

A comparison of two sampling methods for surveying mammalian herbivore impacts on beetle communities in the canopy of *Acacia drepanolobium* in Kenya

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Even though several methods are used to sample and monitor canopy arthropods, there are no studies to indicate which of these methods is more effective. We compared the efficacy of the beating and canopy fogging methods in collecting beetles that inhabit *Acacia drepanolobium* (Harms) tree canopies at Mpala Research Centre in Laikipia district, Kenya. These trees grow naturally on the black cotton soils of the Laikipia ecosystem, accounting for more than 98 % of the overstorey at the study site, and are important for local cattle and wildlife production. The ultimate objective of this study was to determine the effect of differential grazing and browsing pressure from large mammalian herbivores on the beetle communities of *A. drepanolobium*. Seven hundred and twenty trees 1.0–2.5 m tall were sampled using each method, making a total of 1440 trees. Sampling using the two methods was done concurrently and repeated quarterly over a period of 14 months. In total, 4320 individuals were collected, 1456 by beating and 2864 by fogging. The methods jointly yielded beetle specimens from 13 families and 55 morphospecies. Fogging collected significantly more beetle morphospecies than beating, and there was a significant interaction effect between method and sampling date. We found that numerically Anthicidae and Curculionidae responded positively to the presence of cattle. We also found that Anthicidae sp. A and *Mylocerus* sp. A numbers significantly increased in plots where livestock were grazed.

Key words: canopy fogging, beating, Coleoptera, grazing, browsing, wildlife, conservation, Laikipia.

INTRODUCTION

Overstorey habitats are an important component of many terrestrial ecosystems, and so should be incorporated into conservation strategies, land-use planning and environmental impact assessment and monitoring. The 'black cotton soil' vegetation type (Taiti 1992) is a common and highly productive East African habitat used for cattle ranching, wildlife conservation and management (Western & Pearl 1989; Young *et al.* 1998) and charcoal production (Okello *et al.* 2001). The vegetation in this habitat is surprisingly uniform, with a single tree species, *Acacia drepanolobium* (Harms), accounting for over 90 % of the overstorey and the herbaceous layer being dominated by just four grass species (Young *et al.* 1997). Canopy arthropods constitute a significant portion of the biomass in this ecosystem (Hocking 1970), and play important roles in its functioning (*e.g.* Isbell 1998; Huntzinger *et al.* 2004; Palmer *et al.* 2008). A pri-

mary objective of this study was to determine how land-use patterns such as cattle grazing influence the diversity and abundance of canopy arthropods inhabiting *A. drepanolobium*. Accurate description of those effects, however, relies on the nature and intensity of sampling.

Largely because of their relative inaccessibility, canopy arthropod communities have historically been under-studied. Early canopy surveys relied on observations from the ground, either using binoculars or relying upon materials that had fallen from the canopy (Lowman & Wittman 1996). However, development of new methods of canopy access has resulted in a better understanding of the diversity of arthropod communities occupying these habitats (Lowman & Wittman 1996; McWilliam & Death 1998; Werner *et al.* 2004). The access methods include branch clipping (Majer & Recher 1988; Werner *et al.* 2004), rope ladders (Perry 1978; Perry & Williams 1981; Stelzl & Devetak 1999; Memmott *et al.* 2000), aerial walkways

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(Mitchell 1986), helium balloons (Fukuyama *et al.* 1994), construction cranes (Parker *et al.* 1992; Morell 1994; Odegaard 2000) and tree felling (Werner *et al.* 2004). Some of the sampling methods used to access the canopy include fogging (Erwin & Scott 1980), light trapping (Kitching *et al.* 2000; Orr & Kitching 2003) and hand collecting (Basset 1996; Chen & Tso 2004). Canopies exist in a myriad of heights and sizes, and different sampling methods are biased towards certain groups of arthropods. Therefore, canopy sampling methods should be selected based on the objectives of the study, canopy height, type of habitat and the taxa of interest.

The structure of arboreal arthropod communities can vary in both time and space, but the observed variation may relate to sampling method used (Blanton 1990; Basset 2001). For instance, canopy fogging was found to sample more rare and sedentary species than flight interception trapping (Basset 1988). Werner *et al.* (2004) suggested that it may be essential to sample canopy arthropods using more than one method to collect arthropods having different behaviours. Disparity between species collected using different survey techniques caused them to urge caution when comparing results from samples collected by different methods.

