Conservation implications of deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania

Article *in* Biological Conservation · November 2009

DOI: 10.1016/j.biocon.2009.05.028

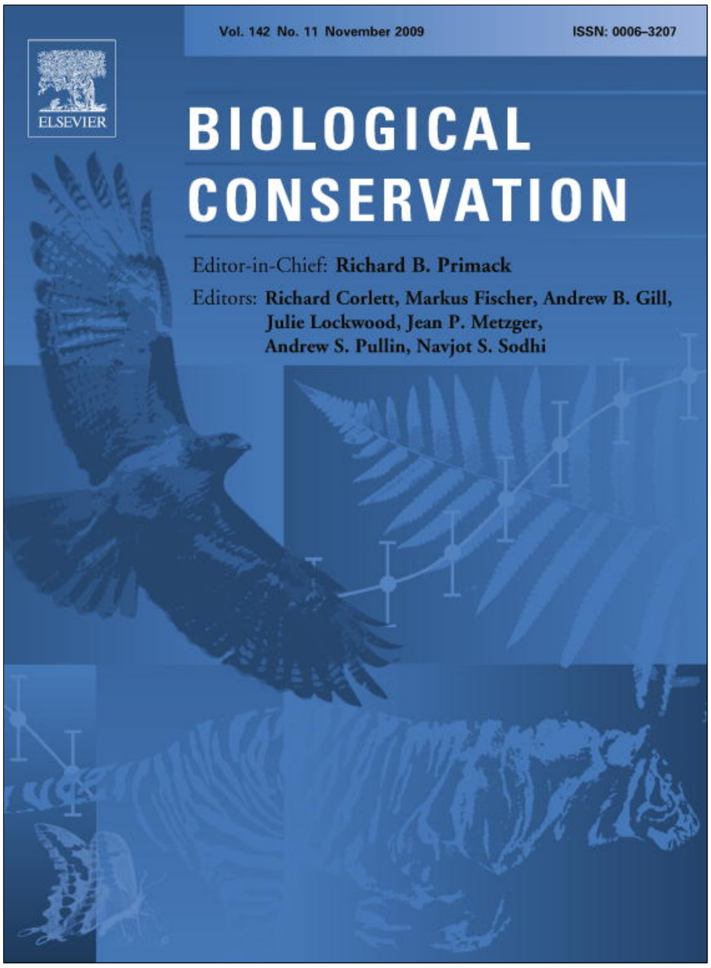
5 authors, including:

Jaclyn Hall
University of Florida
27 PUBLICATIONS 483 CITATIONS

Neil D. Burgess
UN Environment Programme World Conservation Monitoring Centre
412 PUBLICATIONS 29,949 CITATIONS

Jon C. Lovett
University of Leeds
291 PUBLICATIONS 14,862 CITATIONS

Boniface P. Mbilinyi
Sokoine University of Agriculture (SUA)
64 PUBLICATIONS 2,146 CITATIONS


Vol. 142 No. 11 November 2009
ISSN: 0006-3207
ELSEVIER
BIOLOGICAL CONSERVATION
Editor-in-Chief: Richard B. Primack
Editors: Richard Corlett, Markus Fischer, Andrew B. Gill, Julie Lockwood, Jean P. Metzger, Andrew S. Pullin, Navjot S. Sodhi

Biological Conservation 142 (2009) 2510–2521

Contents lists available at ScienceDirect

Biological Conservation

journal homepage: www.elsevier.com/locate/biocon

Conservation implications of deforestation across an elevational gradient in the Eastern Arc Mountains, Tanzania

Jaclyn Hall [a,*], Neil D. Burgess [b,c], Jon Lovett [d], Boniface Mbilinyi [e], Roy E. Gereau [f]

[a] Department of Geography, University of Florida, 3124 Turlington Hall, Gainesville, FL 32611, USA
[b] WWF-US, Conservation Science Program, 1250 24th St. NW, Washington, DC 20037-1193, USA
[c] Conservation Science Group, Zoology Department, Cambridge University, CB2 3EJ, UK
[d] Environment Department, University of York, Heslington, York YO10 5DD, UK
[e] Sokoine University of Agriculture, P.O. Box 3003, Morogoro, Tanzania
[f] Missouri Botanical Garden, P.O. Box 299, St. Louis, MO 63166-0299, USA

ARTICLE INFO

Article history:
Received 4 December 2008
Received in revised form 19 May 2009
Accepted 22 May 2009
Available online 1 July 2009

Keywords:
Eastern Arc Mountains
Forest loss
Endemic plants
Africa
Red list

ABSTRACT

Deforestation is a major threat to the conservation of biodiversity, especially within global centers of endemism for plants and animals. Elevation, the major environmental gradient in mountain regions of the world, produces a rapid turnover of species, where some species may exist only in narrow elevational ranges. We use newly compiled datasets to assess the conservation impact of deforestation on threatened trees across an elevational gradient within the Eastern Arc Mountains of Tanzania. The Eastern Arc has suffered an estimated 80% total loss in historical forest area and has lost 25% of forest area since 1955. Forest loss has not been even across all elevations. The upper montane zone (>1800 m) has lost 52% of its paleoecological forest area, 6% since 1955. Conversely, the submontane habitat (800–1200 m) has lost close to 93% of its paleoecological extent, 57% since 1955. A list of 123 narrowly endemic Tanzanian Eastern Arc tree taxa with defined and restricted elevational ranges was compiled and analyzed in regard to mountain block locations, elevational range, and area of forest within each 100 m elevational band. Half of these taxa have lost more than 90% of paleoecological forest habitat in their elevational range. When elevational range is considered, 98 (80%) of these endemic forest trees should have their level of extinction threat elevated on the IUCN Red List. Conservation efforts in montane hotspots need to consider the extent of habitat changes both within and across elevations and target conservation and restoration efforts throughout these ecosystems' entire elevational ranges.

1. Introduction

Small geographic range has been cited as the single best predictor of extinction threat for terrestrial species (Harris and Pimm, 2008; Gaston and Fuller, 2009). The global loss of tropical forest is one of the driving forces behind the decline in range and population of terrestrial species (Brooks et al., 2002). A forest dependent species may be limited by extent of forest cover, but the spatial distribution of other environmental factors affecting the species must also be taken into account when evaluating geographic range size and area of available habitat.

Patterns of diversity in tropical forests are strongly associated with environmental gradients, including gradients of precipitation, temperature, seasonality, evapotranspiration, soil, and topography (Givnish, 1999; McCain, 2007a). As such, an understanding of habitat heterogeneity is important for conservation planning and management (Currie and Paquin, 1987; Condit et al., 2002; Tuomisto et al., 2003; Davidar et al., 2007). Elevation is one of the main environmental gradients, with rapid turnover of species accompanying changes in elevation (Lieberman et al., 1996; Colwell et al., 2008; Nogués-Bravo et al., 2008).

The spatial distribution of threats is an important factor requiring consideration when the conservation needs of species of concern are being investigated. Extant habitat, area lost, and extent of habitat fragmentation are essential determinants of extinction risk for species and are important for prioritizing conservation management (IUCN, 2001). Habitat reduction and fragmentation result in an increased threat of extinction, including reduced species number due to the established species–area relationship, increased effect of edges, diminished opportunity for genetic exchange, and decreased ability to disperse (Debinski and Holt, 2000). The species–area relationship successfully predicts the effect of habitat reduction on extinction, and the distribution of habitat loss also influences this process (Ney-Nifle and Mangel, 2000; Ulrich and Buszko, 2004).

Determination of amount of available habitat is critical to any evaluation and must take species' elevational requirements into account in order to improve conservation assessment. Protecting

* Corresponding author. Tel.: +1 352 374 4970; fax: +1 352 392 8855.
E-mail address: jhall@geog.ufl.edu (J. Hall).

0006-3207/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.biocon.2009.05.028

and maintaining habitats throughout their entire elevational gradients is imperative for species conservation, yet few tropical forest gradients across the world remain intact. An analysis of the elevational distribution of forest cover loss has a fundamental bearing on the design of effective conservation strategies within biodiverse ecosystems that are confined by elevation and topography. This study determines if forest loss in mountain areas demonstrates a distinct pattern with respect to the elevational gradient, and how this may effect the conservation of endemic species.

The Eastern Arc Mountains of Tanzania are a tropical forest region of exceptional biological and conservation importance, supporting numerous narrowly endemic species of plants and animals threatened by deforestation (Lovett and Wasser, 1993; Newmark, 2002; Burgess et al., 2007a). In the Eastern Arc, as in other tropical mountains, environmental gradients such as precipitation, temperature, and length of dry season vary with elevation (Rickart, 2001; McCain, 2005). A common biological pattern seen in tropical mountains is a decrease in species richness with elevation; along with a mid elevation hump (Rahbek, 1995, 1997; Heaney, 2001). In the Eastern Arc, plot-level floristic richness remains consistently high throughout the range of elevations due to continuous turnover of species (Lovett, 1999, 2001). Tallents et al. (2005) found that generic and family richness actually increase with elevation in the Eastern Arc. Eastern Arc endemic tree species show rapid turnover with elevation (Lovett, 1996, 1999; Tallents et al., 2005; Lovett et al., 2006), with half of the endemic trees occupying an elevational range of 600 m or less. The combination of these two factors, high species richness throughout all elevations and significant numbers of endemic species occupying narrow elevational bands, suggests that it is imperative to ensure that forests are protected throughout the entire range of elevations in tropical mountains. Establishing protected areas only at the upper elevations of this ecosystem will not ensure that habitat is protected for species whose elevational requirements are within the lower or middle elevations.

The Indian Ocean remained warm during the last glacial maximum 20,000 years ago (Prell et al., 1980), and orographic uplift of moist Indian Ocean winds is considered to have contributed to the long-term climate stability of the Eastern Arc Mountains (Lovett and Wasser, 1993; Fjeldså and Lovett, 1997). Because of their long history of stability the mountains harbor a high degree of species richness (Lovett and Wasser, 1993). Fjeldså and Lovett (1997) suggested that orographic precipitation and cloud mist has created long-term environmental stability in the Eastern Arc. Mumbi et al. (2008) analyzed data from a core from a swamp in the Udzungwa Mountains to determine that the climate has changed little since the Holocene, the contributions of C_3 and C_4 plants have been stable, the transition of upper montane and montane forest has shifted minimally, and there has been moist forest in the region since 21,000 ^{14}C year BP. Finch et al. (2009) analyzed a sedimentary record from the Uluguru mountains found moist forest species richness was stable further supports the long-term stability of the Eastern Arc forests. Newmark (1998) estimates that because Eastern Arc forest is found throughout all elevations of the Eastern Arc Mountains, it can be assumed that nearly all of the mountain area was covered with orographically maintained forest >2000 year BP.

In this paper we use the most recent data of elevational occurrences of strictly endemic tree species and infraspecific taxa in the Eastern Arc Mountains of Tanzania to understand better how the pattern of habitat loss can affect the extinction risk of endemic taxa. This study comprises two research questions: (1) is there an elevational pattern of deforestation in the Eastern Arc Mountains? (2) are endemic species under a greater threat of extinction than previously estimated?

