
Abstract: Analysis of prey remains in scats, particularly hairs, is widely used to study diet of mammalian predators, but identification of hair is often difficult because hair structures vary considerably both within and between species. Use of photographic reference of diagnostically important hair structures from mammals occurring in a predator's habitat has been found to be convenient for routine identification. A photographic reference key was developed for the identification of hairs of the mammals known to occur in a snow leopard (Panthera uncia) habitat in the Annapurna Conservation Area, Nepal. The key included a photographic reference of the diagnostic hair structures of nine species of wild and five species of domestic mammals. The cross-sectional appearance, shape and arrangement of medulla, the ratio of cortex to medulla, and the form and distribution of pigment in medulla and cortex were important diagnostic aids in the identification of hairs.
A key for the identification of the hair of mammals of a snow leopard (Panthera uncia) habitat in Nepal

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Analysis of prey remains in scats, particularly hairs, is widely used to study diet of mammalian predators, but identification of hair is often difficult because hair structures vary considerably both within and between species. Use of photographic reference of diagnostically important hair structures from mammals occurring in a predator’s habitat has been found to be convenient for routine identification. A photographic reference key was developed for the identification of hairs of the mammals known to occur in a snow leopard (Panthera uncia) habitat in the Annapurna Conservation Area, Nepal. The key included a photographic reference of the diagnostic hair structures of nine species of wild and five species of domestic mammals. The cross-sectional appearance, shape and arrangement of medulla, the ratio of cortex to medulla, and the form and distribution of pigment in medulla and cortex were important diagnostic aids in the identification of hairs.

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Introduction

Knowledge of a predator’s diet is important for understanding its ecology and for predicting its influence on the dynamics of prey populations. However, it is often difficult to study the diet of mammalian predators, especially if the study species is solitary and elusive, as is the snow leopard (Panthera uncia). This is because of difficulties in observing elusive predators hunting and feeding. Even when kills are available for examination, they are usually too few to draw any conclusion. Furthermore, this method of studying a predator’s diet may be biased towards larger prey as the remains of larger prey are relatively easily detected, whereas small prey may be consumed completely. Analysis of stomach contents is one of the methods used to study the diet of
mammalian carnivores but for endangered species these are seldom available. Therefore, analysis of prey remains in scats (faecal deposit) is often the only method available for the investigators to study the diet of mammalian predators.

A common problem in dietary studies of mammalian predators based on faecal analysis is that more obvious characteristics of the prey consumed are lost in the process of mastication and digestion. Investigators, therefore, have to depend entirely on hard, indigestible parts of the prey such as hair, teeth and bones. Larger bones and teeth are generally fragmented, and are of little use. However, hair suffers little in the process of digestion, and retains many identifiable features. The identification of remains, in particular, hairs, has been reliably used in the dietary studies of a wide range of mammalian carnivores (e.g. coyote *Canis latrans*: Howethorne, 1972; Gipson, 1974; Leopold & Krausman, 1986; fox *Vulpes vulpes*: Leopold & Krausman, 1986; bobcat *Lynx rufus*: Frickett, 1971; Beasom & Moore, 1977; Bailey, 1979; Maheer & Brady, 1986; wolves *Canis lupus*: Voigt, Kolenosky & Pimlott, 1976; Fritts & Mech, 1981; mountain lion *Felis concolor*: Leopold & Krausman, 1986; Emmons, 1987; feral cats *Felis catus*: Coman & Brunner, 1972; Liberg, 1984; jaguar *Panthera onca* and ocelot *Felis pardalis*: Emmons, 1987; cougar *Felis concolor*: Ackerman, Lindsey & Hemker, 1984; snow leopard *Panthera uncia*: Oli, 1991).

