The development of a key to the mammals of the Udzungwa Mountains, Tanzania, based on their hair morphology and its use in identifying samples collected in the area from hair traps

PHILLIPA BROWN

Advisor: DR JOHN EDDISON

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Phillipa J. Brown
School of Biological Science, University Of Plymouth, DEVON, PL4 8AA, UK
Paignton Zoo Environmental Park, Paignton, DEVON, TQ47EU, UK

Abstract:
A key to the hairs of mammalian species of the Udzungwa Mountains has started to be devised for use with hair trap analysis. The key is based on cuticular scale patterns of hairs but other features of hair morphology are discussed. The limitations of the key are examined; the main limitation being that small differences in cuticular scale patterns are sometimes used as diagnostic criteria to enable identification to species level. Other aspects that could affect the interpretation of the key such as age and sex are also discussed. The success of hair trapping is compared to camera trapping to see which is most useful for estimating relative population abundance. Both the hair samples and the camera images provided evidence for the rare Abbott's duiker (*Cephalophus spadix)*, a flagship species for the global biodiversity hotspot of the Eastern Arc Mountains.

Keywords: hair trapping, Udzungwa Mountains, cuticular scale patterns, small mammals

Introduction:
Hair identification can be traced back to the late 1800's when W.McMurtrie first observed cuticular scale patterns on the surface of hairs (Kitsosi 1995). Since then many authors have studied these patterns to help with research in ecology and conservation. Hair microstructure is a useful tool to identify mammals and is applied in several disciplines such as forensic sciences, ecology, epidemiology, archaeology and paleontology (Quadros and Monteiro 2006). The identification of hair samples is highly valuable for taxonomic and

wildlife research (Chestnutt and Jordan 2001), it can help to detect species in an area, measure relative abundance of species and identify animal diets through the analysis of prey species (Rustiati and Chanin 2000; Pocock and Jennings 2006; Bothma and Le Riche 1994).

One of the main reasons for identifying hair samples is to work out the diet of species by looking at their scat, since often the only identifiable remains of prey species in predator scats are hair fibres and pieces of bone (Perrin and Campbell 1980). It is a relatively simple and reliable method and is widely used for determining food habits of carnivores (Breuer 2005; Rustiati and Chanin 2000; Bothma and Le Riche 1994; Henschel *et al.* 2005; Silvestre *et al.* 2000; Perrin and Campbell 1980). It is inexpensive, easy to apply, non intrusive and allows relatively large samples sizes (Rustiati and Chanin 2000; Perrin and Campbell 1980). If the samples are collected from known animals then the diet could be compared between seasons and between sexes or size classes of these animals (Glen and Dickman 2006). Scat analysis can have very important implications for species survival: for example Marker *et al.* (2003) looked at the prey species of the Namibian cheetah to quantify predation on livestock species. This study was of interest to farmers seeking to protect their livestock and to conservationists trying to protect the endangered cheetah.

To detect animals and measure abundance, live trapping is often used. However, live trapping normally requires expensive equipment, is time consuming as frequent visits are required to release trapped animals and is highly invasive (Pocock and Jennings 2006). For these reasons, researchers have developed alternative methods to assess the activity and abundance of animals, such as hair traps. Hair traps do not require frequent checking and can often be constructed from light, cheap and widely available materials (Pocock and Jennings 2006; Gonzalez-Esteban *et al.* 2006). Hair tubing or trapping allows hair samples to be collected from animals that pass them, these samples can then often be analysed to species level. This could mean that species that are very elusive not often seen by people can be identified and relative population abundance estimated. However, to identify hair fibres

by comparing with known samples is a tedious and time consuming process, to obviate this other researchers have formulated keys based on differences in species hair morphology (Perrin and Campbell 1980).

The presence of hair distinguishes mammals from all other vertebrates (Ryder 1973). The type and structure of hairs provide useful characteristics for identifying hairs to species. Hair usually grows out of the skin at a slant which means that the hairs tend to lie flat on the skin pointing backwards this provides stream-lining when the animal moves forward. However, there is much variation between species, there can be changes of direction to give hair tracts and sometimes whorls (Ryder 1973). When a hair begins to grow it has a pointed tip and, provided the coat does not receive too much wear, the tip will remain pointed throughout the hair's lifetime.

The gross structural features of hairs are visible with an ordinary light microscope. Different species have different structural features, which allow them to be classified into groups. Mammalian hair is recognized by three distinct structural components: cortex, medulla and cuticle (Meyer *et al*. 2002). This project will use cuticular scale patterns to analyse hair samples as it is the cuticle shape and arrangement of the scales that show a large amount of variation along the length of a single hair and between types of hairs and between species (Ryder 1973).