Insecticide fogging has been used broadly in passively sampling of canopy arthropods (Southwood *et al.* 1982; Watanabe & Ruaysoongnern 1989; Majer 1990; Basset 1991a,b; Kitching *et al.* 1993; Chey *et al.* 1998; Floren & Linsenmair 2005). This method uses vaporized contact insecticides, where arthropods coming into contact with the chemical are killed or rendered immobile, and fall to the ground where they are collected on sheets (Southwood *et al.* 1982; Watanabe & Ruaysoongnern 1989; Simandl 1993; Ozanne *et al.* 2000; Wagner 2001) and trays (Basset *et al.* 1996; Stork *et al.* 2001). The fogging method has been shown to sample the top of the canopy, which is usually inaccessible to other sampling methods (Lowman & Wittman 1996). However, the method has some disadvantages. For example, sedentary forms such as scale insects and grubs living inside tree trunks are difficult to sample (Srinivasa *et al.* 2004), and repeated sampling cannot be carried out on the same or surrounding trees (Hijii *et al.* 2001).

The beating method is also a passive method that involves beating a smaller tree repeatedly using a wooden pole and collecting the fallen arthropods. This method was used by Jenser *et al.*

(1999) to test the effect of broad spectrum and selective insecticides on herbivorous and carnivorous invertebrate communities in apple orchards in Hungary. Costello & Daane (2005) used beating and vacuum sampling to collect spiders when they compared diurnal and nocturnal sampling in a California vineyard. Beating can be used at any time since its efficiency is not affected by either season or time of day (McCaffrey *et al.* 1984). However, it is likely to be more effective at cooler times when flying insects are less likely to escape. The method is cheap and environmentally friendly, given that it does not pollute the environment as do chemical-based methods. However, it has limitations because small trees may be damaged (Vincent *et al.* 1999) and it favours certain taxa of low mobility that drop readily from branches (Suckling *et al.* 1996) and may fail to sample highly mobile, winged insects and sessile insects (Suckling *et al.* 1996).

This study aims to investigate: (a) the efficacy of beating and insecticide canopy fogging in sampling beetles inhabiting canopies of *A. drepanolobium*; and (b) the response of the beetle communities to differential grazing and browsing pressures by large mammalian herbivores. The two methods were chosen because they are commonly used in sampling canopy arthropods. Since different sampling methods exhibit different biases, it was expected that there would be a method-related difference in apparent community structure. Beetles were chosen because they are the most abundant and diverse group of insects in the environment (Speight *et al.* 2008). Previous studies have shown that beetles are sensitive to environmental change and can be used as bioindicators (Davis *et al.* 2001; Sieren & Fischer 2002; Pearce & Venier 2006; Pohl *et al.* 2007; Work *et al.* 2008).

MATERIAL AND METHODS

Study area

The experiments were carried out at Mpala Research Centre in the semi-arid Laikipia district (0°17'N 36°53'E; 1800 m a.s.l.) in north-central Kenya. Rainfall in the study area ranges between 500–600 mm per year. Experiments were conducted on six plots within the Kenya Long-term Exclosure Experiment (KLEE) (Young *et al.* 1995, 1998) and three other plots outside the KLEE. The KLEE exclosures were set up in 1995 to examine interactions between native ungulates and livestock, and

how these interactions affect the environment (Young *et al.* 1998). For our experiments we used three KLEE plots to which only cattle had access (C), three from which all large herbivores including cattle were excluded (0) and three plots outside KLEE which allowed access to all large herbivores including cattle (E). For more detailed description of the KLEE enclosures and the study site see Young *et al.* (1998). The study was conducted during a period of 14 months between October 2003 and November 2004.

Sample collection

Beating. Two hundred and forty trees were marked in each of the three herbivory treatments. This was carried out by following a compass direction in a straight line and tagging trees within 20 m of that transect line. For each tree, the height and diameter of the trunk at 20 cm above ground was measured to the nearest centimetre. Only trees with heights ranging from 1.0 to 2.5 m were tagged (Table 1). Trees within this height range were exclusively colonized by one of four species of symbiotic ant (*Crematogaster sjostedti* Mayr, *C. mimosae* Santschi, *C. nigriceps* Emery and *Tetraponera penzigi* Mayr), whereas most trees >2.5 m were inhabited by *C. sjostedti*, and small trees below 1.0 m were inhabited mainly by *T. penzigi* (Young *et al.* 1997; Palmer *et al.* 2000). For each herbivory treatment, 60 trees occupied by each of the four ant species were marked, making a total of 240 trees. Twenty trees occupied by each of the four acacia-ants were marked in each plot and each treatment had three replicates. Random numbers were used to assign trees to one of four groups for each of the four sampling sessions (Zar 1974). The sampling dates were as follows: first sampling (27 October – 13 November 2003), second sampling (11–28 February 2004), third sampling (26 May – 12 June 2004) and the fourth sampling (10–27 September 2004).