To answer these questions we developed datasets of forest extent around the year 2000 and during the mid 1970s using satellite images, from the mid 1950s using digitized land cover maps, and estimated a maximum paleoecological extent of forest for each major mountain. We then extracted the elevational ranges of endemic tree taxa from herbarium databases (www.tropicos.org) and synthesized this information with forest extent in the year 2000 to reassign taxa to the International Union for Conservation of Nature (IUCN) Red List categories according to the geographic range criteria of the Red Listing process.

2. Methods

2.1. Study area

The Eastern Arc Mountains of Tanzania consist of 12 ancient block-faulted mountain ranges (henceforth referred to as mountain blocks) arching from northeast to southwest in eastern Tanzania (Fig. 1) that support humid montane forest habitats. Recent palynological research from the Udzungwa Mountains demonstrates that the Eastern Arc has had a relatively stable climate throughout the Holocene (21,000 14C year BP) as a result of stability of the warm Mozambican current in the Indian Ocean (Mumbi et al., 2008). The humid montane forests on individual Eastern Arc mountain blocks are isolated from each other by the drier vegetation types of the coastal plain. These factors have contributed to the forests' high levels of species richness and endemism in all biological groups, with many species endemic to just one or a few mountain ranges (Lovett, 1990). The forests of the Eastern Arc Mountains have long been recognized by biologists as important and are classified as a unique ecosystem. These forests, referred to as the Eastern Arc Forests, and the adjacent tropical dry forests on the East African coastal plain, referred to as the East African Coastal Forest, were collectively recognized as one of the most important global biodiversity hotspots because of the extremely high concentrations of rare and endemic species in this ecosystem (Myers et al., 2000; Burgess et al., 2007a). A worldwide reappraisal of biodiversity hotspots (Mittermeier et al., 2004) has placed the Eastern Arc Forests within a newly named regional hotspot, the Eastern Afromontane; however, the Eastern Arc and Coastal Forests combined remain an ecosystem of elevated global biodiversity importance.

Recent studies of the remaining humid forest fragments within the Eastern Arc have investigated the number of species of flora and fauna, area of remaining forest, and degree of threat (Doggart et al., 2006; Burgess et al., 2007a). Various estimates have been generated for the historical area of forest cover of the Eastern Arc Mountains (Newmark, 1998, 2002; FBD, 2006; Burgess et al., 2007a). Recent research has estimated that the ecosystem has lost at least 70% of its natural forest habitat and concluded that it contains many species that are threatened with extinction as a result of reduction of suitable habitat (Newmark, 1998, 2002; Burgess et al., 2002, 2007a). Newmark (2006) uses long-term avian studies to demonstrate the importance of primary forest in the Eastern Arc. Forest loss in this ecosystem has been and continues to be caused by a number of factors, including clearance for new farmland, fires that spread from other agricultural practices and hunting, pitsawing, and harvesting for building materials (timber and poles) and fuel wood (Burgess et al., 2002).

The Eastern Arc Forests have been divided into four broad habitat zones based on elevation, with the suite of endemic species varying according to elevation. Sub-humid lowland montane forest (~200–800 m) grades into the biodiverse coastal forests at lower elevations, and at higher elevations grades into the Eastern Arc humid forest classes of submontane (~800–1200 m), montane (~1200–1800 m), and upper montane (~1800–2700 m). Some small-scale variations based on local environmental gradients such as microtopography and disturbance also occur (Pócs, 1976; Lovett

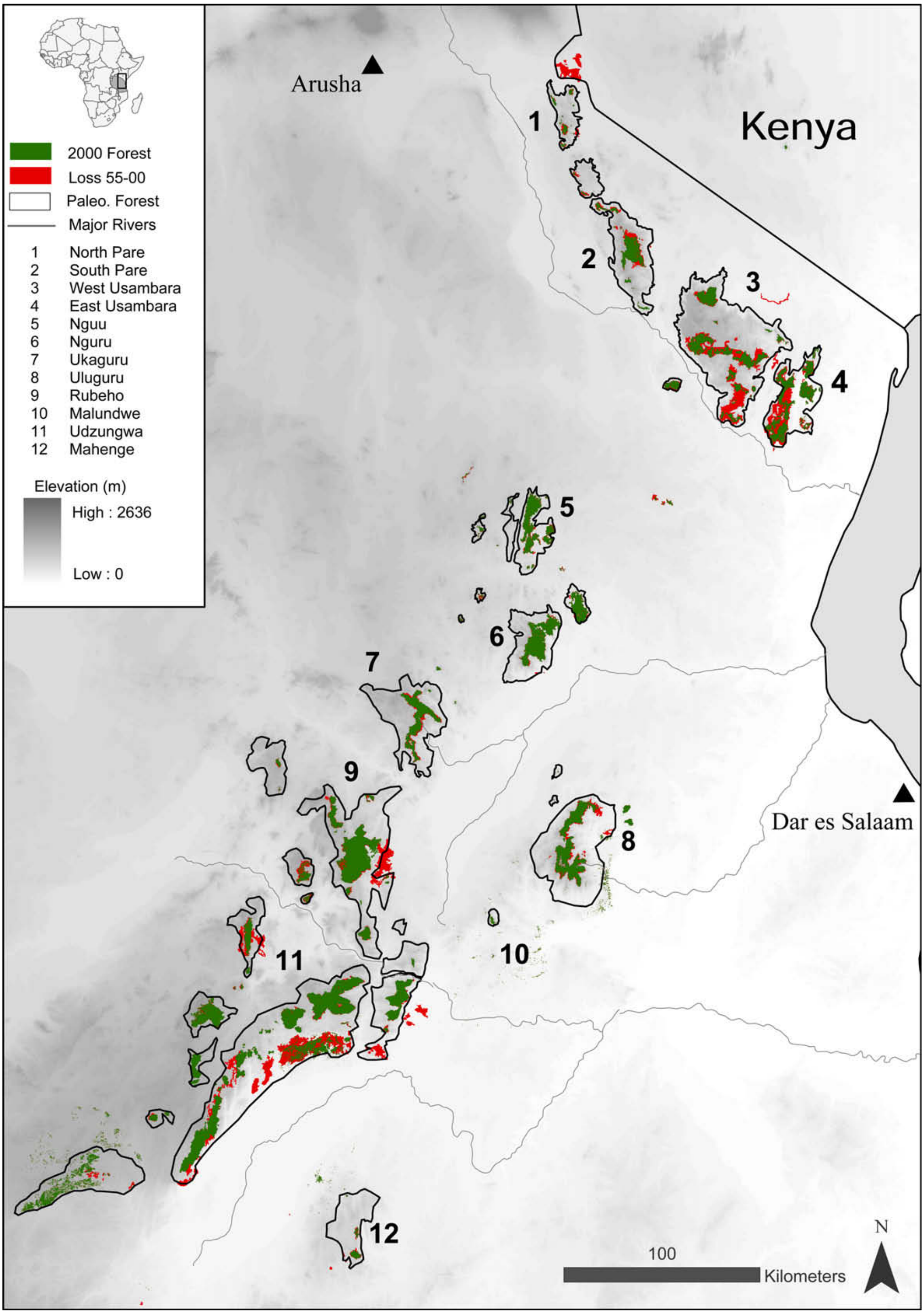


Fig. 1. The Eastern Arc Mountains of Tanzania, illustrating area of forest in year 2000, forest lost since 1955 and the paleoecological estimation of forest extent, with elevation as a background.

and Wasser, 1993; Lovett et al., 2001). Few of these mountain blocks, however, presently contain contiguous forest throughout the full extent of the lowland elevations.

2.1.1. Forest cover

2.1.1.1. Paleoecological prediction. Newmark (1998) defined the paleoecological maximum extent of forest as occurring >2000 years

BP. To estimate the paleoecological forest area, we followed Newmark (1998) in assuming that the prehistoric forest cover was unbroken with forest extending down to the base of each mountain block on the windward side, and around 400 m higher on the leeward side. We then finely adjusted the maps of prediction of paleoecological forest area by analyzing the slope and aspect of each mountain block and by scrutinizing 1970s MSS Landsat satellite images. Areas with steep or significant increases in slope on the windward sides, leeward side peaks that were higher than windward peaks, and steep river valleys on both leeward and windward sides were assumed to have been forested. Montane agricultural areas showing healthy photosynthesizing vegetation in the 1975 images (taken during the dry season and thus representing better soils and climate) were all assumed to have been forested in the past. The paleoecological forest extent has been estimated in a similar manner by members of the conservation community (Newmark, 1998, 2002), though we feel that using 1975 Landsat MSS images along with topographic data have given better results. This process resulted in a new map of the *extrapolated paleoecological* extent of the Eastern Arc mountain blocks, which we have used for descriptive purposes only in this paper.

2.1.1.2. 1950s. The 'Tanganyika First Series' paper 1:50,000 scale topographic maps from the 1950s were digitized at the Tanzanian Natural Resource Information Center (TANRIC) at the University of Dar es Salaam using funds provided by United Nations Development Program (UNDP-GEF) and the KITE project at the University of York, UK. This approach allowed us to create a GIS shapefile including 20 land cover classes, only one class being Eastern Arc Forest. Two small gaps exist in the 1955 dataset where we were not able to obtain the relevant paper maps: Nguru South Forest Reserve and the western half of Kisinga-Rugaro Forest Reserve of the Udzungwa Mountains. Here we substituted data from the next oldest date from which we have information (1970s Landsat MSS based land cover). The substituted area of forest for the Udzungwas equaled <5% of the forest area in that mountain block for 1955. The missing 1955 map area for the Nguru South Forest Reserve was more than half of the western side of the forest block, and equaled 45% of the area of forest for the mountain block. Although experts in the area believe that most lowland and submontane forest on the Nguru mountain block was cleared before 1955, estimates of lowland and submontane forest area in 1955 for this mountain block are unsatisfactory due to the absence of this map sheet. These two areas of missing data for 1955 do not affect the forest area coverages for 1975 and 2000.

2.1.1.3. 1975 and 2000. Existing land cover classifications for the year 1975 and the years around 2000 were produced for the Forestry and Beekeeping Division of Tanzania's Ministry of Natural Resources and Tourism from Landsat MSS and ETM+ satellite images by the Remote Sensing Laboratory of Sokoine University of Agriculture. SPOT satellite images for Uluguru, East Usambara, and Nguru were obtained where needed to assure that all areas of closed forest were obtained without clouds. Classification methodologies followed those of Conservation International's Center for Applied Biodiversity Science (Harper et al., 2007), and details and specific image dates used can be found in the Forest Area Baseline for the Eastern Arc Mountains at http://www.easternarc.or.tz/strategy (FBD, 2006). The land cover classifications were produced at a spatial resolution of 30 m and mosaiced where required. The natural closed forest class was isolated from the 1975 and 2000 land cover classifications and this was the only land cover class used for this analysis.

