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Assessment of threat status and management effectiveness in Kakamega Forest, Kenya

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Abstract. To counteract an increasing biodiversity decline, parks and protected areas have been established worldwide. However, many parks lack adequate management to address environmental degradation. To improve management strategies simple tools are needed for an assessment of human impact and management effectiveness of protected areas. This study quantifies the current threats in the heavily fragmented and degraded tropical rainforest of Kakamega, western Kenya. We recorded seven disturbance parameters at 22 sites in differently managed and protected areas of Kakamega Forest. Our data indicate a high level of human impact throughout the forest with illegal logging being most widespread. Furthermore, logging levels appear to reflect management history and effectiveness. From 1933 to 1986, Kakamega Forest was under management by the Forest Department and the number of trees logged more than 20 years ago was equally high at all sites. Since 1986, management of Kakamega Forest has been under two different organizations, i.e. Forest Department and Kenya Wildlife Service. The number of trees logged illegally in the last 20 years was significantly lower at sites managed by the Kenya Wildlife Service. Finally, logging was lower within highly protected National and Nature Reserves as compared to high logging within the less protected Forest Reserves. Reflecting management effectiveness as well as protection status in Kakamega Forest, logging might therefore provide a valuable quantitative indicator for human disturbance and thus an important tool for conservation managers. Logging might be a valuable indicator for other protected areas, too, however, other human impact such as e.g. hunting might also prove to be a potential indicator.

Introduction

Recent decades have seen a serious biodiversity decline due to habitat loss and alteration especially of tropical forests leading to a profound species-extinction crisis (Heywood 1995; Pimm et al. 1995; Whitmore 1997). Thus, much of tropical biodiversity is unlikely to survive without effective protection (Pimm et al. 1995; Myers et al. 2000). To counteract the anthropogenic impact and conserve biodiversity and ecosystem processes parks and protected areas have been established worldwide. Some studies demonstrate that parks can indeed provide basic safeguard against land-clearing in the context of high land-use pressure (Brunner et al. 2001). However, more often parks appear to lack adequate management to address a host of threats within their borders (Brunner et al. 2001; Putz et al. 2001; Ervin 2003a, b). Protected areas face increasing levels of environmental degradation with more than 70% of 201 parks surveyed across 16 tropical countries being affected by poaching, encroachment and logging (van Schaik et al. 1997). Consequently, the improvement of management strategies of protected areas is of top priority for conservation practitioners.

To improve and optimise management strategies methods to assess the threat status of protected areas and to measure management effectiveness of conservation efforts have become a major environmental concern (Margoluis and Salafsky 1998; Salafsky and Margoluis 1999; Hockings et al. 2000; Salafsky et al. 2002; Ervin 2003c; Hockings 2003). These assessments are an essential component of systematic conservation planning (Margules and Pressey 2000); they can enable conservation managers and policymakers to identify management strengths and weaknesses, reveal severity and distribution of levels of human impact, respond to pervasive management problems, refine their conservation strategies and reallocate budget expenditures (Brunner et al. 2001; Ervin 2003 a, c; Parrish et al. 2003). Therefore, the development of simple tools to monitor and assess whether conservation succeeds for protected areas are of great importance and require indicators that are measurable, scientifically sound, and comparable among protected areas over time, but also practical and cost-effective (Margoluis and Salafsky 1998).

Traditionally, biological indicators have been used to assess the level of human impact in protected areas and measure management success. Ideally, they are supposed to serve as indicators for changes in the overall biodiversity of a site (Noss 1990; Sparrow et al. 1994). However, relationships between potential indicator species and total biodiversity as well as critical ecosystem processes are not that well established (Lindenmayer et al. 2000). Few of these methods using biologically based indicators are practical and cost-efficient, especially for use in the developing countries as they require substantial effort and resources beyond day-to-day project activities (Salafsky and Margoluis 1999). Finally, their results are often difficult to interprete for non-specialists and generally require the presence of baseline data against which to compare changes (Salafsky and Margoluis 1999).

Another approach to assess human impact in protected areas and to assess management effectiveness is to identify and monitor threats directly as a proxy measurement of conservation success such as e.g. implemented in the *Threat Reduction Assessment* (TRA) (Salafsky and Margoluis 1999) and the *Rapid assessment and Prioritization of Protected Area Management* (RAPPAM) program recently established by WWF's Forest for Life program (Ervin 2003c). This approach of directly identifying threats is sensitive to changes over short time periods and throughout a site, comparisons among projects and sites are possible, data can be collected through simple techniques and the method is practical and cost-effective. Furthermore, the results can be readily interpreted by conservation staff and can provide detailed, adaptive management guidance to protected area managers. The primary tool for RAPPAM is the rapid assessment questionnaire which covers management planning, input and processes, and the identification of future threats and past pressures (Ervin 2003c). However, quantitative and objective approaches are still urgently required for the assessment of threat status and management effectiveness of protected areas to provide reliable, scientifically sound data.