However, it is often difficult to identify hairs because hair structures vary considerably both within and between species, and also because hair structures of distantly related or even unrelated mammals may overlap considerably. A key for the identification of the unknown hairs is often necessary as an aid to identify accurately unknown hairs in scat samples. Descriptive keys for the identification of mammalian hairs have been attempted in the past (e.g. Mathaik, 1938; Mayer, 1952; Stains, 1958), but such keys are often difficult to use for the routine identification of unknown hair, mainly because hair structures vary considerably and are vulnerable to subjective description. Similarly, direct comparison of hair structures (cross-section, whole mount and scale pattern) with the known reference slides are time consuming for routine identification. Compared to the direct comparison and descriptive dichotomous key, photographic reference has been found more convenient and easy to use in the routine identification of unknown hairs (Brunner & Coman, 1974).

This paper presents a photographic reference key for the identification of the hair of mammals known to occur in the upper Marsyangdi valley of the Annapurna Conservation Area, Nepal (28° 30’ N. 82° 15’ E– 84° 5’ E). Although this key was developed to study the diet of the snow leopard in Nepal, with the addition of a few more mammals in the key it can also be used to study the diet of snow leopards and other predators of high-altitude Himalayan and trans-Himalayan ecosystems.

*Hair types and structure*

To use the key conveniently, a knowledge of hair types and structures is essential. Therefore, a brief description of main hair types and basic structure is given below.

Broadly, five types of hair have been recognized (Brunner & Coman, 1974): vibrissae, bristle hair, over-hairs, guard hair and under-hair. Other types exist, such as pad hair, but are seldom encountered during dietary studies. Vibrissae are widest in the proximal half and become narrower towards the tip. Bristle hairs are rigid and of uniform diameter, with narrow or no medulla, and are found only in some mammals such as some breeds of domestic pig. Over-hairs are sparsely distributed along the body and are conspicuously longer than other hairs. They generally appear circular in cross-section, and like vibrissae and bristle hairs, are of little diagnostic value. Under-hairs or fur are fine and very short. They are generally wavy, and of uniform thickness except at the
tip, where they taper. Guard hairs are of intermediate length, and are the larger and coarser of the hairs that form the main portion of pelage of most mammals. The base and tip are circular but the central portion becomes flattened and wider, and is known as the shield. It is the largest of these guard hairs, known as primary guard hairs, which are most important in hair identification as they exhibit diagnostically useful features.

Hair is composed of keratin, and consists of three layers (Brunner & Coman, 1974): the central core or medulla, a layer of cortex surrounding the medulla, and an outermost layer, the cuticle. The medulla is composed of an aggregation of shrunken cells and air spaces and appears dark under the microscope. By infiltrating the air spaces between the cells of the medulla with suitable mounting medium, detailed structure can be revealed which varies greatly between species, and also between different hair types of the same species. On the basis of the general shape and arrangement of medullary materials, 12 distinctly different types of medulla have been recognized (Brunner & Coman, 1974).

The cortex is also composed of dead cells packed into a homogeneous mass not clearly visible under the light microscope. There is considerable variation in its width and in the ratio of cortex to medulla between the hair of different species, and also along the length of the same hair.

The cuticle or the epidermal layer forms the thinnest, outermost and often transparent layer of hair and consists of overlapping scales. Along the length of a hair, scales are flattened against the main hair body with their main body pointing towards the hair tip, and are arranged in a way similar to tiles on a roof. Brunner & Coman (1974) recognized 12 different types of scale patterns on the basis of their shape and arrangement.

Methods

Reference hair samples were collected from mammals, both domestic and wild, known to occur in and around the study area. Hairs were collected in complete tufts from different body parts which included a representative sample of all hair types. Although the Himalayan tahr (Hemitragus jemlahicus) is not found in the study area, it was included in the key because it occurs in the snow leopard’s range elsewhere in Nepal (Jackson & Ashburn, 1989). Hairs of Himalayan marmot (Marmota himalayana) and Himalayan tahr were generously provided by the British Museum (Natural History), London, and the National Museums of Scotland (Natural History), Edinburgh, respectively.

A full tuft of hair, that included all hair types, was cleaned thoroughly in an ether-alcohol mixture (1:1) and was dried between blotting paper. The hairs were then studied according to the methods described by Brunner & Coman (1974) with some modifications.

