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FOREST HEALTH MONITORING IN THE NGANGAO FOREST, TAITA HILLS, KENYA: A FIVE YEAR ASSESSMENT OF CHANGE

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ABSTRACT

Forest Health Monitoring (FHM) provides a standardized detection-level survey of forest and tree characteristics for large forested areas. We have adopted FHM methods from this temperate-based program to tropical forests in the Eastern Arc Mountains (EAM) of Kenya and Tanzania. This paper reports the first assessment of trend data in the EAM over a period from 2001 to 2006. Growth and diversity statistics are presented for 11 forest plots in Ngangao Forest; only six (of 45) species constitute the predominance (68%) of basal area growth. Four endemic trees were tallied in our survey: *Dasylepis integra, Leptonychia usambarensis, Macaranga conglomerata*, and *Polyscias stuhlmannii*. We contrast diversity statistics with the nearby Chawia Forest and confirm the basic principal of species area relationships. Additionally, we examine visual crown assessments and tree damages. Tree crowns appeared healthy overall, although one species (*Albizia gummifera*) displayed increased dieback and foliage transparency and decreased crown density. Tree damages increased slightly over the survey period with stem decays constituting the most prominent symptom. Overall, we found no significant change in this first remeasurement of forest conditions at Ngangao Forest. The results reported here, however, may require more intense inspection of conditions. The Forest Health Monitoring approach constitutes a detection-level survey; it is dependent on follow-up by local experts to determine more precise causality where initial problems are found.

Keywords: Eastern Arc Mountains, change assessment, biodiversity, crown conditions, tree damage

INTRODUCTION

The Eastern Arc Mountains (EAM) are considered one of the world's "biodiversity hotspots" based on global concentrations of species endemism (Myers *et al.*, 2000). A long period of climatic stability, concentration of Indian Ocean moisture on EAM uplands, and geographic isolation on the East African plain (Wasser & Lovett, 1993) are contributing factors toward the highest density of endemism in the world (Myers *et al.*, 2000). Where high biological diversity is concentrated in relatively small patches there is great potential for species loss from numerous factors, such as increased population pressure, forest fragmentation, decreasing core forest area, and introduction of invasive species. The northern portion of the EAM (Usambara, Pare, Taita ranges) include the highest level of endemism for tree species, including 50% of all endemics found throughout the EAM (Lovett, 1993).

The Taita Hills, comprising the northern terminus of the EAM and the sole mountain group of this chain arising in Kenya (Wasser & Lovett, 1993), consist of highly fragmented forest patches interspersed with agriculturally-based rural enclaves. Of the 11 major mountain areas of the Eastern Arc range of Kenya and Tanzania, the Taita Hills is estimated to have lost the greatest percentage of forest area (98%) over the past 2,000 years (Newmark, 1998). The greatest portion of this forest loss has come with the accelerating human population growth of the past 250 years (Newmark, 1998). Contemporary EAM forest loss due to agricultural expansion, fuel wood cutting, legal and illegal logging, livestock grazing, and forest burning has been noted by numerous authors (Rodgers, 1993; Wasser & Lovett, 1993; Newmark, 1998; Rogo & Oguge, 2000; Madoffe e*t al.*, 2005; Pellikka *et al.*, 2005). The net result of shrinking forests in the Taita Hills (and EAM more broadly) has been decreased forest patch sizes and increasing forest fragmentation. These factors lead to a greater number of forest "islands" and the oft-noted corollary of overall declines in species richness (MacArthur & Wilson, 1967; Newmark, 1998).

The Taita Hills, like much of the EAM, had undergone significant impacts through the colonial period (Lovett, 1993). Among the most potent impacts was the establishment of tree plantations. Remnants of that era are exotic species, such as *Pinus patula*, which is common throughout the Taita Hills. Colonial forest practices did not acknowledge the benefits of biological diversity in the Taita Hills or elsewhere in Africa. Early forest records suggest that the loss of evergreen mist forests is mostly attributable to historical policies that supported exotic plantations, contributing to loss of indigenous forests. At lower elevations, montane forests were gradually encroached upon for agriculture uses (Mbuthia, 2003).

We focus on a single forest patch within the Taita Hills as an application of forest health monitoring methods developed in the USA (USDA Forest Service, 2007). The Ngangao

Forest (excluding surrounding plantations) is approximately 120 ha in extent and has apparently undergone a moderate level of human intrusion in recent years. For context, in the Taita Hills, the Chawia Forest (86 ha) defines a more highly modified fragment and the Mbololo Forest (220 ha) is relatively lightly impacted (Pellikka, unpublished data). Our goal is to make a preliminary assessment of change at Ngangao in forest structure, growth, crown conditions, and tree damage over a five year period (2001–2006).

Forest Health Monitoring (FHM), a national program designed to detect broad-scale change in temperate forests of the United States, was first implemented in the early 1990s (Rogers *et al.*, 2001). The purpose of this program is to detect the status, changes, and trends of select forest "indicators" using a regular (1–5 year) cycle. This program was initially implemented in response to international agreements—the Montreal Process and Santiago Declaration (Anonymous, 1995)—of six ecological criteria: biological diversity, productive capacity, ecosystem health, soil resources, water resources, and global carbon cycles. In the United States, FHM now monitors six indicators (tree crowns, tree damage, epiphytic lichen diversity, ozone damage, soils and understorey vegetation) as a portion of their more intensive forest inventory program (USDA Forest Service 2007). Thus far, there has been only preliminary use of FHM methods, and little analysis conducted, in tropical environments of the United States. In East Africa, we implemented a pared-down version of the United States FHM/forest inventory program using only the crown, damage, and forest mensuration indicators due to the lack of expertise and funding to carry out the full program. Wherever FHM is implemented, its intention is to have an ongoing survey of forest conditions that can quickly detect change and inform corrective actions by managers prior to ecosystem crises developing. It is important to monitor forest change over time, whether significant anthropogenic damage is detected or not, to establish baseline conditions or natural rates of change.