In this paper we present results from a survey quantifying human impact and evaluating management effectiveness in Kakamega Forest, western Kenya. Kakamega Forest is one of the last remaining indigenous forests of Kenya situated in an agricultural area with a high human density of more than 175 individuals per km^2 (Tsingalia 1988). Like many other countries Kenya harbours an on-going conflict between forest conservation and land use needs of its increasing population (Tsingalia 1988; Wass 1995). This has put a long-term pressure on Kakamega Forest leading to its severe reduction and fragmentation in the last century. Additionally, it has suffered increasing degradation through both, extensive commercial and local exploitation of timber (Tsingalia 1988; Fashing et al. 2004; Mitchell, 2004). Large-scale commercial logging was reduced in the last decades, mostly through official presidential decree banning all indigenous tree species exploitation in the forest in the early 1980s (Tsingalia 1988; Mitchell, 2004), the transfer of the northern part of the forest under the rigorous authority of the Kenya Wildlife Service (KWS), the establishment of forest stations and ranger patrols, and through tourism and long-term research (e.g. Zimmerman 1972; Cords 1987; Mutangah 1996; Fashing et al. 2004). However, illegal activities including logging, fuel-wood collection and extraction of bark for medicinal purposes occur to this day and appear to be heterogeneously throughout the forest with some sites providing more protection than others (Kiama and Kiyiapi 2001; Fashing et al. 2004; Fashing, in press). Our study presents a quantitative assessment of the current threats in the main forest block of Kakamega Forest and its fragments comprising areas of different management regimes and different protection priorities. In order to evaluate effectiveness of conservation measures we asked how differently managed and protected areas differ in their level of human impact. With this assessment we aim to provide a quantitative, simple site-level monitoring tool and a first guidance to management planners and decision makers on problems related to human impact and management in Kakamega Forest.

Kakamega Forest and its forest history

Study site

We conducted the study at Kakamega Forest (between latitudes 00°08′30.5″ N (41,236 in UTM 36 N) and 00°22′12.5″ N (15,984) and longitudes 34°46′08.0″ E (696,777) and 34°57′26.5″ E (717,761), G. Schaab, personal communication), western Kenya, at an altitude of 1500–1700 m (Figure 1). Kakamega Forest is a mid-altitudinal tropical rainforest and considered to be the eastern most remnant of the lowland Congo Basin rainforests of Central Africa (Kokwaro

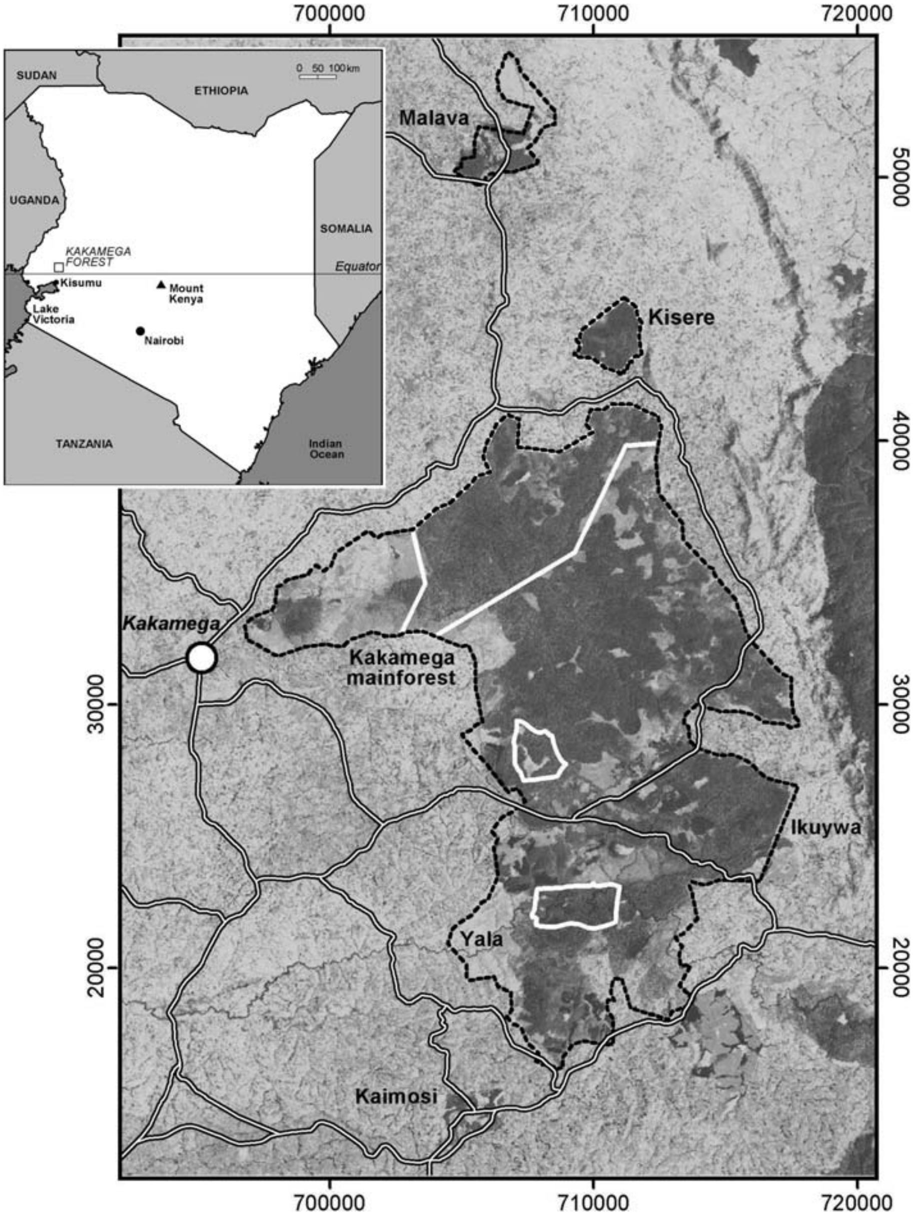

Figure 1. Satellite image (channel 5 of Landsat 7 ETM + , 05 Feb 2001) of Kakamega main forest and its five fragments in western Kenya with official forest boundaries as gazetted in 1933 (dashed line) and official boundaries of National and Nature Reserves (white line). Coordinates in UTM 36 N.