The Udzungwa Mountains are part of the Eastern Arc range in Tanzania; these mountains are a global biodiversity hotspot and have a high level of endemic and endangered fauna (Lovett *et al*. 2006; Burgess *et al.* 2007). This includes a rich but very poorly studied forest antelope community, including the endangered Abbott's duiker. The Udzungwas has a long but variable dry season lasting for about seven months in the west and five months in the east (Dinesen *et al*. 2001). Many surveys have been carried out to estimate populations of mammals and birds particularly primates and duikers (Dinesen *et al.* 2001; Rovero and Marshall 2004; Rovero *et al.* 2005).

During 2005 a researcher spent six months in the Mwanihana Forest in the Udzungwa Mountains range. Hair traps were used to try and estimate mammal abundance, particularly antelope. The traps were set up at 0.5km intervals along two 4km long transects in separate forest areas and were monitored throughout the six months. The main aim of this project is to examine the hair samples from the hair traps and try to identify them to species level. To do this a reference set of known hair samples from mammal species known to occur in the area will be examined and analysed. A key will be drawn up detailing characteristics of the hairs such as colour, length and texture along with microscopic characteristics such as cuticular scale patterns; this will then be used to identify the unknown samples from the Udzungwa Mountains.

If sufficient hairs can be identified the hair trap method will be compared with other abundance estimate methods that were undertaken at the same time (principally camera trapping) to evaluate its potential use in population monitoring.

This project will develop a key to identifying East African mammals and evaluate the potential use of hair trapping to study rainforest mammals. It will also be of conservation importance if hair analysis proves useful in monitoring threatened species, such as the vulnerable Abbott's duiker (IUCN 2007), in this fragile habitat.

2. Methods:

2.1 Subjects and study site:

A researcher from Paignton Zoo spent six months in 2005 in the Mwanihana Forest in the Udzungwa mountain range carrying out various surveys to try and identify if the rare and endangered Abbott's duiker live in the area. One method was to use hair traps (Bowkett 2006).

The hair traps were set up at 0.5km intervals along two transects named Campsite 3 and Mwanihana. These two transects were in the Mwanihana Forest approximately 5km apart and were monitored for a six month period

from June to November 2005. Within the two transects there were three different habitats: miombo (savannah woodland), open canopy regenerating vegetation, forest (mature evergreen and riverine forest). Each trap consisted of four plant stems (c. 1-2cm diameter) wrapped in sellotape and suspended over an animal path at fixed heights. The outer two stems were set at 60cm and the inner two at 40cm.This arrangement allows for taller animals such as Abbott's duiker to leave hairs on the higher stems before they encounter the lower stems. Hair traps were checked at the same time as tracking strips (approximately every other day). Other hairs were collected opportunistically, principally from antelope sleeping sites.

All hairs were stored in a clear plastic bag labelled with site identification, date and number of hairs, along with possible species on the basis of colour and thickness. These hairs were then brought back to the United Kingdom for identification.

The most effective way to identify the hairs from the Udzungwa Mountains in Tanzania was to compile a reference collection of hair samples from as many local mammal species as possible (Perrin and Campbell 1980). A list of the local mammal species was compiled (F. Rovero and D. de Luca unpubl.) and this was then edited to list only the mammals likely to be 'caught' by the hair traps [Appendix 1]. Hair samples were collected from the listed mammal species from the Natural History Museum of Zimbabwe.

2.2 Experimental design and procedures:

The reference hair samples were first catalogued according to gross morphological characteristics such as length and colour and put into five groups (see below). The unknown collected hair samples were then examined and compared to the reference samples, and put into one of the five groups. Within group differences were not apparent from gross morphology therefore microscopic examination was required. Cuticular scale patterns were investigated by making an impression of each hair on a slide and then examining it using a light microscope.

Two methods were tested:

Method One:

3mls of glycerine were mixed with 94mls of warm water, 3g of gelatine and 1g of carbolic acid (a preservative; Kitsosi 1995). This mixture was then slowly heated, allowing the gelatine to dissolve in the glycerine. A few drops were then placed on a clean slide and spread evenly. The hair specimen was then placed in the fluid, and left for 1 hour allowing the medium to solidify around the hair. After an hour the hair was removed with a fast jerk revealing the scale pattern (Kitsosi 1995). The impression was then examined with a light microscope at 10x and 40x magnification.

Method Two: adapted from Quadros and Monteiro (2006)

A thin coat of clear fingernail polish was applied to a clean microscope slide, it was then allowed to dry for a minute. After which the hair specimen was placed on the nail polish and left for 1 hour to set. The hair was then removed with a fast jerk and examined with a light microscope at 10x and 40x magnification.

Method one was found to only work with long, or coarse hairs. The shorter, non-coarse hairs did not leave an impression in the gel, which meant that over half of the hairs could not be examined fully. It was decided to use method two to examine all the hairs as it worked with over 90% of the unknown hairs and all of the reference collection.

