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共域黃喉貂與黃鼠狼之食物資源分配

Food Resource Partitioning between Sympatric

Yellow-throated Marten (*Martes flavigula chrysosphila*)

and Siberian Weasel (*Mustela sibirica taivana*)

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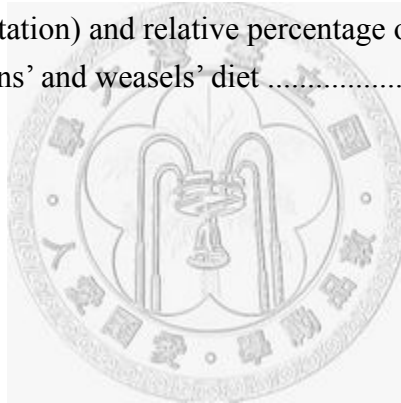
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Abstract

Similar species are often found to partition resources where they are sympatric. In carnivore community, interspecific competition is often considered an important force in forming resource partitioning. Resource partitioning among species usually corresponds to their body size. Moreover, resource availability and behavior of species may also influence resource partitioning. This study investigated food resource partitioning between two sympatric carnivores, yellow-throated marten (*Martes flavigula chrysosphila*) and Siberian weasel (*Mustela sibirica taivana*) in Nan-Hu Mountain, a high mountain ecosystem of Taiwan. The abundances of their possibly important food resources (small mammals) were also surveyed to examine the relationship between resource partitioning and resource availability. Results showed that both marten and weasel mainly preyed on small mammals, with large mammals as secondary diet item. Marten and weasel had similar diet niche breadth and high degree of diet overlap. The absence of resource partitioning related to predator body size is probably due to that weasel could also consume large mammals by exploiting their carrions. Resource partitioning between marten and weasel, both opportunistic generalists, was not in accordance to small mammal abundance but probably to seasonal availability of other food resources. Small mammals were limited resources but still important for both species in winter. Segregation in some food items between marten and weasel occurred but was not strong enough to allow the two mustelids to avoid overlap in diet.

Keywords: resource partitioning, yellow-throated marten, *Martes flavigula chrysosphila*, Siberian weasel, *Mustela sibirica taivana*, sympatry, diet, interspecific competition, opportunistic generalist

中文摘要

　　相似物種在共域活動時經常發生資源分配的情形。在食肉目動物群聚中，種間競爭常是造成資源分配的主要原因。物種間資源分配的狀況常與牠們的體型大小相關，且資源的可得性以及物種的行為也常會影響物種間資源分配。本研究探討台灣南湖大山高山生態系中共域的兩種食肉目動物：黃喉貂（*Martes flavigula chrysosphila*）與黃鼠狼（*Mustela sibirica taivana*）之間食物資源分配的情形，同時調查牠們可能的重要食物資源(小獸類)的豐度，以檢視資源分配與資源可得性之間的關係。結果顯示黃喉貂與黃鼠狼均以小獸類為最主要食物，其次為大型哺乳動物。黃喉貂與黃鼠狼有相似的食性區位幅度，以及高度的食性重疊。兩物種間並未依其體型大小產生食物資源的分配，可能原因是黃鼠狼可以透過使用屍體的方式來取食大型哺乳動物。對黃喉貂與黃鼠狼這兩種機會主義廣食者而言，決定食物資源分配的型態，不受小獸類豐度消長的影響，而可能與其他類型食物在季節上的可得性有關。在冬季，小獸類雖然是有限的食物資源，但仍是兩種掠食者重要的食物來源。黃喉貂與黃鼠狼之間在某些特定食物類別上有分化的情形發生，但其分化程度並不足以使這兩種貂科動物避開食性上的重疊。

關鍵字：資源分配，黃喉貂，黃鼠狼，共域，食性，種間競爭，機會主義廣食者

Introduction

Species with similar ecological niches are often found to shift their uses of
resources where they are sympatric (Schoener 1986). This pattern is referred as
"resource partitioning" (Walter 1991). This pattern might be caused by many factors,
such as interspecific competition (Schoener 1974), changing tolerance to
physical-chemical variables, environmental change, spatial and temporal variation in
resource availability, predation (Ross 1986) and intraguild predation (Fedriani 2000,
MacDonald 2002). Interspecific competition has long been considered an important
force in structuring the composition and resource partitioning of carnivore community
(e.g., Delibes 1983, Hersteinsson and MacDonald 1992, White *et al.* 1994, Garcia and
Virgos 2007). If competition exclusion does not occur in the assemblage of similar
species, species would be expected to coexist in suboptimal state (i.e., population size
lower than carrying capacity) or to segregate their utilization of resources (e.g., habitat,
food and time) to reduce competition and facilitate coexistence of these species (Lotka
1932, Schoener 1974, Pianka 1988).

Resource partitioning could be enhanced by difference in body size of involving
species (Schoener 1974). The divergence in morphological traits (e.g., body size) often
corresponds to the divergence in ecological traits (e.g., food) (Brown and Wilson 1956,
Sih 1993, Dayan and Simberloff 1998, 2005). That is, larger animals generally consume
larger and more varieties of prey, and have broader trophic niche breadth (Schoener
1974). Association between food resource partitioning and species body size has been
reported in fishes (Ross 1986, Schafer *et al.* 2002), invertebrates (e.g., Woodward and
Hildrew 2002, Tall *et al.* 2006), shrews (Brannon 2000) and carnivores (e.g., Martin

1994, Jones 1997, Dayan and Simberloff 1998, Jones and Barmuta 2000, Garcia and Virgos 2007). Fedriani *et al.* (2000) found that larger carnivores ate more food types and had broader niche breadth than the smaller ones. Carvalho and Gomes (2004) reported a pattern of partitioning in food resource that sympatric small carnivores take rodents as their most important food source in common and had a different secondary food item in the size corresponding to their body size.

Resource partitioning is also influenced by resource availability. In general, the degree of diet overlap among sympatric similar species would increase when their common food is abundant and decrease during lean time (Schoener 1974, 1982, Wiens 1989, Smith 1991), assuming that species would shift their diet to different food types during the lean time. However, the foraging strategy of the involving animals might also affect the result of resource partitioning. For example, opportunistic generalists may shift their diet to all of the remaining food resources. If those available food resources are similar among patches, which often is the case in lean time, overlap in the diet of these species would increase (e.g., Serafini and Lovari 1993, Padial *et al.* 2002), whereas in a community consisted of both generalists and specialists, diet overlap among species may either increase or decrease during the lean time (Carvalho and Gomes 2004). For example, when rabbits declined in autumn, the diet overlap between red fox (*Vulpes vulpes*, generalist) and wild cat (*Felis silvestris*, specialist) decreased and that between red fox and stone marten (*Martes foina*, generalist) increased. In winter, when all food resources declined and rodents were abundant, all predators preyed on rodents and their diet overlap increased (Carvalho and Gomes 2004).

Three musteline carnivores, yellow-throated marten (*Martes flavigula*

chrysosphila), Siberian weasel (*Mustela sibirica taivana*) and Formosan ferret-badger

(*Melogale moschata subaurantiaca*), were reported to be sympatric in Nan-Hu

Mountain area of Taiwan (Wu 2004a). The badger is generally considered to prey on

arthropods and earthworms (Chuang and Lee 1997, Wu 1999a). In contrast, both marten

and weasel are considered as flesh-eating carnivores and probably have strong

competition for food resource. Partitioning in food resource between yellow-throated

marten and Siberian weasel provides a suitable instance to examine how sympatric

carnivores coexist.

Species of *Martes* are generally believed to be opportunistic generalists, such as

American marten (*Martes americana*) (Strickland and Douglas 1987, Thompson and

Colgan 1990, Ben-David *et al.* 1997), pine marten (*Martes martes*) (Jędrzejewski *et al.*

1989, Brainerd 1990, Storch *et al.* 1990, Zalewski *et al.* 1995, Pulliainen and Ollinmäki

1996, Helldin 2000, Putman 2000), sable (*Martes zibellina*) (Brzezinski 1994, Bao *et al.*

2003), stone marten (*Martes foina*) (Lanszki *et al.* 1999, Padial *et al.* 2002, Carvalho

and Gomes 2004) and Tsushima marten (*Martes melampus tsuensis*) (Tatara and Doi

1994). Diet of yellow-throated marten includes rodents, birds, fruits (Lekagul and

McNeely 1977, Roberts 1997, reviewed in Grassman *et al.* 2005), as well as Himalayan

tahr (*Hemitragus jemlahicus*), flying-squirrels, insects and reptiles (Green 1985,

reviewed in Sathyakumar 1999), which suggests that yellow-throated marten is a

generalist predator consuming a variety of food items.

Siberian weasel varies their diet in different habitats but generally consumes

considerable amount of small mammals. Ma (1990) reported that, in an alpine grassland

ecosystem of Taiwan, 92 % of the diet of Siberian weasel was small mammals. In a

subtropical broadleaf forest ecosystem of Taiwan, weasel mainly consumed arthropods (44 %) and mammals (26 %, dominated by shrews) (Wu 1999a). Tatara and Doi (1994) reported that Siberian weasel in a temperate deciduous broad-leaved forest of Japan mainly preyed on small mammals, birds, insects, earthworms and plant fruits. Results from Tatara and Doi (1994) and Wu (1999a) both suggest that Siberian weasel is an opportunistic predator.