MATERIAL AND METHODS

The Taita Hills comprise the northern most extension of the EAM of Kenya and Tanzania. They are located in southeast Kenya (03°25'S, 38°20'E), approximately 120 km east of Kilimanjaro and 175 km inland of the Indian Ocean (figure 1). The Taita Hills constitute a moist upland (average elev. 1500 m) surrounded by dry savannah grasslands (*ca.* 700 m). Rainfall averages 1500 mm annually and normally arrives in two distinct seasons: the long rains, from March to June, and the short rains, from October to December (Pellikka *et al.*, 2005). Moisture accumulating in these mountains provides municipal water supply to communities within the Taita Hills, as well as the surrounding settlements and portions of Tsavo National Park. Loss of forest cover, in addition to threatening water supplies, contributes to erosion and biodiversity loss.

Forest monitoring measurements were taken at two points in time in the Taita Hills. In 2001 and 2006 we used procedures adopted from the USDA Forest Service, Forest Inventory/Forest Health Monitoring programs in the United States to assess basic conditions of forest structure, tree crown conditions, and tree damages (USDA Forest Service, 2007). We specifically selected dry seasons to facilitate easier access to field sites:in 2001 we measured from January to February; due to logistical restraints, our 2006 field season was conducted during the later dry season of August–September. Eleven forest plots were randomly selected in the Ngangao Forest within the Taita Hills based on selection criteria presented below. At each site we measured tree growth using diameter at breast height (dbh) by species; tree crowns by visually assessing the live crown of each tree for its density, dieback, and transparency; and examining recent damages to tree roots, boles, branches, and crowns. By comparing these same measures over a 5-year time period we were able to make a cursory assessment of change to these forests at the stand-level, and by extrapolation, the forest-level. All field crew members attended required training sessions and attained standardized field certifications to ensure consistency in both measured and estimated variables.

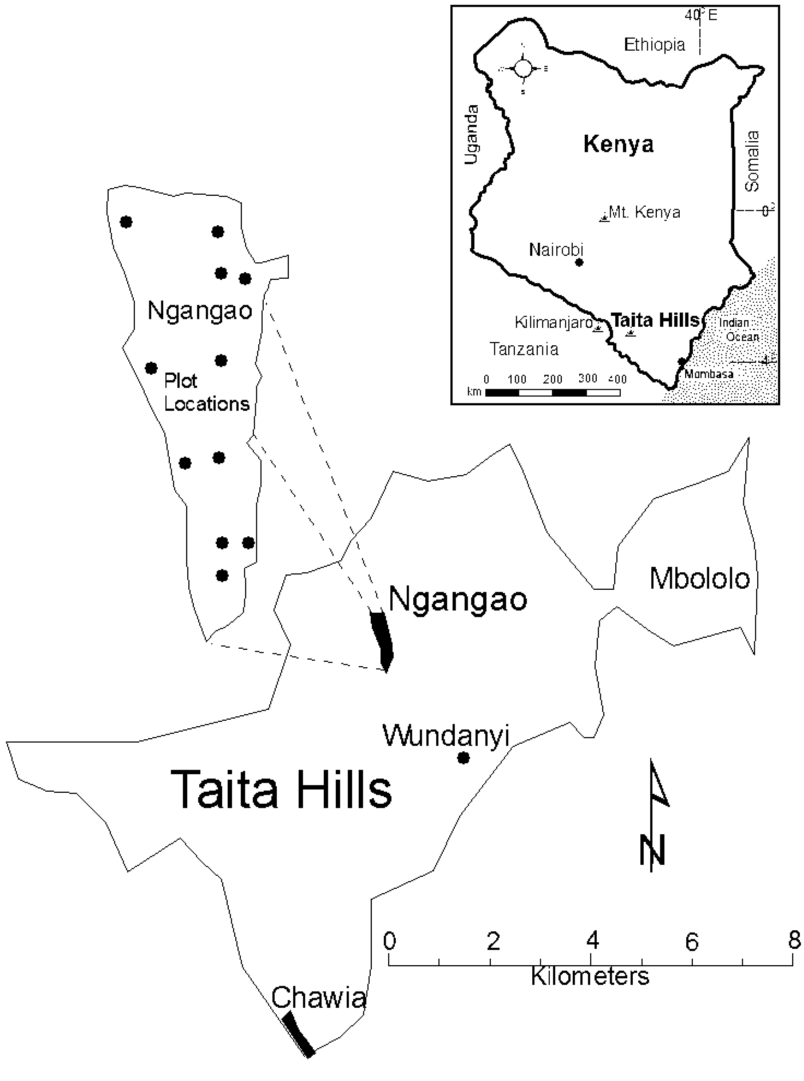


Figure 1. The Taita Hills study area is depicted with a blowup of Ngangao plot locations. The Taita Hills are shown in relation to East African geography in the upper right.