1988). Annual rainfall in Kakamega Forest is approximately 2007 mm (as averaged from FD records at Isecheno Forest Station from 1982 to 2001) and highly seasonal with a rainy season from April to November and a short dry season from December to March. The average monthly maximum temperature ranges from 18 to 29 °C while the average monthly minimum ranges from 4 to 21 °C (Muriuki and Tsingalia 1990).

Management history

Kakamega Forest was first gazetted as Trust Forest under proclamation No. 14 in 1933 and has since been managed by the FD; in 1964 it was declared to be a Central Forest (Blackett 1994). Three small Nature Reserves, Isecheno, Kisere and Yala, were established and gazetted within the Forest Reserve in 1967 (Blackett 1994). In 1986, the northern part of Kakamega Forest called Buyangu together with the adjacent Kisere Forest was gazetted as Kakamega National Reserve and fell under management of the KWS. Today, Kakamega Forest is part Forest Reserve, part Nature Reserve and part National Reserve, and management is under the authority of both, FD and KWS, on behalf of the state.

Fragmentation and disturbance history

Kakamega Forest is a highly fragmented and disturbed forest and has been continually exploited for many years due to the high surrounding population pressure (Kokwaro 1988; Wass 1995). The main forest block gazetted in 1933 by the FD to control human activities covered 23,777 ha (Kokwaro 1988, for original forest boundaries see Figure 1). The FD aimed mostly at provision of timber for local communities and commercial demand. Clear-felling of indigenous forest to make way for fast-growing exotic tree and softwood plantations was extensive under colonial forest service. Especially the southern parts of Kakamega were exploited until the late 1980s (Bennun and Njoroge 1999; Mitchell, 2004). Clearance for settlement and tea plantations slowed over the 1980s as forest protection was better enforced, but more areas were cleared south of the Yala river (Brooks et al. 1999). Furthermore, selective logging was intense in the past and the general trend of timber extraction showed a continued rise from 1933 to 1981 (Tsingalia 1988; Mutangah 1996). Consequently, the main agents of forest degradation have been mostly logging and extraction of commercially valuable timber, followed by charcoal burning, cattle grazing, shamba system farming, hunting for bush-meat, tree debarking and removal of dead trees for firewood (Oyugi 1996; Mitchell, 2004). In the early 1980s a presidential decree banned all indigenous tree species exploitation, leading to a halt of commercial logging, however, tree poaching and other illegal activities still exist.

Table 1. List of 22 disturbance survey sites in Kakamega Forest.

Site No.	Site name	Main forest/ fragment[a]	Area (ha)[b]	Transect length (m)	Area surveyed (ha)	Management regime[c]	Protection status[d]
1	Malava	f	77	1200	2.4	fd	fr
2	Kisere	f	420	2600	5.2	kws	nr
3	Colobus	mf	8245	2400	4.8	kws	nr
4	Buyangu	mf	8245	1600	3.2	kws	nr
5	Shikusa	mf	8245	1000	2.0	kws	nr
6	Salazar I	mf	8245	1000	2.0	kws	nr
7	Salazar II	mf	8245	2000	4.0	kws	nr
8	Shamiloli	mf	8245	1000	2.0	fd	fr
9	Central II	mf	8245	1000	2.0	fd	fr
10	Central I	mf	8245	1000	2.0	fd	fr
11	Chemneko	mf	8245	1000	2.0	fd	fr
12	Vihiga	mf	8245	1000	2.0	fd	fr
13	Sawmill	mf	8245	1000	2.0	fd	fr
14	Isecheno II	mf	8245	1000	2.0	fd	nr
15	Isecheno I	mf	8245	1600	3.2	fd	nr
16	Chepsugor	f	1370	1000	2.0	fd	fr
17	Ikuywa I	f	1370	1000	2.0	fd	fr
18	Ikuywa II	f	1370	1600	3.2	fd	fr
19	Yala	f	1178	2000	4.0	fd	nr
20	Kibiri	f	1178	1000	2.0	fd	nr
21	Ishiru	f	1178	1000	2.0	fd	fr
22	Kaimosi	f	65	280	0.6	fd	fr

[a]*Abbreviationss*: f, fragment; mf, main forest block.
[b]Area sizes obtained from satellite image 05 Feb 2001 Landsat 7 ETM+.
[c]*Abbreviations*: fd, Forest Department; kws, Kenya Wildlife Service.
[d]*Abbreviations*: fr, Forest Reserve; nr, National or Nature Reserve.

As a consequence of the long fragmentation and disturbance history Kakamega Forest was reduced and broken up in several fragments over the last century and today the main forest block covers only 8245 ha (G. Schaab, personal communication; for fragment sizes see Table 1) comprising a heterogenous mixture of different succession stages including disturbed primary forest, secondary forest, clearings and glades, as well as tea and timber plantations (Bennun and Njoroge 1999). For more detailed information on the fragmentation and disturbance history of Kakamega Forest see Tsingalia (1988) and Mitchell (2004).

