Comparative Study of Sampling Methods for Efficient Diagnosis of Health Status of Selected Natural Forest Ecosystems in Kenya

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The research is financed by Africa Forest Network (AFORNET)

Abstract

The lack of universally acceptable definition and indicators of forest health has been a major challenge in developing forest health assessment methods. This study evaluated four selected methods (simple systematic sampling (SSS), simple random sampling (SRS), trail-based systematic sampling (TSS) and cluster sampling with annular and nested plots (CSANP)) for their efficiency in assessing forest stocking and structure, disturbances, pathogens and insect pests as health indicators. Surveys were undertaken in 2005 to 2006 to compare and rank the four sampling methods using the total enumeration over one-hectare block as benchmark in both Kakamega and Mt Elgon natural forests, western Kenya. Frequencies of occurrence of each health indicator were used. Absolute errors in % were calculated for each indicator as a measure of accuracy. TSS method ranked the best in accuracy at Mt Elgon and Kakamega in capturing forest anthropogenic disturbances. However, CSANP, SRS and SSS were most accurate in capturing other forest health indicators. More research is still needed to find more refined sampling methods.

Keywords: sampling, forest health, indicators, disturbance

1. Introduction

The concept of forest health is rather relative and thus its assessment often subjective. Different interest groups have different definitions and indicators of forest health (Kumar, 2001; Mutiso, 2009). The scope of assessment also varies in scale and depends on the type of forest ecosystem (Bailey, 2009; Fuller et al. 1998). According to Kumar (2001) forest health assessment is a difficult undertaking and any method used must match a specified definition and specific indicators of forest health, the scale of assessment and the forest ecosystem under evaluation. The earliest methods of forest health assessment include making inference to “past written reports and photographs” to construct disturbance regimes and the “reconstruction techniques” of palobotany and dendrochlonology to determine prehistoric outbreaks (Mutiso, 2009). Conventional forest inventory sampling methods used to assess a wide variety of ecological data such as systematic, stratified and simple random sampling have also been used to collect information useful in evaluating forest health. More recent sampling methods include the Trail-Based Systematic (TBS), Cluster with Annular and Nested Plots (CANP) as well as the use of Geographic Information System (GIS).

Forests in Kenya, particularly natural ecosystems, are mainly protected and preserved for environmental services and conservation of biodiversity. However, they have often been used as a source of hardwood timber thus subjecting them to selective logging. As such, their protection has not been that effective as indicated by human encroachment, uncontrolled utilization of forestland and forest resources leading to deforestation and resource degradation. Other anthropogenic disturbances that have compromised the health of natural forests in Kenya and elsewhere include charcoal production, nature walk trails, illegal logging, fuelwood extraction, fires, grazing among others (Leung & Marion, 2000; Hitimana et al. 2004, Momanyi, 2007; Ouma et al. 2011). These anthropogenic disturbances, in most cases, result in colonization of natural forests by weedy species which subsequently alter the post-disturbance species successional pathways (Frelich & Reich, 1998 & 1999; Mesquita et al. 2001; Dovciak et al. 2005; Mutiso et al. 2011) to the detriment of forest health. Emergence of such invasive species in most of the natural forests in Kenya (Hitimana et al. 2006; Mutiso et al. 2011 and 2013) is of great concern. Though challenges of invasives are common elsewhere (Henderson, 2001; Kuffer, 2006), their extend of invasiveness in some natural forests in Kenya has greatly affected the forest health through modification of regeneration patterns and forest structure.

The current Forest Act of 2005 advocates for better management and conservation of forest resources. However, no much evidence of the current health state of natural forest ecosystems in the country is available due to rare research work. No study has also been designed to evaluate effectiveness and practicability of the many sampling methods for health assessment in any forest type. Yet, reliable methodologies are needed to motivate research in our forests including monitoring changes in forest health over time and generate information package on which to base decision-making by policy makers and resource managers. This comparative study attempted to evaluate efficiency of sampling methods for the diagnosis of health state of Kakamega and Mt Elgon rain forests in western Kenya. Specifically, the study documented identified indicators of forest health based on total enumeration method over a one-hectare forest block in each ecosystem, compared and ranked four selected sampling methods for their accuracy in capturing different kinds of forest health indicators.

2. MATERIALS AND METHODS

2.1 Study Sites

The study was conducted in two ecosystems: Mt Elgon montane forest and Kakamega tropical rain forest, both in western Kenya. The two were selected to represent typical montane and lowland rainforest ecosystems in Kenya. Both forests, like many others in the country, have for a long period been subjected to a wide range of natural and human induced processes such as logging, fuelwood extraction, cultivation, grazing and soil erosion which interfered with their protective and productive functions. Mt Elgon is one of the few remaining natural montane forests in Kenya (Stuart & Adams 1990) and one of the priority conservation areas due to a rich biological diversity (Mutiso, 2009). Similarly, Kakamega forest is the only remaining Gueneo-Congolan tropical rain forest in Kenya and known for its rich biodiversity (Kiama & Kiyiapi, 2001; Kokwaro, 1989; Mutiso, 2009). However, this wealth has been under threat of degradation over decades tree regeneration patterns (Fashing et al. 2003; Fashing 2004), endemic butterflies, snakes as well as the endangered *Colobus guerezas* (Fashing 2004). In both forests, selected timber tree species have been subject of overexploitation since 1920's and include *Croton macrostachys* and *Olea capensis ssp welwitschii* (Connell 1978; Crow 1980; Fashing et al. 2003; Hitimana et al. 2004; Mutiso, 2009). As a result of these disturbances, the two ecosystems have been invaded by invasive weed species; *Solanum mauritianum* (Hitimana et al. 2006, Mutiso, 2009; Mutiso et al. 2011 & 2013) thereby compromising their health status.