For every sampling session, 60 trees were sampled for each treatment, 20 from each plot. Of the 20 trees, five were occupied by each of the four acacia-ant species. This ensured that beetle samples were not biased by sampling trees occupied by particular acacia-ant species. Sampling involved beating a tree twenty times using a wooden pole and collecting all falling beetle samples using four pale blue sheets (each 1 m²) spread beneath the tree. Samples from the four sheets were pooled to make one sample, labelled and placed in a polythene bag. It took one person ap-

Table 1. Height (means \pm S.D.) and diameter at knee height (means \pm S.D.) of *Acacia drepanolobium* trees sampled (beating and canopy fogging) within plots subjected to three herbivory treatments.

Herbivory treatments	Height (cm)	Diameter (cm)
Cattle only	167.03 \pm 1.86	3.57 \pm 0.05
All large herbivores excluded	163.28 \pm 1.71	3.38 \pm 0.04
All herbivores allowed	159.35 \pm 1.79	3.54 \pm 0.08

proximately 30–40 minutes to sample a tree, which was regarded as one sampling unit.

Samples were later transported to the laboratory and stored at -4 °C. They were later sorted to family and morphospecies and preserved in 70 % ethanol. These groupings were later confirmed at the National Museums of Kenya (Nairobi), Iziko South African Museum (Cape Town), Plant Protection Research Institute (Pretoria, South Africa), and The Natural History Museum (London). The four sampling sessions were carried out at three-month intervals.

The insecticide canopy fogging. Along the same belt transects used to sample trees for the beating method, an additional sample of trees of similar height was tagged in all nine plots. During each sampling session five trees occupied by each of the four ant species were sampled in each plot, making a total of 60 samples. A hand-pump knap-sack sprayer (Solo 425, Germany) was used to spray the trees. Alphacypermethrin 100 g/l from Bilag Industries Ltd (traded as Alfix[®] 10EC) was used to dislodge and kill beetles. It was first diluted with water in the ratio of 5 ml to 10 l. Approximately 300 ml of the diluted insecticide was used to spray one tree. Canopy fogging was carried out only in dry conditions in the mornings (07:30–10:30) when winds were light. Each tree was sprayed for 30–40 seconds, making sure the mist from the mist-blower penetrated the canopy. All samples falling from the canopy were collected as described above. After 40–50 minutes the catch was removed from the sheets and placed in polythene bags and treated as described above. Specimens that were different from those collected by the beating method were also sent to the above-named institutions either to have their identity determined or confirmed. Sampling using the two methods was carried out concurrently. Voucher specimens were deposited at the National Museums of Kenya, Nairobi.

Data analysis

Ordination was performed by non-metric multi-dimensional scaling (MDS). The analysis used a Bray-Curtis similarity matrix derived from the log-transformed ($\log(x + 1)$) data and ten iterations. Ordination of the beetle samples was done at both family and morphospecies levels.

Two descriptors of community diversity, Shannon-Wiener (H') diversity index and total species richness (S), were computed for each tree. Indices were generated for both family and morphospecies levels. Other workers have used diversity indices to compare sampling methods (Suckling *et al.* 1996; Green 1999). The data were tested for normality using Shapiro-Wilks W -tests, Kolmogorov-Smirnov tests and Lilliefors' tests. The indices were later analysed using permutational multifactor analysis of variance (PERMANOVA) as implemented in the software program PERMANOVA (Anderson 2005). For all analyses, 999 permutations were used to generate the P -value. Whenever a significant difference ($P < 0.05$) was recorded, further pair-wise comparisons were carried out using 99 permutations, because this involved a subset of the data. PERMANOVA was chosen because it tests several factors together, unlike the Kruskal-Wallis test which compares one factor at a time. However, Kruskal-Wallis ANOVA tests were carried out on the square-root-transformed abundance data (pooled for the two methods) to test the effect of herbivory treatment on the four most abundant families and the three most abundant morphospecies. Whenever significant results ($P < 0.05$) were obtained, pair-wise comparisons were performed using Mann-Whitney U -tests (Statsoft 1999).