Whole mount

A tuft of clean hair was placed on a clean microscope slide. Individual hairs were well separated from each other to avoid an untidy jumble of hairs on the slide. Long hairs were cut into 2 or more pieces before they were placed on the glass slide. Euparal was used as mounting medium for preparing permanent reference slides, whereas paraffin oil was used as a temporary mounting medium for the routine identification of unknown hairs.

Cross-section

Hair cross-sections were obtained using a stainless steel slide of 75 × 25 × 0.25 mm dimensions with 2 holes of 0.5 mm diameter. A folded nylon thread was sent through the hole into which a packing yarn of 330 decitex cellulose acetate was introduced. The packaging material was pulled a short distance with the help of the thread, and a tuft of clean and dry hairs was introduced into the centre of the fan of the packaging material. The hair and the packaging material were then pulled through the hole until the whole bundle was tightly
secured in the hole. The hair bundle with the packaging material of the cellulose acetate yarn was cut flush on both sides of the plate with a new sectioning blade. The cross-sections were then studied under the microscope after placing a drop of liquid paraffin and a coverslip directly over the sectioning hole. It was important to keep the sectioning slides highly polished, clean and slightly contoured on both sides to obtain good results. The plate could be re-used after removing the cross-sections from the hole, and cleaning it thoroughly.

**Scale replication**

A thin coating of 5% polyvinyl acetate (pva) in acetone was applied to one side of a coverslip using a flat brush. It was then allowed to dry until no longer sticky. Clean, dry hairs were placed on the coverslip, some with the lower shaft region overhanging and some with the tip overlapping the edge of the coverslip. A clean glass slide was placed on top of the cover slip and all hairs were gently pressed into the medium which was then allowed to dry. The hairs were then removed gently from the medium by holding individual hairs with a pair of fine forceps. The coverslip was then inverted on to a microscope slide and the scale replica was studied under the microscope. It was often necessary to make several cross-sections or scale casts before a good one could be obtained.

**Microphotography**

Microphotographs of the representative cross-sections, medulla and scale patterns along the length of the hairs of each species were taken at a standard magnification. Permanent slides could be prepared only of whole mounts. It was therefore necessary to photograph the scale patterns and cross-sections as soon as possible. Since both medullary arrangements and cuticular scale patterns varied considerably along the length of an individual hair, it was necessary to take several photographs of each of these structures for each species. However, only photographs of representative and predominant patterns were included in the key for the sake of convenience.

*Using the key for the identification of unknown hairs in scat samples and determination of prey consumed*

Scat samples were washed with tap water in a fine mesh sieve and oven dried at a temperature of approximately 60°C. Each sample was further cleaned in an ether-alcohol mixture (1:1) and dried between absorbent paper for detailed examination.

The clean and dry hairs were examined visually or studied under the binocular microscope, and different types of hair present in each scat sample were separated. It was often possible to differentiate the major prey groups, such as small and large mammals, only on the basis of the texture and colour of hair after examining them visually or under the binocular microscope. Cross-sections, whole mounts, and scale casts of each hair present in each scat sample were prepared according to the methods described above. The hairs were then grouped and sub-grouped on the basis of cross-sectional appearance and arrangement of medulla, which made further comparisons easier. Prey species consumed were ascertained after making a detailed comparison of all hair structures (cross-sections, medulla and scale pattern) with the photographic key.

**Results**

The key included a total of 14 species (nine wild and five domestic) of mammals known to occur in the study area (Table 1). The photographic reference key developed in the study was used to analyse snow leopard scats to study their diet (Oli, 1991).

The most valuable aids in the identification of the unknown hair was cross-sectional details,
ratio of medulla to cortex, distribution of pigments and pattern and arrangement of medulla. Scale patterns were often confusing as they varied considerably along the length of a hair and overlapped between species. However, details of cross-sections and medulla were often sufficient to identify most of the unknown hairs and producing scale casts was seldom necessary. Maximum diameter of primary guard hairs and important diagnostic features of the hairs of the mammals included in the key are presented in Table II. The photographic reference key follows (Plates I-XVI).