Plot selection criteria for Ngangao were based on an ongoing study by Kamau Wakanene Mbuthia. Dr. Wakanene Mbuthia used a stratified random sampling method, whereby the forest was subdivided into six blocks measuring 400 m in width. Random points were established within the blocks to determine the positions of east-west transects. Beginning at these points, 20 x 50 m plots were established perpendicular to the slope for a total of 29 plots in 6 east-west transects (Mbuthia, 2003). We randomly selected two plots per transect, and then located the FHM plot centers 30 m west of the SW corner of Dr. Mbuthia's plots (figure 1). Plots referenced in this study from Chawia Forest were randomly selected after touring that forest with local managers. Chawia plots, therefore, should be viewed as a random sampling of trees, but not as a complete, statistically valid, sample of forest area.

Briefly, survey methods at each plot consist of four "subplots" systematically located within an approximately 1 ha area (USDA Forest Service, 2007). This sub-sampling approach provides a means for statistically representing one hectare of forest cover immediately surrounding the plot center (Bechtold & Patterson, 2005). At each subplot, every tree within a fixed-plot radius of 7.3 m and over 12.7 cm dbh is identified and measured. Additional data are taken so that trees may be precisely relocated upon remeasurement, as well as whether the tree is live or dead. Live trees are further assessed for recent damages, such as excessive vines in the crowns, root and stem pathogens, insect infestations, and bud and foliage injuries. Injuries must meet thresholds, such as 20% of the stem circumference or 30% of the live crown area (foliage), in order to be considered significant. Occasionally, binoculars are required to examine damages to upper portions of tree branches, buds, or foliage. For clarity, we emphasize that "damage" is used here generically to denote ant injuries or maladies arising from either natural or human causes.

Tree crowns are examined visually and rated according to specific methods perfected on temperate trees in North America (Schomaker *et al.*, 2007). After defining a given tree's live crown area, two field workers rate crown conditions at 90° separation from each other and a distance from the target tree equal to at least one-half of the tree's height. Positioning personnel apart from each other ensures that the field crew is rating the entire live crown and not just from a single vantage point. Ratings are made in 5% classes from 0–99% for crown density, dieback, and transparency. Density is defined as the percent of the crown area which blocks out sunlight as viewed by each surveyor. Dieback is the percent of the crowns upper and outer branches that are not foliated due to recent die-off of buds, branches, or foliage. Crown transparency rates the amount of light that passes through just the foliated portion of the crown. Density and transparency are not exactly opposite to each other since crown density accounts for branches and foliage, while transparency only examines light passing through foliage.

A list of the entire array of attributes collected on FHM plots in the study area is provided in Appendix A (available as Supplementary Material). On each plot we collected a minimum of 89 forest and tree attributes. In the interest of brevity, we do not describe each attribute measured on the plots, although detailed explanations are provided in USDA Forest Service (2007).

Monitoring plots identical to the ones discussed here were also established and remeasured over the same time period in Chawia Forest, Taita Hills, as well as in other EAM ranges. Initial estimates of conditions in these forests based on forest health monitoring methods found generally healthy stands (Madoffe *et al.*, 2005; Madoffe *et al.*, 2006), although caution should be placed on these findings given the baseline nature of those studies. This study, then, is intended to act as a demonstration of forest health monitoring applications to trend data that may be applied to EAM forests, associated mountain groups, or potentially, African or tropical forests at-large.

RESULTS

Tree growth

Within Ngangao Forest we remeasured 11 forest plots—9% of the entire forest (figure 1)—and tallied a total of 416 mature ($\geq$ 12.7 cm dbh) trees (37 dead), and 105 (10 dead) saplings ($\leq$ 2.5 cm dbh). Though saplings may be examined as a measure of forest regeneration, the present analysis is focused on forest change as measured in mature trees only; thus we will not discuss saplings further in this treatment. We tallied a total of 45 mature tree species at Ngangao, though many species were encountered sparsely and only account for a small percentage of the total trees measured (table 1). Nine percent of mature trees were dead, but still standing; many of these had died prior to the initial 2001 measurement.

Plot-level stand structure data and diversity indices are shown in table 2. We tallied an average of 559 mature trees per hectare, with a minimum of 397 and a maximum of 779 trees. Average basal area for Ngangao plots was 51.69 m^2/ha. Our results netted a total of 45 tree species (gamma diversity), with a mean plot diversity of 12.8 species (alpha diversity). Beta diversity, denoting community turnover or the number of distinct communities in the data set, was 3.52. Simpson's diversity index provides a measure of species richness, while Shannon's diversity index reflects evenness within the sample (table 2) (Lovett, 1996).

The predominant measure of change from the 5-year period beginning with the 2001 field sample was basal area growth. Figure 2 displays growth by plot as a percentage of the total growth of the Ngangao sample. Four plots represented more than half the growth. We also evaluated growth based on dominant species in the forest (figure 3). Over two-thirds of the growth was found in six common species, while the other 39 tree species constituted the remaining volume of change over five years. Four of the species tallied by our survey are endemic to the Taita Hills (Burgess *et al.*, 2007): *Dasylepis integra, Leptonychia usambarensis, Macaranga conglomerata*, and *Polyscias stuhlmannii*. *M. conglomerata* exhibited the greatest percent of basal area growth among all species (figure 3). In contrast, *P. stuhlmannii* and *L. usambarensis* each made up less than 1% of growth and 1.4 and 0.5% frequency, respectively, of all trees tallied (table 1).