Methods

Disturbance survey

In February and April 2002 and in June and July 2003, disturbance surveys were carried out at 22 forested sites in Kakamega main forest and its peripheral fragments (for a complete list of all sites see Table 1). Twelve of the 22 sites

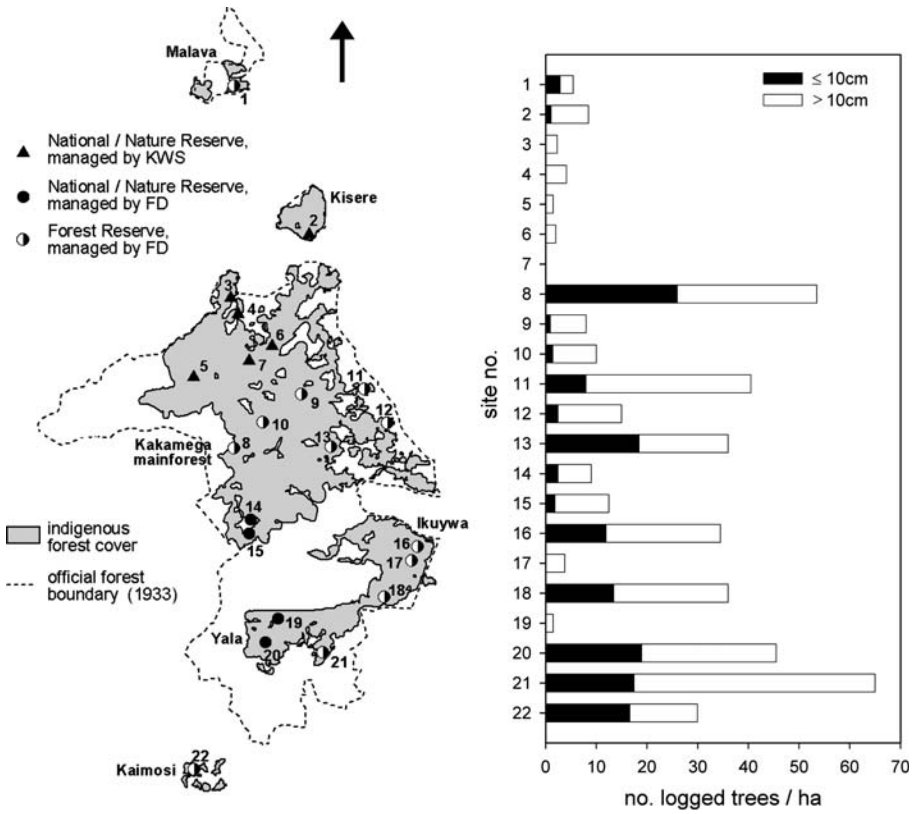

Figure 2. Location of 22 disturbance survey sites in Kakamega Forest (left) and the number of trees logged per hectare in the last 20 years for both, trees ≤10 cm in diameter and >10 cm in diameter for each site, respectively (right).

chosen for surveys were close to the 12 sites where Mutangah (1996) carried out his disturbance surveys in 1992/1994 (see Table 1); an additional 10 new sites where chosen where Mutangah (1996) had not carried out any surveys in the past (e.g. in the fragments Kisere, Malava and Kaimosi). This was done in order to obtain a large sample size of representative sites distributed over the whole Kakamega Forest. The sites chosen were not necessarily near points of easy access (Figure 2); in fact, many of the sites are located in the centre of the forest (e.g. No. 5, 9, 10). With many trails running through the whole of Kakamega Forest, it is easily accessible for local exploitation. At each site except for the smallest fragment (Kaimosi), transects were run at least 1000 m in length (Table 1). Transects sometimes followed existing trails, e.g. at Colobus site we chose some of the former overgrown monkey research transects established by Gathua in 1996 (Fashing and Gathua, in press). In all other cases where trails did not exist, we made our way through undergrowth along a line. Surveys included recording any of seven disturbance parameters in a belt of 10 m on each side of the transect thereby covering a total area of 56.6 ha with a median of 2 ha per site (range 0.6–5.2). All disturbances recorded are thought to present mostly illegal activities.

Disturbance parameters recorded were

1. the number of trees logged: For each tree stump the circumference was measured to calculate its diameter. Trees with a diameter of less than 10 cm were assumed to be collected mostly by women and used as firewood, whereas trees with a diameter of more than 10 cm were assumed to be cut mostly by men and used as polewood or timber. For each stump the approximate time since cutting was estimated to be either less than 20 years or more than 20 years for a distinction between recent and past logging, respectively. Age was estimated according to the degree of decomposition and the shape of the remaining tree stump, i.e. stumps with smooth surfaces or freshly cut stumps with clear cutting profiles were estimated to be logged in the last 20 years, whereas stumps with wavy or semi-decayed cut surfaces were estimated to be logged more than 20 years ago (following Mutangah 1996). Tree species were identified when possible; however, for trees having been logged more than 20 years ago, species identification was not always possible due to a higher level of decomposition.
2. the number of trees exhibiting any signs of debarking for medicinal use.
3. the number of charcoal kilns, i.e. areas with charcoal remains such as black half-burned pieces of wood and in some cases still burning charcoal heaps.
4. the number of sawing pits, i.e. pits used for cutting large trees.
5. the number of honey gathering sites, i.e. tree stems with bee-hives from which honey had been extracted.
6. the number of abandoned and current paths used by locals e.g. for firewood collection.
7. the number of cattle tracks used to bring cattle to the glades for grazing.

Data analysis

We tested the influence of management regime and protection status on the disturbance parameters 1–7 for all 22 sites. For disturbance parameter 1, we tested the influence separately on the number of logged trees of two different age classes (trees logged in the last 20 years, trees logged more than 20 years ago) and two different size classes (diameter $\leq$ 10 cm, diameter $>$10 cm). For management regime we distinguished between sites being managed by the KWS (n = 6) and the FD (n = 16) (Table 1). For protection status we distinguished between sites with high protection priority i.e. National or Nature Reserves (n = 10) and sites with low protection priority i.e. Forest Reserves (n = 12) (Table 1). Consequently, 6 National/Nature Reserves are managed by the KWS and 4 National/Nature Reserves and 12 Forest Reserves by the FD. Furthermore, we tested the influence of fragmentation on the number of logged trees for both, the two different age and size classes. We calculated *t*-tests (*t*) for normally distributed data with an adjustment in case variances were unequal and Mann–Whitney *U*-tests (*U*) for non-normally distributed data. We correlated the different disturbance parameters calculating non-parametric pairwise Spearman correlations.