Because martens and weasels are considered generalist predators that consume similar types of food items, and marten (head and body length: 44–46 cm) is larger than weasel (head and body length: 25–34 cm), I expect that they would partition their food resources according to their body size. In other words, marten is expected to have larger preys, more food types and broader diet niche breadth than weasel. In addition, because small mammals are considered as the most important food resources of both marten and weasel, I expect that the food resource partitioning between marten and weasel would respond to seasonal variation in small mammal abundance. When small mammals were scarce, marten and weasel would focus their diet on other food resources. Furthermore, because both marten and weasel have been suggested as generalist predators, I expect that their diet overlap would increase when small mammals were scarce.

The main purpose of this study is to examine food resource partitioning between the two sympatric mustelids, i.e., yellow-throated marten and Siberian weasel, in a high mountain ecosystem of Taiwan. Specific objectives of this study are to:

(1) investigate the overall diet composition of both species,

(2) examine overall and seasonal resource partitioning between marten and weasel,

in terms of degree of diet overlap and diet niche breadth of both species, and (3) study the relationship between resource partitioning and seasonal variation of small mammal abundance.

Methods

Study site

This study was conducted in the Nan-Hu Mountain (24° 37´ N, 121° 10´ E) of northern Taiwan (Figure 1). The altitude of the study site ranges from 2300 m to 3700 m. Average annual temperature at the Nan-Hu meteorological station (3500 m above sea level) in 2004 was ranging from -2.75 ˚C (January) to 7.74 ˚C (August). The coldest three months were January, February and December. Annual precipitation at the Nan-Hu meteorological station was 4772 mm in 2004, which was mainly brought by typhoons and Northeastern monsoon from July to December.

The main vegetation types found along the altitudinal gradient from low to high in the study site were forests of Taiwan red pine (*Pinus taiwanensis*), Taiwan spruce (*Picea morrisonicola*), Taiwan hemlock (*Tsuga chinensis*), Taiwan fir (*Abies kawakamii*) and Yushan cane shrub (*Yushania niitakayamensis*), respectively (Figure 2) (Chen 2004). The study site showed a high vertebrate richness in Taiwan; for example, at least 69 bird species and 20 mammal species have been reported in previous surveys (Lin *et al.* 1991, Lee 1992b, Wang and Chen 1992, Pei 2000, Wu 2004a).

Scat collection and identification

Scats collection was conducted monthly along a loop transect within the study site (Figure 1) from January 2005 to May 2006. The study site contained several hiking trails and numerous animal tracks. In a preliminary collection conducted in December

2004, I found that it was more efficient and effective to collect marten and weasel scats along the hiking trails than animal tracks (7.4 and 4.8 scats per day, respectively). Therefore, scats were mainly collected along existing hiking trails. This transect was 22.6 km in total length and covered most of the core areas and all of the forest types of the study site.
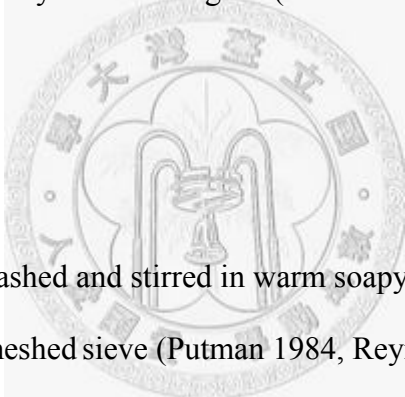
Besides yellow-throated marten and Siberian weasel, another small carnivorous mammal, the Formosan ferret-badger, was also known to exist in the study site. Unlike the dirt-like scats of the ferret-badger, scats of marten and weasel always consisted of solid matter, looked like a spiral strip and could be easily distinguished from the scats of ferret-badger. The identification between marten's and weasel's scats was based on morphological characters. The odor of marten's and weasel's scats has been reported to be possible key of identification (e.g., Tatara and Doi 1994, Bright and Smithson 1997). However, I found the scat odor undistinguishable under the influence of harsh weather and environmental condition of the study site and, therefore, it was not used as a key of identification in this study.

Both marten and weasel produce simple and complex scats. The simple scats are single-strand and self-twisted (Figure 3a) and the complex scats are formed by several (usually 2–3) strands in a complicated structure (Figure 3b). Once a scat was collected in the field, the length and diameter of simple scats and the width of the widest strand of complex scats were measured immediately. Later, the collected scats were dried in oven at 50 ˚C for storage.

The classification of all collected scats followed the logistic regression procedures

detailed in Appendix 1. The diameter of simple scats and strand width of complex scats were used to calculate the probability that the scat belongs to marten. Simple and complex scats which obtained predicted probability from the models greater than 0.5 were classified as marten scats, others were classified as weasel scats. Simple scats with predicted probability between 0.1 and 0.5 were not included in following analyses because they could be produced by either marten or weasel. Three fresh scats (two simple scats and one complex scat) collected from the field were classified as weasel scats by the models and confirmed as weasel scat with genetic analysis performed by a polymerase chain reaction (PCR) with the primer designed by Kurose *et al.* (2005) to amplify partial mitochondrial cytochrome b gene (112–347 bp).

Diet analysis

Collected scats were washed and stirred in warm soapy water with hot plate and then filtered by a 0.5 mm^2 meshed sieve (Putman 1984, Reynolds and Aebischer 1991). The remains in the sieve included mammal hairs, skeletons, bird feathers, egg shells, reptile scales, insect exoskeletons, fruits, plant debris, mud, and unknown residuals.

Mammal hairs in the scats were identified by the scale and medulla patterns with a microscope (detailed in Appendix 2). All mammal hairs in the scats could be identified to species level except hairs of *Petaurista alborufus lena* and *Petaurista philippensis*, which exhibited similar characters to each other and were recorded as *Petaurista spp*. The skeletons were used as complementary clues for species identification.

Bird feathers, reptile scales and insect exoskeletons were difficult to be identified

to species or genus levels and thus were classified to class level. Plant debris and fruits were further examined with the degree of digestion and fragmentation to determine whether these remains were eaten on purpose, unintentionally or through plant-eating preys. Those plant debris and fruits which were undigested or considered being eaten unintentionally were excluded from the diets (Helldin 2000). The plant materials were identified by their morphology of fruits or leaves as far as possible. Mud occurring with earthworm chaetae was considered as earthworm dirt nodule and recorded as earthworm; otherwise it was not included in the diets.

Food item categories used in this study were Soricomorpha (*Episoriculus fumidus* and *Mogera insularis*), *Microtus kikuchii*, *Apodemus semotus*, *Niviventer culturatus*, Sciurinae (*Callosciurus erythraeus, Dremomys pernyi* and *Tamiops maritimus*), Pteromyinae (*Belomys pearsonii* and *Petaurista spp.*), Artiodactyla (*Muntiacus reevesi micrurus, Naemoheadus swinhoei* and *Cervus unicolor swinhoei*), other mammals (Chiroptera and unknown mammals), birds, reptiles (*Trimeresurus gracilis* and unknown reptiles), arthropods (insect exoskeleton and larvae), eggs and fruits (Table 1).

Small mammal abundance survey

Small mammal abundance was surveyed in July and October of 2005 and January and April of 2006. Each survey lasted for four trap nights.

The surveys were designed to fully represent the availability of small mammals within the whole study site. Small mammal communities have found to be strongly affected by vegetation types (Lin *et al.* 1991). Grassman *et al.* (2005) reported that

yellow-throated marten traveled 966 m (± 834 m) daily, which implies the maximum

daily movement distance of yellow-throated marten was approximate 1.8 km. To avoid

survey bias caused by the uneven distribution of vegetation types and small mammals,

sixteen trap stations were set in proportion to the major vegetation types in the study

site (Figure 2). The vegetation composition within the 1.8 km buffer zone of the transect

was calculated, based on the results of The Third Survey of Forest Resources and Land

Use in Taiwan conducted by Taiwan Forestry Bureau in 1995.

At each trap station, I used five Sherman live traps ($23 \times 8 \times 9$ cm^3) which were set

at 10 m apart and one set of pit-fall trap in "I" shape with a 2 m fence. The trail above

snow line (3200 m above sea level) was closed by heavy snow in January 2006; hence

four trap stations were not used in winter of 2006. All captured individuals were

recorded and released free in the field.
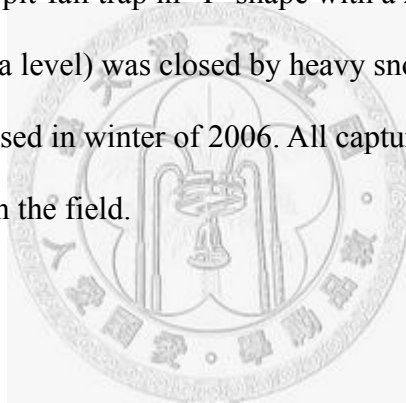
Data analysis

I used absolute frequency of occurrence (*A %*) and relative percentage (*R %*) to

quantify the diets of marten and weasel. The absolute frequency of occurrence of food

item *i* is calculated as:

$$Ai\% = \frac{no.\ of\ scats\ containing\ food\ item\ i}{no.\ of\ total\ scats}$$

The relative percentage of food item *i* is calculated as:

$$Ri\% = Ai\% \Big/ \sum_{i=1}^{k} Ai\%$$

where *k* is the number of food items in the diet.