For comparison, we examined a complimentary data set from Chawia Forest using the same plot design and tree measurements. Though we only sampled six plots from this much smaller forest, and the sample was not stratified by systematic methods, the number of plots in Ngangao and Chawia were roughly proportional to their forested extent (*i.e.*, 120 and 86 ha, respectively). We tallied an average of 360 mature trees per hectare, with a minimum of 206 and a maximum of 691 trees. Mean basal area per plot was 49.13 m^2/ha. At Chawia we tallied 22 total tree species (gamma diversity), with an alpha diversity of 6.5 and a beta diversity of 3.38. The endemics, *M. conglomerata, L. usambarensis* and *Syzygium micklethwaitti* Verdc. were sampled at Chawia, while *M. conglomerata* was the 4th most tallied species here as opposed to its 2nd place frequency at Ngangao.

Tree crown assessment

Our next assessment indicator for Ngangao Forest is foliar crown conditions. We assessed crown density, dieback, and transparency estimates for live trees $\geq$ 12.7 cm dbh. Change in

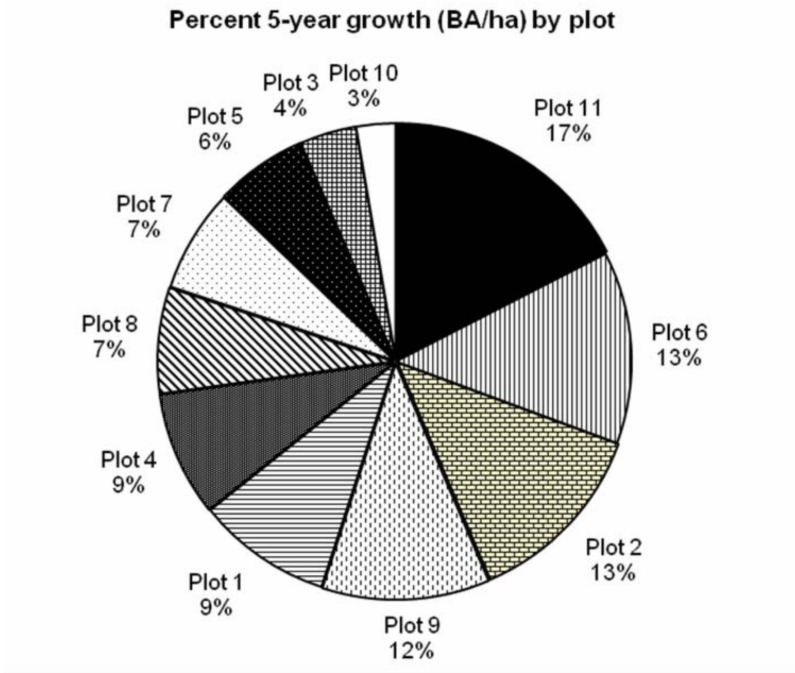


Figure 2. Change in tree growth (BA m^2/ha) as a percent of total growth on the 11 monitoring plots in Ngangao Forest from 2001 to 2006. Tree growth is unevenly distributed within the forest with only four sample plots comprising greater than half of the total growth measured at Ngangao.

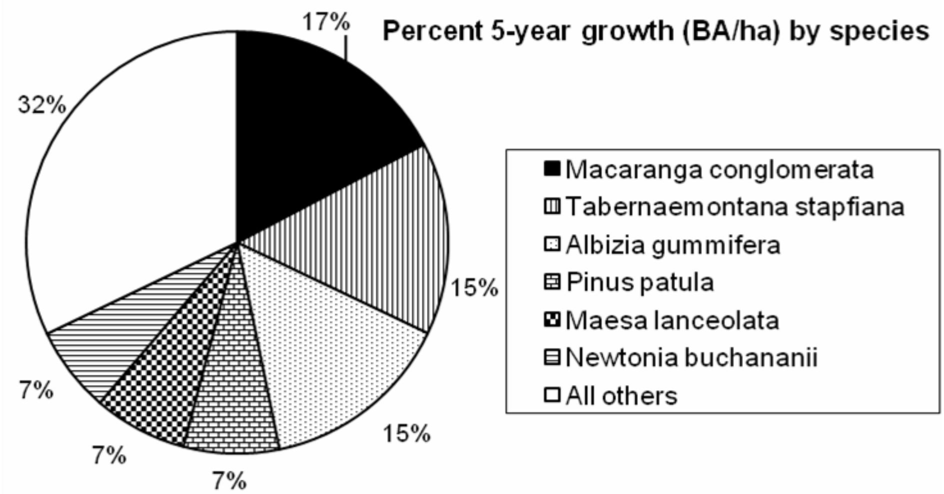


Figure 3. Change in tree growth (BA m^2/ha) as a percent of total growth by species tallied at Ngangao Forest from 2001 to 2006. The six most common species, Macaranga conglomerata *being endemic to the northern Eastern Arc Mountains (Burgess* et al*., 2007), constitute more than two-thirds of the growth in our study.*

Table 1. Tree species by frequency and percent of total for Ngangao Forest, Taita Hills. Species marked in bold type are endemic to the Taita Hills (Burgess et al.*, 2007).*