2.3 Analysis

The first stage of analysis was to compile a key to make identification of unknown samples possible. The reference samples were divided into five groups:

Group 1: Red coloured hairs

Group 2: Various colours, fluffy hairs

Group 3: Black hairs

Group 4: Miscellaneous hairs

Group 5: Two tone coloured hairs

They were then examined microscopically as explained in the procedure outlined above. The classification of the different forms of cuticular scale pattern was adapted from Perrin and Campbell (1980) and Kitsosi (1995):

- Cupped: one scale across the diameter of the grooved side of the hair. Clear overlapping of the scales with the distal edges being smooth and rounded on the shoulders of the groove. There is a shallow depression in the scale edge in the groove of the hair.
- Coronal: one scale across the diameter of the hair. The scales clearly overlap and appear to completely encircle the shaft of the hair
- Chevron: the scales are roughly 'V' shaped with definite crests and troughs.
- Petal: scales appear as distinct overlapping units. The arrangement and shape of the scales may be regular or irregular.
- Pectinate: scales may appear as discrete units or as a row of units. They are of a more elongate shape, with more pointed tips and straighter sides compared to petal scales.
- Mosaic: scale pattern appears as a number of discrete non-overlapping units. Mosaic scales are of a circular form or a more common flattened form. Flattened mosaic scales have a greater transverse than longitudinal dimension. In circular mosaic scales these dimensions are approximately equal.
- Waved: (divided into coarse waved and fine waved): this scale pattern is generally characteristic of coarser hairs. The scales do not appear as discrete units. In the coarse waved pattern the scale margins are the greater distance apart, in fine waved pattern the scale margins are lesser distance apart.
- Elongate: Scales overlap each other tapering to a rounded point
- Simple: Coronal scales (make a complete circle around hair) with flat edges

Each hair was identified from this classification, if it did not fit in to any of the descriptions it was left as unidentified, some hairs had no cuticular scale pattern [Appendix 2].

The second stage of analysis was to use the key to identify the samples collected from the hair traps in Tanzania.

Results:

A total of 163 unknown hair samples were analysed. As shown in Table 1 the majority of the unknown hair samples were from mongooses, genets and Harvey's duiker (*Cephalophus harveyi*). Some samples could not categorically be assigned to one species in these cases hairs were assigned to the closest reference sample and classed as "possible". Hairs that did not look like any of the reference samples or did not make a good impression were classed as "unassigned" (See Table 1)

Table 1: Number of unknown hairs identified per species. See text for definitions of Possible and Unassigned

Species:	**Number:**	**Possible:**
Common duiker (*Sylvicapra grimmia)*	8	2
Harvey's duiker *(Cephalophus harveyi)*	13	1
Abbott's duiker (*Cephalophus spadix)*	1	1
Bushbuck (*Tragelaphus scriptus)*	7	0
Suni (*Neotragus moschatus)*	6	0
White tailed mongoose (*Ichneumonia albicauda)*	12	1
Bushy tailed mongoose (*Bdeogale crassicauda)*	8	0
Mellers mongoose (*Rhynchogale melleri)*	11	7
Savanna Cane Rat (*Tryonomys swinderianus)*	1	0
African Palm Civet (*Nandinia binotata)*	1	0
Aardvark (*Orycteropus afer)*	6	1
Banded Mongoose (*Mungus mungu)*	4	0
Natal Red rock hare (*Pronolagus crassicaudatus)*	1	0
Serval (*Felis serval)*	0	1
Crested Porcupine (*Hystrix africaeaustralis)*	4	0
Small spotted genet (*Genetta genetta)*	11	0
Ratel (Honey badger) (*Mellivora capensis)*	4	1
Zorilla (*Ictonyx striatus)*	9	0
Blotched genet (*Genetta maculate)*	1	0
Wild cat (*Felis sylvestris)*	7	1
Warthog (*Phacochoerus africanus)*	2	0
Slender mongoose (*Herpestes sanguinea)*	2	0
African Civet (*Civettictis civetta)*	1	0
Marsh mongoose (*Atilax paludinosus)*	4	0
Chequered elephant shrew *(Rhynchocyon cirnei*)	2	0
Unassigned	21	

Of these 163 unknown hair samples 108 hairs (not including those that are unassigned) were collected from different traps at known locations along the transects. The remaining 34 hairs were collected opportunistically therefore cannot be assigned to a habitat. Within the two transects there were three different habitats: miombo (savannah) woodland, open regenerating vegetation, and mature forest. Table 2 shows how many of the hairs were identified to each species in each of the three habitats.