Relative percentage was used in calculating the following indexes for dietary comparison. I compared the diet niche breadth of marten and weasel by using standardized Levins index (*Lst*) (Levins 1968, Colwell and Futuyma 1971) which is calculated as:

$$L = \left(\sum_{i=1}^{n} p_i^2 \right)^{-1} \qquad \text{and} \qquad Lst = \frac{L-1}{n-1}$$

where p_i is the relative percentage of food item *i* and *n* is the number of food items. Levins index is a value ranging from 0 to 1. A higher *Lst* indicates broader diet niche of the animal.

I used Pianka index (*Ojk*) (Pianka 1973) to evaluate the degree of diet overlap between the marten and weasel. The formula of Pianka index is:

$$O_{jk} = \sum_{i=1}^{n} p_{ij} p_{ik} \bigg/ \sqrt{\sum_{i=1}^{n} p_{ij}^2 \sum_{i=1}^{n} p_{ik}^2}$$

where p_{ij} (or p_{ik}) is the relative percentage of food item *i* in diet *j* (or *k*). The Pianka index ranges from 0 to 1 and the higher value indicates higher degree of overlap in diet.

Seasonal variation in diet and diet niche breadths of marten and weasel, as well as the degree of diet overlap between them, were also calculated and examined. I defined the coldest three months as winter (December to February) and the following three quarters as spring (March to May), summer (June to April) and autumn (September to November), according to the temperature data of the Nan-Hu meteorological station in 2004.

I used the number of captured individuals per trap station to represent the relative abundance of each small mammal species. Spearman rank order correlation analysis was used to examine the relationship between the relative small mammal abundance and the relative percentage of each small mammal species in the diets of marten and weasel respectively.

All statistic procedures were conducted by Statistica 7 (StatSoft, 2004).

Results

Scat collection and identification

There were 318 simple scats and 152 complex scats collected in the field during the study period. Based on the discriminate functions described in Appendix 1, 73 simple scats were classified as marten scats, 142 as weasel scats and 103 scats with predicted probability between 0.1 and 0.5 were discarded from following analyses (Figure 4a). Among the 152 complex scats, 67 were classified as marten scats and 85 were classified as weasel scats (Figure 4b). In summary, 140 marten scats and 227 weasel scats were used in the diet analyses. For both simple and complex scats, the distribution of predicted probability was very similar between the scats collected in the field (Figure 4a, b) and in the laboratory (Figure A1-2a, b). According to the collected locations of marten and weasel scats in the study site (Figure 5), these two species showed no geographical segregation in their occurring range.

Diet analysis

Scats of marten contained slightly higher number of food items per scat than scats of weasel during the six seasons (Table 2 to Table 7) but the difference was not significant (*Student's* paired t-test, $p = 0.26$). The fruits found in the scats all belonged to Family Rosaceae except for two that were identifiable. Because scats that contains fruits never had other food items in them, which suggested that these fruits were fed intentionally, all fruits found in scats were included in the diet analysis. The plant debris found in scats was mainly consisted of Yushan cane (*Yushania niitakayamensis*)

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and alpine silvergrass (*Miscanthus transmorrisonensis*) and was not digested completely. The mud was present in scats without earthworm chaetae. The plant debris and mud were therefore considered being fed involuntarily and were not included in the diet analysis.

Diet of yellow-throated marten

Marten fed on mammals (*R %* = 88.14 %), birds (7.34 %), arthropods (3.95 %), and fruits (0.56 %) during the study period (Table 1). Eleven mammal species were found in the diet of marten and the three most frequently occurred mammal food items in marten's scats were Soricomorpha (*R %* = 28.81 %), *Microtus kikuchii* (20.34 %) and Artiodactyla (12.99 %).

In each season, mammals, especially small mammals (Soricomorpha and Muroidea), dominated the diet of marten (Table 2 to Table 7, Figure 6). Mammals made up at least 75.86% (*R %*, 2006 spring) and small mammals made up at least 41.38% (*R %*, 2006 spring) of marten's diet. Relative percentage of mammals in the diet of marten was highest in both winter of 2005 (96.3 %) and 2006 (100 %), when small mammals occupied 70.37 % and 62.85 % in the diets respectively. Marten consumed birds in the spring (both 2005 and 2006), summer and autumn (Figure 6). Arthropods were mainly fed in the spring of 2005(*R %* = 8.33 %) and 2006 (10.34 %) and fruits were only fed in the spring of 2006 (3.45 %).

Diet of Siberian weasel

The major diet of weasel was also mammals ($R \% = 84.33 \%$), including 12 species dominated by Soricomorpha (28.36 %), Pteromyinae (15.67 %) and *Microtus kikuchii* (10.82 %) (Table 1). Reptiles (1.12 %) and eggs (0.75 %) were only found in the diet of weasel. Other food items in weasel's scats from high to low were birds ($R \% = 5.97 \%$), arthropods (4.85 %) and fruits (2.99 %).

Seasonal diet of weasel also mainly consisted of mammals, mostly dominated by small mammals (Figure 6). In winter of 2005 (Table 2) and 2006 (Table 6), the relative percentages of mammals ($R \% = 95.45 \%$ and 90.91 %) and small mammals (59.09 % and 65.15 %) were higher and those of non mammal food items were lower than in other seasons. In the spring of 2006, weasel consumed low percentage of small mammals ($R \% = 15.79 \%$) and shifted its diet to large mammals (Pteromyinae 31.58 % and Artiodactyla 21.05 %). Birds were mainly consumed in the summer of 2005. Both reptiles and eggs only appeared in the diet of weasel, but the occurrence was low. Arthropods appeared in the diet of weasel in all of the six seasons and the highest relative percentage was in 2006 spring. Fruits mostly occurred in the diet in 2005 autumn.

Diet comparison between marten and weasel

Diet of marten and weasel showed little difference to each other (Table 1). Weasel consumed more food items than marten did, but those additional food items occupied low proportions in its diet. The diet niche breadths of marten ($Lst = 0.50$) and weasel ($Lst = 0.49$) were very similar. The degree of diet overlap between marten and weasel was very high ($O = 0.93$).

Diets of marten and weasel overlapped at high degrees in all seasons except the spring of 2006 ($O = 0.43$, Table 7). Diet niche breadth generally ranged from 0.53 to 0.69 for both carnivores seasonally, except for weasel in the summer of 2005 ($Lst = 0.36$) and for marten in the autumn of 2005 ($Lst = 0.46$).

Small mammal abundance

Four mammal species were captured from 2005 summer to 2006 spring: *Episoriculus fumidus*, *Apodemus semotus*, *Niviventer calturatus* and *Microtus kikuchii*. Figure 7 illustrates the seasonal variation of small mammal abundance and the relative percentage of occurrence of each species in the diet of marten and weasel. The amounts of *Episoriculus fumidus*, *Apodemus semotus* and *Niviventer calturatus* captured were all declined in the winter and increased in the spring of 2006. The number of *Microtus kikuchii* captured was low in the summer and autumn of 2005 and none was caught in the winter and spring of 2006.

The amounts of small mammals consumed by marten and weasel did not correspond significantly to the relative abundance of small mammal in each season (r was between –0.95 and 0.95, all $p > 0.05$) (Figure 7). In 2006 winter, when low number of small mammals were captured in the field, considerable proportion of small mammals was still found in the scats of marten and weasel (total *R %* of the four species = 57.14 % and 63.65 % respectively) (Table 6).

Discussion

Diet of yellow-throated marten

The importance of respective food items in yellow-throated marten's diet has not been compared in previous reports (Sathyakumar 1999, Grassman *et al.* 2005). In this study, I found yellow-throated marten mainly consumed small mammals as other marten species do, such as American marten (Thompson and Colgan 1990, Zielinski and Duncan 2004), pine marten (Jędrzejewski *et al.* 1989, Pulliainen and Ollinmäki 1996, Helldin 2000, Putman 2000), sable (Xu *et al.* 1996, Bao *et al.* 2003), stone marten (Serafini and Lovari 1993, Lanszki *et al.* 1999, Carvalho and Gomes 2004), and Tsushima marten (Tatara and Doi 1994). However, in comparison to these marten species, yellow-throated marten ate more large mammals and fewer non-mammal food items (e.g., birds, reptiles, insects and fruits).

The consumption of large mammals of some martens is usually considered as use of carrion (e.g., pine marten, Sidorovich *et al.* 2000; stone marten Lanszki *et al.* 1999, Padial *et al.* 2002). However, yellow-throated marten is suggested large enough to have the ability to prey on large mammals (Matjushkin 1974, cited in Powell and Zielinski 1983) and has been observed chasing ungulates in Himalayas (Sathyakumar 1994) and hunting *Muntiacus reevesi micrurus* in Central Mountains of Taiwan (Wu 2004b, Koh 2007). Yellow-throated marten may be the only mustelid that can hunt large animals directly.

Diet of Siberian weasel

Comparing their diet in different habitats of Taiwan, Siberian weasel primarily preyed on small mammals in alpine forests (Nan-Hu Mountain) in this study and in alpine grasslands (Hohuanshan) (Ma 1990). However, in subtropical forests (Guandaushi), it mainly preyed on arthropods instead (Wu 1999a). This is probably due to higher species richness and population densities of small mammals in high elevation of Taiwan (e.g., Lin and Shiraishi 1992, Yu 1993, Adler 1996, Wu 1998) than those in mid-elevational subtropical forests (e.g., Lee 1994, Wu and Yu 2000). Siberian weasel in high mountain areas can rely on its preferred preys and does not need to shift its diet. In this study, weasel also consumed more large mammals than at the other two locations (Guandaushi and Hohuanshan), probably because Artiodactyla was rare in these two locations (Wu 1999b, 2004a).