2.1.2. Forest cover at different elevations

Area of forest in different elevational bands across the Eastern Arc Mountains was calculated using the 90 m resolution (16 m vertical accuracy) Digital Elevation Model (DEM) from February 2000 NASA Shuttle Radar Topography Mission (SRTM), Version2 SRTM3, downloaded from http://srtm.csi.cgiar.org/. The DEM was used to create a raster dataset with categories of area within each 100 m elevational band following the elevation contours (200–300 m, 300–400 m, up to 2600–2635 m). The 100 m elevational categories are henceforth referred to as elevational bands.

2.1.3. Distributional data on endemic trees

A list of trees that are forest obligate and endemic to the Eastern Arc in Tanzania was compiled from the Missouri Botanical Garden's TROPICOS herbarium specimen database (www.tropicos.org) and contains 123 taxa (species, subspecies, and varieties) including each taxon's elevational range and localities of occurrence. The list of taxa was created using a strict definition of "endemic" and the most recent collection data as of January 2009. In addition to specimens deposited at the Missouri Botanical Garden, the TROPICOS database contains specimen records of the rare and endemic plants of the Eastern Arc Mountains compiled from numerous other sources (Tanzanian, Kenyan, and European herbaria, literature citations, etc.) to provide comprehensive distributional data for use in Red List evaluations (Gereau et al., in press). As such, 104 (85%) of the endemic taxa were present in the dataset Lovett (1999) used to analyze patterns of endemic species. Over the past four years targeted fieldwork has been conducted by a team led by the Missouri Botanical Garden in areas shown to be undercollected by analysis of initial specimen data, and this fieldwork has filled important gaps in previously reported species distributions (Gereau, unpublished). Extensive curation of herbarium collections to correct misidentifications and incomplete identifications and inclusion of data from all available sources have resulted in the most complete dataset available for these taxa and mitigate to the greatest extent currently possible the inherent biases of herbarium databases. Although no part of Tropical East Africa's biodiversity has been exhaustively explored, the Eastern Arc Mountains are certainly among the best-studied parts of this region (Newmark, 2002), with a relatively small number of new plant species currently being described from the area despite extensive recent collections (e.g. only two of the 123 endemic tree taxa in this study are not yet published, and only one has been published within the past five years).

These plant collection data contain information on forest patch, Tanzanian district, latitude and longitude, elevation, and other location information that was used to refine taxon distributions throughout the ecosystem. They have been assembled from herbarium specimens collected from the late 1800s to the present day. The list includes only those endemic taxa for which we have elevational information and is not an exhaustive list of Tanzanian Eastern Arc endemic trees. These data are used to infer the effect that loss of habitat area since the paleoecological period may have on the conservation significance of each forest zone. Elevational range was taken from the elevation data of each specimen entry. If any specimen of a given taxon was collected within a mountain range, that taxon is considered as present in that block and the forest within the block that is within that taxon's elevational range is considered as potential habitat. Although the land cover has been estimated for different years from various sources of data, the specimen collection data, spanning back to the 1800s for some areas, is considered one dataset.

2.1.4. Threat status of endemic trees

The IUCN sets criteria for establishing a taxon's category of the risk of extinction. The globally threatened categories are Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). In identifying a taxon's category of threat, "a decline in area of occupancy, extent of occurrence and/or quality of habitat" is considered when specific population information for a taxon is lacking (IUCN, 2001).

The IUCN Red Listing process considers multiple threat factors including small or declining population size, fluctuations in area of occupancy or numbers, locations and stability of subpopulations, fragmentation of habitat, and exploitation, hybridization, and/or competitors. Thanks to remote sensing technologies, one of the most straightforward criteria to determine is area of habitat. Among these other factors, taxa are classified as CR, EN, or VU if extent of habitat occurrence is <100 km^2, <500 km^2, or <20,000 km^2, respectively, and if habitat fragmentation and conversion are continuing to occur.

According to the current IUCN Red List (accessed through the internet January 26th 2009, www.iucnredlist.org), the 123 Tanzanian Eastern Arc endemic tree taxa include 1 Critically Endangered, 12 Endangered, and 91 Vulnerable taxa, while 19 currently have no IUCN designation of threat. The analysis of current threat considers only the year 2000 forest coverage produced from Landsat images, and does not fully integrate other threats that together influence a taxon's risk of extinction.

2.1.5. Analyses

We compiled vector forest cover data for 1955 and the estimated paleoecological period with the forest cover in 2000 and 1975 and analyzed these against the raster data for the categories of 100-m elevational bands. Vector layers (forest in 1955 and paleoecological area) were converted to raster at a spatial resolution of 90 m. Because forest cover would be compared for all time periods on the basis of elevation categories, forest coverages for 1975 and 2000 were resampled to a raster resolution of 90 × 90 m to correspond with the elevation dataset. Scaling resolutions up to the largest grain is necessary when comparing raster GIS data of different resolutions. In this study, resampling a 30-m land cover image of montane forest to 90 m may introduce minimal error for the forest area of the lowest elevational bands of each mountain. Image subtraction was used to assess change in forest between layers (forest regrowth was minimal and made up less than 0.3% of forest area). We determined forest area within each elevational band for each mountain block for each time period and extracted area information for each category from the raster attribute tables and placed the information within a database for further analysis. With these data we calculated the area of forest and the area of forest lost between years for the following: (a) the entire Eastern Arc region; (b) within each mountain block; and (c) within 100 m elevational bands. Forest loss between paleoecological times and year 2000 were estimated throughout the ecosystem, and area of forest for only year 2000 is used to assess if current IUCN status for strictly endemic species is adequate. For each taxon, habitat in year 2000 was determined in two ways: (1) using total area of forest in each mountain block in which the taxon had been located (not elevation-specific); and (2) considering area of forest only in each taxon's elevational range and mountain blocks of collection. Forest loss in the elevational range occupied by each taxon was determined for each timestep. Totals for available habitat area within each endemic taxon's range (elevational and mountain block) in year 2000 were used to examine the current IUCN category of extinction threat and to recommend reassessments for some endemic tree taxa based on this one criterion—amount of available habitat. The IUCN level of threat that would be recommended for each taxon if only total area of the forest blocks were used is also determined in order to highlight the importance of considering a taxon's elevational range.

The biological importance of forest area within each 100-m elevational zone was analyzed after correcting the results for influence of forest area (Rosenzweig, 1995, 2003; Hubbell, 2001). The use of an area-correcting procedure is intended to estimate the species–area relationship, which is non-linear, for a given ecosystem. This highlights areas with a higher than expected contribution to endemic taxon presence in this ecosystem and may reveal a biogeographic pattern influenced by biological processes other than area. Area correction was performed using the equation:

$$S_a = S/A^z$$

where S is the number of species, A is area (km^2), z is the species–area exponent which is obtained from the slope of the regression line of $\log S$ on $\log A$, and S_a is species per area after correcting for the species–area relationship. Parameter z describes the rate at which new species are encountered with increasing area within a specific ecosystem (Lomolino, 2000). Rosenzweig (1995) developed an average standard z value of 0.25 based on empirical results from a wide variety of terrestrial taxa and ecosystems. The value for S_a defines the species–area relationship and is a power function of A. This relationship is usually determined using inventory data from a more defined time-period, and thus our use of botanical collection data spanning over 100 years in comparison to habitat area estimates ranging from pre-historic through year 2000 is not standard. However, investigating changes in the species–area relationship is important from a conservation and ecological standpoint.

For our datasets there were too few points to attempt to estimate the z value for each zone independently; thus we use the established 0.25 value, as this has been used in many studies. Our use of this standard value is not to estimate the number of endemic species in a given area of forest, but to illustrate a possible pattern in the ecosystem due to changing area of forest—decreasing due to deforestation.

3. Results

3.1. Elevational distribution of forest loss

Overall, the Eastern Arc has suffered an *estimated* 80% total loss of area of paleoecological forest extent, and 75% of this loss occurred before 1955. Between 1955 and 2000, the ecosystem lost 25% of forest area (Table 1). Forest loss demonstrates a pronounced elevational pattern with greatly disproportionate clearance of forest in lower elevations (Fig. 2). By the year 2000 lowland montane habitat (200–800 m) had lost close to 92% of its paleoecological extent and submontane habitat (800–1200 m) had lost close to 91% of its paleoecological extent. Montane forest habitat (1200–1800 m) had lost 77% of its estimated paleoecological extent, with

Table 1
Forest area (km^2) in different habitat zones from the paleoecological period and in years 1955, 1975, and 2000, with corrected species values, according to the standard species–area relationship (Rosenzweig, 1995), given to demonstrate the species–area pattern in this ecosystem. Some taxa may have ranges that span parts of two habitat zones.

Zone	Paleoecologic (km^2)	1955 (km^2)	1975 (km^2)	2000 (km^2)	Rate of change per year (%)		Endemic taxa	Species/area corrected	
					1955–1975	1975–2000		Paleo.	2000
Lowland montane (200–800 m)	3463	609	347	274	−2.84	−0.95	42	5.5	10.3
Submontane (800–1200 m)	4861	748	480	440	−2.25	−0.35	47	7.2	10.3
Montane (1200–1800 m)	6819	1954	1649	1559	−0.85	−0.22	63	9.2	10.0
Upper montane (>1800 m)	2734	1410	1309	1262	−0.37	−0.15	41	6.6	6.9

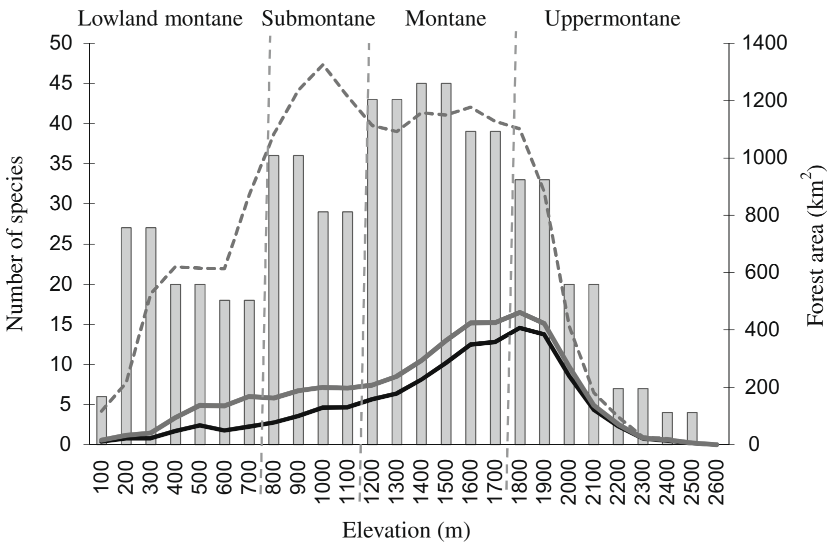


Fig. 2. Number of tree taxa endemic to Eastern Arc Forests of Tanzania by 100 m wide elevational band (bars) compared to paleoecological forest area (grey dashed line), forest area in 1955 (grey solid line), and forest area in 2000 (black solid line).

only 23% of area deforested since 1955. In contrast, upper montane forest habitat (>1800 m) had lost only 54% of its estimated paleoecological extent, having lost only 10% since 1955.