**Table I**

<table>
<thead>
<tr>
<th>Vernacular name</th>
<th>Scientific name</th>
<th>Photo reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue sheep</td>
<td><em>Pseudois nayaur</em></td>
<td>1a 1f</td>
</tr>
<tr>
<td>Domestic goat</td>
<td><em>Capra hircus</em></td>
<td>2a 2d</td>
</tr>
<tr>
<td>Domestic sheep*</td>
<td><em>Ovis aries</em></td>
<td>3a 3d</td>
</tr>
<tr>
<td>Domestic yak*</td>
<td><em>Bos grunniens</em></td>
<td>4a 4d</td>
</tr>
<tr>
<td>Ox cow*</td>
<td><em>Bos taurus</em></td>
<td>5a 5d</td>
</tr>
<tr>
<td>Horse*</td>
<td><em>Equus caballus</em></td>
<td>6a 6d</td>
</tr>
<tr>
<td>Snow leopard</td>
<td><em>Panthera tigris</em></td>
<td>7a 7f</td>
</tr>
<tr>
<td>Red fox</td>
<td><em>Vulpes vulpes</em></td>
<td>8a 8d</td>
</tr>
<tr>
<td>Least weasel</td>
<td><em>Mustela nivalis</em></td>
<td>9a 9e</td>
</tr>
<tr>
<td>Stone marten</td>
<td><em>Martes foina</em></td>
<td>10a 10f</td>
</tr>
<tr>
<td>Himalayan marmot</td>
<td><em>Marmota himalayana</em></td>
<td>11a 11d</td>
</tr>
<tr>
<td>Royle's pika</td>
<td><em>Ochotona roylei</em></td>
<td>12a 12d</td>
</tr>
<tr>
<td>Royle's vole</td>
<td><em>Arcticus roylei</em></td>
<td>13a 13d</td>
</tr>
<tr>
<td>Himalayan tahr</td>
<td><em>Hemigalus reinhardi</em></td>
<td>14a 14c</td>
</tr>
</tbody>
</table>

* Pure, native breeds from Manang valley, Nepal

**Table II**

<table>
<thead>
<tr>
<th>Species</th>
<th>Width of primary guard hair (µm)</th>
<th>Diagnostic features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue sheep</td>
<td>250</td>
<td>Brittle hairs, irregular c/s and wide medulla lattice.</td>
</tr>
<tr>
<td>Domestic goat</td>
<td>120</td>
<td>Details of c/s and scalloped type of medulla.</td>
</tr>
<tr>
<td>Domestic sheep</td>
<td>50</td>
<td>Wavy hairs and details of c/s.</td>
</tr>
<tr>
<td>Domestic yak</td>
<td>90</td>
<td>Details of c/s and heavily pigmented cortex.</td>
</tr>
<tr>
<td>Domestic ox</td>
<td>110</td>
<td>Details of c/s and pigmented cortex.</td>
</tr>
<tr>
<td>Horse</td>
<td>140</td>
<td>Oval to oblong c/s and widest medulla in the proximal 1/4 of hair.</td>
</tr>
<tr>
<td>Snow leopard</td>
<td>110</td>
<td>Oval to circular c/s and arrangement of medulla.</td>
</tr>
<tr>
<td>Red fox</td>
<td>100</td>
<td>Hair colour (which is black in proximal half and orange/brown in distal half).</td>
</tr>
<tr>
<td>Least weasel</td>
<td>90</td>
<td>Details of c/s and arrangement of medulla.</td>
</tr>
<tr>
<td>Stone marten</td>
<td>100</td>
<td>Medulla and scale patterns are similar to least weasel, but details of cross-section differ greatly from those of stone marten.</td>
</tr>
<tr>
<td>Himalayan marmot</td>
<td>130</td>
<td>Details of c/s, and multiserial ladder type of medulla.</td>
</tr>
<tr>
<td>Royle's pika</td>
<td>80</td>
<td>Dumb-bell to femur-shaped c/s, and typical arrangement of medulla.</td>
</tr>
<tr>
<td>Royle's vole</td>
<td>70</td>
<td>Shape of c/s similar to that of Royle's pika but arrangement of medulla is distinctly different.</td>
</tr>
<tr>
<td>Himalayan tahr</td>
<td>120</td>
<td>Details of c/s and arrangement of medulla.</td>
</tr>
</tbody>
</table>