The consumption of fruits by Siberian weasel was reported by Tatara and Doi (1994) and was characterized as opportunistic foraging behavior. Ma (1990) suggested that plant materials might not be Siberian weasel's food items and discarded two occurrences of fruits from the diet of weasel in his study. However, I found eight scats of weasel containing fruits solely without other animal remains. This indicates that these fruits were not exploited accidentally with the consumption of other herbivores. One of these scats was confirmed as weasel scat with genetic analysis performed by a polymerase chain reaction (PCR) with the primer designed by Kurose *et al.* (2005) to amplify partial mitochondrial cytochrome b gene (112–347 bp) (unpublished data). Therefore, Siberian weasel in the high mountain ecosystems of Taiwan would also take fruits as food.

Martinoli *et al.* (2001) suggested that fruits were food items with low cost and could provide male stoats' (*Mustela erminea*) energy requirement while they need higher mobility to search for mate. Remonti *et al.* (2007) had similar opinions that least weasel (*Mustela nivalis*) and stoat were allowed to easily maintain their energy budget by consuming fruits. Juveniles of Siberian weasel were found to leave their parents in August (Lee 1992a) and increase dispersal at the mean time (Wong 1997). This is simultaneous with the mature period of Rosaceae in autumn (Lu 1991). Therefore, the peak of consuming fruits by Siberian weasel in autumn may be attributed to the energy requirement of the dispersal individuals. Moreover; the accessibility of fruits may also allow the juveniles which are less-experienced in hunting to survive during the early stage of dispersal.
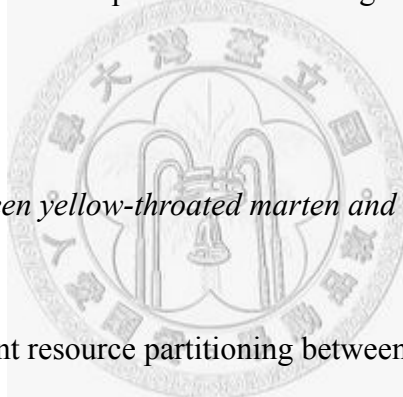
Resource partitioning between yellow-throated marten and Siberian weasel

There was no significant resource partitioning between yellow-throated marten and Siberian weasel according to their body size. The high diet overlap between marten and weasel was generally based on the consumption of small mammals. This is in accordance with my expectation that small mammals are the most important food for both carnivores. Since marten and weasel primarily preyed on small mammals, the diet overlap in small mammals would occur spontaneously. Besides small mammals, marten consumed Artiodactyla and weasel consumed Pteromyinae as their secondary food item. This may resemble to the idea of Carvalho and Gomes (2004) that all predators mainly preyed on rodents and the size of their secondary food items corresponded to predators' body size. However, in my study, weasel also consumed considerable proportion of Artiodactyla which did not differ much from that in

marten's diet. Therefore, I suggest that marten and weasel might share all sizes of mammal food resources in the study site. This seems contrary to Schoener's (1974) prediction that coexisting animals would partition the resource along size dimension (e.g. Martin 1994, Carvalho and Gomes 2004).

Schoener's prediction implies that larger predators have better ability than smaller ones to kill larger preys without considering the difference in foraging approaches. However, diet analysis is not able to express the outcome of different foraging behaviors, which may have different cost and advantage to the animals. When using diet analysis to examine Schoener's prediction, the difference in foraging approaches should be considered. In Taiwan, hunters usually found weasel feeding on the meat and organs from the carrion of Artiodactyla (Tsai, Zhen-Guang 2004, personal observation, interviewed by the author). In this case, since weasel can exploit the carrion of large mammals, the restriction to weasel for consuming large mammals does not exist. In other words, even though marten and weasel have different ability to hunt large mammals, weasel can still use this food resource through the carrion. Serafini and Lovari (1993) suggested that when concerning opportunist species, extensive diet overlap could occur even if their body sizes differ widely. A similar pattern was reported by Sidorovich *et al.* (2000) that, in a generalist carnivore community which contained a wide range of sizes of species including brown bear (*Ursus arctos*), red fox, badger (*Meles meles*), pine marten, polecat (*Mustela putorius*), and raccoon dog (*Nyctereutes procyonoides*), all predators were able to use the carrion of ungulates and overlapped their diets in winter.

It is also possible that marten and weasel might adopt partitioning in prey size

within this same food item. In other words, marten might exploit large individuals of Artiodactyla and weasel might exploit the small or immature ones. However, this hypothesis could not be examined in this study because it is difficult to determine body size or age of the preys from their remains occurred in marten and weasels' scats.

Resource partitioning and resource availability

Contrary to my expectation, total consumption of small mammals by both marten and weasel was the highest in both winters during the study period. However, the numbers of each small mammal species captured were the lowest in winter of 2006. This indicates that small mammals are still important food resources for marten and weasel in winter. This result may be due to that availability of non-mammal food resource may also be low in winter. In this study, seasonal availability of non-mammal food resource is not estimated. However, referring to other studies in high mountain ecosystem of Taiwan, density of birds in conifer forests is lower in non-breeding season, i.e. October to January, than in breeding season (Shiu 2003) and abundance of insects mainly peaks from March to July (Huang and Chen 2002). Reptiles are inherently in low abundance in high altitudinal areas of Taiwan (Lin *et al.* 1991, Yang and Huang 2005) and may hibernate under the cold weather of winter (average -1.18 °C in 2004, Nan-Hu meteorological station). The scarceness of these non-mammal food items in winter might force yellow-throated marten and Siberian weasel to consume more small mammals in winter.

Is it possible that the extensive consumption of small mammals in winter could be attributed to that small mammals were still abundant in the field in spite of their rare

occurrence in my traps and thus predators could still exploit them as main food sources regardless of the availability of non-mammal foods? The answer is probably negative. Results of my survey on small mammal abundance indicate that small mammals were comparatively more abundant in summer and autumn of 2005 and spring of 2006. If above suggestion is correct, marten and weasel should have exploited higher proportion of small mammals in these three seasons than in the winter. However, both marten and weasel used lower proportions of small mammals in these three seasons (except the diet of marten in autumn of 2005). Moreover, non-mammal food items indeed have occurred in the diets of marten and weasel in those seasons when they are considered more abundant. For example, in the spring of 2006, although small mammals were more available than in previous winter season, both marten and weasel decreased their consumptions of small mammals and increased consumptions of non-mammal food items, especially birds and arthropods. The decline of diet overlap in 2006 spring may be attributed to the diet divergence when food abundance restored and the diets of generalist predators were subsequently released from the limited resources in winter.

Moreover, in a specie specific level, the proportions of each small mammal ate by marten and weasel did not correspond to the numbers of each small mammal captured in the field. Taking a further examination on the consumption of small mammals of marten and weasel, *Apodemus semotus* and *Niviventer calturatus* were less consumed in summer and autumn of 2005 and spring of 2006 than in winter of 2006 despite that they were relatively more abundant in these seasons. It seems that *Apodemus semotus* and *Niviventer calturatus* are less preferred preys for marten and weasel. This might be attributed to the spatial distribution of these species. In my study site, *Apodemus*

semotus and *Niviventer calturatus* were usually captured in hemlock and spruce forests with dense understory and logs. *Microtus kikuchii* were only captured in Yushan cane grasslands. *Episoriculus fumidus* appeared in all type of forests but were mostly captured in pine forests with sparse understory of alpine silvergrass. *Apodemus semotus* and *Niviventer calturatus* may prefer dense ground cover and fallen logs which might provide them good shelters (Yu 1993) and make them more difficult to be captured by predators than *Microtus kikuchii* and *Episoriculus fumidus*. Hansson (1987) suggested that *Apodemus* mice are less valuable to predator than voles because *Apodemus* species are usually granivores with shorter alimentary canal and better escape abilities and voles are usually herbivores with longer alimentary canal and clumsy bodies. Therefore, *Apodemus semotus* may be less preferred by predators. In winter, both marten and weasel tended to increase their consumption of *Apodemus semotus* and *Niviventer calturatus*. The shortage of small mammals, as well as non-mammal food resource, might force predators to use the less preferred preys in winter. This is in accordance with my suggestion that opportunistic generalists will focus their diet on the available food resources and thus result in convergence of diets during the lean time (e.g., Serafini and Lovari 1993, Carvalho and Gomes 2004).

Marten consumed more *Microtus kikuchii* and fewer *Apodemus semotus* than weasel did in each season. This might be a sign of resource partitioning that dominant predator took more favorite preys. However, marten and weasel did not employ this segregation in their diet extensively to avoid diet overlap. The abundance of *Microtus kikuchii* and *Apodemus semotus* might not be able to supply predators to coexist without exploiting other food resources. In addition, marten and weasel seemed to have seasonal segregation in consumption within the assemblage of large mammals. But this

segregation was also not strong enough to allow predators to reduce diet overlap except the spring of 2006 when weasel exploited more Pteromyinae and Artiodactyla and less Sciuridae and small mammals than marten did.