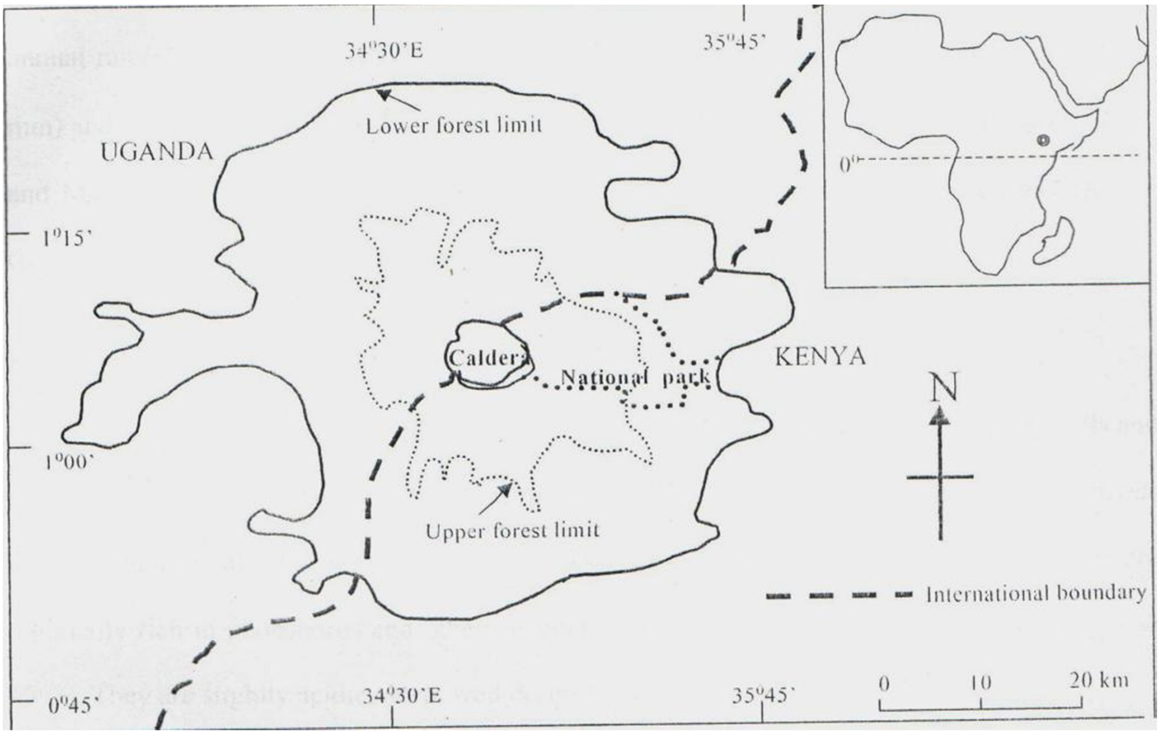

Figure 1a: Mt Elgon montane forest study site

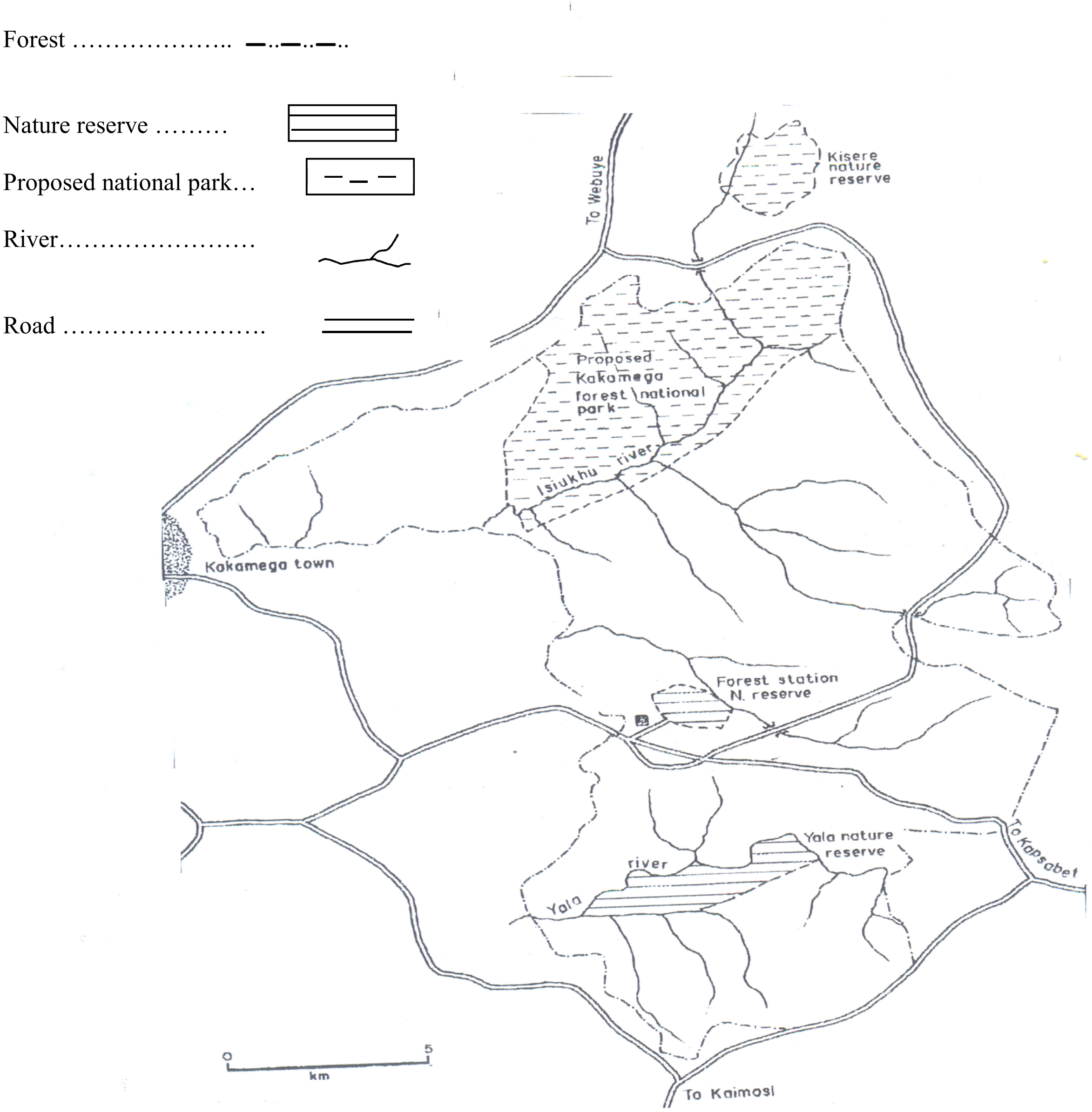

Figure 1b: Kakamega lowland tropical rain forest study site

2.2 Field procedures

In each forest, four forest health assessment methods namely simple systematic, simple random, trail-based systematic and cluster sampling with annular and nested plots were tested against total enumeration. Four indicators of forest health namely tree size distribution (regeneration and mature trees), anthropogenic disturbances, pathogenic and insect pest indicators were used to assess forest health. Two plots of one hectare each were established in each forest and total enumeration carefully done for each type of forest health indicators.

2.2.1 Cluster sampling with annular and nested plots (CSANP)

The core field plot consisted of four annular plots, each 0.01ha (a radius of 17.95m) (Figure 2). Each annular plot contained a subplot of 0.017 ha (a radius of 7.32m). The center subplot was coded