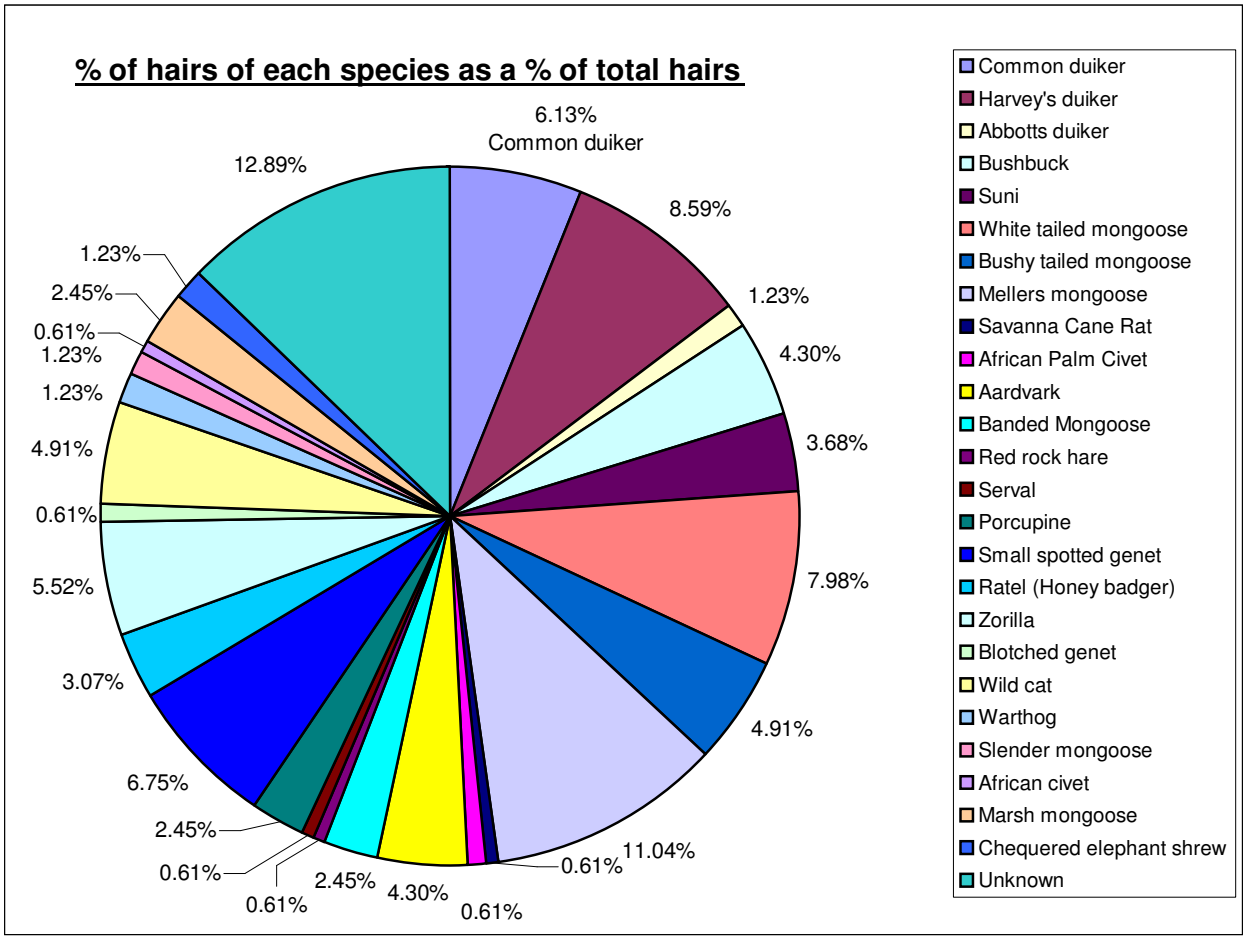
Table 2: Number of hairs per species identified in the three different habitats of the Udzungwas

Habitat -	**Mature Forest:**	**Miombo Woodland:**	**Open regenerating vegetation:**	**Unknown habitat:**
No of traps per habitat:	9	6	1	
Mean no of hairs per trap:	7	5.67	11	
Species:				
Common duiker	2		2	6
Harvey's duiker	3	1		10
Abbott's duiker				2
Bushbuck				7
Suni	1	1	1	3
White tailed mongoose	5	5	1	2
Bushy tailed mongoose	4	1	2	1
Mellers mongoose	4	12	1	1
Savanna Cane Rat				1
African Palm Civet				1
Aardvark	5	2		
Banded Mongoose	1	3		
Red rock hare		1		
Serval		1		
Porcupine	3	1		
Small spotted genet	8		3	
Ratel (honey badger)	4		1	
Zorilla	8	1		
Blotched genet	1			
Wild cat	6	2		
Warthog	2			
Slender mongoose	1	1		
African Civet		1		
Marsh mongoose	3	1		
Chequered elephant shrew	2			
TOTAL	63	34	11	34

As shown in the table the most 'successful' habitat for the hair traps was the open regenerating vegetation – this trap 'caught' a variety of species. The majority of the species identified in each of the different habitats are expected to inhabit the habitats they have been found in, apart from the warthog – this species would normally be found in open grass or woodland savannah (Stuart and Stuart 1997).

To identify the species most found in the Udzungwa Mountains through hair samples percentages were calculated showing how many of each species were present as a percentage of the total hairs identified. As shown in Figure 1 the majority of species identified were antelopes particularly Harvey's duiker and mongooses particularly Mellers mongoose.