The consumption of Artiodactyla by marten and weasel mainly occurred in winter and spring when it became an important or more available food source for both species (e.g., Jędrzejewski *et al.* 1989, Sidorovich *et al.* 2000). For marten, although it can hunt Artiodactyla directly, hunting large animal is still too costly and less preferred when food resource is abundant. Only in the season when food resource is scarce, such as in winter, would marten hunt Artiodactyla for food. As additional evidence indicated, observations of hunting *Muntiacus reevesi micrurus* by yellow-throated marten all occurred in winter (Wu 2004b, Koh 2007). For weasel, carrion of Artiodactyla may be more available in winter due to low temperature, starvation (e.g., Cooke *et al.* 1996) or killing by marten. Jędrzejewski *et al.* (1989) suggested that the carrions killed by large carnivores (e.g., wolf *Canis lupus*) may supply foods for some small carnivores (e.g., pine marten) in winter and thus provide some stable effect in the carnivore community.

Possible Directions of Further studies

The food resource availability I surveyed in this study focused on small mammal abundance. But diet variation of marten and weasel might be related to the availability of other food resource. To investigate the relationship of resource partitioning among generalist carnivores, resource availability survey should include other food types, such as large mammal and non-mammal food types.

Population dynamic of small mammals usually exhibits dramatic annual fluctuation and may influence predator populations (e.g., Jędrzejewski *et al.* 1995, Cypher *et al.* 2000, Zalewski and Jedrzejewski 2006). In this study I only surveyed the diets of marten and weasel for six seasons and small mammal abundance for four seasons. Although small mammal abundance declined in the winter of 2006, predators seemed still able to exploit these food resources. This may indicates that small mammal abundance during the study period did not drop severely in winter. The influence of small mammal population fluctuations on resource partitioning between marten and weasel is unknown and deserved attention. In addition, dispersal of Siberian weasel for mate searching might be a possible explanation for the absence of resource partitioning in winter. The mating season of Siberian weasel is from late winter (February) to spring (April) and males would abandon their territoriality to search for mate (Lee 1992a, Wong 1997). Male weasels searching for females would only stay in limited areas for short time (e.g. Eringe 1974) and thus number of weasel at any area might become unstable. If the number of emigrant weasels had exceeded the number of immigrants, the number of Siberian weasel in the study site would decline during this season. Thus the competition for food between marten and weasel may be reduced. However, these issues are unfortunately not addressed in this study. Marten and weasel in high mountain ecosystem in Taiwan are still understudied in these aspects. Long-term monitoring on marten and weasel's diets, populations and resource partitioning would help us to solve these questions.

Conclusions

In general, both yellow-throated marten and Siberian weasel mainly consumed

small and large mammals. There was no resource partitioning according to predator body size between marten and weasel because weasel could also consume large mammals by using the carrion. When examining Schoener's prediction, the difference in foraging approaches should be considered. Resource partitioning between marten and weasel was not in accordance to the small mammal abundance but might be affected by the availability of other food resources. The increasing consumption of less-preferred rodents in winter indicates that small mammals were limited resources but still important for predators in winter. Artiodactyla may also be an important food source for marten and weasel in winter. Some segregation in specific food items was found between marten and weasel but was not intense enough to allow the two mustelids to avoid diet overlap.

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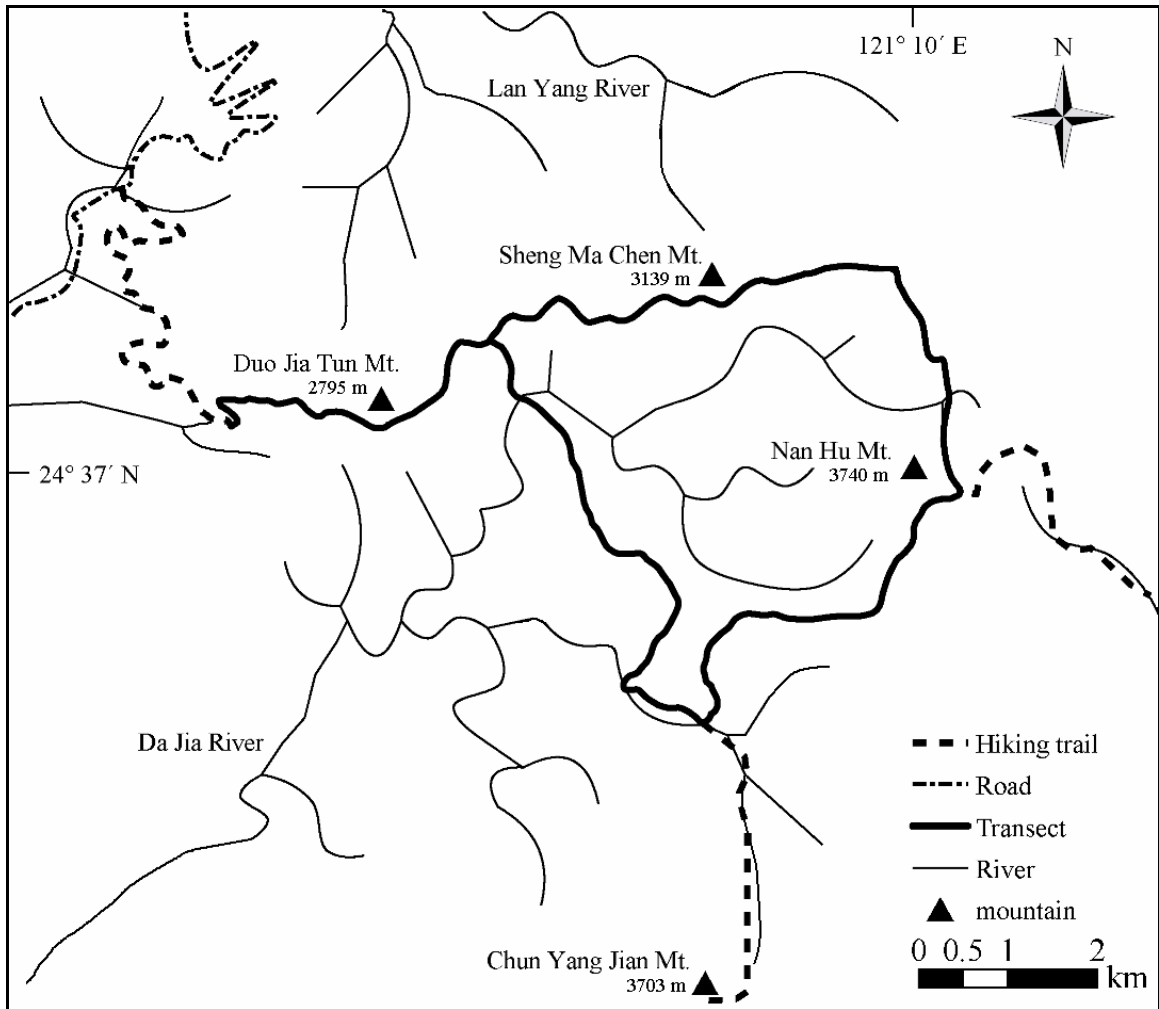
Figure 1 Map of the study site. Field work was conducted along the transect (solid bold line), which is 22.6 km in length, ranging from 2500 m to 3700 m above sea level.
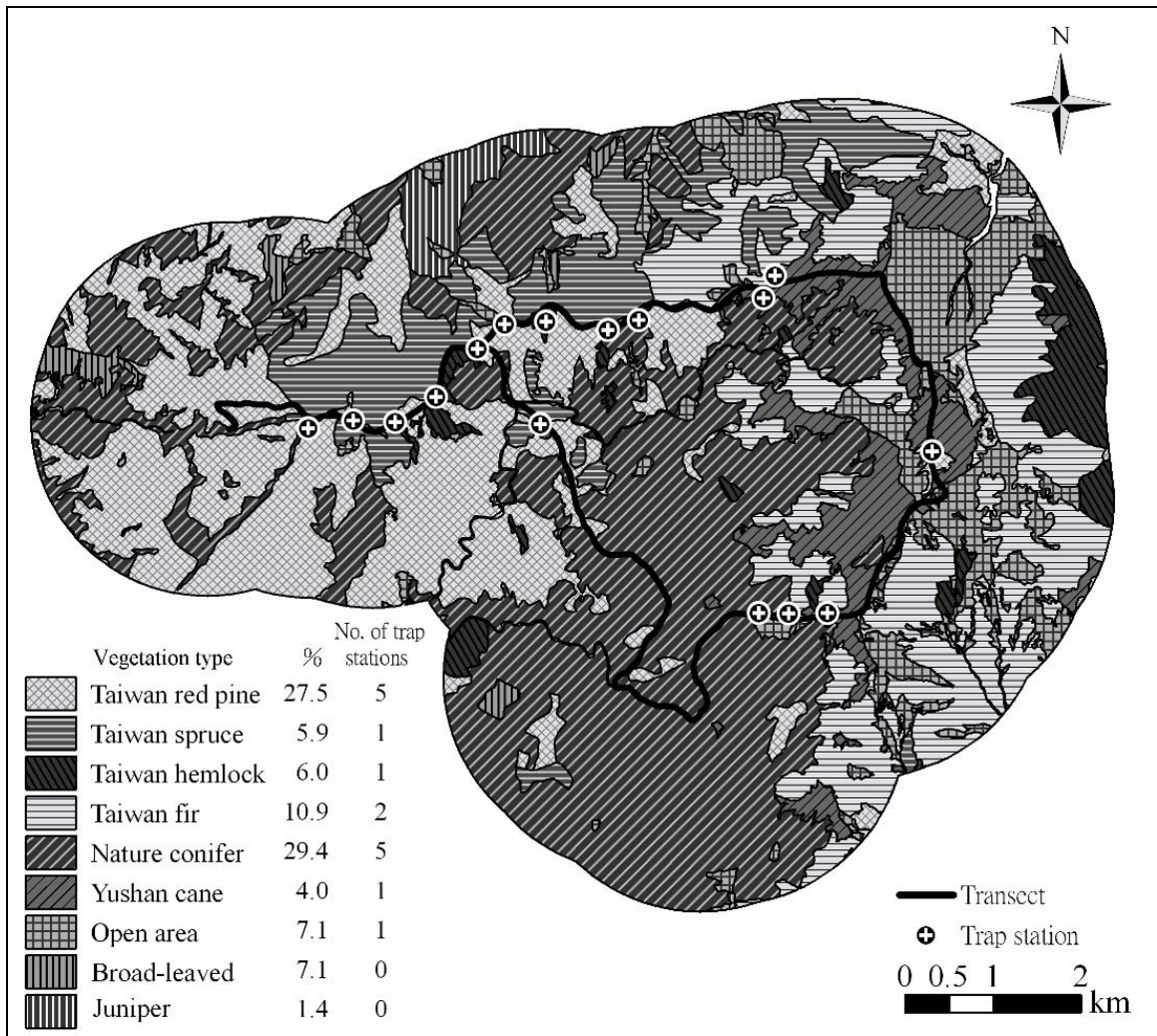
Figure 2 Vegetation composition and location of trap stations at the study site. Trap stations were set up along a transect. The proportion of each forest type (%) and the number of trap stations proportionally set up in each forest type were listed at the lower left. The broad-leaved and Juniper forests did not contain trap station because of their low coverage percentage and remoteness.