Rates of loss have decreased since 1975 in all zones except for submontane, where rates of loss have increased. Compound rates of forest loss per year between 1955 and 1975 were 1.76%, 1.55%, 0.73%, and 0.35% for lowland montane, submontane, montane, and upper montane forest, respectively, while between 1975 and 2000 rates of loss were 0.95%, 1.85%, 0.27%, and 0.18%. The lowland montane zone suffered the highest rate of forest loss from 1955 to 1975 and the submontane zone suffered the highest rate of forest loss from 1975 to 2000. Current forest area in the submontane zone has dropped to 9% of paleoecological area due to high levels of conversion to other land uses.

3.2. Deforestation by mountain block

Deforestation of different elevations has been uneven across Eastern Arc mountain blocks, partly due to different patterns of land clearing and partly related to variations in the elevation of different mountain blocks. Significant forest loss has occurred in 10 of the 12 major Eastern Arc mountain blocks in Tanzania since paleoecological times, and forest loss is still continuing today. The greatest overall losses of forest cover between 1955 and 2000 have been in West Usambara (2041 km^2, 0.82%/year), Udzungwa (4507 km^2, 0.53%/year), Rubeho (2171 km^2, 0.52%/year), and Uluguru (1341 km^2, 0.36%/year). Rates of forest loss have slowed in recent years, with 623 km^2 of forest lost over the 20 year period between 1955 and 1975 (approximately 0.75% per year), compared with 252 km^2 over the 25 year period between 1975 and 2000 (approximately 0.26% per year) (Table 2). Rates of forest loss since 1975 have been greatest for Uluguru (0.49%), East Usambara (0.46%), Rubeho (0.39%), Ukaguru (0.30%), and West Usambara (0.28%). Most mountain blocks saw a greater loss in forest area in the lowland and submontane zones with West Usambara, Uluguru, Udzungwa, and Rubeho having lost close to or more than 50% of lowland forest and submontane forest since 1955 and North and South Pare Mountains, which did not have significant lowland forest, yet having lost close to 100% of their submontane forest (Table 3). Forest has been relatively stable on Malundwe, a small peak of Eastern Arc forest surrounded by thick woodland within Mikumi National Park, and Mahenge, which has seen only a small reduction in forest within the Nawenge Forest Reserve on the southern part of the mountain.

Table 2
Changes in forest cover for elevations 200–2640 m across the Eastern Arc Mountain blocks against the paleoecological estimate, also showing total area lost and percent change and rate of change (percent per year).

Mountain block	Forest area (km^2)				Paleoe. – 1955		Paleo. – 2000		1955–1975			1975–2000		
	Paleo.	1955	1975	2000	Change (km^2)	(%)	Change (km^2)	(%)	Change (km^2)	(%)	rate	Change (km^2)	(%)	rate
East Usambara	714	425	299	263	−405	−48.8	−567	−68.3	−126	−29.6	−1.31	−36	−12.0	−0.46
Mahenge	557	35	24	24	−522	−93.7	−533	−95.7	−11	−31.4	−1.38	0	0.0	0.00
Malundwe	37	9	6	9	−28	−75.7	−28	−75.7	−3	−33.3	−1.45	3	50.0	2.73
Nguru	920	[a]	313	297			−623	−67.7				−16	−5.1	−0.20
Nguu	668	207	198	188	−461	−69.0	−480	−71.9	−9	−4.3	−0.21	−10	−5.1	−0.20
North Pare	323	36	27	26	−287	−88.9	−297	−92.0	−9	−25.0	−1.12	−1	−3.7	−0.15
Rubeho	2648	652	532	477	−1996	−75.4	−2171	−82.0	−120	−18.4	−0.85	−55	−10.3	−0.39
South Pare	1088	195	147	139	−893	−82.1	−949	−87.2	−48	−24.6	−1.11	−8	−5.4	−0.21
Udzungwa	5861	1745	1402	1354	−4116	−70.2	−4507	−76.9	−343	−19.7	−0.90	−48	−3.4	−0.13
Ukaguru	1076	200	181	167	−876	−81.4	−909	−84.5	−19	−9.5	−0.45	−14	−7.7	−0.30
Uluguru	1620	338	321	279	−1282	−79.1	−1341	−82.8	−17	−5.0	−0.25	−42	−13.1	−0.49
West Usambara	2364	579	348	323	−1785	−75.5	−2041	−86.3	−231	−39.9	−1.69	−25	−7.2	−0.28
Total	17,876	4421	3798	3546	−13,571	−75.4	−14,446	−80.3	−623	−14.1	−0.66	−252	−6.6	−0.26

[a] 1955 data on Nguru unavailable.

Table 3
Forest area changes across the Eastern Arc Mountain blocks in 1955, 1975 and 2000 and within lowland montane (200–800 m), submontane (800–1200 m), montane (1200–1800 m) and upper montane (above 1800 m) habitat divisions.

Mountain block	1955				1975				2000				Change 1955–2000 (%)				Rate of change 1955–2000 (%)			
	Lowland montane	Sub montane	Montane	Upper montane	Lowland montane	Sub montane	Montane	Upper montane	Lowland montane	Sub montane	Montane	Upper montane	Lowland montane	Sub montane	Montane	Upper montane	Lowland montane	Sub montane	Montane	Upper montane
East Usambara	199	212	14	0	148	137	14	0	127	123	12	0	−36	−42	−12		−0.68	−0.78	−0.25	0.00
Mahenge	5	11	19		1	7	16		2	6	16		−60	−43	−17		−1.05	−0.80	−0.36	0.00
Malundwe	3	5			0	5			3	5			1	0			0.01	−0.01	0.00	0.00
Nguru	[a]	[a]	[a]	[a]	39	73	142	59	130	0	110	57	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
Ngu	13	113	81		11	106	81		10	100	78		−23	−11	−4		−0.47	−0.24	−0.09	0.00
North Pare		3	28	7		0	20	6	−1	0	20	6		−94	−30	−12	0.00	−1.48	−0.58	−0.24
Rubeho	90	55	262	245	5	26	261	239	0	26	242	212	−100	−53	−8	−14	−1.55	−0.95	−0.16	−0.29
South Pare	2	2	101	89	0	0	68	79	0	0	62	76		−99	−39	−15		−1.54	−0.73	−0.31
Udzungwa	310	111	664	660	147	66	572	617	127	63	562	602	−59	−43	−15	−9	−1.04	−0.80	−0.32	−0.19
Ukaguru		70	138	61	0	70	123	58		70	134	58		0	−3	−6		0.00	−0.07	−0.12
Uluguru	3	38	162	135	6	26	156	133	0	16	132	131	−97	−58	−18	−3	−1.52	−1.02	−0.37	−0.07
West Usambara	11	104	328	135	3	31	195	118	3	28	183	109	−73	−73	−44	−20	−1.23	−1.22	−0.82	−0.40
Total	637	724	1799	1332	360	550	1649	1309	402	438	1552	1250	−37	−39	−14	−6	−0.70	−0.74	−0.29	−0.13

[a] 1955 data on Nguru unavailable.

3.3. Reassessment of the threat status for endemic trees

The Eastern Arc extends from near the coastal plain to 2638 m at the highest peak on the Uluguru mountain block. Of the 123 Tanzanian Eastern Arc endemic tree taxa, 32 (26%) have an elevational range of ⩽200 m, while 66 (54%) have a range of ⩽400 m. Only two endemic taxa have a range of 1400 m, three taxa have a range of 1200 m, while 118 taxa have elevational ranges of 1000 m or less. Forty-nine endemic tree taxa (40%) have been recorded in only one mountain range, while 101 (82%) have been identified in three or fewer ranges.

Twenty-three taxa have lost more than 50% of their habitat since 1955. Nine taxa have less than 10 km^2 of possible habitat in this ecosystem within their elevational range (Table 4). Three taxa, *Cynometra ulugurensis* (Fabaceae), *Drypetes usambarica* var. *stylosa* (Euphorbiaceae), and *Mimusops penduliflora* (Sapotaceae) appear to have virtually no remaining humid forest within their elevational range (based on estimates of remotely sensed land cover) and warrant on-the-ground investigation of their status.

Ninety-eight taxa (80%) should have their IUCN Red List level of threat upgraded. Thirty-nine (19%) endemic taxa have less than 100 km^2 of total remaining habitat. These 39 taxa deserve the IUCN category of CR. Of these taxa, eight are listed as EN, 22 as VU, and seven have no IUCN Red List status. Fifty-two (41%) endemic taxa receive the category of EN or higher, as they have between 100 and 500 km^2 of remaining habitat. Currently only two of these taxa are listed as EN, 43 are listed as VU, and six have no listing. Thirty-one (33%) endemic taxa have 500–2000 km^2 of remaining habitat and deserve the category of VU. Twenty-six are presently included in this threat category, while five have no IUCN Red List status. Full details of this reassessment of the threat status for the 123 Tanzanian Eastern Arc endemic trees can be found in Table 4.

Based on available suitable habitat we recommend that at least 39 tree taxa be given Critically Endangered status (seven of which do not feature on the current IUCN Red List), 50 taxa be given Endangered status (six of which have no listing currently and need to be added), and five taxa be added to the Red List as Vulnerable. Conversely, one taxon, *Drypetes usambarica* var. *rugulosa*, is currently listed as CR while this assessment determines there is 192 km^2 of habitat remaining within the elevational range and mountain blocks where this species occurs, which would warrant categorization of EN. However, this study considers only one of many threat criteria that could be affecting a taxon.

If elevational range for each taxon were not included in the examination of extinction threat, the recommendation for IUCN Red Listing would be very different. Of 123 trees endemic to the Tanzanian Eastern Arc, no taxon would appear to have less than 100 km^2 of remaining habitat and merit to be categorized as CR, and only 43 taxa would appear to have less than 500 km^2 of remaining habitat and deserve the category of EN. Excluding elevation from estimation of habitat extent would result in a recommendation of only 42 taxa having their category of threat elevated, compared to this assessment of 98 taxa that deserve an upgraded listing to vulnerable, endangered or critically endangered. If elevation were to be disregarded, a further 14 taxa would not be listed in any Red List category, while our elevation based habitat availability indicate they should be listed as VU (10), EN (3), and CR (1).

Land cover analysis shows that no forest remains in the elevational range of one or two mountain blocks for six endemic taxa that inhabit the lowland montane zone. These taxa may have been lost from some mountain blocks where they had at one time been collected. On the ground surveys should be conducted to see if this has indeed been the case for the following taxa, listed with their elevational range and mountain block of possible exclusion: *Coffea pocsii* (200–800 m, Ukaguru), *Millettia elongatistyla* (200–400 m,

Table 4
Recommendations for updating the Red List status of tree taxa endemic to the Eastern Arc of Tanzania based on remaining habitat area. Includes area (km^2) of forest only in mountain blocks and elevation range occupied by each taxon, area of forest if a taxon's elevational range were not considered, and percent difference between the two.