Figure 1: Percentage (to 2 decimal places) of hairs of each species as a percentage of the total number of hairs collected



Another method of surveying the Udzungwa Mountains was using camera traps. These were set up in the same area of the hair traps; the data shown below is from the same period in which the hair traps were checked plus another six-month period. Comparisons were made to see if hair trapping is a valuable way of measuring abundance.

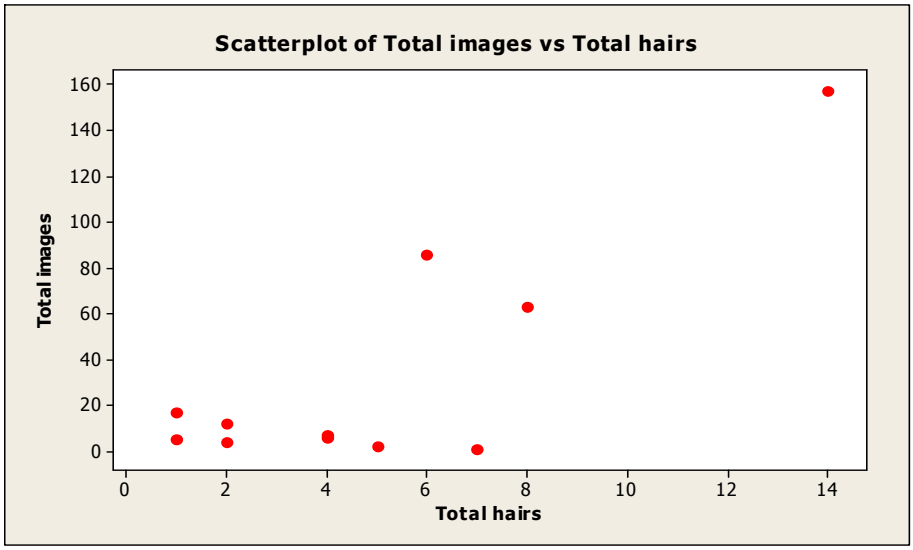
Table 3: Number of times each species was 'caught' by a camera trap (F. Rovero unpubl.). Also % of times each species was identified by camera images and hair samples. (Species in red recorded by both methods)

Species	Total events	% of camera images	% of hairs
Abbott's duiker	12	2.42	1.23
Bushy tailed mongoose	63	12.70	4.91
Buffalo	4		
Bush pig	19		
Giant pouched rat	38		
Harvey's duiker	157	31.65	8.59
Leopard	1		
Mangabey	54		
African Palm civet	5	1.01	0.61
Porcupine	6	1.21	2.45
Servaline genet	10		
Suni	86	17.34	3.68
Aardvark	1	0.20	4.30
BW Colobus	2		
African civet	17	3.43	0.61
Elephant	1		
Fruit bat	2		
Honey badger	2	0.40	3.07
Marsh mongoose	7	1.41	2.45
Chequered elephant shrew	4	0.81	1.23
Sykes monkey	4		
Unidentified	1		
TOTAL	**496**	**72.58**	**33.13**

Only 11 of the 21 species caught by the camera traps were also found in the hair samples. There were also many species identified by hairs but not on camera traps: common duiker, bushbuck, white tailed mongoose, mellers mongoose, savanna cane rat, banded mongoose, red rock hare, serval, small spotted genet, zorilla, blotched genet, wild cat, warthog, slender mongoose.

A spearman rank correlation coefficient test was carried out between the total number of hairs and the total number of camera images for the 11 species 'caught' by both to show if there is a correlation between the two methods used. The correlation test showed that for those species included in the test there is a strong positive correlation between the number of hairs and the number of images and there is a significant relationship between hair trap and camera trap captures across species ($r = 0.825$, $p = 0.002$).

Figure 2: Scatterplot to show correlation between total images and total hairs



A paired t test was carried out between the total number of hairs and the total number of camera images for the 11 species 'caught' by both to show if there is a significant difference for capturing hairs between the two methods used. The paired t test showed that for the 11 species included in the test there is no significant difference in the number of images and the number of hairs ($t = 1.98$, $df = 10$, $p = 0.076$).

The two tests showed that hair trapping generally correlates with camera trapping in that it picks up many of the same species, however there is a lot of error and many species do not correspond all that well therefore there are also significant differences between the techniques. Given these results there is scope for further work to test the validity of these two techniques for measuring species population.

Discussion:

The key that has been formulated has identified 37 species of mammal on the basis of cuticular scale patterns. However, the key has a number of limitations. The main limitation is that it is not always possible to differentiate between some species in the same group. Perrin and Campbell (1980) were unable to differentiate between Cape and Scrub Hare; the same problem was encountered with this project. Further work is required to develop the key to avoid this overlap. Another limitation is that the key is based on hair samples from one region of the pelage of one specimen for each species. Although in all cases at least 5 hair fibres of each species were studied when determining diagnostic criteria, it would not be realistic to assume that all hairs from all individuals of a species would show the same characteristics. Many previous studies have looked at whether or not diet, age, season and the sex of an individual have an effect on the cuticular scale pattern (Day 1966; Keogh 1975; Rustiati and Chanin 2000). Day (1966) and Keogh (1975) both found that the only parameter that caused significant scale pattern variation was age – the hair of sub adults in small mammals was presented in a simplified form compared to those of adults. Perrin and Campbell (1980) and Dreyer (1966) also found that hair fibres from younger individuals varied slightly in morphology, however the sex of an individual had no effect on the cuticular scale patterns of the hairs.