(a) Simple scat

(b) Complex scat

Figure 3 Photos of a simple scat (a) and a complex scat (b). Simple scats is formed by one strand along and complex scats are constituted by two or more strands and were twisted into complicated shape. The diameter of simple scat and the strand width of complex scat were used to classify the species that produce them.
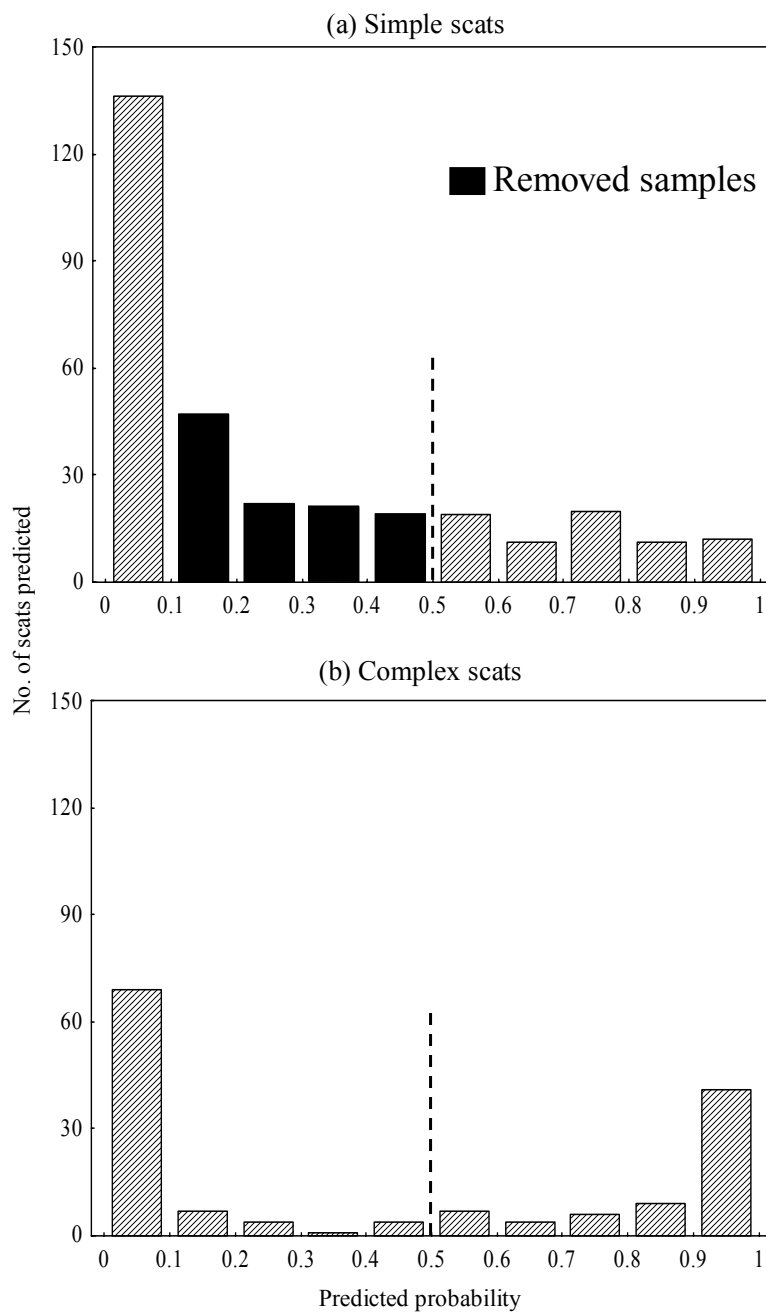
Figure 4 Distributions of predicted probability by logistic regression of simple scats (a) and complex scats (b) collected in the field and used in this study. Scats with predicted probability > 0.5 were classified as marten scats, otherwise weasel scats. Simple scats with predicted probability ranged from 0.1 ~ 0.5, were discarded due to high risk of error in classification.
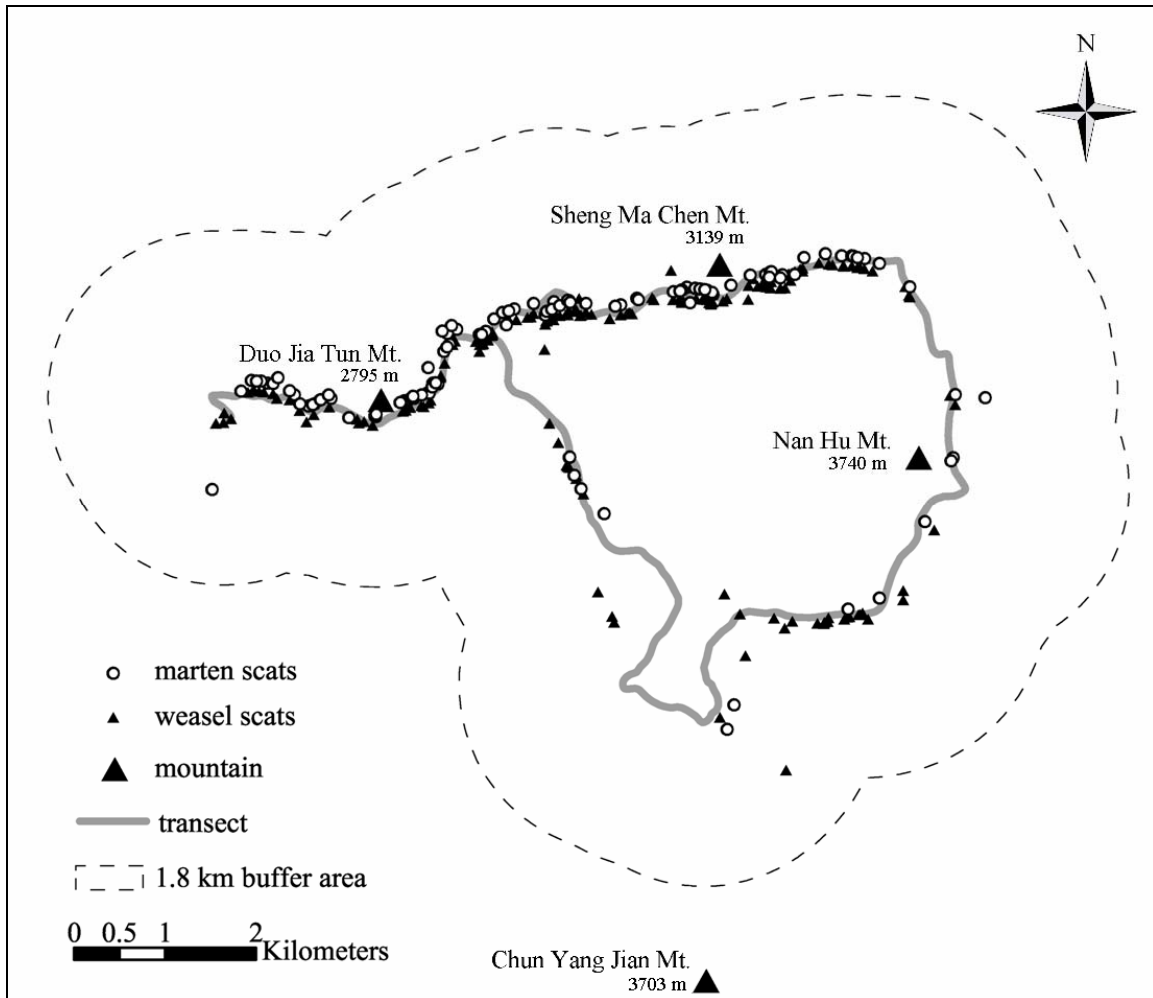
Figure 5 Locations of the scats of yellow-throated marten and Siberian weasel. Most marten and weasel scats were collected along the transect and distributed closely.
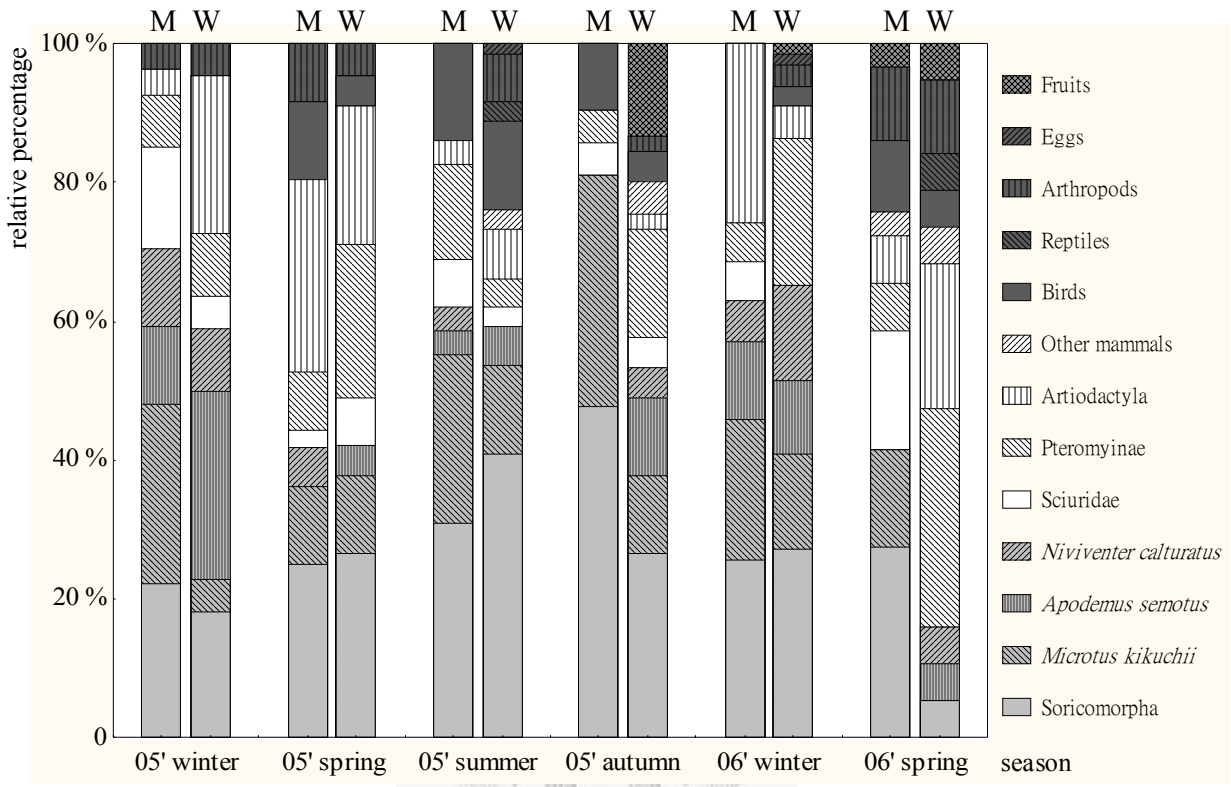
Figure 6 Seasonal diet compositions of yellow-throated marten (M) and Siberian weasel (W). The gray plots represent small mammal food items; the white plots represent the other mammal food items and the dark plots represent non-mammal food items.
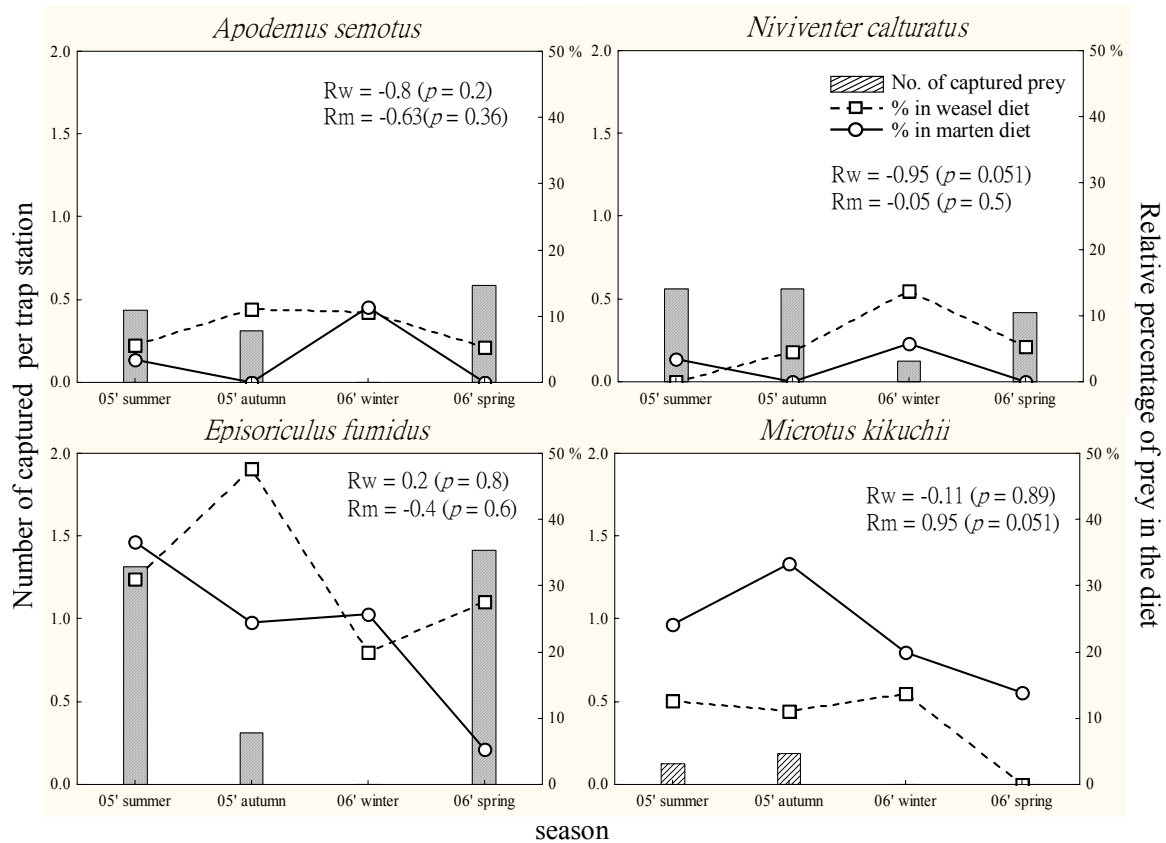
Figure 7 Seasonal variations of four small mammal relative abundance (number of captured per trap station) and relative percentage of each small mammal occurring in martens' and weasels' diet. The species-specific Spearman correlation coefficient between prey abundance and relative percentage of prey occurrence in diet of marten (Rm) and weasel (Rw) are listed in the figures.