Species	Frequency total	Frequency dead	Percent frequency
Albizia gummifera (J.F.Gmel.) C.A.Sm.	37	5	8.87
Allophylus abyssinicus (Hochst.) Radlk.	1		0.24
Aphloia theiformis (Vahl) Benn.	3	1	0.72
Canthium oligocarpum Hiern	2	1	0.48
Chrysophyllum gorungosanum Engl.	1	1	0.24
Coffea fadenii Bridson	1		0.24
Cola greenwayi Brenan	10	1	2.40
Craibia zimmermanni (Harms) Dunn	16		3.84
Croton megalocarpus Hutch.	3		0.72
Cupressus lusitanica Miller	11	3	2.64
Cussonia spicata Thunb.	13		3.12
Dasylepis integra Warb.	10		2.40
Diospyros abyssinica (Hiern) F.White	1		0.24
Drypetes gerrardii Hutch.	1		0.24
Ekebergia capensis Sparrm.	3		0.72
Erica arborea L.	1	1	0.24
Garcinia volkensii Engl.	2		0.48
Leptonychia usambarensis K.Schum.	2		0.48
Macaranga conglomerata Brenan	39	5	9.35
Maesa lanceolata Engl.	23	4	5.52
Manilkara sulcata (Engl.) Dubard	1		0.24
Millettia oblata Dunn.	13	1	3.12
Rapanea melanophloeos (L.) Mez	15		3.60
Newtonia buchananii (Baker f.) G.C.C.Gilbert & Boutique	8		1.92
Nuxia congesta R.Br. ex Fresen.	1		0.24
Ochna holstii Engl.	5	1	1.20
Ochna atropurpurea DC.	2		0.48
Ocotea usambarensis Engl.	2		0.48
Oxyanthus speciosus DC.	7		1.68
Phoenix reclinata Jacq.	23	4	5.52
Pinus patula Schiede ex Schlecht. & Cham.	21	3	5.04
Podocarpus latifolius R.Br. ex Mirb.	2		0.48
Polyscias fulva (Hiern) Harms	7		1.68
Polyscias stuhlmannii Harms	6	1	1.44
Pouteria adolfi-friedericii (Engl.) A.Meeuse	9		2.16
Psychotria crassipetala E.M.A.Petit	1		0.24
Psychotria petitii Verdc.	4		0.96
Rytigynia eickii (K.Schum. & K.Krause) Bullock	2		0.48
Rytigynia uhligii (K.Schum. & K.Krause) Verdc.	5		1.20
Strombosia scheffleri Engl.	13	1	3.12

Species	Frequency total	Frequency dead	Percent frequency
Syzygium guineense (Willd.) DC.	19		4.56
Tabernaemontana stapfiana Britten	50	1	11.99
Vepris trichocarpa (Engl.) Mziray	2		0.48
Vitex keniensis Turrill	2		0.48
Xymalos monospora (Harv.) Baill.	16	3	3.84
Totals	416	37	100.00

Table 2. Plot-level tree data and species diversity indices for Ngangao Forest, Taita Hills.

Plot number	Number of trees tallied	Number of species tallied	Basal area m^2/ ha (2006)	Shannon's diversity index	Simpson's diversity index
1	27	13	48.45	2.29	0.87
2	45	12	59.15	1.79	0.73
3	33	16	59.37	2.65	0.92
4	53	15	41.01	2.35	0.88
5	35	14	48.49	2.35	0.87
6	28	8	53.99	1.50	0.69
7	53	11	40.57	1.84	0.78
8	30	12	67.27	1.95	0.77
9	30	14	58.41	2.31	0.86
10	46	10	32.58	1.95	0.81
11	36	16	59.27	2.58	0.91
Averages	37.82	12.82	51.69	2.14	0.83

Table 3. Five years of changes in primary tree damages in Ngangao Forest, Taita Hills.

	2001		2006		
Tree damage	Frequency	Percent	Frequency	Percent	Percent change
No damage	202	55.65	185	49.33	-6.31
Cankers & galls	6	1.65	11	2.93	1.28
Conks, decays, fruiting bodies	93	25.62	120	32.00	6.38
Open wounds	4	1.10	2	0.53	-0.57
Resinosis	1	0.28	0	0.00	-0.28
Cracks and seams	5	1.38	5	1.33	-0.04
Broken bole or roots	1	0.28	1	0.27	-0.01
Vines in crown	31	8.54	38	10.13	1.59
Broken or dead roots	13	3.58	9	2.40	-1.18
Broken or dead branches	4	1.10	3	0.80	-0.30
Damaged buds, foliage, shoots	1	0.28	1	0.27	-0.01
Vine girdling stem (Ficus spp.)	2	0.55	0	0.00	-0.55

the population is based on visual comparison of trend data between 2001 and 2006 (figure 4). There was little change in dieback (figure 4b) during this period. However, both density (figure 4a) and transparency (figure 4c) show a "flattening" of the data set (less severe peaks); the apparent visual shifts in bars (*i.e.*, lower density and higher transparency) are not borne out by average population values (see legends, figure 4). Without significant change in population-level crown health, we examined the five most common species in more detail (figure 5). In general, a healthy tree exhibits a pattern of increased or stable density and decreased or stable transparency over time. Dieback should be near zero or decreasing for all species, while density and foliage transparency numbers are relative to a particular species' normal branch and leaf morphology. While most of the common species tallied confirmed our overall trend of little change in crown variables, *Albizia gummifera* displayed a marked decrease in density and increases in dieback and transparency (figure 5).