Symbol used: c/s = Cross-sections
PLATE I. Blue sheep (Pseudis narae). 1a. Cross-section of various hairs; 1b. Whole mount of primary guard hair at the widest region; 1c. Whole mount of primary guard hair near base; 1d. Predominant scale pattern.
PLATE III. Domestic goat (cont.). 2c. Whole mount near base; 2d. Predominant scale pattern. Domestic sheep (Ovis aries). 3a. Cross-section of various hairs; 3b. Whole mount in the mid-staft region.
PLATE IV. Domestic sheep (cont.). 3c. Predominant scale pattern of primary guard hair. 3d. Scale pattern of fur hair. Domestic yak (Bos grunniens).
4a. Cross-section of various hairs. 4b. Whole mount at the widest region.
PLATE V. Domestic (control). 4c. Predominant scale pattern. 4d. Another scale pattern. Domestic ox (Bos taurus). 5a. Cross-section of various hairs. 5b. Whole mount of the widest region.
PLATE VI. Domestic ox (cont.). 5c. Scale pattern of the widest region. 5d. Another scale pattern. Horse (Equus caballus). 6a. Cross-section of various hairs. 6b. Whole mount at the widest region.
Plate VII. Horse hair. 6a. Whole mount near base showing fragmented medulla. 6b. Predominant scale pattern near root. 6c. Cross-section of various hairs. 7b. Whole mount at the widest region.
PLATE VIII. Snow leopard (cont.). 7c. Whole mount near base; 7d. Whole mount near tip; 7e. Predominant scale pattern; 7f. Scale pattern near base.
PLATE IX. Red fox (*Vulpes vulpes*). 8a. Cross-section of various hairs; 8b. Whole mount of medulla at widest region; 8c. Predominant scale pattern; 8d. Scale pattern near tip.
PLATE X. Least weasel (Mustela nivalis). 9a. Cross-section of various hairs; 9b. Whole mount at the widest region; 9c. Whole mount near base; 9d. Scale pattern near base.
PLATE XI. Least weasel (cont.). 9e. Predominant scale pattern. Stone marten (*Martes foina*). 10a. Cross-section of various hairs; 10b. Whole mount at the widest region; 10c. Whole mount near base.
Pt. XI. XII. Some matters (cont.). 10d. Scale pattern near base. 10e. Prominent scale pattern. 10f. Another scale pattern. Himalayan marmot (Molossas).

11a. Cross-section of various hairs.
Discussion

The cross-sectional appearance of the primary guard hair is one of the most important features used in hair identification (Brunner & Coman, 1974). Apart from this, other diagnostic features included the shape and arrangement of medulla, width of the medulla, the ratio of cortex to medulla, the form and distribution of pigment in medulla and cortex, and the shape and arrangement of cuticular scales.

Although there is no doubt that the study of hair in faecal remains is the most useful aid in the identification of mammalian prey consumed by a predator, it is not free from problems. Brunner & Coman (1974) noted the following problems associated with the identification of unknown hairs in carnivore scats:

1. The considerable variety of hair types encountered even on an individual mammal;
2. Variation in structure along the length of an individual hair;
3. An appreciable degree of inter-species overlap in certain characteristics, limiting the usefulness of some structures as diagnostic aids; and
4. The laborious preparations required to study some aspects of hair structure which are used as diagnostic aids.

Indeed, the key presented here has certain limitations. First, it is primarily based on the structure of the guard hairs, so could be vulnerable to incorrect identification of the prey if the sample does not contain guard hairs. Secondly, the key does not include the structural details of the hairs from the extremes of an animal’s body such as face and food pad. And thirdly, hair of mammals which may occur in the study area but are not included in the key may be incorrectly identified. However, the key was conveniently used to analyse snow leopard scats to study their diet and gave good results (Oli, 1991). The key can also be used to analyse the scats of other predators found in the study area, and with the addition of some other species, it could be used to study the diet of snow leopards in different parts of its range in the Himalayas.

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