Variations in hair characteristics might also occur between different regions of the pelage. Rustiati and Chanin (2000) found no differences within species in hairs from different parts of the body, sex or age of the animal. Day (1966) also found that hairs of the head, feet and other extremities of small mammals had a similar but reduced form to the scale patterns of body hairs. This is consistent with the results in this study. Unfortunately it was not possible to collect hairs from the species listed in the key, as these animals are not held in the Paignton Zoo collection, therefore hairs from Black and white colobus (*Colobus polykomos polykomos*), Abyssinian colobus (*Colobus guereza kikuyuensis*), Brazilian Tapir (*Tapirus terrestris*), Hartmann's Mountain zebra (*Equus zebra hartmannae*) and Domestic cat (*Felis catus*) were examined.

The hairs were taken from the head, shoulder region, arm (or fore leg), rear leg and tail, from different aged individuals and both males and females. There did not appear to be any difference in the cuticular scale pattern of any of the hair fibres.

All of the hair samples used in the formulation of the key were obtained from a museum. Keogh (1975) compared the cuticular scale patterns of hair from live specimens with those of museum specimens to determine the effect of museum storage on cuticular structure – the effect was found to be negligible.

A final source of variation is the variation that is always present between individuals of a particular species. The sampling and comparison of a large number of individuals of a particular species is the only way to eliminate this factor. Unfortunately, due to the nature of hair collection this was not possible. The only variation found in this study was in African Clawless Otter (*Aonyx capensis*), Perrin and Campbell (1980) reported the hairs had a distinct fine waved pattern, however the reference hair samples showed an elongate pattern. The reason for this discrepancy between the two studies is unclear.

It should therefore be noted that due to the nature of the collection method of the unknown hair samples, it is not known where on the body these hair samples were taken from or indeed the age of the animal at the time of sampling. Although this study, along with others have shown there to be no differences in hair samples compared to age, sex or sample site the characteristics stated in this report should not be considered absolute.

The use of other features of hair morphology in addition to cuticular scale pattern might enable the determination of more definite criteria to differentiate between species with similar scale patterns. Others studies have used a range of morphological characteristics of hair in the formulation of keys for hair identification. Rustiati and Chanin (2000) and Gonzalez-Esteban *et al*. (2006) used medulla type. In general only thicker hairs have a medulla, and the thicker the hair, the greater the width of the medulla (Ryder 1973). Melville *et al*. (2004) and Kaunda and Skinner (2003) used methods to examine the

cross section shape of hairs. A scanning electron microscope was used by Perrin and Campbell (1980) – the electron micrographs showed more detail of cuticular scale patterns than images from a light microscope. However, an electron microscope does not always produce clear images especially when the hairs are fine and short.

The method used in this study worked well for all of the reference samples and unknown samples. It was cheap, easy and quick to set up and execute and once prepared the impressions could be kept for weeks without deterioration (in a cool, dry, dust free environment). The only limitation to the method was the quality of the images, a scanning electron microscope would be better, however this is more time consuming and costly.

The use of hair traps for surveying and monitoring the mammalian species of the Udzungwa Mountains relies on the fact that hairs can be identified to species accurately and reliably. This study has successfully identified 25 different mammal species in the areas surveyed, however out of these 25 only 11 were caught by the camera traps set up in the same area at the same time and other species were caught by the camera traps and not found in the hair samples. The reason why some animals may have been caught on camera but not by the hair traps could be due to the size and shoulder height of the animal. For example, an elephant or a buffalo would just crush the hair traps due to its sheer size and weight; and a colobus or Sykes monkey might just stay too high above ground to be caught by the hair traps.

Some of the species, servaline genet (*Genetta servalina lowei*), are thought to inhabit this area, however, it was not possible to get reference hair samples for every species particularly the East African endemics (Appendix 1). Therefore there may well be hairs of these species in the collected samples but identification was not possible due to the lack of reference samples. There are also other species for which reference samples were not collected, as it was not thought they would be 'caught' by the hair traps – elephant, buffalo, leopard, mangabey, Sykes, colobus monkey and fruit bat. Only two of the species caught by the camera traps for which there were reference samples

were not identified in the hair samples – bush pig and giant pouched rat. There appears to be no explanation for this discrepancy.

Further work is required to develop this study, to make the key more absolute. More reference hair samples need to be collected to include the remaining possible species that inhabit the area such as servaline genet, also samples from different parts of each animal such as head, tail and shoulder to see if there is a variation amongst these species and if this effects the identification of collected samples. A micrometer could also be used to measure the distances between scales on the cuticular pattern as for some species such as the common and harvey's duiker the patterns look very similar. If distances were to be noted then a definitive key with measurements could be given. A scanning electron microscope would also be very useful and could help to produce better quality images to help refine the key.