Endemic tree taxon	Year 1955[a]	Year 1975[a]	Year 2000[a]	Not elevation specific[a]	Difference (%)	2007 listing[b]	Recommended listing
Afrocanthium shabanii (Bridson) Lantz [Red Listed as *Canthium shabanii* Bridson]	0.0	0.0	18.6	322.8	94	EN (C2b, D)	CR
Allanblackia ulugurensis Engl.	1600.6	1688.2	1621.5	1958.6	17	VU (B1+2c)	VU
Allophylus grotei F.G. Davies and Verdc.	212.3	210.4	193.1	563.6	66		EN
Allophylus melliodorus Gilg ex Radlk.	706.9	643.7	572.5	1171.4	51		VU
Alsodeiopsis schumannii (Engl.) Engl.	1935.3	1589.2	1486.3	2545.3	42	VU (B1+2c)	VU
Annickia kummerae (Engl. and Diels) Setten and Maas	129.6	78.7	70.1	263.9	73	VU (B1+2bc)	CR
Balthasaria schliebenii (Melch.) Verdc. var. *schliebenii*	62.4	56.3	54.7	285.0	81		CR
Balthasaria schliebenii (Melch.) Verdc. var. *glabra* (Verdc.) Verdc.	117.8	99.1	96.7	607.8	84		CR
Balthasaria schliebenii (Melch.) Verdc. var. *greenwayi* (Verdc.) Verdc.	224.5	196.5	184.6	461.4	60		EN
Baphia pauloi Brummitt	248.7	180.3	166.5	1658.9	90	EN (C2b, D)	EN
Baphia semseiana Brummitt	355.0	165.7	164.6	1673.6	90	VU (B1+2b, D2)	EN
Beilschmiedia kweo (Mildbr.) Robyns and R. Wilczek	1473.3	1539.8	1472.3	2222.5	34	VU (B1+2b)	VU
Bersama rosea Hoyle	1332.8	1219.0	1187.0	1851.7	36	VU (B1+2b)	VU
Bertiera pauloi Verdc.	459.4	514.5	481.3	1980.7	76	VU (B1+2b)	EN
Calodendrum eickii Engl.	88.2	76.4	69.1	322.8	79	EN (B1+2c)	CR
Casearia engleri Gilg	643.8	449.3	419.8	461.4	9	VU (B1+2b)	EN
Chassalia albiflora K. Krause	786.7	479.1	443.9	1025.0	57	VU (B1+2b)	EN
Chytranthus longibracteatus F.G. Davies	258.3	32.3	30.9	299.7	90		CR
Coffea mongensis Bridson	482.8	374.4	352.1	2260.3	84	VU (B1+2b)	EN
Coffea pocsii Bridson	30.1	39.0	38.0	466.8	92	VU (B1+2c, D2)	CR
Cola scheffleri K. Schum.	649.2	445.2	410.8	1937.5	79	VU (B1+2b)	EN
Craibia brevicaudata (Vatke) Dunn subsp. *schliebenii* (Harms) J.B. Gillett	2028.7	1688.9	1577.6	2723.4	42	VU (B1+2b)	VU
Craterispermum longipedunculatum Verdc.	692.1	676.8	651.5	1980.7	67	VU (B1+2b)	VU
Croton dictyophlebodes Radcl.-Sm.	219.1	136.3	126.7	322.8	61	VU (B1+2b)	EN
Cynometra engleri Harms	56.4	44.5	41.3	263.9	84	VU (B1+2b, D2)	CR
Cynometra longipedicellata Harms	129.6	78.7	70.1	263.9	73	VU (B1+2b)	CR
Cynometra ulugurensis Harms	1.5	0.2	0.1	285.0	100	EN (C2b, D)	CR
Dombeya amaniensis Engl.	180.8	97.9	88.6	1659.9	95	VU (B1+2b)	CR
Drypetes gerrardinoides Radcl.-Sm.	460.9	364.2	352.5	1512.5	77	VU (B1+2c)	EN
Drypetes usambarica (Pax) Hutch. var. *rugulosa* Radcl.-Sm.	223.5	196.4	192.8	1373.9	86	CR (B1+2c)	EN
Drypetes usambarica (Pax) Hutch. var. *stylosa* Radcl.-Sm.	10.5	0.5	0.5	285.0	100	EN (C2b, D)	CR
Englerodendron usambarense Harms	129.6	78.7	70.1	263.9	73	VU (B1+2c)	CR
Erythrina haerdii Verdc.	530.5	457.1	451.0	1373.9	67	VU (B1+2b, D2)	EN
Garcinia bifasciculata N. Robson	2.0	5.5	5.5	285.0	98	EN (C2b, D)	CR
Garcinia semseii Verdc.	641.0	192.3	190.8	1980.7	90	VU (B1+2b, D2)	EN
Gomphia scheffleri (Engl. and Gilg) Verdc. subsp. *scheffleri* [Red Listed as *Campylospermum scheffleri* (Engl. and Gilg) Farron]	196.2	152.4	141.2	563.6	75	VU (B1+2b)	EN
Gomphia scheffleri (Engl. & Gilg) Verdc. subsp. *schusteri* (Gilg ex Engl.) Verdc.	1387.3	1279.3	1201.9	2136.7	44		VU
Greenwayodendron suaveolens (Engl. and Diels) Verdc. subsp. *usambaricum* Verdc.	508.9	348.2	308.9	871.6	65	VU (B1+2b)	EN
Heinsenia diervilleoides K. Schum. subsp. *mufindiensis* (Verdc.) Verdc.	530.5	457.1	451.0	1373.9	67	VU (B1+2b)	EN
Hirtella zanzibarica Oliv. subsp. *megacarpa* (R.A. Graham) Prance[Red Listed as *Hirtella megacarpa* R.A. Graham]	1503.5	1235.9	1201.5	1696.6	29		VU
Ilex mitis (L.) Radlk. var. *schliebenii* Loes.	100.6	61.7	58.0	2290.1	97		CR
Isoberlinia scheffleri (Harms) Greenway	1287.9	986.3	943.4	2245.5	58	VU (B1+2b)	VU
Ixora albersii K. Schum.	138.3	116.2	106.9	461.4	77	VU (B1+2b)	EN
Keetia koritschoneri Bridson	334.6	126.9	126.9	1981.6	94	VU (B1+2b, D2)	EN
Lasianthus laxinervis (Verdc.) Jannerup [Red Listed as *L. kilimandscharicus* K. Schum. subsp. *laxinervis* Verdc.]	135.3	118.0	108.6	322.8	66	VU (B1+2b)	EN
Lasianthus macrocalyx K. Schum. (synonymy in Jannerup 2006) [Red Listed as *L. grandifolius* Verdc.]	45.6	33.1	33.0	285.0	88	VU (B1+2b, D2)	CR
Lasianthus pedunculatus E.A. Bruce	885.1	865.9	846.9	2125.7	60	VU (B1+2b)	VU
Lasianthus wallacei E.A. Bruce	174.2	172.5	157.0	285.0	45	VU (B1+2b)	EN
Lijndenia brenanii (A. and R. Fern.) Jacq.-Fél.	1001.4	789.2	760.5	1637.8	54	VU (B1+2b)	VU
Lingelsheimia sylvestris (Radcl.-Sm.) Radcl.-Sm. [Red Listed as *Aerisilvaea sylvestris* Radcl.-Sm.]	12.5	6.0	6.0	285.0	98	EN (C2b, D)	CR
Mammea usambarensis Verdc.	643.8	449.3	419.8	461.4	9	VU (B1+2b)	EN
Meineckia nguruensis (Radcl.-Sm.) Brunel ex Radcl.-Sm. [Red Listed as *Zimmermannia nguruensis* Radcl.-Sm.]	100.6	50.0	47.7	299.7	84	VU (B1+2c, D2)	CR
Meineckia paxii Brunel ex Radcl.-Sm. [Red Listed as *Zimmermannia capillipes* Pax]	145.1	92.1	81.6	263.9	69	VU (B1+2c)	CR
Meineckia stipularis (Radcl.-Sm.) Brunel ex Radcl.-Sm.. [Red Listed as *Zimmermannia stipularis* Radcl.-Sm.]	844.7	791.5	756.2	1851.7	59	VU (B1+2b)	VU
Millettia elongatistyla J.B. Gillett	81.3	25.6	25.6	1825.9	99	VU (B1+2b)	CR
Millettia oblata Dunn subsp. *oblata*	669.6	330.4	310.5	2683.9	88	VU (B1+2b)	EN
Millettia sacleuxii Dunn	83.5	52.8	47.1	563.6	92	VU (B1+2b)	CR
Millettia sericantha Harms	42.4	37.0	33.0	584.7	94	VU (B1+2b, D2)	CR
Mimusops penduliflora Engl.	1.5	0.2	0.1	285.0	100	EN (B1+2d)	CR
Monodora globiflora Couvreur	952.9	849.1	838.4	1373.9	39		VU
Mussaenda microdonta Wernham subsp. *microdonta*	849.3	748.0	682.9	907.5	25	VU (B1+2b)	VU
Mussaenda monticola K. Krause var. *glabrescens* Bridson	355.0	126.7	126.5	1540.9	92	VU (B1+2b)	EN

(*continued on next page*)

Table 4 (*continued*)