We compared our data from 12 sites (i.e. site No. 5, 7, 8, 11–13, 15–17, 19–21) with data from Mutangah (1996) who quantified the same disturbance parameters in 1992/1994 at the same 12 sites. Although the sites were the same, transects were not; thus, data are not dependent data. For comparisons of the two data sets we calculated Pearson and Spearman rank correlations for normally and non-normally distributed data, respectively.

Data analysis was carried out using JMP (1995).

Results

Evidence for human impact was found at all our 22 sites with a median number of 21.1 disturbance events per hectare ($q_1 = 9.8$, $q_3 = 44.6$, range 1.8–81.5, $n = 22$). The sites Salazar II (No. 7) situated in the northern Kakamega National Reserve and managed by the KWS as well as Yala (No. 19) situated in the Yala Nature Reserve managed by the FD showed lowest disturbance levels with 2.8 and 4.9 disturbances per hectare, respectively (Table 2). The site Ishiru (No. 21) had highest disturbance levels with 68.5 disturbances per hectare; is situated at the southern forest edge and is managed by the FD.

Management, protection status and logging

Of all seven disturbance parameters, logging of trees was the most widespread at all 22 sites (Table 2), thus providing the most useful indicator of forest disturbance in this study. Over a total survey area of 56.6 ha, we found 1023 logged trees from 68 species. The most frequent tree species logged were *Funtumia africana* (2.1 trees logged per hectare), *Prunus africana* (1.3), *Celtis new species name: Celtis gomphophylla* (1.0), *Trilepisium madagascariensis* (0.9), *Diospyros abyssinica* (0.8) and *Aningeria altissima* (0.7). The average diameter of tree stumps was 27.0 cm ± 9.6 (if not otherwise noted mean ± 1 SD).

Past and present logging

We could not find differences in the number of logged trees for past logging (i.e. more than 20 years ago) between different sites indicating that logging levels in the past might have been similar throughout Kakamega Forest (Figures 3a, b; management regime, *U*: $Z = 0.26$, $p = 0.79$; protection status, *t*: $t = 2.32$, df $= 1$, $p = 0.15$). In contrast, a significant effect of management regime and protection status was found for present logging (i.e. in the last

Table 2. Summary data of disturbance survey for all 22 sites.

Site No.	No. trees logged/ha > 20 years	No. trees logged/ha < 20 years	Total No. trees logged/ha	No. trees with signs of debarking/ha	No. charcoal kilns/ha	No. sawing pits/ha	No. honey gathering sites/ha	No. paths/ha	No. cattle tracks/ha	Total no. trees logged/ha in 1992/1994
1	3.8	5.4	9.2	1.7	0	2.1	0	8.8	0.4	–
2	1.9	8.5	10.4	1.7	0	1.0	0	2.3	0.2	–
3	2.9	2.3	5.2	0	0	0	0	0.2	0	–
4	5.0	4.1	9.1	0	0	0	0	0	0	–
5	1.5	1.5	3.0	0	1.0	0.5	0	1.5	0	14.0
6	3.0	2.0	5.0	0	0	3.0	0	2.0	0	–
7	2.0	0	2.0	0.3	0	0	0	0.5	0	1.0
8	6.0	53.5	59.5	0.5	2.0	1.0	0	1.0	4.5	52.0
9	2.0	8.0	10.0	0	0	2.5	0	7.5	0	–
10	2.0	10.0	12.0	0	0	0	0	1.0	0	–
11	1.5	40.5	42.0	0	4.5	0	0	6.5	0	74.0
12	6.0	15.0	21.0	3.0	2.5	0	0	7.0	0	29.0
13	1.0	36.0	37.0	0	0.5	0	5.0	0	0.5	8.0
14	0	9.0	9.0	1.0	0	0.5	0	2.0	0	–
15	0	12.5	12.5	2.5	0	0.3	0	0	11.3	16.0
16	8.0	34.5	42.5	0.5	0	0	0	6.5	0	83.0
17	0	3.8	3.8	1.3	1.3	0.3	0	5.9	1.9	23.0
18	3.5	33.5	37.0	0	1.0	0	0	0.5	0	–
19	1.3	1.5	2.8	1.3	0	0.8	0	0	0	11.0
20	3.0	45.4	48.9	0	0	0	0	13.0	0	99.0
21	10.5	65.0	75.5	0.5	0.5	0	0	5.0	0	77.0
22	0	30.0	30.0	6.7	0	0	0	0	0	–

For logging, numbers per hectare are given separately for trees logged > 20 years ago, trees logged < 20 years ago and for all trees logged. For a comparison of logging between today and 1992/1994, the total number of trees logged as recorded by Mutangah (1996) are given.