Tree damage and mortality

There we no large-scale incidence of tree damage in the 5-year period studied here. Change in percent of trees damaged and by specific damage agents is presented in table 3. Population-level tree damage increased by approximately 6%, although "no damage" results are approximately 15–25% lower than found in temperate forest health monitoring studies in North America (Keyes *et al.*, 2001; Rogers *et al.*, 2001). The most common damages found in Ngangao are various stem decays and vines in tree crowns, and both of these damage types increased over the survey period (table 3). Of the most common species sampled several had high incidences of damage: *Xymalos monospora* (92%), *Tabernaemontana stapfiana* (73%), *Syzygium guineense* (58%), and *Macaranga conglomerata* (53%). In contrast, *Albizia gummifera* recorded only 34% damage. Tree mortality–death since the previous survey–between 2001 and 2006 was 3.85%. Though causes of tree mortality are often difficult to determine, we found no evidence of human-caused death. Mortality most commonly resulted from competition or suppression from adjacent trees, although we also were unable to determine cause of death in approximately one-third of cases and at least one tree was thought to be killed by severe wind.

DISCUSSION

Within the EAM there has been significant loss of forest cover and degradation of ecosystems in recent history (Rodgers, 1993; Wasser & Lovett, 1993; Rogo & Oguge, 2000; Burgess *et al.*, 2007). It is estimated that 76% of the original EAM have been deforested and the highest percentage (98%) among EAM ranges has been in the Taita Hills (Newmark, 2002). With only small fragments of forest remaining it is important to track changes in tree cover and health so that policymakers may efficiently direct resources to areas likely to have the greatest affect. There are several matrices that may be applied to problems of forest degradation, such as forest extent, degree of fragmentation, measures of biodiversity, and enumeration and condition of endemic species. In this study, we have focused specifically on forest health within the Ngangao Forest as an application of monitoring protocol and assessment tools used in temperate forests of North America (Rogers *et al.*, 2001; Schomaker *et al.*, 2007; USDA Forest Service, 2007). We have found that over the five year period tracked in this study forest health conditions are generally good, although there are a few cautionary notes highlighted below.

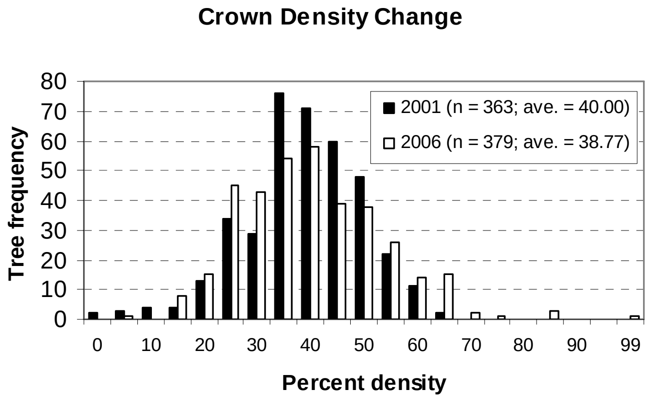
First, overall tree growth appears healthy, although only a few tree species made up the majority of growth (figure 3). Although the endemic species *Macaranga conglomerata* was among the highest growth species (figure 3), we have some concern regarding the lack of other endemics within Ngangao. Further, in the much smaller Chawia Forest, we tallied only one endemic species (*M. conglomerata*) and its ranking among the most common species encountered had dropped significantly, indicating a potential loss of endemics with greater fragmentation. On the other hand, *M. conglomerata's* status as a declining pioneer species may simply indicate a maturing forest responding to local conservation efforts at Chawia designed to increase canopy continuity (James Mwang'ombe, pers. comm.). Occurrence of pioneer species *Macaranga conglomerata* and *Albizia gummifera* at Ngangao is an indication of a gradual replacement of pioneer species by more shade tolerant species. Past logging activities evidenced by numerous old saw pits created tree fall gaps that created ideal conditions for these pioneer species (see Mbuthia, 2003). In either case, however, future management strategies should account for decreasing stands of pioneer species, especially where those species are endemics. In other words, managers need to account for species diversity bolstered by a range of natural disturbance-induced successional stages (Rogers, 1996; Ciancio *et al.*, 1999) so we do not loose endemic species at the landscape-scale.

Diversity values presented here were comparable to those of earlier work (Wilder *et al.*, 1998) that examined Ngangao and other Taita Hills forest fragments. This small difference—our Shannon's diversity index was slightly lower at 2.14 compared to Wilder *et al.* (1998) at 2.44—can likely be attributed to different survey methods. When we compare the same methods between different forests, the lower species tally at Chawia and higher beta diversity suggest that there is greater turnover between stands sampled there, as compared to Ngangao, probably as a result of fewer sample plots and smaller area, higher fragmentation, and presence of scattered, but large, *Phoenix reclinata* clones. Our results comparing diversity indices between these two forests also confirms the basic ecological principal of species-area relationships found in other works (MacArthur & Wilson, 1967; Lovett, 1996; Wilder *et al.*, 1998).

Second, crown assessments gave us the most positive overall sign of good tree conditions at Ngangao. There was little change at the population- or tree-level regarding foliar health (figures 3 & 4). One species of concern, however, was *Albizia gummifera*. Across the study area, this species displayed an increase in dieback and transparency with a decreasing crown density. We have some concern, however, that remeasurement during August–September may have contributed to this the negative trend in *Albizia gummifera* crown conditions, though our data only note two trees where leaves appeared to be actively shedding at the time of data collection. Continued monitoring of the health of this species, as well as remeasurement of cohort crown conditions, is recommended to track this apparent trend. Additionally, a closer examination of links between species specific crown and damage conditions by local authorities may further elucidate this situation.