RESULTS

Beetle community

In total 1440 trees were sampled using the two methods (beating and fogging). A total of 4320 individuals (beetles) were caught using the two methods; 66.29 % of these were sampled by canopy fogging (Appendix 1). The two methods jointly collected representatives of 13 families; canopy fogging collected all 13 families, while beating collected 11 families (Appendix 1). The two methods jointly collected 55 morphospecies. Curculionidae and Anthicidae numbers contributed 53.82 % and 19.91 %, respectively, of the pooled samples (Appendix 1). The four most numerically

abundant families were Curculionidae, Anthicidae, Cleridae and Buprestidae (Appendix 1). Scarabaeidae and Staphylinidae were collected only by the canopy fogging method, with a single specimen each (Appendix 1).

At the morphospecies level, beating and canopy fogging failed to collect 25.45 % and 16.36 %, respectively, of the morphospecies found using the other method (Appendix 1). Chrysomelidae (15 species) was the most speciose family, followed by Curculionidae (11), and Buprestidae (11) (Appendix 1).

Comparison of methods

At the level of beetle families, beating and fogging yielded significantly different values for the two community descriptors (Shannon-Wiener: $F = 15.760$, d.f. = 1, $P = 0.001$; total number of taxa: $F = 19.059$, d.f. = 1, $P = 0.001$). Across all samples, estimated family-level beetle diversity and richness were greater based on the fogging method (0.312 and 1.368, respectively) than on the beating method (0.148 and 0.840, respectively). The low diversity and richness could be as a result of the small size of trees that were sampled. There was no significant variation for the two diversity descriptors among the sampling dates (Shannon-Wiener: $F = 1.578$, d.f. = 3, $P = 0.285$; total number of taxa: $F = 1.731$, d.f. = 3, $P = 0.284$) or between herbivory treatments (Shannon-Wiener: $F = 3.767$, d.f. = 2, $P = 0.121$; total number of taxa: $F = 1.731$, d.f. = 2, $P = 0.284$), but there was a marginally significant interaction between sampling method and sampling date for the Shannon-Wiener diversity index ($F = 3$, d.f. = 3, $P = 0.058$). There was a significant difference between the first and the second sampling dates ($t = 2.089$, $P = 0.010$), first and third sampling dates ($t = 1.436$, $P = 0.050$), second and fourth sampling dates ($t = 2.586$, $P = 0.010$) and between the third and fourth sampling dates ($t = 1.859$, $P = 0.040$) for samples collected by canopy fogging. The mean Shannon-Wiener diversity index was lower on the first sampling date (0.158) compared to the second (0.366) and the fourth (0.240) sampling dates. The mean Shannon-Wiener diversity index was higher on the third (0.483) compared to the fourth (0.240) sampling dates.

At the morphospecies level, the two methods yielded different values for both diversity descriptors (Shannon-Wiener: $F = 15.469$, d.f. = 1, $P = 0.001$; total number of taxa: $F = 19.092$, d.f. = 1, $P =$

Table 2. Results of Kruskal-Wallis ANOVA to test the effect of herbivory treatments on the abundance data (pooled from fogging and beating) of Anthicidae, Buprestidae, Cleridae and Curculionidae. Herbivory treatments are abbreviated as follows: 0 = all large mammalian herbivores (including cattle) excluded, C = only cattle allowed; and E = all large mammalian herbivores (including cattle) allowed. Treatments with the same superscript lower case letter are not significantly different.

Family	Factor	Mean abundance \pm S.E.	<i>H</i>	d.f.	<i>P</i>	Number of individuals
Anthicidae	Herbivory treatment		14.726	2	0.001	861
	E ^a	1.017 \pm 0.133				
	C ^b	1.750 \pm 0.201				
	0 ^a	0.821 \pm 0.103				
Buprestidae	Herbivory treatment		1.124	2	0.570	222
	E	0.371 \pm 0.058				
	C	0.267 \pm 0.040				
	0	0.288 \pm 0.044				
Cleridae	Herbivory treatment		4.429	2	0.109	514
	E	0.604 \pm 0.093				
	C	0.813 \pm 0.091				
	0	0.725 \pm 0.104				
Curculionidae	Herbivory treatment		6.281	2	0.043	2323
	E ^a	4.121 \pm 0.842				
	C ^a	3.892 \pm 0.559				
	0 ^b	1.667 \pm 0.192				