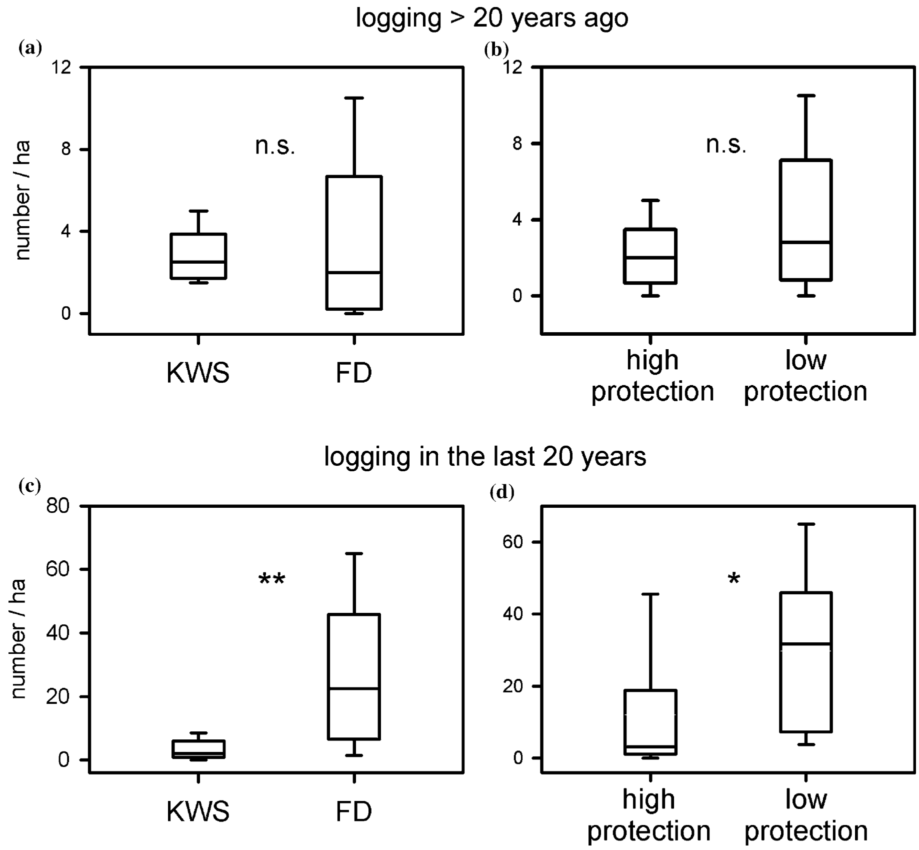

Figure 3. Number of trees logged more than 20 years ago (a, b) and in the last 20 years (c, d) for sites under management by the Kenya Wildlife Service (KWS, $n = 6$) and the Forest Department (FD, $n = 16$) (a, c) and for sites having high protection priority (i.e. situated within National/Nature Reserves, $n = 10$) and low protection priority (i.e. situated within Forest Reserves, $n = 12$) (b, d). Given are medians, quartils, minimum and maximum values and significance levels. n.s., not significant; * $p < 0.05$; ** $p < 0.005$.

20 years) with fewer trees logged at sites managed by the KWS and with high protection priority (Figures 3c, d; management regime, *t*: $t = 19.21$, df $= 1$, $p = 0.0004$; protection status, *U*: $Z = -2.54$, $p = 0.0111$).

Firewood and polewood/timber use in the last 20 years

Traces of firewood collection (tree diameter ≤ 10 cm) were often found at sites managed by the FD but rarely at sites managed by the KWS (Figure 2). The FD-managed sites situated within Nature Reserves (No. 14, 15, 19), in the centre of the forest (No. 9, 10) and in central Ikuywa (No. 17) had the lowest levels of firewood collection (Figure 2). In contrast, sites at the forest edge (No. 8, 11, 12, 16, 18, 20, 21) adjacent to local settlements had the highest logging levels (Figure 2). Tree cutting for polewood/timber (tree diameter > 10 cm) had low levels at KWS sites, but high levels at FD sites (Figure 2). Both, firewood collection and logging for polewood/timber was significantly higher at FD sites as compared to KWS sites (firewood/ha: KWS median = 0, $q_1 = 0$, $q_3 = 0.3$, range 0–1.2, FD median = 5.5, $q_1 = 1.6$, $q_3 = 17.3$, range 0–26.0; U: $Z = -3.04$, $p = 0.0024$; polewood/ha: KWS 2.9 ± 2.6; FD 16.9 ± 12.7; t: $F = 16.54$, df = 1, $p = 0.0007$).

Similarly, significant differences in the number of logged trees for both firewood and polewood/timber, were found between sites of high and low protection priority (firewood/ha: high protection median = 0, $q_1 = 0$, $q_3 = 2.0$, range 0–19.0, low protection median = 10.0, $q_1 = 1.8$, $q_3 = 17.3$, range 0–26.0; U: $Z = -2.55$, $p = 0.011$; polewood/ha: high protection median = 3.2, $q_1 = 1.5$, $q_3 = 8.1$, range 0–26.5, low protection median = 15.4, $q_1 = 7.4$, $q_3 = 26.3$, range 2.5–47.5; U: $Z = -2.61$, $p = 0.0092$).

Fragmentation and logging

No differences were found between the main forest and the fragments for the number of trees logged more than 20 years ago and less than 20 years ago, as well as for the number of trees logged for firewood and for polewood/timber (trees logged > 20 years ago: U: $Z = 0.44$, $p = 0.64$; trees logged < 20 years ago: U: $Z = 0.83$, $p = 0.4037$; firewood/ha: U: $Z = 1.57$, $p = 0.1164$; polewood/ha: U: $Z = 0.03$, $p = 0.97$).

Re-assessment of logging: 1992/1994 and today

No differences for the number of logged trees per hectare were found between our data and those of Mutangah's (1996) survey in 1992/1994. This suggests a similar overall logging level (1992/1994: 40.6 ± 34.4, today: 29.2 ± 25.2; t: $t = 0.92$, df = 22 $p = 0.37$). Furthermore, we found a significant positive correlation between both data sets suggesting that transects at the same sites still have same logging levels after 10 years (Pearson: $r = 0.72$, $p = 0.0088$).