Endemic tree taxon	Year 1955[a]	Year 1975[a]	Year 2000[a]	Not elevation specific[a]	Difference (%)	2007 listing[b]	Recommended listing
Mwasumbia alba Couvreur, sp. nov. ined. (T.L.P. Couvreur, pers. comm. 2008)	12.5	6.0	6.0	285.0	98		CR
Necepsia castaneifolia (Baill.) Bouchat and J. Léonard subsp. *kimbozensis* (Radcl.-Sm.) Bouchat and J. Léonard	2.0	5.5	5.5	285.0	98	EN (C2b, D)	CR
Neohemsleya usambarensis T.D. Penn.	227.2	175.2	159.7	322.8	51	VU (B1+2b)	EN
Octoknema orientalis Mildbr.	159.3	146.9	139.3	1695.7	92	VU (B1+2b)	EN
Omphalocarpum strombocarpum Y.B. Harv. and Lovett	575.9	498.2	458.2	1658.9	72		EN
Oxyanthus lepidus S. Moore subsp. *kigogoensis* Bridson	307.0	260.7	258.2	1373.9	81	VU (B1+2b, D2)	EN
Pavetta abyssinica Fresen. subsp. *viridiflora* Bridson	59.5	38.8	38.0	299.7	87		CR
Pavetta axillipara Bremek.	23.9	113.8	107.5	299.7	64	VU (B1+2b)	EN
Pavetta holstii K. Schum.	2561.6	2190.3	2068.6	2683.9	23	VU (B1+2b)	
Pavetta manyanguensis Bridson	615.9	533.7	526.0	1673.6	69	VU (B1+2b)	VU
Pavetta nitidissima Bridson	664.4	572.3	561.8	1373.9	59	VU (B1+2b, D2)	VU
Pavetta sparsipila Bremek.	1078.4	925.1	879.0	1958.6	55	VU (B1+2b)	VU
Pavetta sphaerobotrys K. Schum. subsp. *sphaerobotrys*	79.3	20.2	20.2	1373.9	99	VU (B1+2b)	CR
Pavetta subumbellata Bremek. var. *subcoriacea* Bridson	450.6	403.9	394.6	1851.7	79		EN
Pittosporum goetzei Engl.	71.8	52.2	51.0	285.0	82	VU (B1+2d)	CR
Placodiscus amaniensis Radlk.	476.1	237.5	222.9	1659.9	87		EN
Placodiscus pedicellatus F.G. Davies	133.9	115.2	110.8	1373.9	92		EN
Platypterocarpus tanganyikensis Dunkley and Brenan	88.2	76.4	69.1	322.8	79	EN (B1+2b, C2b)	CR
Polyceratocarpus scheffleri Engl. and Diels	1171.5	970.7	908.9	1922.8	53	VU (B1+2b)	VU
Polysphaeria macrantha Brenan	979.1	775.9	740.1	1802.8	59	VU (B1+2b)	VU
Polysphaeria ntemii S.E. Dawson and Gereau, sp. nov. ined.	71.9	57.9	52.8	263.9	80		CR
Pouteria pseudoracemosa (J.H. Hemsl.) L. Gaut.	318.1	237.4	219.1	1922.8	89	VU (B1+2b, D2)	EN
Psychotria elachistantha (K. Schum.) E.M.A. Petit	1127.1	1021.5	995.4	1658.9	40	VU (B1+2b, D2)	VU
Psychotria megalopus Verdc.	1404.6	1267.9	1216.9	1681.0	28	VU (B1+2b)	VU
Psychotria megistantha E.M.A. Petit	452.3	409.6	386.5	584.7	34	VU (B1+2b)	EN
Psychotria peteri E.M.A. Petit	212.3	137.0	123.2	263.9	53	VU (B1+2b)	EN
Psydrax kibuwae Bridson	15.5	13.3	11.5	263.9	96	VU (B1+2b, D2)	CR
Pterocarpus mildbraedii Harms subsp. *usambarensis* (Verdc.) Polhill	110.9	84.3	75.8	263.9	71	VU (B1+2b)	CR
Pycnocoma macrantha Pax	212.7	176.4	158.6	563.6	72	VU (B1+2b)	EN
Rhipidantha chlorantha (K. Schum.) Bremek.	111.7	116.1	102.3	285.0	64	VU (B1+2b, D2)	EN
Rytigynia caudatissima Verdc.	805.2	854.3	829.0	1673.6	50	VU (B1+2b, D2)	VU
Rytigynia hirsutiflora Verdc.	1603.3	1476.4	1420.2	1851.7	23	VU (B1+2b)	VU
Rytigynia lichenoxenos (K. Schum.) Robyns subsp. *lichenoxenos*	320.5	172.5	169.6	584.7	71	VU (B1+2b)	EN
Rytigynia nodulosa (K. Schum.) Robyns	253.2	245.0	220.0	285.0	23	VU (B1+2b)	EN
Rytigynia pseudolongicaudata Verdc.	1599.4	1587.4	1486.9	2867.4	48	VU (B1+2b)	VU
Sericanthe odoratissima (K. Schum.) Robbr. var. *odoratissima*	198.2	129.8	111.1	263.9	58	VU (B1+2b)	EN
Sibangea pleioneura Radcl.-Sm.	244.6	181.5	174.0	1373.9	87	VU (B1+2c)	EN
Suregada lithoxyla (Pax and K. Hoffm.) Croizat	1080.9	731.3	683.1	1922.8	64	VU (B1+2b)	VU
Syzygium micklethwaitii Verdc. subsp. *subcordatum* Verdc.	1642.9	1440.2	1393.6	2287.3	39		VU
Tarenna luhomeroensis Bridson	617.8	552.3	534.1	1851.7	71	VU (D2)	VU
Tarenna quadrangularis Bremek.	145.2	155.6	132.3	285.0	54	VU (B1+2b)	EN
Ternstroemia polypetala Mechior	1738.4	1680.3	1605.3	2436.4	34	VU (B1+2d)	VU
Tetrorchidium ulugurense Verdc.	100.6	51.9	48.8	299.7	84	VU (B1+2b)	CR
Tricalysia acidophylla Robbr.	443.5	210.3	201.8	2132.8	91	VU (B1+2b)	EN
Tricalysia anomala E.A. Bruce var. *anomala*	156.6	79.3	71.7	586.7	88	VU (B1+2b)	CR
Tricalysia pedicellata Robbr.	48.8	71.6	66.9	591.0	89	VU (B1+2b)	CR
Trichilia lovettii Cheek	664.4	572.3	561.8	1373.9	59	VU (B1+2b)	VU
Turraea kimbozensis Cheek	12.5	6.0	6.0	285.0	98	EN (C2b, D)	CR
Uvariodendron oligocarpum Verdc.	465.6	262.9	240.1	586.7	59	VU (B1+2d)	EN
Uvariodendron pycnophyllum (Diels) R.E. Fr.	372.6	209.0	186.8	586.7	68	EN (A1c, B1+2d)	EN
Uvariodendron usambarense R.E. Fries	824.2	385.4	358.7	1937.5	81	VU (B1+2b)	EN
Vangueria bicolor K. Schum.	129.6	78.7	70.1	263.9	73	VU (B1+2c, D2)	CR
Vangueria rufescens (E.A. Bruce) Lantz subsp. *angustiloba* (Verdc.) Lantz [Red Listed as *Lagynias rufescens* (E.A. Bruce) Verdc. subsp. *angustiloba* Verdc.]	273.1	203.1	194.4	1396.0	86	VU (B1+2b, D2)	EN
Vangueriopsis longiflora Verdc.	355.0	126.7	126.5	1373.9	91	VU (B1+2b)	EN
Vepris morogorensis (Kokwaro) Mziray	1242.6	1181.4	1121.0	2222.5	50		VU
Vitellariopsis cuneata (Engl.) Aubrév.	322.1	120.9	120.9	1696.6	93	VU (B1+2b)	EN
Vitex amaniensis W. Piep.	208.0	181.5	155.2	548.9	72	VU (B1+2b)	EN
Zenkerella capparidacea (Taub.) J. Léonard subsp. *capparidacea*	220.3	350.1	324.6	584.7	44	VU (B1+2b)	EN
Zenkerella capparidacea (Taub.) J. Léonard subsp. *grotei* (Harms) Temu	291.6	186.5	174.0	586.7	70	VU (B1+2b)	EN
Zenkerella egregia J. Léonard	125.4	91.2	82.7	1349.5	94	VU (B1+2b)	CR
Zenkerella perplexa Temu	49.4	55.0	45.4	285.0	84	VU (B1+2c)	CR

CR (B1+2c): extent and area of occurrence <100 km^2, continuing to decline, and exhibiting fluctuations.
EN (B1+2d): extent of occurrence severely fragmented, area of occupancy continuing to decline.
EN (C2b, D): population <250, area of occupancy continuing to decline.
EN (A1c, B1+2d): area reduced >70% in past 10 years, extent of occurrence severely fragmented, habitat area and quality declining.
VU (B1+2b): restricted extent of occurrence, area of occupancy continuing to decline.
VU (B1+2b, D2): restricted extent of occurrence, area of occupancy continuing to decline, population acutely restricted.
VU (B1+2c): restricted extent of occurrence, extent and/or quality of habitat declining.
Jannerup, P.L. 2006. A revision of the genus Lasianthus (Rubiaceae) in Africa, excluding Madagascar. Nordic Journal of Botany 23: 641–702.

[a] All area values in km^2.
[b] Critically endangered (CR), endangered (EN), vulnerable (VU), lower risk (LR).

Ukaguru), *Mussaenda monticola* var. *glabrescens* (400–800 m, Ukaguru), *Tricalysia acidophylla* (200–600 m, Nguu and Mahenge), *Tricalysia pedicellata* (200–1000 m, Malundwe), and *Zenkerella egregia* (200–600, Rubeho).

Correcting for the species–area relationship reveals that for the paleoecological period there were more species per area in the montane zone (6.9), slightly less for the upper and submontane zones (5.7, 5.6), and still less for the lowland (5.4). The species per area increased greatly by year 2000 in the lower three zones (to 10.2, 10.3, and 10.0), while species per area increased only slightly in the upper montane zone (Table 1).

4. Discussion

n this paper we have investigated the patterns of deforestation in the Eastern Arc Mountains of Tanzania, an area of exceptional global importance for the conservation of endemic plants and animals. We have shown that deforestation has preferentially occurred in the lower and middle elevations of the mountains and that this has happened more in some mountain blocks than others. By linking deforestation trends to the distribution of endemic trees, we have also been able to better address concerns in the current Red Listing of these threatened trees. A consideration of the effective area of suitable habitat in other montane ecosystems would likely elevate the threat status of many endemic species. The elevational distribution of Eastern Arc closed forest and the processes of deforestation affecting the ecosystem are important factors to consider when developing a comprehensive conservation plan for an ecosystem in which species of concern are restricted to defined elevation ranges.

Forest loss in the Eastern Arc Mountains has occurred in all elevations, but it has been the greatest in the lowland, submontane, and montane forest habitats. This is consistent with deforestation patterns found in other mountain ecosystems around the world (McCain, 2007b; Nogués-Bravo et al., 2008) including northern temperate deciduous and boreal forest (Boucher et al., 2009). In Sumatra, for example, lower mountain slopes have seen 16 times the rate of deforestation of upper slopes (Kinnaird et al., 2003), and Brooks et al. (1999a) found that a high degree of lowland deforestation had placed fauna in Southeast Asia under extreme extinction risk. A similar elevationally influenced pattern of deforestation and thus extinction risk will exist in other biodiversity and endemism hotspots where species substitution occurs across elevation gradients (e.g. the tropical Andes, Mesoamerica, and the Philippines).

Correcting for the species–area relationship reveals that the montane habitat zone has more endemic taxa compared to the other zones, which supports the established pattern of the mid elevation hump in species richness that has been demonstrated with many taxa across elevational gradients (Rahbek, 1997; Nogués-Bravo et al., 2008). We theorize that the upper elevations that have seen less deforestation may exhibit a species–area relationship that is a function of multiple evolutionary factors from a long-term biogeographic standpoint, and the lowlands may exhibit a species–area relationship that has been modified due to recent widespread clearing of forest. Direct comparison with the lowland zone may be erroneous, as we have already recognized that our strict definition of 'endemic to Tanzanian Eastern Arc' has resulted in reduced numbers of taxa on our list, underestimating the true ecological importance of this zone. The three lower habitat zones in year 2000 would appear to have similar species–areas, again reflecting the high importance of the montane zone for endemic taxa historically and the heightened importance of all three zones today due to habitat loss. Examining changes in the species–area suggests that the species–area relationship has been greatly affected by the significant loss of habitat.

4.1. Deforestation patterns within the Eastern Arc

The results show that deforestation has not been the same in all of the Eastern Arc Mountain blocks, with some much more heavily deforested than others. Rates of forest loss have slowed in recent years due to both the high slope of much of the remaining montane and upper montane forest and the fact that most remaining forest currently lies within some form of protected area. Mountain blocks that experienced a greater amount of deforestation between 1955 and 1975, as compared to 1975 and 2000, were those blocks in which deforestation had already reached close to the protected reserve boundaries by 1975. Reserves still require proper monitoring given that over 110 km^2 of deforestation occurred within reserves from 1975 to 2000 (J.M. Hall, unpublished), and clearing and disturbance is still continuing within the forest reserves (Struhsaker, 2005; Burgess et al., 2007a). Because of the high biological importance of the Eastern Arc Forest, across all elevations, continued loss of forest area must be mitigated. Reducing future forest loss should be a key focus of conservation activities in the region.