subplot 1. Subplots 2, 3 and 4 were located at 36.6 m of horizontal distance from the center of subplot 1 with azimuths of 360°, 120° and 240° respectively, using a Suunto compass and a linear tape. In this method, the word ‘plot’ refers to the entire set of the four annular plots. ‘Plot center’ refers to the center of annular plot 1, which in this study coincided with the center of a one-hectare (100m x 100m) block.

Each subplot contained a microplot of 0.0013 ha (a radius of 2.07 m). The center of the microplot was offset 90^0 and 3.66 m horizontal distance from each subplot center. Microplots were numbered in the same way as subplots and annular plots. Data on forest health indicators were thus collected at three levels: Annular plot level, Subplot level and Microplot level. The sampling intensities were 40%, 6.8% and 0.52% represented by the plot, subplot and microplot respectively.

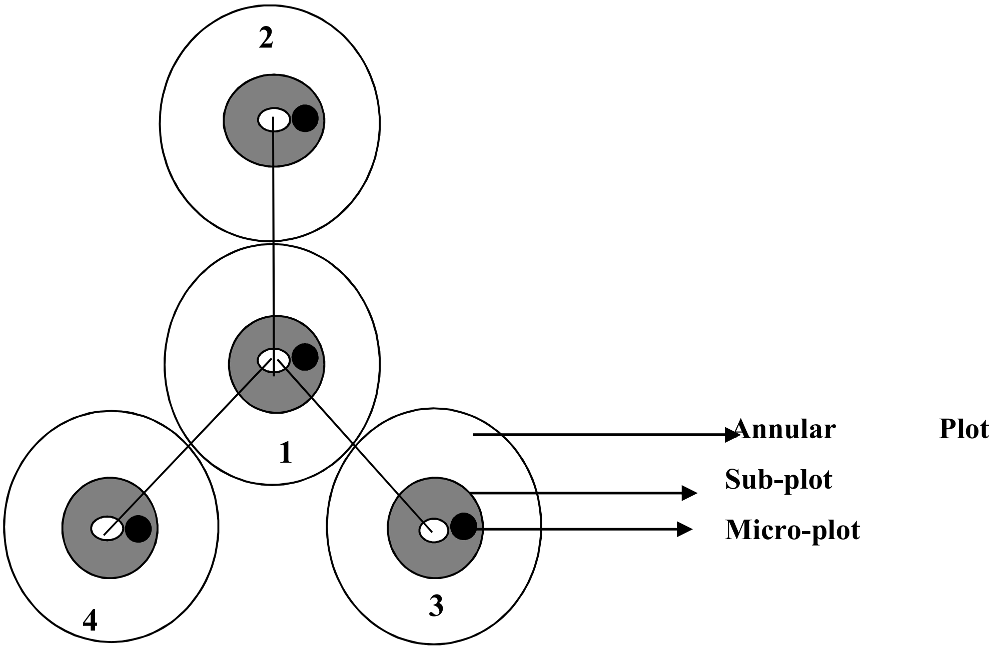

Figure 2: Plot layout for CSANP in Mt Elgon and Kakamega forests 2005-2006.