Management, protection status and other human impact

For all other disturbance parameters differences between differently managed and protected sites were only found for the number of charcoal kilns with significantly lower numbers in highly protected sites (high protection: median = 0, $q_1 = 0$, $q_3 = 0$, range 0–1.0, low protection: median = 0.5, $q_1 = 0$, $q_3 = 1.8$, range 0–4.5; U: $Z = -2.26$, $p = 0.024$). However, in contrast to the number of logged trees, all other disturbance parameters were mostly rare events and appear to be indicators only for localized threats (Table 2). Burning of charcoal, e.g., seems to be a serious threat at the eastern (No. 11, 12) and western edge (No. 8) of the main forest block, whereas cattle tracks appear to be a problem mostly at Isecheno I (No. 15) and at the eastern edge of the forest (No. 8) (Table 2). In general, no correlation could be found between the disturbance parameters when calculating non-parametric pairwise Spearman correlations ($p > 0.05$).

Discussion

Status quo of human impact

According to our survey human impact is found everywhere in Kakamega Forest with logging being most widespread. This confirms the expressions of alarm over the misuse and overexploitation of Kakamega's forest resources through illegal human activities (Kowkaro 1988; Emerton 1991; Mutangah et al. 1992; Wass 1995; Oyugi 1996; Fashing et al. 2004). Our data support Mutangah's (1996) survey from 1992/1994 indicating the highest logging levels occur in the most southerly part of the forest as well as along the western edge. Furthermore, some of the disturbed sites (e.g. No. 11, 21) in Mutangah's (1996) survey have been degraded heavily in the meantime and the canopy cover reduced substantially (N. Saijita and C. Analo, personal communication). In both, Mutangah's (1996) and our survey, the lowest logging levels were found in the northern Kakamega National Reserve, central Ikuywa and Yala.

Human impact in differently managed areas

Our data do not only show the current status quo of the human impact on Kakamega Forest, but also reflect its management history in the last 20 years. Before 1986, when all of Kakamega Forest was managed by the FD, Colobus, Buyangu and Salazar sites (No. 3, 4, 6, 7) in the northern part were well known for intensive commercial logging through timber companies (Tsingalia 1988; Mitchell, 2004). Correspondingly, the number of trees logged more than 20 years ago appears to be equally high at those sites as compared to others. In 1986, the KWS took over the northern part of Kakamega Forest as a National Reserve and the changes in management appear to have resulted in changes in logging numbers in the last 20 years. Illegal tree poaching was reduced at sites under KWS management probably due to tightened security, whereas FD sites still experience higher tree poaching rates today. Furthermore, FD sites show various other local threats such as e.g. charcoal burning and cattle grazing. Under FD management, sites with high protection priority such as Yala and Isecheno Nature Reserves (No. 14, 15, 19) still show lower overall threat levels as compared to sites with low protection priority. For example, Fashing et al.'s (2004) results of a long-term study of tree populations in Kakamega Forest indicate that their study plots in Isecheno remained relatively undisturbed over the last 20 years. A decrease of pioneer species density by 21% in these sites are taken as evidence that the forest is maturing towards a climax forest and that at least the conservation measures applied to Isecheno appear to have succeeded Fashing et al. 2004). Nevertheless, prospects for other severly disturbed sites are assumed to be bad, as is the general prognosis for Kakamega Forest if protection efforts are not increased and illegal exploitation by local people remains high, particularly on its periphery (Cords and Tsingalia 1982; Kokwaro 1988; Tsingalia 1988; Fashing et al. 2004).

How do the two conservation boards KWS and FD differ in their management aims and strategies? The overall aim of the KWS is 'to conserve, protect and sustainably manage the wildlife resources' and its areas are set aside for conservation and tourism only (Wass 1995). People are not allowed to collect any forest products and these policies are strictly enforced through regular patrols by up to five game rangers (E.W. Kiarie, personal communication). The overall aim of the FD is to 'enhance conservation and protection of indigenous forest, to improve the production of timber and fuelwood and to establish a framework for the long-term development forestry' (Wass 1995). Some sites are also set aside for conservation, however, some used to be plantations of exotic tree species or mixtures of indigenous species, while others experienced enrichment planting (A. Oman, personal communication). Logging, tree debarking and charcoal burning is prohibited, whereas fuelwood collection was licenced until recently (A. Oman, personal communication). It appears that the FD has been largely restricted in its capacity to implement conservation policies effectively due to the lack of adequate resources in contrast to the better funded KWS, leading to insufficient levels of staffing, patrols, weaponry etc. These differences in resources might have led to different disturbance levels as found in our survey.

Besides overall funding and the number of staff, other potential factors associated with management regime and effectiveness might be e.g. accessibility to the forest or proximity of the forest to neighbouring settlements, population density, community relations and compensation programs to locals. In a recent assessment of the impact of anthropogenic threats on 93 protected areas of 22 tropical countries park effectiveness was shown to correlate most strongly with density of guards i.e. the more guards the higher effectiveness (Brunner et al. 2001). Furthermore, effectiveness correlated with the level of deterrence of illegal activities in the parks and with the degree of border demarcation and existence of direct compensation programs for local communities (Brunner et al. 2001). However, it did not correlate with enforcement capacity (i.e. a composite variable of training, equipment and salary), accessibility, budget, number of staff working on economic development or education, or the local involvement of communities in park management (Brunner et al. 2001). To obtain more information on the factors influencing management effectiveness in Kakamega Forest more studies are highly recommended following the RAPPAM guidelines.