Third, tree mortality at Ngangao was not unusually high between 2001 and 2006. We found that overall damage recorded between field visits increased significantly, although we could not accurately link a specific causal agent to this trend. Given that the greatest increase among damage types was in general stem decays and vines in the crown we suspect a climate-related agent, but this is purely speculative. Based on the data gathered and field notes accumulated, we do not suspect anthropogenic agents in this trend. We must also consider the possibility that decays, and damages more generally, that are coded as serious pathogenic agents in temperate forests may not fulfill the same (deleterious) ecological role in EAM forests. The purpose of implementing this generalized monitoring system is not so much to determine causality, as it is to apply a "broad net" approach to *detection* monitoring that is based on standardized methods. It is our purpose in casting this broad net to find biogeographical anomalies in our data and then focus further investigations at those sites.

a.



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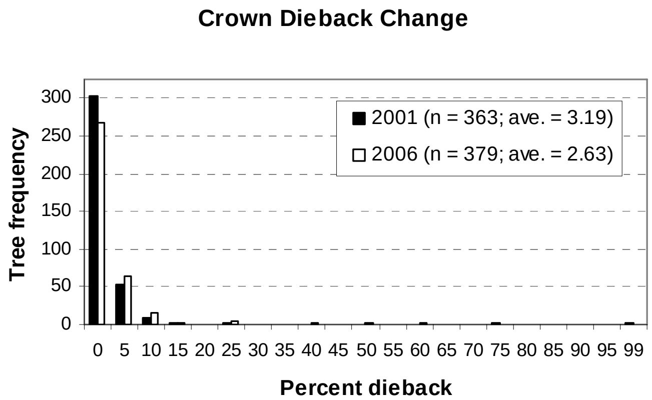

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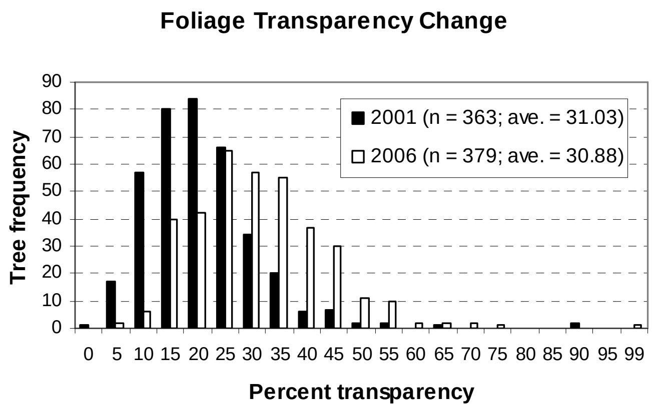

Figure 4. Population-level tree crown change over a 5-year period at Ngangao Forest. Density is an estimation of fullness of a tree crown. Dieback is recently dead upper and outer branches, buds, and leaves of the crown. Transparency refers to the amount of light penetrating just the foliated portion of the crown.

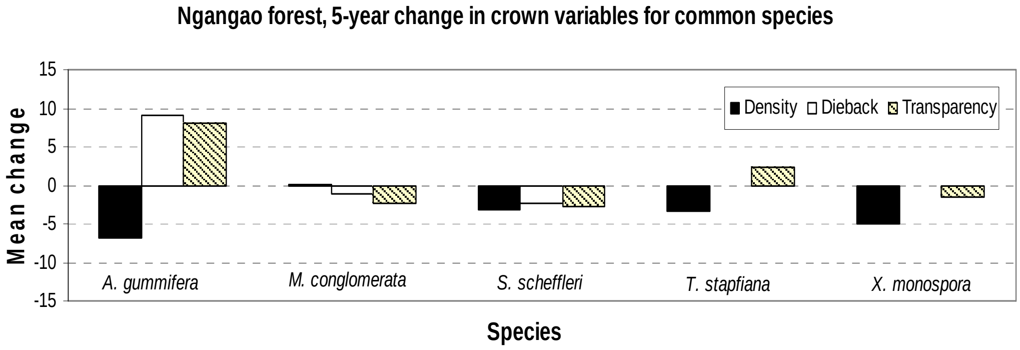

Figure 5. Species-level tree crown change for the most commonly tallied species (table 1) at Ngangao Forest. The graph depicts net loss (below zero), net gain (above zero), and relative stability of individual crown variables for each species. Crown density decreases combined with dieback and transparency increases are considered detrimental to overall tree and/or species health.

Ultimately, the particular results reported here must be examined within a local ecological context before concrete conclusions concerning forest health can be drawn. It is likely that more detailed investigations, especially where anthropogenic causality may be implicated, will involve complex explanations, as well as multifaceted remedial actions. In this light, we expect that adaptive solutions involving local populations will gain the most traction toward successful outcomes (Gunderson & Holling, 2002). First approximation monitoring efforts, such as those presented here, represent not only a primary step, but a continuing requirement, of an effective land management cycle. If we share common goals—healthy landscapes and healthy communities—then integration and education of local peoples about all phases of the land management cycle logically constitutes a natural step toward achieving those goals.

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REFERENCES

Anonymous (1995). Sustaining the World's forests: the Santiago agreement. *Journal of Forestry* **93**: 18–21.

Bechtold, W.A. & P.L. Patterson (2005). The enhanced forest inventory and analysis program—national sampling design and estimation procedures. USDA Forest Service, Southern Research Station, Asheville, N.C. SRS-GTR-80. URL: http://www.treesearch.fs.fed.us/pubs/20371.