2.2.2 Simple Systematic Sampling (SSS)

In the 100 m x 100 m block, a cruise line divided it into two parts labeled A and B (Figure 3); the starting point of the line being subjectively chosen. Another cruise line was run across A, dividing it into two equal parts. Along this second cruise line, we established two adjacent 20m x 50m plots (P1 and P2) using sisal string as centerline, a linear tape for distance measurements and three ranging poles for alignment (Figure 3). The same procedure was repeated for part B to create plot P3 and plot P4. The total sample area in the four plots totaled 0.4 ha (equivalent to 40 % sampling intensity). The distance between the two cruise lines in A and B was 50m. Further, 0.1 ha plots were divided into five 10 m x 10 m contiguous subplots. In each subplot, ten 2 m x 10 m contiguous micro-plots were established.

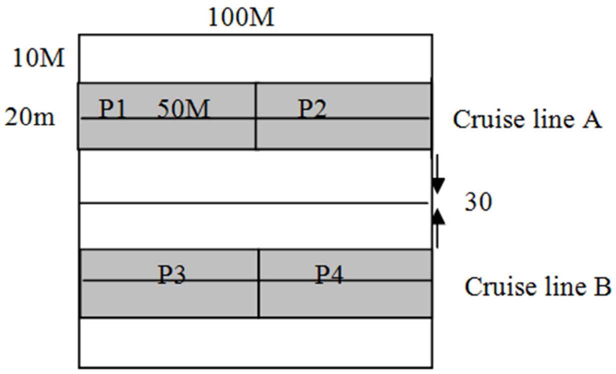

Figure 3: Plot layout for the systematic sampling method in Mt Elgon and Kakamega forests 2005-2006.

A survey was done in the area around the 100m x 100m block to identify a trail at least 100m long that could lead to any of the four corners of the block. The longest trail was over 200m and led to corner A (CA) of the Labaa block at Mt Elgon. From corner A, 10m were measured towards corner B (CB) then 25m were measured towards corner C (CC) (Figure 4). The 25m mark was labeled plot center 1 (PC1). From PC1, a 20m by 50m rectangular plot was established with PC1 as the center. This rectangular plot was labeled P1 with its corners being A, B, C and D (Figure 4). From corner D of P1, 10m were measured towards CB then 25m were measured towards corner CC. The 25m mark was used as the center of plot 2 (P2) and labeled plot center 2 (PC2). From

PC2, a 20m by 50m plot was established. The corners of P2 were labeled in the same way as those of P1. From corner D of P2, 10m were measured towards CD then another 25m towards CB. The 25m mark was used as the center plot (CP3) of plot 3 (P3) and was used to establish a rectangular 20m by 50m plot. From corner B of plot P3, 10m were measured towards CD then 25m were measured towards CBA. The 25m mark was labeled plot center 4 (CP4) of plot 4 (P4). From CP4, a rectangular 20m by 50m plot was formed. The 20 m x 50 m plots were further divided into 10 m x 10 m subplots and 2 m x 10 m microplots as in the systematic sampling above.

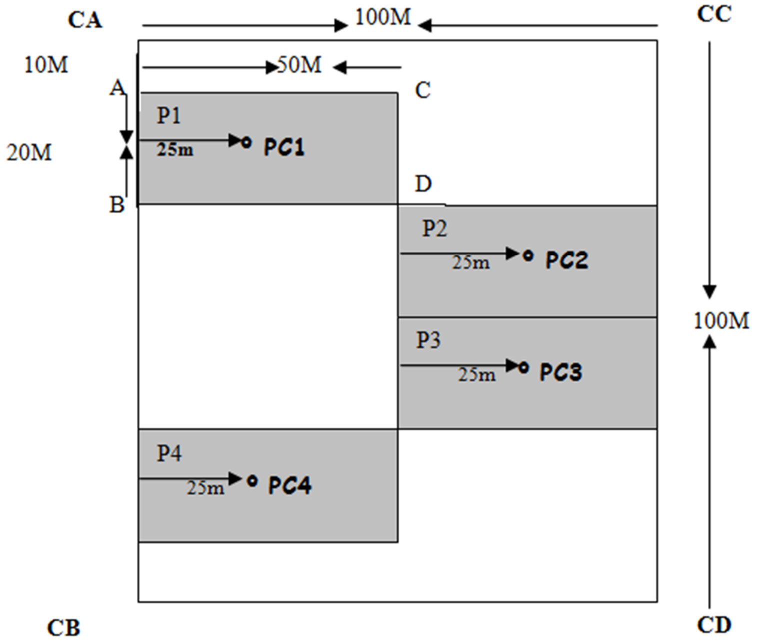

Figure 4: Plot layout for trail-based systematic sampling in Mt Elgon and Kakamega forests 2005-2006.

2.2.4 Simple Random Sampling (SRS)

The 100m x 100m block was subdivided into ten 20m by 50m plots, systematically numbered as indicated (Figure 5). Random numbers were generated and used to select any four plots. Random plots at Mt Elgon were 2, 3, 5 and 8 at Labaa; 3, 6, 8 and 9 at Kapsokisio. In Kakamega, they were 1, 3, 7 and 9 at Isecheno after the glade; 2, 4, 7 and 8 at Isecheno before the glade. The random plots were subdivided into subplots and microplots using same procedure as in the systematic sampling method.

P1	**P2**
P3	**P4**
P5	**P6**
P7	**P8**
P9	**P10**

Figure 5: Plot layout for simple random sampling in Mt Elgon and Kakamega forests 2005-2006.