Conclusion:

This study has shown that hair trapping is a valuable way of showing, which species live in an area including those that may be difficult to survey visually. There were differences in results between hair analysis and camera trapping in terms of species recorded and it may be that hair analysis is best employed in the identification of prey remains in scat or in situations where camera traps are not available. If the key illustrated is developed further it will be possible to use it in other studies to identify species from other East African areas.

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Appendix One **Reference hair samples**

Common name	Scientific name	Accession number (begins MAMNMZB) from Natural History Museum, Zimbabwe
	Macroscelidea	
	Macroscelidinae	
Four-toed elephant shrew	*Petrodromus tetradactylus*	80591
	Rhyncocioninae	
Chequered elephant shrew	*Rhynchocyon cirnei*	64749
Grey-faced elephant shrew	*Rhynchocyon sp. nov. (In press)*	
	Rodentia	
	Hystricidae	
Crested (South African) porcupine	*Hystrix africaeaustralis*	55719
Savanna cane rat	*Tryonomys swinderianus*	50114
Giant pouched rat	*Cricetomys gambianus*	69352
	LAGOMORPHA	
	Leporidae	
Scrub Hare	*Lepus saxatilis*	66094
Cape Hare	*Lepus capensis*	67635
Natal Red Rock Hare	*Pronolagus crassicaudatus*	29439
	Carnivora	
	Mustelidae	
African clawless otter	*Aonyx capensis*	68643
Zorilla	*Ictonyx striatus*	10382
Striped Weasel	*Poecilogale albinucha*	
Ratel (Honey Badger)	*Mellivora capensis*	66005
	Viverridae	
Small spotted (Common) genet	*Genetta genetta*	68119
Blotched (Large spotted) genet	*Genetta maculata*	54653
Lowe's servaline genet	Genetta servalina lowei	
African Civet	*Civettictis civetta*	68588
African Palm civet	*Nandinia binotata*	68566
	Herpestidae	
Slender mongoose	*Herpestes sanguinea*	7096
Egyptian mongoose	*Herpestes ichneumon*	68547

Dwarf mongoose	*Helogale parvula*	68474
Banded mongoose	*Mungus mungu*	10262
Marsh mongoose	*Atilax paludinosus*	68338
White-tailed mongoose	*Ichneumonia albicauda*	54259
Meller's mongoose	*Rhynchogale melleri*	27206
Bushy-tailed mongoose	*Bdeogale crassicauda*	Corpse found at 4000m Mwanihana Trail
Jackson's mongoose	*Bdeogale jacksoni*	
	Felidae	
Wild Cat	*Felis sylvestris*	9954
Serval	*Felis serval*	55024
Caracal	*Felis caracal*	67916
	Tubulidentata	
	Orycteropodidae	
Aardvark	*Orycteropus afer*	34408
	Hyracoidea	
	Procavidae	
Eastern tree hyrax	*Dendrohyrax validus*	
Bush (yellow spotted) hyrax	*Heterohyrax brucei*	68859
Rock hyrax?	*Procavia capensis*	68695
	Artiodactyla - Suidae	
Bush pig	*Potamochoerus larvatus*	20695
Warthog	*Phacochoerus africanus*	25988
	Artiodactyla - Bovidae	
Blue duiker	*Cephalophus monticola*	
Harvey's duiker	*Cephalophus harveyi*	Corpse found at Mizimu, Mwanihana Forest
Abbott's Duiker	*Cephalophus spadix*	Found in confirmed sleeping site
Common (bush) duiker	*Sylvicapra grimmia*	31285
Suni	*Neotragus moschatus*	56425
Bushbuck	*Tragelaphus scriptus*	60843
Klipspringer	*Oreotragus oreotragus*	21923

Species in red text are ones known to inhabit the Udzungwa Mountains but reference samples were not obtained.

Appendix Two
Key to mammal hairs from the Udzungwa Mountains, Tanzania

Species:	**Hair characteristics:**	**Cuticular scale pattern:**
Group 1: Reddish coloured hairs		
Bushbuck *Tragelaphus scriptus*	Red/brown, short and coarse	Flattened
Suni *Neotragus moschatus*	Light brown/red with white tip, shot and fluffy	Simple, flattened in some places
African Clawless Otter *Aonyx capensis*	Some dark brown, others light brown. Very short and velvety	Elongate
African Civet *Civettictis civetta*	Red with black parts, some short and fluffy, other long and coarse	Fine waved (very faint)
Common Duiker *Sylvicapra grimmia*	Bright red colour, short and fairly coarse	Coarse waved
Bush Pig *Potamochoerus larvatus*	Light brown mostly with dark brown/black on tip. Some long, some short and coarse	Flattened mosaic (very faint)
Savanna Cane Rat *Tryonomys swinderianus*	Dark brown/red with light brown bits, short and coarse	Flattened mosaic (very faint, extra border)
Harvey's duiker *Cephalophus harveyi*	Red, fairly long	Coarse waved (similar to common duiker but more compact and wider)
Group 2: Soft hair, different coloured hairs		
Cape Hare *Lepus capensis*	Some light beige/white, short and fluffy. Others coarse, short and brown	Chevron*[1]
Scrub Hare *Lepus saxatilis*	Beige, short and fluffy	Chevron*[1]
Natal Red Rock Hare *Pronolagus crassicaudatus*	Light brown, very soft and short	Chevron*[1]