0.001). The Shannon-Wiener diversity index and total species richness across all samples for fogging were higher (0.329 and 1.419, respectively) compared to beating (0.159 and 0.861, respectively). There was no significant variation among herbivory treatments or sampling dates for the two diversity descriptors. There was no interaction effect between sampling method and sampling date ($F = 1.284$, $P = 0.209$) and between herbivory treatment and sampling date ($F = 1.151$, $P = 0.405$) for the total number of species. The results showed a significant relationship between sampling method and sampling date ($F = 1.823$, $P = 0.036$) for the Shannon-Wiener diversity index. Further analysis of sampling dates revealed that there was a significant interaction between the first and second sampling dates ($t = 2.094$, $P = 0.010$), the second and fourth sampling dates ($t = 2.566$, $P = 0.010$) and between the third and fourth sampling dates ($t = 1.880$, $P = 0.040$) for samples collected by canopy fogging. The Shannon-Wiener diversity index was higher during the second sampling date (0.380) compared to the first (0.167) and the fourth (0.257) sampling dates. The Shannon-Wiener diversity index was higher on

the third (0.512) compared to the fourth (0.257) sampling dates.

Effect of differential grazing and browsing pressure on the four most abundant families

Kruskal-Wallis ANOVA was carried out individually on the four numerically dominant families (beating and canopy fogging samples were pooled) to test for effects of herbivory treatment on the number of individuals. There were no significant differences for the abundances of Buprestidae and Cleridae as a result of differential grazing and browsing pressures (Table 2). However, there was a significant relationship for the abundances of Anthicidae and Curculionidae and herbivory treatment (Table 2). Mann-Whitney *U*-tests showed that there was a significantly higher abundance of Anthicidae in plots in which only cattle were allowed compared to plots in which all large mammalian herbivores including cattle were allowed and in plots in which all large mammalian herbivores were excluded (Table 2). Results also showed that there were more Curculionidae in plots in which only cattle had access and in plots in which all large mammalian herbi-

Table 3. Results of Kruskal-Wallis ANOVA to test the effect of herbivory treatments on the abundance (pooled from beating and fogging) of Anthicidae sp. A, Cleridae sp. 1 and *Mylocerus* sp. A. Herbivory treatments are abbreviated as follows: 0 = all large mammalian herbivores (including cattle) excluded, C = only cattle allowed; and E = all large mammalian herbivores (including cattle) allowed. Treatments with the same superscript lower case letter are not significantly different.

Morphospecies	Herbivory treatment	Mean abundance \pm S.E.	<i>H</i>	d.f.	<i>P</i>	Number of individuals
Anthicidae sp. A	E ^a	1.013 \pm 0.133	15.196	2	0.001	858
	C ^b	1.750 \pm 0.201				
	0 ^a	0.813 \pm 0.102				
Cleridae sp. 1	E	0.604 \pm 0.093	4.456	2	0.108	508
	C	0.813 \pm 0.091				
	0	0.700 \pm 0.102				
<i>Mylocerus</i> sp. A	E ^b	4.054 \pm 0.842	8.689	2	0.013	2238
	C ^b	3.788 \pm 0.559				
	0 ^a	1.483 \pm 0.174				

vores including cattle were allowed compared to plots in which all large mammalian herbivores were excluded (Table 2).

Effect of differential grazing and browsing pressure on the three most abundant morphospecies

Further analyses to test the effect of differential grazing and browsing pressures were carried out on the three most abundant morphospecies (pooled beating and canopy fogging samples); Anthicidae sp. A, Cleridae sp. 1 and *Mylocerus* sp. A (Curculionidae). There was a significant effect for the abundances of Anthicidae sp. A and *Mylocerus* sp. A and herbivory treatment (Table 3). Pair-wise comparisons using Mann-Whitney *U*-tests showed that there were significantly more individuals of Anthicidae sp. A in plots in which only cattle were allowed compared to plots in which all large mammalian herbivores were allowed and in plots in which all large mammalian herbivores were excluded (Table 3). Anthicidae sp. A was positively affected by the presence of cattle alone and negatively affected by the presence of cattle and other large mammalian herbivores put together or exclusion of all large mammalian herbivores (Table 3). Mann-Whitney *U*-tests showed that *Mylocerus* sp. A samples collected in plots in which only cattle had access and in plots in which both cattle and wildlife were allowed were significantly different compared to those collected in plots in which all large mammalian herbivores were excluded (Table 3). There were more individuals of *Mylocerus* sp. A in plots in which only cattle

had access and in plots in which both cattle and wildlife were allowed compared to plots in which all large mammalian herbivores were excluded (Table 3).

Community structure

At the family level, the stress of the MDS ordination was 0.07, which meant that the model was a reasonable representation of the beetle communities occurring in the canopies of *A. drepanolobium*. There was no consistent pattern reflecting sampling method, herbivory treatment or sampling date and the corresponding convex hulls overlapped extensively. However, there was a tendency of samples collected during the second sampling session to group together (Fig. 1a).