3. Data analysis

The extent to which the four methods captured the identified indicators of forest health was evaluated by comparing them with total enumeration. Absolute error in percentage were calculated for each indicator and sampling method as a measure of accuracy taking results of total enumeration as a benchmark. Absolute frequencies were subjected to pair-wise comparisons among sampling methods and total enumeration for diameter size distributions, using paired-t test ($p = 0.05$). The error percentage values for different forest health indicators were subjected to two and one-way Analyses of Variance for significant differences among methods after arcsin transformation (Zar, 1984). Simple correlation analysis examined covariance in occurrences between indicators of anthropogenic disturbance and indicators of insect pests or pathogens. SPSS version 16 software was used.

4. RESULTS

4.1 Sampling for indicators of anthropogenic disturbance

In both Kakamega and Mt Elgon forests, trail-based systematic sampling captured the highest number of anthropogenic disturbance indicators followed by cluster sampling with annular and nested plots, simple random sampling and lastly systematic sampling. Trail-based systematic sampling had the lowest absolute error percentage (11, -29) in Mt Elgon and Kakamega respectively, followed by cluster sampling (42, 24) then systematic sampling (56, 33) and lastly simple random sampling (47, 48). The extent at which the four methods captured the disturbance indicators was statistically different ($p < 0.05$), with trail-based systematic sampling method capturing the highest indicators of anthropogenic disturbance. Under this method, a strong positive correlation ($n = 5$, $r_s = 0.85$, $p < 0.05$) was found between indicators of anthropogenic disturbance and the stocking of *Solanum mauritianum* forest weed in Mt Elgon forest.

4.2 Sampling for stocking levels

All the sampling methods tested captured overall diameter size distribution in similar manner as total enumeration with slight but non-significant variations ($p > 0.05$; Paired-t tests, $n = 5$). All methods, including total enumeration also revealed exceptionally higher number of individuals in the lower diameter classes in Mt Elgon forest than in Kakamega forest but other size categories were represented in the same manner for both forests (Figures 6a & 6b). In Kakamega, only TSS tended to constantly underestimate stocking levels of trees below 50 cm dbh (Figures 6a & 6b), but observed differences were not statistically significant ($p <0.05$). Except SRS, other three sampling methods overestimated stocking above 50 cm dbh with the smallest error (Table 1). The TSS was best for two diameter classes 5-10 and 20-50 cm. The SSS was best for sampling class 3-5 cm dbh, while CSANP was best for 10-20 cm dbh. Overall, SRS and CSANP were most accurate (lowest average % error).

Table 1: Absolute frequencies and error (%) of diameter classes captured by the four methods and total enumeration in sampled sections of Mt Elgon and Kakamega forests in 2005/2006

M	S	**3.0 – 5.0**		**5.0 – 10.0**		**10.0 – 20.0**		**20.0 – 50.0**		**>50**	
		F	E (%)	F	E (%)	F	E (%)	F	E (%)	F	E (%)
A	MT	870	-4	**260**	5.8	**187.5**	0.8	**82.5**	7.3	50	-8.7
	KA	361.3	-0.08	217.5	0.9	153.8	5.1	102.5	6.4	55	-0.9
B	MT	812.5	2.9	263.8	4.4	187.5	0.8	87.5	1.7	53.8	-17
	KA	356.3	1.3	231.3	-5.4	152.5	5.9	97.5	11	58.8	-7.9
C	MT	942.5	-12.6	253.8	8	182.5	3.4	86.3	3	40	13
	KA	342.5	5.1	218.8	0.3	152.5	5.9	106.3	2.9	55	-0.9
D	MT	901.3	-7.7	305	-10.5	187.5	0.8	82.5	7	48.8	-6.1
	KA	375	-3.9	235	-7.1	166.3	-2.7	103.8	5.2	55	-0.9
T.E	MT	837		**276**		**189**		**89**		46	
	KA	361		**219.5**		162		**109.5**		54.5	

**M – Methods: A – Systematic, B – Simple random, C – Trail-based systematic, D – Cluster sampling with annular and nested plots (CSAN), T.E. = Total enumeration*
S – Sites: MT – Mt Elgon, KA – Kakamega
*Error % = (TE- Sample value)*100. Negative values = overestimates; Positive values = underestimates*

At Mt Elgon, for trees above 10 cm dbh, all sampling methods tend to give similar results on stocking (Figure 6b). Differences among methods emerged for trees below 10 cm dbh, with CASNP constantly overestimating the stocking levels in this size category. The SSS and SRS were on average the most accurate with slight under- and over-estimation, respectively. SRS was particularly for trees 3-10 cm and 20-50 cm dbh. CSANP was the most accurate for trees over 50 cm dbh. Except TSS, other three sampling methods overestimated stocking in class 10-20 cm dbh (Table 1). On average, SRS and CSANP were the most accurate in Mt Elgon with underestimates of 1% and overestimates of 1.9 %, respectively.

