asner, D.E. Knapp, A. Almeyda, R. Galvan-Gildemeister, S. Keene, R.F. Raybin, R.C. Smith (2007). Land-use allocation protects the Peruvian Amazon. Science **317**: 1233–1236

Olson, D.M., E. Dinerstein, E.D. Wikramanayake, N.D. Burgess, G.V.N. Powell, E.C. Underwood, J.A. D'amico, I. Itoua, H.E. Strand, J.C. Morrison, C.J. Loucks, T.F. Allnutt, T.H. Ricketts, Y. Kura, J.F. Lamoreux, W.W. Wettengel, P. Hedao, & K.R. Kassem (2001). Terrestrial ecoregions of the world: a new map of life on Earth. *BioScience* **51**: 933–938.

Ongada, H., J. Salehe, R. Mabunda & N.D. Burgess (eds.) (2009). *Coastal Forests of Eastern Africa: Atlas*. WWF Eastern Africa Regional Programme Office, Nairobi.

Prins, E. & P. Clarke (2006). Discovery and enumeration of the Swahilian Coastal Forests in the Lindi region, Tanzania, using Landsat TM data analysis. *Biodiversity Conservation* **16**(5): 1551–1565.

Ricketts T.H., E. Dinerstein, T. Boucher, T.M. Brookes, S.H.M. Butchart, M. Hoffmann, J.F. Lamoreux, J. Morrison, M. Parr, J.D. Pilgrim, A.S.L. Rodrigues, W. Sechrest, G.E. Wallace, K. Berlini, J. Bielby, N.D. Burgess, D.R. Church, N. Cox, D. Knox, C. Loucks, G.W. Luck, L.L. Master, R. Moore, R. Naidoo, R. Ridgely, G.E. Schatz, G. Shire, H. Strand, W. Wettengel & E. Wikramanayake (2005). Pinpointing and preventing imminent extinctions. *Proceeding of the Natural Academy of Sciences of the USA* **102**(51): 18497–18501.

Robertson, S.A. & W.R.Q. Luke (1993). Kenya Coastal Forests: the report of the NMK/WWF Coast Forest Survey. WWF Project 3256 : Kenya, Coast Forest Status, Conservation, and Management. WWF, Nairobi.

Rodgers, W.A. & K.M. Homewood (1998). Species richness and endemism in the Usambara Mountain forests, Tanzania. *Biological Journal of the Linnean Society* **18**(3): 197–242.

Rodgers, W.A., W. Mizray & E.K. Shishra (1985). The extent of forest cover in Tanzania using satellite imagery. University of Dar es Salaam Institute of Resource Assessment Research Paper **12**: 1–15.

Sayer, J.A., C.S. Harcourt & N.M. Collins (1992). *The Conservation Atlas of Tropical Forests: Africa.* WCMC/IUNC, Cambridge.

Schipper, J, & N. Burgess (2003). Ecoregional reports: Northern Zanzibar-Inhambane coastal Forest Mosaic. Eastern and southern Africa Bioregions. www.nationalgeographic. com/wildworld/profiles/terrestrial/at/at0109.html [accessed 1 September 2006].

Skole, D. & C.J Tucker (1993). Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978–1988. *Science* **260**: 1905–1910.

Staddon, S., E. Fanning, & K.M. Howell (eds.) (2002). Bombo East I Forest Reserve: A biodiversity survey. East Usambara Conservation Area Management Programme Technical Paper No. 56. Frontier Tanzania; Forestry and Beekeeping Division, Dar es Salaam, Tanzania; and Indufor / Metsähallitus Group, Vantaa, Finland.

Staddon, S., E. Fanning, & K.M. Howell (eds.) (2002). Bombo East II Forest Reserve: A biodiversity survey. East Usambara Conservation Area Management Programme Technical Paper No. 58. Frontier Tanzania; Forestry and Beekeeping Division, Dar es Salaam, Tanzania; and Indufor / Metsähallitus Group, Vantaa, Finland.

Steininger, M.K. (1996). Tropical secondary forest regrowth in the Amazon: age, area and change estimation with Thematic Mapper data. *International Journal of Remote Sensing* **17**(1): 9–27

Steininger, M.K., C.J. Tucker , J.R.G. Townshend, T.J. Killeen, A. Desch, V. Bell & P. Ersts (2001). Tropical deforestation in the Bolivian Amazon. *Environmental Conservation* **28**: 127–134.

Story, M. & R. Congalton (1986). Accuracy assessment: a user's perspective. *Photogrammetric Engineering & Remote Sensing* **52**(3): 397–399.

Tucker, C.J., D.M. Grant. & J.D. Dykstra (2004). NASA's Global Orthorectified Landsat Data Set. *Photogrammetric Engineering & Remote Sensing* **70**(3): 313–322.

Wang, Y.Q., G. Bonynge, J. Nugranad, M. Traber, A. Ngusaru, J. Tobey, L. Hale, R. Bowen & V. Makota (2003). Remote sensing of mangrove change along the Tanzania coast. *Marine Geodesy* **26**(1): 35–48.

WCST (2006). Coastal Forests of East Africa Aerial Survey. Wildlife Conservation Society of Tanzania Flight Conservation Programme,Tanzania.

WWF-EARPO (2002). Coastal Forests of Eastern Africa: Action Plan. WWF EARPO, Nairobi.