Management recommendations for Kakamega Forest

The high human impact on Kakamega Forest especially along the western and eastern edge of the main forest block indicates an imminent danger of further fragmentation. The main forest block might fall into two separate forest blocks, i.e. Kakamega National Reserve in the North and Isecheno Nature Reserve in the South. To prevent this from happening in the near future, we strongly recommend following the management plan of forest zoning as outlined by the Kenya Indigenous Forest Conservation Programme (KIFCON 1994; Wass 1995): establishing a protection zone to provide a core for biodiversity conservation extending from the North to South; setting up a rehabilitation zone with enrichment planting where degradation has reached high levels; and establishing a subsistence use zone flanking the protection zones where local people are allowed to extract forest products. This forest zoning aims both, to maintain as much indigenous forest cover as possible and to permit optimal use of forest resources on a sustainable basis (Wass 1995). We recommend placing the protection zone under strict KWS management as our survey indicates that areas of Kakamega Forest managed by the KWS appear to hold surprisingly low disturbance levels despite high land-use pressure.

The degradation and logging levels in the suggested subsistence zones are already alarming, so that we suggest enrichment planting there. Finally, encouragement of on-farm-forestry projects might provide resources in the long-term and thus might relieve the subsistence use zone. This is supported by the fact that a tree nursery run by the local grassroot conservation organization KEEP (Kakamega Environmental Education Program) at Isecheno Forest Station has been successfully nursing seedlings of both, indigenous and exotic tree species, for sale to local farmers. Beyond conservation measures for the main forest block, high protection priority must also be given to the low-disturbance sites central Ikuywa (No. 17), Yala (No. 19) and the 400 ha fragment of Kisere (No. 2). Kisere Nature Reserve is of particurlar conservation significance because it has been relatively undisturbed in the past and still harbours species-rich forest communities that include the rare DeBrazza monkeys (*Cercopithecus neglectus)* (Muriuki and Tsingalia 1990; Chism and Cords 1997). Although managed by KWS, it appears to have experienced increasing disturbance levels in the last few years (N. Saijita and C. Analo, personal communication). This might be due to the lack of ranger outposts in Kisere (KWS headquarters is at Buyangu), and the fact that the number of rangers (10–20) might not be sufficient to cover both, Buyangu and Kisere. Therefore, an immediate increase of regular ranger patrols to control logging more effectively is highly recommended, as suggested by previous authors (Kokwaro 1988; Mutangah 1996; Chism and Cords 1997).

Logging as indicator for quantitative threat assessment

In our survey only logging appeared to be an effective indicator for human impact on the forest and might offer a valuable tool to conservation managers. First, the recording of the number of logged trees provides a quantitative, objective measure of the human impact on protected areas. Most other assessments of threat status and management effectiveness used qualitative rather than quantitative approaches (see e.g. Salafsky and Margoluis 1999; Brunner et al. 2001; Ervin 2003c). For example, following the RAPPAM methodology and using a questionnaire, the question arises whether the protected area managers themselves answering questions on their own management will supply objective answers. Consequently, our method collecting empirical data on the number of logged trees is more objective.

Second, methods using logging as a disturbance indicator assess disturbance directly and not through biological indicators. Often, human impact is inferred from long-term studies on plant species composition or population structure as a biological indicator (e.g. Fashing et al. 2004). However, biological indicators can only assess the present situation resulting from past human impact. In contrast, quantifying disturbances directly can provide empirical data on the present human impact. Furthermore, logging as a disturbance indicator can enable us to differentiate between recent and past disturbance and might consequently help to evaluate past management policies.

Third, despite its quantitative approach this method provides a simple, low-budget method important especially for rapid and repeated assessment of disturbed forests. Repeated assessments are crucial especially in protected areas such as Kakamega Forest where heterogeneity in forest condition occurs over small spatial scales (Fashing et al. 2004). Consequently, surveys using logging as a disturbance indicator can provide the maximum amount of current up-to-date and scientifically sound information for management planners in return for the effort and time involved.

Finally, although the list of potential threats facing protected areas worldwide is long, logging appears to affect nearly 70% of more than 200 parks throughout the tropics (van Schaik et al. 1997) and emerges as one of the most hotly debated issues in tropical forest conservation (Rice et al. 1997; Bowles et al. 1998; Laurance 2001). Consequences of logging do not only include loss of habitat, but also changes in the microclimatic environment, erosion of soil and modification of fire regimes (Barlow et al. 2002; Cochrane and Laurance 2002) with the impact depending on the type of logging, i.e. whether commercial mechanized logging with heavy equipment or local exploitation of timber through e.g. pit-sawying and firewood collection. Furthermore, secondary effects of logging might be increased access to remote forested areas through the creation of roads and paths leading to further logging, forest colonization and hunting (Wilkie et al. 1992; Rice et al. 1997; Laurance 1998; Robinson et al. 1999). Consequently, logging appears to be a serious constant threat to tropical forests worldwide making its validity as an useful indicator even more probable.

Disturbance or impact assessments in combination with long-term studies on forest structure and composition after logging (e.g. Plumptre 1996; Chapman and Chapman 1997; Struhsaker 1997; Fashing et al. 2004) can provide important information on regeneration dynamics after human impact. Studies from Kakamega Forest indicate that regeneration from the severe human impact of the last century might be possible though not without rigorous conservation measures (Fashing et al. 2004, this study). Finally, repeated disturbance assessments are important to keep track of the human impact in protected areas and can provide feedback to management planners when evaluating past management decisions and setting up new conservation goals.

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