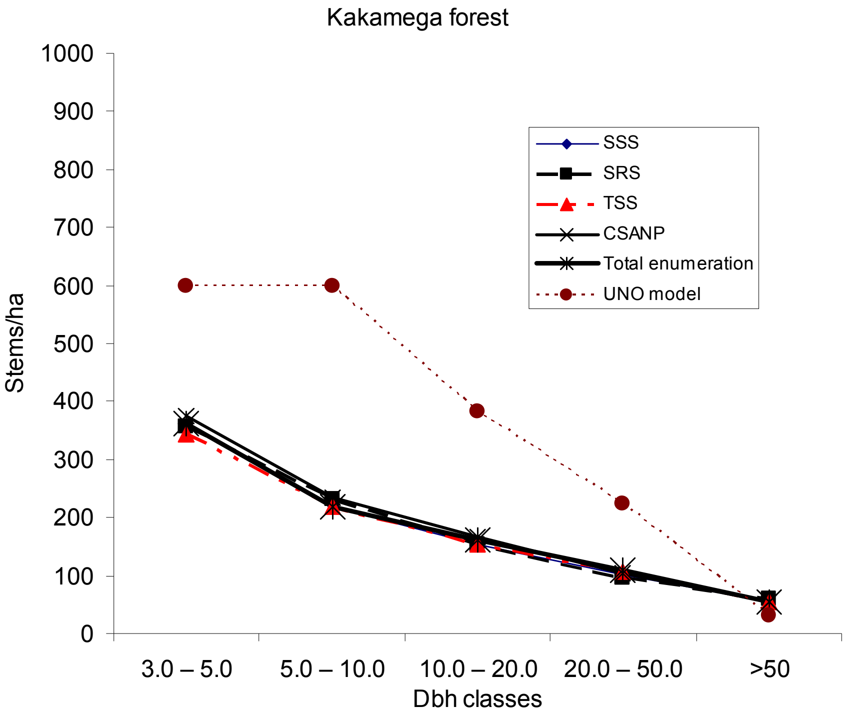

Figure 6a: Efficiency of the Diameter class distribution recorded by four methods in Kakamega forest as compared with the UNO (1994) model for structurally stable East Africa natural forest.

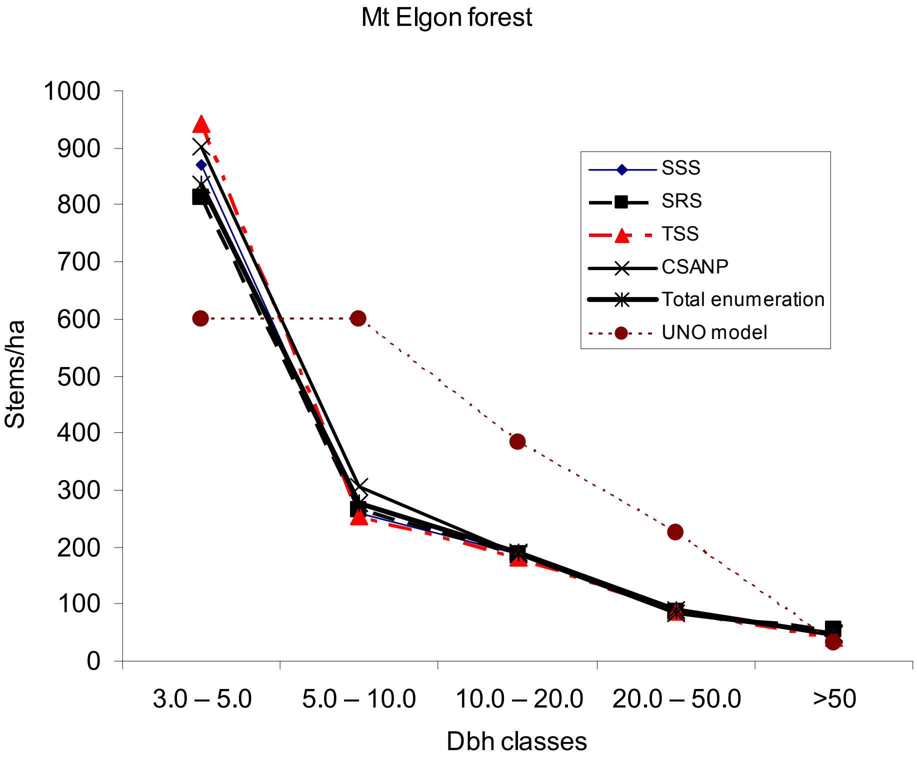

Figure 6b: Efficiency of the Diameter class distribution recorded by four methods in Mt Elgon forests as compared with the UNO (1994) model for structurally stable East Africa natural forest.2.2.3 Trail-based systematic sampling (TSS)

Apart from both extreme ends of tree size categories in Mt Elgon and one extreme end in Kakamega forests where stocking levels were higher than the provisions of the UNO model (1994), all sampling methods as well as total enumeration showed that both Kakamega and Mt Elgon forests had lower stocking levels than expected (Figures 6a & 6b).

3.3 Sampling for presence of pathogenic indicators

The accuracy superiority among the sampling methods based on the recorded error % (Table 2) is as follows for Mt Elgon forest: CSANP (16% error) > TSS (25 % error) > SRS (30 % error) > SSS (33 % error) and for Kakamega forest: CSANP (17 % error) > TSS (28 % error) < SSS (30 % error) > SRS (33 % error).