The North and South Pare Mountains in the northern part of the Eastern Arc are both steep-sided and relatively flat-topped blocks. The flatter plateau areas have been settled by people for many years and contain high human population densities. Forest has been slowly removed from the plateau areas and is now almost entirely confined to government Forest Reserves, proposed Forest Reserves and sacred (clan) forests. The West Usambara mountain block has forest across a wide elevational span, and has one of the highest population densities in Tanzania (Jambiya, 1998). At the lower to medium elevations significant areas of forest were lost when tea estates were established in the area, both for planting of tea and to provide agricultural areas for new villages populated by descendants of estate workers. At all elevations large areas of forest have been gradually lost to subsistence agriculture; in addition to this some areas of former mountain forest were converted to cyprus (*Cupressus lusitanica*) and pine (*Pinus patula*) plantations in the 1970s (Kaoneka and Solberg, 1994). Most of the natural forest that remains is within government Forest Reserves, which have maintained their area over the past 30 years.

In the East Usambara Mountains some lower elevation forest has been converted to teak and rubber plantations, and large areas of submontane forest have been converted to tea estates and associated eucalyptus plantations. Lowland montane dry forest has been lost due to expanding agriculture and most of the remaining forest is within government Forest Reserves and some newly established Village Forest Reserves. One 10 km^2 area of unprotected cardamom forest has now been left to regrow within the 'Derema Corridor', an area which is currently being gazetted as a Forest Reserve.

In the Udzungwa Mountains strong protection of the entire elevational range of forest occurs on the eastern escarpment within a network of Forest Reserves, and more recently a National Park and a Forest Nature Reserve. This strong protection has helped maintain the submontane forest in this block. At higher elevations forest has been lost to tea estates, softwood, eucalyptus (*Eucalyptus globulosus* and other species), pine (*Pinus patula*), fruit tree plantations, and to local agriculture. Most forest now remains in protected areas although clearing and disturbance within the reserves remains a major conservation concern (Dinesen et al., 2001; Struhsaker, 2005). The small area of forest on Malundwe Hill is strongly protected within Mikumi National Park. The forested peak is remote and surrounded by extensive woodland and thicket.

In the Nguu, Nguru, Ukaguru, Rubeho, Mahenge, and Uluguru Mountains the deforestation trends are due to competing factors of forest lost to agriculture as human populations expand, the establishment of teak plantations in the lowlands (14.5 km^2 in Nguru) and softwood and eucalyptus plantations in the highlands (Ukaguru, Uluguru), and the creation of a network of government

Forest Reserves and Forest Nature Reserves. Almost all of the remaining forest is now found in these protected areas, but in a few locations with lower human population density there are some remaining ungazetted forest patches.

4.2. Caveats

There are a number of caveats to the results presented in this paper. First, in terms of the taxon data not every location in every forest has been collected, therefore presenting a potential underestimate of species distributional data. Second, the gaps in the 1955 map coverage for South Nguru and Kisinga-Rugaro Forest Reserves mean that we cannot calculate the deforestation trends in lower elevations for those two areas. Third, we have taken a strict definition of taxa endemic to only the Eastern Arc montane forest in Tanzania and this has excluded many taxa that are endemic to East Africa and/or endemic to the combined Eastern Arc Mountains and Coastal Forests Biodiversity Hotspot (Myers et al., 2000); the number of endemic trees in the list used is thus lower than the number of trees endemic to the Eastern Arc Mountains and Coastal Forests (Burgess et al., 1998; Burgess and Clarke, 2000; Tallents et al., 2005; Lovett et al., 2006). The lowland montane elevational range, which grades into Eastern African Coastal Forest (Burgess and Clarke, 2000; Burgess et al., 2004), is extremely species rich and harbors an exceptional number of endemic species (Burgess et al., 1998; Tallents et al., 2005; Lovett et al., 2006). Because lowland and coastal forests are found in southern Kenya, due to our strict definition of tree taxa that are endemic to the Eastern Arc within only Tanzania, the number of Tanzanian endemic taxa used in this study does not reflect the full conservation importance of this elevational range.

4.3. Conservation relevance

We demonstrate here that consideration of forest extent and deforestation patterns by elevation is critical to a proper understanding of extinction threat due to habitat loss. Deforestation pressures and forest loss are not consistent across elevation and species confined to lower elevations suffer the greatest threat of extinction. Thirty-seven taxa out of 123 have ranges entirely contained below 1000 m. Endemic taxa with lower elevational ranges deserve increased conservation consideration because of the extent of deforestation in their habitat (Buchanan et al., 2008). If survey data were available to address all threat factors, we believe that the extinction threat of Eastern Arc endemic taxa would appear even more distressing than is presented here.

By including elevational distributions in a risk assessment approach based on habitat threat, we demonstrate that many species in montane ecosystems should have their IUCN Red List status upgraded on the basis of remaining habitat area alone. This is significant as estimation of habitat area from satellite image data is less expensive and less time-consuming than collecting the data needed to assess other IUCN threat criteria (e.g. population size and stability, subpopulation location, etc.). However we note that other ecological and evolutionary processes also affect the conservation of endemic tree species and may be amplified by habitat loss (Thomas et al., 2004; Gaston and Fuller, 2009). An important consequence of our findings is that the loss of forest at particular elevations may intensify the other significant impacts of fragmentation and habitat reduction such as edge effects and competition, and can increase loss of genetic diversity and inbreeding (Rosenzweig, 2001; Honnay and Jacquemyn, 2007). When the phenomenon of extinction time-lag is considered (Brooks et al., 1999b; Debinski and Holt, 2000), together with the long generation time and slow rates of speciation and molecular evolution for angiosperm trees (Petit and Hampe, 2006; Smith and Donoghue, 2008), it could be decades or even centuries before extinctions are realized. The lowland and submontane zones have less than 10% of their paleoecological forest extent remaining; could Fig. 2 be forecasting extinctions to come?

Assessment of the biological value of forests should include consideration of landscape position, including evaluation of isolation, fragmentation and/or connectivity of the habitat and, as this research supports, more detailed information on elevational ranges. These findings further demonstrate the conservation issues surrounding successful management of tropical montane regions with high species richness and endemism. In order to conserve the biological richness of the Eastern Arc, it is necessary to conserve these forests across their full elevational extent. The remaining forest at low and middle elevations is critically important for the large number of species they may harbor, and warrant improved conservation and rehabilitation efforts. Tropical montane forests are priority areas for conservation that also support high human population densities (Cordeiro et al., 2007; Burgess et al., 2007b), and thus require innovative conservation strategies (Rondinini et al., 2006) such as utilizing private land for conservation in lowland montane areas (Gallo et al., 2009). Conservation strategies must be well planned with clear goals including assessment of the biological value of forests based on elevation (Moore et al., 2004).

Acknowledgements

We thank Sokoine University of Agriculture, the University of Dar es Salaam, the Critical Ecosystem Partnership Fund, Conservation International, The United Nations Development Program Global Environmental Facility, York Institute for Tropical Ecosystem Dynamics (KITE), J.C. Rodgers (Mississippi State University) for advice, and A. Balmford (University of Cambridge) for constructive suggestions. We also thank The Missouri Botanical Garden for developing the TROPICOS online database, accessible from www.tropicos.org, which made this paper possible. In addition, we are grateful to two anonymous reviewers who provided valuable comments on this manuscript. N.D. Burgess was supported by the UNDP-GEF Eastern Arc Project and by WWF-US during the completion of initial data gathering for this paper, and by Valuing the Arc Program of Cambridge University (funded by the Leverhulme Trust and WWF) during the final stages. J. Hall was supported by the University of Florida, Fulbright, and the American Association of University Women.

References

Boucher, Y., Arseneault, D., Sirois, L., Blais, L., 2009. Logging pattern and landscape changes over the last century at the boreal and deciduous forest transition in Eastern Canada. Landscape Ecology 24, 171–184.
Brooks, T.M., Pimm, S.L., Kapos, V., Ravilious, C., 1999a. Threat from deforestation to montane and lowland birds and mammals in insular south-east Asia. Journal of Animal Ecology 68, 1061–1078.
Brooks, T.M., Pimm, S.L., Oyugi, J.O., 1999b. Time lag between deforestation and bird extinction in tropical forest fragments. Conservation Biology 13, 1140–1150.
Brooks, T.M., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Rylands, A.B., Konstant, W.R., Flick, P., Pilgrim, J., Oldfield, S., Magin, G., Hilton-Taylor, C., 2002. Habitat loss and extinction in the hotspots of biodiversity. Conservation Biology 16, 909–923.
Buchanan, G.M., Stuart, H.M., Butchart, S.H.M., Dutson, G., Pilgrim, J.D., Steininger, M.K., Bishop, K.D., Mayauxg, P., 2008. Using remote sensing to inform conservation status assessment: estimates of recent deforestation rates on New Britain and the impacts upon endemic birds. Biological Conservation 141, 56–66.
Burgess, N.D., Clarke, G.P., 2000. The Coastal Forests of Eastern Africa. IUCN Forest Conservation Programme, Gland and Cambridge.
Burgess, N.D., Clarke, G.P., Rodgers, W.A., 1998. Coastal forests of eastern Africa: status, endemism patterns and their potential causes. Biological Journal of the Linnean Society 64, 337–367.
Burgess, N., Doggart, N., Lovett, J.C., 2002. The Uluguru Mountains of eastern Tanzania: the effect of forest loss on biodiversity. Oryx 36, 140–152.
Burgess, N.D., Gordon, I., Salehe, J., Sumbi, P., Doggart, N., Rodgers, A., Clarke, P., 2004. Coastal forests of eastern africa. In: Mittermeier, R.A., Robles-Gil, P., Hoffmann, M., Pilgrim, J.D., Brooks, T.M., Mittermeier, C.G., Lamoreux, J.L.,

