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

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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

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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