Table 2: Absolute frequencies and errors (%) of pathogenic categories captured by the four methods and total enumeration in sampled sections of Mt Elgon and Kakamega forests in 2005/2006

		Pathogenic indicators categorization															
		Necrotic		Hyperplastic		Hypoplastic		Disease products		Reproductive structures		Vegetative structures		Others			
M	S	F	E (%)	F	E (%)	F	E (%)	F	E (%)	F	E (%)	F	E (%)	F	E (%)	T.I	E (%)
TE	MT	344		73		27		131		296.5		14		10		895.5	
	KA	433		61.5		21		129.5		158		44		14		861	
A	MT	245	29	42.5	42	17.5	35	68.8	47	206.3	30	10	29	6.3	37	596.4	33
	KA	300	13	46.3	25	11.3	46	80	38	121.3	23	32.5	26	10	29	601.4	30
B	MT	267.5	22	46.3	37	21.3	21	100	24	242.5	18	8.8	37	8.8	12	695.2	33
	KA	320	4	55	11	16.3	22	72.5	44	111.3	30	32.5	26	12.5	11	620.1	28
C	MT	251.3	27	53.8	26	17.5	39	92.5	29	232.5	22	10	29	7.5	25	665.1	25
	KA	313.8	28	45	27	13.8	34	86.3	33	113.8	28	35	20	8.8	37	616.5	28
D	MT	298.8	13	51.3	30	25	7	105	20	248.8	16	8.8	37	6.3	37	744	16
	KA	365	16	48.8	21	16.3	22	100	23	128.8	18	40	9	15	-7	713.9	17

**M – Methods: A – Systematic, B – Simple random, C – Trail-based systematic, D – Cluster sampling with annular and nested plots (CSAN), T.E. = Total enumeration*
S – Sites: MT – Mt Elgon, KA – Kakamega
*Error % = (TE- Sample value)*100. Negative values = overestimates; Positive values = underestimates*

The extent to which the four methods captured the pathogenic indicators was statistically different ($p < 0.05$) with cluster sampling recording the highest. A correlation analysis showed a positive correlation among pathogenic indicators in both forests (Pearson; $n = 7$, $r_s = 0.887$, $p = 0.05$).

3.4 Sampling for the presence of insect pest indicators

The occurrence of the individual insect pests was statistically significant ($p < 0.05$) among sampling methods. In Mt Elgon forest, CSANP had the lowest error (0.0 %) followed by TSS and SRS (0.1 % error) and lastly SSS (19 % error). This order of efficiency of methods was the same in capturing aphids which was the most common pest indicator. It was different for beetles whereby CSAN was the best but TSS was ranked the least accurate. In Kakamega, CSANP, TSS and SSS showed same accuracy (0.1 % error) while SRS was the least accurate (0.2 % error) in capturing indicators of insect pests. CSANP showed the weakest correlation (Pearson; $n = 13$, $r_s = 0.164$, $p = 0.050$) between indicators of anthropogenic disturbance and indicators of insect pests followed by SRS ($r_s = 0.33$), TSS ($r_s = 0.424$) and SSS ($r_s = 0.552$). Mt Elgon had a high total number of insect pest indicators as recorded in total enumeration and by the four methods than Kakamega. However, spot surveys done on the trees showed that damage from the insect pests was below economic injury level.

5. DISCUSSION

The fact that trails were among the disturbance indicators being assessed could probably have introduced a bias in assessing anthropogenic disturbances; making trail-based systematic sampling capture the highest. However, it is recommended that to capture forest disturbances, assessment using the trails as the baseline is the best approach (UNO, 1994). Trails as a major determinant of disturbance is supported by USDA Forest Service Forest (2000) who found out that a trail leads to a series of other disturbances. Elsewhere, Kokwaro (1989) associated the presence of trails with poaching in Kakamega. He stated that it is hard to assess the extent of poaching of forestry game without a directed effort since traps and snares may be set quietly and are usually placed well off the trails. Fashing et al (2003) found that trails/tracks were the most common current disturbance in Kakamega. Trails were still ranked the most common disturbance in a study in in Kakamega forest (Mutiso, 2009). Similarly, Momanyi (2007) and Mutiso et al (2013) recorded man-made trails as a major disturbance in Kakamega forest.

In different studies, Fashing et al (2003) enumerated trees along existing trails by establishing some plots near the trails while others were away but in the same area. Comparison between the results showed that plots near trails were more disturbed than those far away from existing trails. The exceptionally high number of anthropogenic indicators in Kakamega can be attributed to the extremely high number of man made trails in one site (Isecheno Forest Block, before glade) where ecotourism and ecological research activities are intense. Fashing et al (2003) and Mutiso (2009) found that the trails in Kakamega were 1-2 m wide and were used by monkey researchers, tourists, Forestry Department (now Kenya Forests Service) personnel and occasionally local people traveling through the forest. These findings agree with those obtained in this study though some trails could be as wide as 2.5m.

The ability of CSAN to capture the highest density can be associated mainly to the nature of field plots layout that ensured the entire block was well captured and represented with little or no bias (Figure 3). Establishing field plots using this method was easy since plots 2,3, & 4 were established from one central point (centre of plot 1), thus reducing movement time. The finding is in agreement with USDA Forest Service (2000) and Mutiso (2009) reports that the CSAN method is fast in assessing forest health with minimal bias. Reduced movement by field crew leads to less destruction of seedlings and saplings when setting cruise lines as compared to other methods. Reduced movement and damage such as trampling on seedlings could have increased the chances of the method capturing a higher density of the regeneration as compared with the others. The low density captured by trail-based systematic sampling can be associated with forest disturbances, which tend to increase proportionally with trails. Disturbance indicators such as trails, grazing, grass cutting, fires among others adversely affect regeneration especially seedlings and saplings. Others such as tree cutting, pitsawing, charcoal burning among others affected greatly the number of mature trees. Leung & Marion (1999, 2000), Ouma et al (2011) and Mutiso et al (2013) associated trails to other negative forest impacts such as vegetation trampling, soil erosion, uncoordinated camp sites, pollution and illegal forest activities, trail wetness or muddiness, creation of parallel secondary treads and informal side trails, vegetation cover composition change, soil compaction and trail widening.