A two-dimensional MDS plot generated using morphospecies abundance data had a stress value of 0.08, implying a good ordination of the beetle samples collected using the two methods. Samples collected during the same sampling sessions using the two methods clustered compared to those collected during different sampling periods, particularly those for the first two sessions (Fig. 1b). For the first and second sampling period, sampling method did not discriminate the beetle communities collected. However, for the third and fourth sampling periods, sampling method resulted in different communities being collected (Fig. 1b).

DISCUSSION

Together, the two sampling methods collected beetles of 13 families and 55 morphospecies from

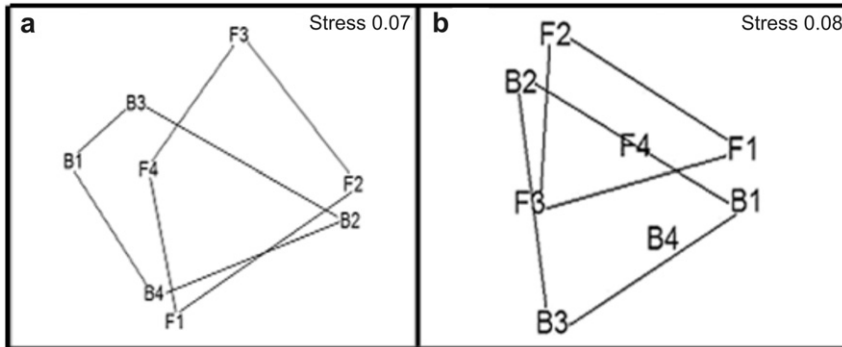


Fig. 1. Ordinations of log-transformed abundances of insects collected by beating (B) and fogging (F) to test for the effect of sampling methods on Coleoptera: **a**, two-dimensional MDS of sampled families; **b**, two-dimensional MDS of abundances of morphospecies. Digits represent the sampling sessions. The values represent the stress of the MDS ordination, and they indicate a reasonable representation of how beetle communities were affected by sampling methods.

canopies of *A. drepanolobium*. This is a fairly high number, given that *A. drepanolobium* has a mutualistic association with aggressive ants (Young *et al.* 1997; Palmer *et al.* 2000). The study clearly demonstrates that a variety of canopy insects can coexist with symbiotic ants.

Sampling methods and potential biases

Canopy fogging collected 13 families and 46 morphospecies, while beating collected 11 families and 41 morphospecies, respectively. There are several possible explanations for this. First, winged, mobile species could have escaped during the beating process, whereas during canopy fogging the insecticide knocked them down. Second, during the beating process some individuals may have firmly gripped the twigs or leaves and remained within the canopies, but when insecticide was used during canopy fogging they were killed or paralysed and eventually fell onto the collecting sheets. Third, some individuals could have fallen on the sheets and then walked or crawled away, whereas the insecticides ensured that most of those individuals falling on the ground could not escape. Finally some tunnelling species, especially Curculionidae, could have remained within their tunnels during beating, but when canopy fogging was used the insecticide may have penetrated the tunnels, flushing them out.

Because the two sampling methods had their own biases, neither alone would produce a complete picture of the beetle communities occupying the canopies of *A. drepanolobium*. The diversity descriptors at family and morphospecies levels revealed a significant difference between the two

methods; fogging collected more beetle families and morphospecies compared to beating, indicating that fogging was a superior method. The majority of the catches comprised Anthicidae and Curculionidae. The two methods collected relatively similar proportions of individuals of Carabidae, Bruchidae, Bostrichidae and Cerambycidae, but canopy fogging collected greater numbers of Curculionidae, Cleridae and Anthicidae, compared to beating. It is also certainly possible that the two methods combined could under-sample some groups of canopy arthropods. Although both sampling methods suggested that *Myloccerus* sp. A and Anthicidae sp. A were the two most abundant morphospecies at the study site, it is possible that other beetle species may actually be more abundant at the study area. Because different sampling techniques differ with respect to the beetle taxa sampled (Chung 2004), utilizing multiple techniques concurrently is likely to increase sampling accuracy and reduce overall sampling bias.