Table 1 Overall diet composition of Siberian weasel and yellow-throated marten (January 2005 - May 2006). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	140		227	
Food item	n	R %	n	R %
Mammals	156	88.14	226	84.33
Soricomorpha[a]	51	28.81	76	28.36
Mogera insularis	2	1.13	6	2.24
Episoriculus fumidus	49	27.68	70	26.12
Muroidea	52	29.38	68	25.37
Apodemus semotus	8	4.52	25	9.33
Microtus kikuchii	36	20.34	29	10.82
Niviventer calturatus	8	4.52	14	5.22
Sciurinae	15	8.47	8	2.99
Callosciurus erythraeus	0	0	1	0.37
Dremomys pernyi	2	1.13	2	0.75
Tamiops maritimus	13	7.34	5	1.87
Pteromyinae	14	7.91	42	15.67
Belomys pearsonii	2	1.13	0	0
Petaurista spp.	12	6.78	42	15.67
Artiodactyla	23	12.99	27	10.07
Muntiacus reevesi micrurus	17	9.60	24	8.96
Naemorhedus swinhoei	6	3.39	3	1.12
Other mammals	1	0.56	5	1.87
Chiroptera	0	0	1	0.37
Unknown mammals	1	0.56	4	1.49
Birds	13	7.34	16	5.97
Reptiles	0	0	3	1.12
Trimeresurus gracilis	0	0	1	0.37
Unknown reptiles	0	0	2	0.75
Arthropods	7	3.95	13	4.85
Insect exoskeleton	2	1.13	6	2.24
Larvae	5	2.82	7	2.61
Eggs	0	0	2	0.75
Fruits	1	0.56	8	2.99
No. of items per scat	1.26		1.17	
Levins index (*Lst*)		0.50		0.49
Pianka Index (*O*)				0.93