The high density of trees in the lower diameter class in Mt Elgon can be associated to the invasion by *Solanum mauritianum* whose individuals were mostly in the seedlings and saplings stages. The presence of *S. mauritianum* in Mt Elgon also made trail-based systematic sampling capture a higher density in the lower diameter classes because *S. mauritianum* is an efficient gap colonizer (Olckers , 1999, Withers et al. 2002; Hitimana et al. 2006, Mutiso et al. 2011) and forest openings associated with trails provide optimum conditions for its regeneration and growth. Spot surveys showed that regeneration of *S. mauritianum* was extremely high along trails, roads and in gaps left after tree fall. Different diameter size structure was observed in Kakamega plots where *S. mauritianum* invasion was low. There is a better balance between regeneration stocking and other tree size categories in plots less infested by the *Solanum* weed than in other plots. The stable regeneration in Kakamega forest was also recorded by Fashing et al (2003) and Mutiso et al (2013) and described it as an indicator of forest sustainability and maturing towards the climax stage, usually characterized by mixed rather than mono-dominant species composition. Should the *S. mauritianum* spotted in one site of Kakamega forest be unleashed from its natural control, this area may in future be subjected to heavy invasion by the weed due to the high intensity of trails/tracks. Among all sampling methods in Kakamega, CSAN and SRS are potentially the most accurate in capturing forest structure mainly due to the plots layout that ensures that all parts of the block are assessed without any bias.

The low number of pathogenic indicators captured by TSS in Mt Elgon is mainly due to the exceptionally high density in the lower diameter classes as a result of high intensity of *S. mauritianum*. Since *Solanum* is an alien species in the ecosystem (Hitimana, 2000), it is likely that its pathogens may be completely absent or at low levels thus reducing the overall pathogenic indicators captured by this method. Absence or low populations of its pathogens probably account for its invasiveness due to lack of natural control (USDA Forest Service, 1995; Holling & Maffe 1996). The fact that most of the *S. mauritianum* stems in Mt Elgon were at the seedlings and sapling stages may also have contributed to the lower number of total pathogenic indicators since most of the pathogenic indicators are clearly evident mostly on mature trees. Lack of forest diversity in terms of species also affects the faunal diversity (Schleuning et al. 2011) and consequently the number and diversity of pathogenic indicators in an ecosystem (FSC, 1999; Lorean & Hector, 2001). As a result, high relative density of *S. mauritianum* and low relative density of other native species might have reduced the diversity of pathogenic indicators captured by the trail-based systematic sampling in Mt Elgon. Mutiso et al (2011) document cases of low diversity due to post-disturbance recovery processes characterized by individualistic successional pathways.

The CSANP method was initially developed to assess forest health (USDA Forest Service, 2000). In this study, it captured the highest number of insect pest indicators. The high insect pest indicators captured in Mt Elgon compared to Kakamega forests may be greatly attributed to differences in the past forest disturbances. Hitimana (2000) and Hitimana et al (2004) recorded that Mt Elgon was disturbed by selective logging in 1990s while Kiama & Kiyiapi (2001) and Mutiso (2009) recorded that Kakamega forest was disturbed by selective logging between 1850-1940. According to Fashing et al (2003) and Mutiso et al (2011 and 2013), Kakamega forest is on its way to full recovery while the fate of Mt. Elgon remains unkown. Kumar (2001) and Mutiso (2009) showed that insect pests easily infect a forest already subjected to other forms of forest disturbances. Both insect pests and pathogens act as stressor agents and an increase in one will lead to increase in the other (Kumar, 2001). The two commonly encountered insect pests (aphids and beetles) are mostly native in most tropical natural forests (Speight & Wylie, 2001). Just like the pathogens, these insects mostly remain below economic injury level since they have co-evolved with their hosts over a longer period of time and have attained equilibrium where they cease to become "pests" and instead assume a positive ecological role in the ecosystem (USDA Forest Service 1995, 1996).

6. CONCLUSION

There was no significant differences among sampling methods and between them and total enumeration in capturing overall tree stocking levels above 3 cm dbh (post-regeneration stages) both in Mt Elgon and Kakamega forests ($p > 0.05$). However, trail-based systematic sampling (TSS) tended to be the best in assessing forest anthropogenic disturbances in Mt Elgon and Kakamega forests. Overall, cluster sampling with annular and nested plots (CSANP) captured the highest number of all stems, pathogenic indicators, and insect pest indicators in both forests. In terms of forest structure, all the methods deviated from UNO 1994 model for structurally stable East African natural forests though CSANP showed the least deviation. No single sampling method among the four can be recommended for all indicators of forest health at once and each forest is unique in terms of the requirements for sampling methods. More research is needed in this area. So far, CSANP offers the best opportunity to assess regeneration, pathogenic and insect pest indicators as well as upper class diameter distribution. Trail-based systematic sampling (TSS) captured best anthropogenic indicators while lower diameter class distribution can appropriately be assessed using simple systematic sampling (SSS). In Mt Elgon where infestation by *Solanum mauritianum* was so heavy, the number of pathogenic indicators recorded dropped drastically compared with the lightly-invaded areas of Kakamega forest. There is need to establish the link between this low pathogenic and insect pest infestation with the increase in the density of invasive species; *S. mauritianum*. An increase in pathogenic indicators led to an increase in insect pest indicators and vice versa. There is need to research on the influence of forest disturbance on the increase of pathogenic and insect pest indicators.

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