Sampling methods have been shown to be biased in terms of numbers of individuals collected of the same insect or taxonomic group, and may yield different results when applied on different dates or habitat types (Norment 1987; Buffington & Redak 1998; Moir *et al.* 2005; Jiménez-Valverde & Lobo 2005). Gibbs & Leston (1970) had a problem in interpreting data on insects collected using two methods because they collected different quantities of the same insects at different times. Spider assemblages collected by vacuum and pit-fall traps were significantly different, implying that different methods have different efficacies (Green 1999). Suction samplers performed better

than other methods in collecting spiders from maize plots (Meissle & Lang 2005), while sweep-netting caught different spider species compared to pitfall traps (Warui 2005). The current study supports the idea that caution is necessary when comparing arthropod communities based on different sampling techniques. An advantage of this study is that the two sampling techniques were applied concurrently, and replicated to the same degree within the same habitats.

Canopy fogging was the most efficient method for collecting canopy beetles in this study system. However, beating was easier to use, less costly, and also more environmentally friendly, with no chemical residues remaining in the ecosystem. Beating is generally best for slow-moving arthropods that dislodge easily from plants when disturbed (Suckling *et al.* 1996) but is less likely to sample highly mobile organisms (Moir *et al.* 2005). Because beating missed 14 morphospecies (found by canopy fogging) and fogging missed 9 morphospecies (found by beating), using the two methods together will clearly provide a closer representation of the true community (also see Ranius & Jansson 2001).

This study highlights the importance of using multiple collection methods to assess the composition of canopy arthropod communities. Neither canopy fogging nor beating was able to sample all of the beetle species. Therefore, researchers must balance costs and the need for sampling accuracy in determining which methods to use to answer a specific question within any particular ecosystem. In the black cotton soil habitats dominated by *A. drepanolobium*, comparing effects of grazing regime, wildlife access, or symbiotic ant occupant on other members of the canopy arthropod community will be more reliable if canopies are sampled using both beating and fogging. If the aim is to collect the most beetle species using the least time and effort, then canopy fogging would be the preferred method. Alternatively, if the aim is to compare arthropod communities quantitatively, it would be best to use both beating and fogging, probably supplemented by hand-collection of taxa that might not be easy to sample using other methods.

Differential grazing and browsing pressure

Previous studies have shown that livestock grazing can affect diversity and abundance of invertebrates (Ranius 2002; Dennis *et al.* 2008) by

trampling (Abensperg-Traun *et al.* 1996) and change in vegetation structure (Kruess & Tschamtko 2002). The current study supports these findings. Grazing and browsing pressure by large mammalian herbivores had an effect on the canopy arthropods, both at the family and morphospecies levels. Anthicidae were more abundant in plots in which only cattle were allowed compared to either plots in which both cattle and wildlife were allowed or in plots in which all large mammalian herbivores were excluded. Also Curculionidae were more abundant in plots in which only cattle had access and in plots in which both cattle and wildlife were allowed compared to plots in which all large mammalian herbivores were excluded. However, abundance of beetle communities is affected by many factors (Apigian *et al.* 2006) and as such it is difficult to identify factors affecting certain groups of beetle communities, especially in this case, anthicid and curculionid beetles.

At the morphospecies level, the abundance of Anthicidae sp. A and *Myllocerus* sp. A were shown to have a positive relationship with the presence of cattle either because this resulted in more open space as a result of trampling and grazing and therefore allowed easier movement during foraging. The findings of this study are in agreement with previous studies carried out in this study area which demonstrated extensive effects of large mammalian herbivores on many species within this ecosystem. Over 10 years, experimental manipulation of grazing and browsing pressure significantly changed the community of ant symbionts occupying *A. drepanolobium* canopies (Palmer *et al.* 2008), as well as the demography of host trees. Warui *et al.* (2005) showed that epigeic spiders collected using pitfall traps from cattle-grazed plots had significantly lower species richness and total numbers of taxa compared to those that had no mammalian herbivores (presumably due to trampling and grazing). The ground-dwelling rodent *Saccostomus mearnsi* was 40 % more abundant in plots without ungulates, compared to those occurring with ungulates (Keesing 1998). Another study at the KLEE plots showed that *A. drepanolobium* seedlings on plots without ungulates were damaged faster than those in plots where ungulates were allowed (Shaw *et al.* 2002).

Community structure

At the family and morphospecies levels there was no clear separation of ordinated samples that

could be related to sampling methods but at morphospecies level some samples grouped together to reflect sampling dates. This observation, together with the response of some families and morphospecies to herbivory treatments, shows the importance of using different taxonomic levels during data analysis. Therefore, depending on the objectives of the study and the availability of funds and manpower, it may be feasible to carry out data analysis using higher taxonomic groupings that can be easily obtained compared to the time-consuming and difficult task of identifying specimens to genus or species. Warwick (1988) showed that at the family level there was no substantial loss of information when he related benthic assemblages to pollution levels using five data sets collected at different times. This was again demonstrated by Warwick *et al.* (1990) when they analysed macrobenthic and meiobenthic community structure in relation to pollution and disturbance in Hamilton Harbour, Bermuda. Other studies have also reported similar observations and support the use of higher taxonomic ranks other than identifying specimens to species (Herman & Heip 1988; Olsgard & Somerfield 2000).