Burgess, N.D., T.M. Butynski, N.J. Cordeiro, N.H. Doggart, J. Fjeldsa, K.M. Howell, F.B. Kilahama, S.P. Loader, J.C. Lovett, B. Mbilinyi, M. Menegon, D.C. Moyer, E. Nashanda, A. Perkin, F. Rovero, W.T. Stanley & S.N. Stuart (2007). The biological importance of the Eastern Arc Mountains of Tanzania and Kenya. *Biological Conservation* **134**: 209–231.

Ciancio, O., P. Corona, F. Iovino, G. Menguzzato & R. Sotti (1999). Forest management on a natural basis: the fundamentals and case studies. *Journal of Sustainable Forestry* **9**: 59–72.

Gunderson, L.H. & C.S. Holling (2002). *Panarchy: Understanding Transformations in Human and Natural Systems*. Island Press, Washington, D.C.

Keyes, C., P. Rogers, L. LaMadeleine & D. Atkins (2001). Utah Forest Health Report: a baseline assessment 1999/2001. State of Utah, Department of Natural Resources, Division of Forestry, Fire and State Lands, State of Utah, Department of Natural Resources, Division of Forestry, Fire and State Lands. URL: http://www.ffsl.utah.gov/foresthealth.htm

Lovett, J.C. (1993). Eastern Arc moist forest flora. In J.C. Lovett & S.K. Wasser (eds.), *Biogeography and Ecology of the Rain Forests of Eastern Africa* University Press, Cambridge. Pp. 33–55.

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.

MacArthur, R.H. & E.O. Wilson (1967). *The Theory of Island Biogeography*. Princeton University Press, Princeton, N.J.

Madoffe, S., J. Mwang'ombe, B. O'Connell, P. Rogers, G. Hertel & J. Mwangi (2005). Forest Health Monitoring in the Eastern Arc Mountains of Kenya and Tanzania: a baseline report from select forest reserves. URL: http://fhm.fs.fed.us/pubs/baseline/eam_01_02.pdf.

Madoffe, S., G.D. Hertel, P. Rogers, B. O'Connell & R. Killenga (2006). Monitoring the health of selected eastern arc forests in Tanzania. *African Journal of Ecology* **44**: 171–177.

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

Mbuthia, K.W. (2003). Ecological and ethnobotanical analyses for forest restoration in the Taita Hills forests, Kenya. Ph.D. dissertation. Miami University, Ohio, USA.

Newmark, W.D. (1998). Forest area, fragmentation, and loss in the Eastern Arc Mountains: implications for the conservation of biological diversity. *Journal of East African Natural History* **87**: 1–8.

Newmark, W.D. (2002). *Conserving Biodiversity in East African Forests: a Study of the Eastern Arc Mountains*. Springer, New York.

Pellikka, P.K.E., B.J.F. Clark, T. Sirviö & K. Masalin (2005). Environmental change monitoring applying satellite and airborne remote sensing data in the Taita Hills, Kenya. Proceedings of the 1st International Conference on Remote Sensing and Geoinformation

Processing in the Assessment and Monitoring of Land Degradation and Desertification, Trier, Germany, 7–9 September, 2005. Pp. 223–232.

Rodgers, W.A. (1993). The conservation of the forest resources of eastern Africa: past influences, present practices and future needs. In J.C. Lovett & S.K. Wasser (eds.), *Biogeography and Ecology of the Rain Forests of Eastern Africa*. Cambridge University Press, Cambridge. Pp. 283–327.

Rogers, P.C. (1996). Disturbance ecology and forest management: a review of the literature. USDA, Forest Service, Intermountain Research Station, Ogden, UT: General Technical Report INT-GTR-336.

Rogers, P., D. Atkins, M. Frank & D. Parker (2001). Forest Health Monitoring in the Interior West: a baseline summary of forest issues, 1996–1999. USDA, Forest Service, Rocky Mountain Research Station, Fort Collins, CO: Gen. Tech. Rep. RMRS-GTR-75. URL: http://www.fs.fed.us/rm/pubs/rmrs_gtr75.html.

Rogo, L. & N. Oguge. 2000. The Taita Hills forest remnants: a disappearing world heritage. *Ambio* **29**: 522–523.

Schomaker, M.E., S.J. Zarnoch, W.A. Bechtold, D.J. Latelle, W.G. Burkman & S.M. Cox (2007). Crown-condition classification: a guide to data collections and analysis. USDA Forest Service, Southern Research Station, Asheville, N.C. SRS-GTR-102. URL: http://www.srs.fs.fed.us/pubs/results-series.jsp.

USDA Forest Service (2007). Field methods instructions for Phase 2 (Forest Inventory) and Phase 3 (Forest Health) of the national Forest Inventory and Analysis program. URL: http://www.fs.fed.us/pnw/fia/publications/fieldmanuals.shtml.

Wasser, S.K. & J.C. Lovett (1993). Introduction to the biogeography and ecology of the rain forests of eastern Africa. In J.C.Lovett & S.K. Wasser (eds.), *Biogeography and Ecology of the Rain Forests of Eastern Africa*, Cambridge University Press, Cambridge. Pp. 3–8.

Wilder, C., T. Brooks & L. Lens (1998). Vegetation structure and composition of the Taita Hills forests. *Journal of East African Natural History* **87**: 1–7.