Fonseca (Eds.), Hotspots Revisited: Earth's Biologically Richest and Most Endangered Ecoregions. CEMEX, Mexico, pp. 231–239.
Burgess, N.D., Butynski, T.M., Cordeiro, N.J., Doggart, N.H., Fjeldså, J., Howell, K.M., Kilahama, F.B., Loader, S.P., Lovett, J.C., Mbilinyi, B., Menegon, M., Moyer, D.C., Nashanda, E., Perkin, A., Rovero, F., Stanley, W.T., Stuart, S.N., 2007a. The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. Biological Conservation 134, 209–231.
Burgess, N.D., Balmford, A., Cordeiro, N.J., Fjeldså, J., Kuper, W., Rahbek, C., Sanderson, E.W., Scharlemann, J.P.W., Sommer, J.H., Williams, P.H., 2007b. Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa. Biological Conservation 134, 164–177.
Colwell, R.K., Brehm, G., Cardelús, C.L., Gilman, A.C., Longino, J.T., 2008. Global warming, elevational range shifts, and lowland biotic attrition in the wet tropics. Science 322, 258–261.
Condit, R., Pitman, N., Leigh Jr, E.G., Chave, J., Terborgh, J., Foster, R.B., Núñez, P., Aguilar, S., Valencia, R., Villa, G., Muller-Landau, H., Losos, E., Hubbell, S.P., 2002. Betadiversity in tropical forest trees. Science 295, 666–669.
Cordeiro, N.J., Burgess, N.D., Dovie, D.B.K., Kaplin, B.A., Marrs, R., 2007. Conservation in areas of high population density in sub-Saharan Africa. Biological Conservation 134, 155–163.
Currie, D.J., Paquin, V., 1987. Large-scale biogeographical patterns of species richness of trees. Nature 329, 326–327.
Davidar, P., Rajagopal, B., Mohandass, D., Puyravaud, J., Condit, R., Wright, S.J., Leigh, E.G., 2007. The effect of climatic gradients, topographic variation and species traits in the beta diversity of rain forest trees. Global Ecology and Biogeography 16, 510–518.
Debinski, D.M., Holt, R.D., 2000. A survey and overview of habitat fragmentation experiments. Conservation Biology 14, 342–355.
Dinesen, L., Lehmberg, T., Rahner, M.C., Fjeldså, J., 2001. Conservation priorities for the forests of the Udzungwa Mountains, Tanzania, based on primates, duikers and birds. Biological Conservation 99, 223–236.
Doggart, N., Perkin, A., Kiure, J., Fjeldså, J., Poynton, J., Burgess, N., 2006. Changing places: how the results of new field work in the Rubeho Mountains influence conservation priorities in the Eastern Arc Mountains of Tanzania. African Journal of Ecology 44, 134–144.
FBD, 2006. Forest area baseline for the Eastern Arc Mountains. In: Mbilinyi, B.P., Malimbwi, R.E., Shemwetta, D.T., Songorwa, K., Zahabu, E., Katani, J.Z., Kashaigili, J. (Eds.), Conservation and Management of the Eastern Arc Mountain Forests. Forestry and Beekeeping Division, Dar es Salaam. Available from: <http://www.tz.undp.org/ToR_Forest_Area.doc>.
Finch, J., Leng, M.J., Marchant, R., 2009. Late Quaternary vegetation dynamics in a biodiversity hotspot, the Uluguru Mountains of Tanzania. Quaternary Research 72, 111–122.
Fjeldså, J., Lovett, J., 1997. Geographical patterns of phylogenetic relicts and phylogenetically subordinate species in tropical African forest. Biodiversity and Conservation 6, 325–346.
Gallo, J.A., Pasquini, L., Reyers, B., Cowing, R.M., 2009. The role of private conservation areas in biodiversity representation and target achievement within the Little Karoo region, South Africa. Biological Conservation 42, 446–454.
Gaston, K.J., Fuller, R.A., 2009. The sizes of species' geographic ranges. Journal of Applied Ecology 47, 1–9.
Gereau, R.E., Luke, W.R.Q., Kindeketa, W., Bodine, S., Schatz, G.E., in press. Plant conservation assessment in East Africa: procedures and first results. In: Burgt, X., Maesen, J., Onana, J. (Eds.), Systematics and Conservation of African Plants, Proceedings of the 18th AETFAT Congress, Yaoundé, Cameroon.
Givnish, T.J., 1999. On the causes of gradients in tropical tree diversity. Journal of Ecology 87, 193–210.
Harper, G.J., Steininger, M.K., Tucker, C.J., Juhn, D., Hawkins, F., 2007. Fifty years of deforestation and forest fragmentation in Madagascar. Environmental Conservation 34, 1–9.
Harris, G., Pimm, S.L., 2008. Range size and extinction risk in forest birds. Conservation Biology 22, 163–171.
Heaney, L.R., 2001. Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. Global Ecology and Biogeography 10, 15–39.
Honnay, O., Jacquemyn, H., 2007. Susceptibility of common and rare plant species to the genetic consequences of habitat fragmentation. Conservation Biology 21, 823–831.
Hubbell, S.P., 2001. The Unified Neutral Theory of Biodiversity and Biogeography. Princeton University Press, Princeton, NJ.
IUCN, 2001. Red List Categories and Criteria, ver. 3.1. IUCN Species Survival Commission, Gland, Switzerland. <http://www.iucnredlist.org>.
Jambiya, G. 1998. The Dynamics of Population, Land Scarcity, Agriculture and Non-agricultural Activities: West Usambara Mountains, Lushoto District, Tanzania. ASC Working Paper. Available from: <https://openaccess.leidenuniv.nl/dspace/handle/1887/423>.
Kaoneka, A., Solberg, B., 1994. Forestry related land use in the Western Usambara Mountains, Tanzania. Agriculture, Ecosystems and Environment 49, 207–215.
Kinnaird, M.F., Sanderson, E.W., O'Brien, T.G., Wibisono, H.T., Woolmer, G., 2003. Deforestation trends in a tropical landscape and implications for endangered large mammals. Conservation Biology 17, 245–257.
Lieberman, D., Lieberman, M., Peralta, R., Hartshorn, G.S., 1996. Tropical forest structure and composition on a large-scale elevational gradient in Costa Rica. Journal of Ecology 84, 137–152.
Lomolino, M.V., 2000. Ecology's most general, yet protean pattern: the species–area relationship. Journal of Biogeography 27, 17–26.
Lovett, J.C., 1990. Classification and status of the moist forests of Tanzania. Mitteilungen aus dem Institut für Allgemeine Botanik Hamburg 23a, 287–300.
Lovett, J.C., 1996. Elevational and latitudinal changes in tree associations and diversity in the Eastern Arc Mountains of Tanzania. Journal of Tropical Ecology 12, 629–650.
Lovett, J.C., 1999. Tanzanian forest tree plot diversity and elevation. Journal of Tropical Ecology 15, 689–694.
Lovett, J.C., 2001. Maintaining biodiversity in forest ecosystems. Environment and Development Economics 6, 151–153.
Lovett, J., Wasser, S.K., 1993. Biogeography and Ecology of the Rain Forests of Eastern Africa. Cambridge University Press, Cambridge.
Lovett, J.C., Clarke, G.P., Moore, R., Morrey, G.H., 2001. Elevational distribution of restricted range forest tree taxa in eastern Tanzania. Biodiversity and Conservation 10, 541–550.
Lovett, J.C., Marshall, A.R., Carr, J., 2006. Changes in tropical forest vegetation along an elevational gradient in the Udzungwa Mountains National Park, Tanzania. African Journal of Ecology 44, 478–490.
McCain, C.M., 2005. Elevational gradients in diversity of small mammals. Ecology 86, 366–372.
McCain, C.M., 2007a. Could temperature and water availability drive elevational species richness patterns? A global case study for bats. Global Ecology and Biogeography 16, 1–13.
McCain, C.M., 2007b. Area and mammalian elevational diversity. Ecology 88, 76–86.
Mittermeier, R.A., Robles Gil, P., Hoffman, M., Pilgrim, J.T., Brooks, T., Mittermeier, C.G., Lamoureux, J., da Fonseca, G.A.B., 2004. Hotspots Revisited: Earth's Biologically Richest and Most Threatened Terrestrial Ecosystems. CEMEX.
Moore, J., Balmford, A., Allnutt, T., Burgess, N., 2004. Integrating costs into conservation planning across Africa. Biological Conservation 117, 343–350.
Mumbi, C.T., Marchant, R., Hooghiemstra, H., Wooller, M.J., 2008. Late quaternary vegetation reconstruction from the Eastern Arc Mountains, Tanzania. Quaternary Research 69, 326–341.
Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.
Newmark, W.D., 1998. Forest area, fragmentation, and loss in the Eastern Arc Mountains: implications for the conservation of biological diversity. Journal of the East African Natural History Society 87, 29–36.
Newmark, W.D., 2002. Conserving Biodiversity in East African Forests: a Study of the Eastern Arc Mountains. Ecological Studies. Springer, Berlin, Germany.
Newmark, W.D., 2006. A 16-year study of forest disturbance and understory bird community structure and composition in Tanzania. Conservation Biology 20, 122–134.
Ney-Nifle, M., Mangel, M., 2000. Habitat loss and changes in the species–area relationship. Conservation Biology 14, 893–898.
Nogués-Bravo, D., Araujo, M.B., Romdal, T., Rahbek, C., 2008. Scale effects and human impact on the elevational species richness gradients. Nature 453, 216–218.
Petit, R.J., Hampe, A., 2006. Some evolutionary consequences of being a tree. Annual Review of Ecology Evolution and Systematics 37, 187–214.
Pócs, T., 1976. Vegetation mapping in the Uluguru Mountains (Tanzania, East Africa). Boissiera 24, 477–498.
Prell, W.L., Hutson, W.H., Williams, D.F., Be, A.W.H., Geitzenauer, K., Molfino, B., 1980. Surface circulation of the Indian-ocean during the last glacial maximum, approximately 18,000 yr BP. Quaternary Research 14, 309–336.
Rahbek, C., 1995. The elevational gradient of species richness – a uniform pattern. Ecography 18, 200–205.
Rahbek, C., 1997. The relationship among area, elevation, and regional species richness in neotropical birds. American Naturalist 149, 875–902.
Rickart, E.A., 2001. Elevational diversity gradients, biogeography and the structure of montane mammal communities in the intermountain region of North America. Global Ecology and Biogeography 10, 77–100.
Rondinini, C., Chiozza, F., Boitani, L., 2006. High human density in the irreplaceable sites for African vertebrates conservation. Biological Conservation 133, 358–363.
Rosenzweig, M.L., 1995. Species Diversity in Space and Time. Cambridge University Press, Cambridge.
Rosenzweig, M.L., 2001. Loss of speciation rate will impoverish future diversity. Proceedings of the National Academy of Sciences 98, 5404–5410.
Rosenzweig, M.L., 2003. Reconciliation ecology and the future of species diversity. Oryx 37, 194–205.
Smith, S.A., Donoghue, M.J., 2008. Rates of molecular evolution are linked to life history in flowering plants. Science 322, 86–89.
Struhsaker, T., 2005. Conservation of Red Colobus and their habitats. International Journal of Primatology 26, 525–538.
Tallents, L.A., Lovett, J.C., Hall, J.B., Hamilton, A.C., 2005. Phylogenetic diversity of forest trees in the Usambara Mountains of Tanzania: correlations with elevation. Botanical Journal of the Linnean Society 149, 217–228.
Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., Erasmus, B.F.N., de Siqueira, M.F., Grainger, A., Hannah, L., Hughes, L., Huntley, B., van Jaarsveld, A.S., Midgley, G.F., Miles, L., Ortega-Huerta, M.A., Peterson, A.T., Phillips, O.L., Williams, S.E., 2004. Extinction risk from climate change. Nature 427, 145–148.
Tuomisto, H., Ruokolainen, K., Yli-Halla, M., 2003. Dispersal, environment, and floristic variation of western Amazonian forests. Science 299, 241–244.
Ulrich, W., Buszko, J., 2004. Habitat reduction and patterns of species loss. Basic and Applied Ecology 5, 231–240.