African Palm Civet *Nandinia binotata*	Some beige, short and fluffy. Others brown, short and coarse	Pectinate
Caracal *Felis caracal*	Light brown, very short and fluffy	Flattened mosaic
Group 3: Black hairs, varying lengths		
Aardvark *Orycteropus afer*	Dark brown, short and very coarse	No pattern (slightly flattened at midpoint, similar to warthog) *2
Warthog *Phacochoerus africanus*	Black, very long and very coarse – bristle like	No pattern *2
Wild Cat *Felis sylvestris*	Brown and black. Short and coarse	Coarse waved (very faint)
Small Spotted Genet *Genetta genetta*	Some black, long and coarse. Others beige, short and fluffy	Flattened mosaic (neater than mongoose, less compact)
Chequered Elephant Shrew *Rhynchocyon cirnei*	Dark brown/black, short and fluffy (some coarse)	Coarse waved
Ratel (Honey badger) *Mellivora capensis*	Black/dark brown. Some short, some long. Coarse	Fine waved *3
Zorilla *Ictonyx striatus*	White, beige, black. Short and fluffy	Petal
Marsh Mongoose *Atilax paludinosus*	Black and dark brown. Some long and coarse, others short and fluffy	Fine waved *3
Bushy Tailed Mongoose *Bdeogale crassicauda*	Black, long and coarse	Flattened mosaic (more erratic pattern and wider gap between scales than genet)
Group 4: Miscellaneous hairs		
Yellow Spotted Hyrax *Heterohyrax brucei*	Beige and black, very short and fairly coarse	Flattened mosaic *4
Rock Hyrax *Procavia capensis*	Greyish, very short and fine	Simple
Giant Pouched Rat *Cricetomys gambianus*	Brown, short and fluffy	Coarse waved
Four Toed Elephant Shrew	Black and grey, short and fluffy	Pectinate

Petrodromus tetradactylus		
Dwarf Mongoose *Helogale parvula*	Dark brown/black. Some short and fluffy, others coarse	Flattened mosaic *4
Abbott's Duiker *Cephalophus spadix*	Pale with black end	Fine waved, wide
Group 5: Two tone coloured hairs		
Blotched Genet *Genetta maculata*	Some brown, some black. Short, some fluffy, some coarse	Petal
Slender Mongoose *Herpestes sanguinea*	Light brown and dark brown. Short and fairly coarse	Fine waved (very faint compared to Egyptian and Banded mongoose)
Mellers Mongoose *Rhynchogale melleri*	Light and dark brown striped. Long and coarse	Coarse waved (neat, overlap of lines)
Egyptian Mongoose *Herpestes ichneumon*	Dark brown with white bits, long and coarse	Fine waved *5
Banded Mongoose *Mungus mungu*	Beige, brown and black. Fairly long and coarse	Fine waved *5
Klipspringer *Oreotragus oreotragus*	White, brown and black. Short and very coarse	Flattened mosaic
Crested Porcupine *Hystrix africaeaustralis*	Dark brown and white, short and thick	No pattern (blotchy)
Serval *Felis serval*	Fawn with black tip. Short and fluffy, some long and coarse	Fine waved (very faint)
White Tailed Mongoose *Ichneumonia albicauda*	Light and dark brown. Short and fluffy, some long and coarse	Coarse waved (more erratic than Mellers no overlapping)

*1 - The hair fibres of *Lepus capensis, Lepus saxatilis* and *Pronolagus crassicaudatus* all show a chevron pattern. No satisfactory criterion was found to differentiate between the hairs of these species. A micrometer or SEM images may help to give more detail.
*2 – As both *Orycteropus afer* and *Phacochoerus africanus* show no pattern, to differentiate between the 2 species morphological characteristics must be used.
*3 - *Mellivora capensis* and *Atilax paludinosus* show the same fine waved cuticular scale pattern. Lengths of hairs (*Mellivora capensis* were longer) were

used to differentiate between the two, a micrometer or SEM images may help to give more detail in future work

*[4] – The hair fibres of *Heterohyrax brucei* and *Helogale parvula* both show a flattened mosaic pattern. To differentiate between the 2 species morphological characteristics must be used, *Helogale parvula* are much darker.

*[5] - *Herpestes ichneumon* and *Mungus mungu* both show the same fine waved cuticular scale pattern. *Mungus mungu* are much lighter hairs.