The two methods used during the current study had two disadvantages: i) some of the beetles would fall onto the sheets and crawl or walk away; ii) neither could collect highly mobile beetles.

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Lastly, canopy fogging could not be used when conditions were wet or windy. Improvement of the collecting devices and addition of other sampling methods such as light trapping and hand collection could improve the catches from this ecosystem.

This study has shown that *Acacia* species with mutualistic associations with ants can still support rich beetle communities. This study has also shown that at family and morphospecies levels, certain beetle families and morphospecies could be used as bioindicators for monitoring the effect of grazing and browsing.

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Appendix 1. Number of individual beetles belonging to various families and morphospecies that were sampled from canopies of *Acacia drepanolobium* at the KLEE plots and their immediate environs at Mpala Research Centre using canopy fogging and beating.

Taxonomic level		No. of specimens	
Family	Morphospecies	Beating	Fogging
Anthicidae		268	592
	Anthicidae sp. A	268	591
	Anthicidae sp. D	0	1
Bostrichidae		8	6
	Bostrichidae sp. 1	8	6
Bruchidae		8	11
	Bruchidae sp. 1	5	9
	Bruchidae sp. 2	0	1
	Bruchidae sp. 3	2	0
	Bruchidae sp. 4	1	1
Buprestidae		73	149
	<i>Agrilus</i> sp. A	3	3
	<i>Agrilus</i> sp. B	1	9
	<i>Agrilus</i> sp. D	1	0
	<i>Agrilus</i> sp. G	0	1
	Buprestidae sp. 1	7	36
	Buprestidae sp. 2	0	6
	<i>Chrysobothris</i> sp. A	4	4
	<i>Hoplistura</i> sp. A	44	74
	<i>Sjoestedtius</i> sp. A	0	2
	<i>Sjoestedtius</i> sp. B	0	1
	<i>Sjoestedtius</i> sp. C	13	13
Carabidae		37	53
	<i>Arsinoe</i> sp. A	0	1
	Carabidae sp. 1	31	50
	Carabidae sp. 2	5	0
	Carabidae sp. 3	1	2
Cerambycidae		11	14
	<i>Enaretta</i> sp. A	11	14
Chrysomelidae		55	114
	Chrysomelidae sp. 1	0	1
	Chrysomelidae sp. 3	1	1

Taxonomic level		No. of specimens	
Family	Morphospecies	Beating	Fogging
	Chrysomelidae sp. 4	17	18
	Chrysomelidae sp. 5	1	1
	Chrysomelidae sp. 6	3	2
	<i>Cryptocephalus</i> sp. A	0	1
	<i>Cryptocephalus</i> sp. B	1	0
	<i>Dorcatrispa</i> sp. A	1	0
	<i>Hispa</i> sp. A	2	6
	<i>Lema</i> sp. A	3	2
	<i>Megalognatha</i> sp. A	0	4
	<i>Monolepta</i> sp. A	13	52
	<i>Monolepta</i> sp. B	10	24
	<i>Monolepta</i> sp. C	1	2
	<i>Monolepta</i> sp. D	2	0
Cleridae		105	409
	Cleridae sp. 1	105	409
Coccinellidae		2	5
	<i>Micraspis</i> sp. A	2	2
	<i>Scymnus</i> sp. A	0	3
Curculionidae		840	1485
	<i>Myllocerus</i> sp. A	801	1440
	<i>Neosphrigodes</i> sp. A	1	18
	<i>Systates</i> sp. A	21	7
	Curculionidae sp. 1	5	13
	Curculionidae sp. 2	5	1
	Curculionidae sp. 4	2	2
	Curculionidae sp. 5	2	2
	Curculionidae sp. 6	0	2
	Curculionidae sp. 7	1	0
	Curculionidae sp. 8	1	0
	Curculionidae sp. 9	1	0
Scarabaeidae		0	1
	<i>Aphodius</i> sp. A	0	1
Staphylinidae		0	1
	<i>Philonthus</i> sp. A	0	1
Tenebrionidae		49	24
	<i>Lagria</i> sp. A	49	24
Total		1456	2864