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 2 Diet composition of Siberian weasel and yellow-throated marten in 2005 winter (January - February). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	18		17	
Food item	n	R %	n	R %
Mammals	26	96.30	21	95.45
Soricomorpha[a]	6	22.22	4	18.18
Mogera insularis	0	0	0	0
Episoriculus fumidus	6	22.22	4	18.18
Muroidea	13	48.15	9	40.91
Apodemus semotus	3	11.11	6	27.27
Microtus kikuchii	7	25.93	1	4.55
Niviventer calturatus	3	11.11	2	9.09
Sciurinae	4	14.81	1	4.55
Callosciurus erythraeus	0	0	1	4.55
Dremomys pernyi	0	0	0	0
Tamiops maritimus	4	14.81	0	0
Pteromyinae	2	7.41	2	9.09
Belomys pearsonii	0	0	0	0
Petaurista spp.	2	7.41	2	9.09
Artiodactyla	1	3.70	5	22.73
Muntiacus reevesi micrurus	1	3.70	4	18.18
Naemorhedus swinhoei	0	0	1	4.55
Other mammals	0	0	0	0
Chiroptera	0	0	0	0
Unknown mammals	0	0	0	0
Birds	0	0	0	0
Reptiles	0	0	0	0
Trimeresurus gracilis	0	0	0	0
Unknown reptiles	0	0	0	0
Arthropods	1	3.70	1	4.55
Insect exoskeleton	1	3.70	1	4.55
Larvae	0	0	0	0
Eggs	0	0	0	0
Fruits	0	0	0	0
No. of items per scat	1..5		1.3	
Levins index (*Lst*)		0.69		0.64
Pianka Index (*O*)				0.66

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 3 Diet composition of Siberian weasel and yellow-throated marten in 2005 spring (March - May). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	24		40	
Food item	n	R %	n	R %
Mammals	29	80.56	41	91.11
Soricomorpha[a]	9	25.00	12	26.67
Mogera insularis	0	0	1	2.22
Episoriculus fumidus	9	25.00	11	24.44
Muroidea	6	16.67	7	15.56
Apodemus semotus	0	0	2	4.44
Microtus kikuchii	4	11.11	5	11.11
Niviventer calturatus	2	5.56	0	0
Sciurinae	1	2.78	3	6.67
Callosciurus erythraeus	0	0	0	0
Dremomys pernyi	0	0	1	2.22
Tamiops maritimus	1	2.78	2	4.44
Pteromyinae	3	8.33	10	22.22
Belomys pearsonii	2	5.56	0	0
Petaurista spp.	1	2.78	10	22.22
Artiodactyla	10	27.78	9	20
Muntiacus reevesi micrurus	7	19.44	8	17.78
Naemorhedus swinhoei	3	8.33	1	2.22
Other mammals	0	0	0	0
Chiroptera	0	0	0	0
Unknown mammals	0	0	0	0
Birds	4	11.11	2	4.44
Reptiles	0	0	0	0
Trimeresurus gracilis	0	0	0	0
Unknown reptiles	0	0	0	0
Arthropods	3	8.33	2	4.44
Insect exoskeleton	1	2.78	0	0
Larvae	2	5.56	2	4.44
Eggs	0	0	0	0
Fruits	0	0	0	0
No. of items per scat	1.5		1.1	
Levins index (*Lst*)		0.64		0.64
Pianka Index (*O*)				0.90

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 4 Diet composition of Siberian weasel and yellow-throated marten in 2005 summer (June - August). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	27		58	
Food item	n	R %	n	R %
Mammals	25	86.21	54	76.06
Soricomorpha[a]	9	31.03	29	40.85
Mogera insularis	0	0	3	4.23
Episoriculus fumidus	9	31.03	26	36.62
Muroidea	9	31.03	13	18.31
Apodemus semotus	1	3.45	4	5.63
Microtus kikuchii	7	24.14	9	12.68
Niviventer calturatus	1	3.45	0	0
Sciurinae	2	6.90	2	2.82
Callosciurus erythraeus	0	0	0	0
Dremomys pernyi	0	0	1	1.41
Tamiops maritimus	2	6.90	1	1.41
Pteromyinae	4	13.79	3	4.23
Belomys pearsonii	0	0	0	0
Petaurista spp.	4	13.79	3	4.23
Artiodactyla	1	3.45	5	7.04
Muntiacus reevesi micrurus	1	3.45	5	7.04
Naemorhedus swinhoei	0	0	0	0
Other mammals	0	0	2	2.82
Chiroptera	0	0	0	0
Unknown mammals	0	0	2	2.82
Birds	4	13.79	9	12.68
Reptiles	0	0	2	2.82
Trimeresurus gracilis	0	0	1	1.41
Unknown reptiles	0	0	1	1.41
Arthropods	0	0	5	7.04
Insect exoskeleton	0	0	2	2.82
Larvae	0	0	3	4.23
Eggs	0	0	1	1.41
Fruits	0	0	0	0
No. of items per scat	1		1.2	
Levins index (*Lst*)		0.57		0.36
Pianka Index (*O*)				0.90

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 5 Diet composition of Siberian weasel and yellow-throated marten in 2005 autumn (September - November). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	19		44	
Food item	n	R %	n	R %
Mammals	19	90.48	36	80
Soricomorpha[a]	10	47.62	12	26.67
Mogera insularis	0	0	1	2.22
Episoriculus fumidus	10	47.62	11	24.44
Muroidea	7	33.33	12	26.67
Apodemus semotus	0	0	5	11.11
Microtus kikuchii	7	33.33	5	11.11
Niviventer calturatus	0	0	2	4.44
Sciurinae	1	4.76	2	4.44
Callosciurus erythraeus	0	0	0	0
Dremomys pernyi	0	0	0	0
Tamiops maritimus	1	4.76	2	4.44
Pteromyinae	1	4.76	7	15.56
Belomys pearsonii	0	0	0	0
Petaurista spp.	1	4.76	7	15.56
Artiodactyla	0	0	1	2.22
Muntiacus reevesi micrurus	0	0	1	2.22
Naemorhedus swinhoei	0	0	0	0
Other mammals	0	0	2	4.44
Chiroptera	0	0	1	2.22
Unknown mammals	0	0	1	2.22
Birds	2	9.52	2	4.44
Reptiles	0	0	0	0
Trimeresurus gracilis	0	0	0	0
Unknown reptiles	0	0	0	0
Arthropods	0	0	1	2.22
Insect exoskeleton	0	0	1	2.22
Larvae	0	0	0	0
Eggs	0	0	0	0
Fruits	0	0	6	13.33
No. of items per scat	1.1		1	
Levins index (*Lst*)		0.46		0.58
Pianka Index (*O*)				0.78

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 6 Diet composition of Siberian weasel and yellow-throated marten in 2006 winter (December 2005 - February 2006). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	29		51	
Food item	n	R %	n	R %
Mammals	35	100	60	90.91
Soricomorpha[a]	9	25.71	18	27.27
Mogera insularis	2	5.71	1	1.52
Episoriculus fumidus	7	20	17	25.76
Muroidea	13	37.14	25	37.88
Apodemus semotus	4	11.43	7	10.61
Microtus kikuchii	7	20	9	13.64
Niviventer calturatus	2	5.71	9	13.64
Sciurinae	2	5.71	0	0
Callosciurus erythraeus	0	0	0	0
Dremomys pernyi	0	0	0	0
Tamiops maritimus	2	5.71	0	0
Pteromyinae	2	5.71	14	21.21
Belomys pearsonii	0	0	0	0
Petaurista spp.	2	5.71	14	21.21
Artiodactyla	9	25.71	3	4.55
Muntiacus reevesi micrurus	7	20	3	4.55
Naemorhedus swinhoei	2	5.71	0	0
Other mammals	0	0	0	0
Chiroptera	0	0	0	0
Unknown mammals	0	0	0	0
Birds	0	0	2	3.03
Reptiles	0	0	0	0
Trimeresurus gracilis	0	0	0	0
Unknown reptiles	0	0	0	0
Arthropods	0	0	2	3.03
Insect exoskeleton	0	0	1	1.52
Larvae	0	0	1	1.52
Eggs	0	0	1	1.52
Fruits	0	0	1	1.52
No. of items per scat	1.2		1.3	
Levins index (*Lst*)		0.69		0.53
Pianka Index (*O*)				0.77

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Table 7 Diet composition of Siberian weasel and yellow-throated marten in 2006 spring (March - May). The number of observation (n) and relative percentage (R %) of each specific food item were listed.

Species	Marten		Weasel	
Number of scats	23		17	
Food item	n	R %	n	R %
Mammals	22	75.86	14	73.68
Soricomorpha[a]	8	27.59	1	5.26
Mogera insularis	0	0	0	0
Episoriculus fumidus	8	27.59	1	5.26
Muroidea	4	13.79	2	10.53
Apodemus semotus	0	0	1	5.26
Microtus kikuchii	4	13.79	0	0
Niviventer calturatus	0	0	1	5.26
Sciurinae	5	17.24	0	0
Callosciurus erythraeus	0	0	0	0
Dremomys pernyi	2	6.90	0	0
Tamiops maritimus	3	10.34	0	0
Pteromyinae	2	6.90	6	31.58
Belomys pearsonii	0	0	0	0
Petaurista spp.	2	6.90	6	31.58
Artiodactyla	2	6.90	4	21.05
Muntiacus reevesi micrurus	1	3.45	3	15.79
Naemorhedus swinhoei	1	3.45	1	5.26
Other mammals	1	3.45	1	5.26
Chiroptera	0	0	0	0
Unknown mammals	1	3.45	1	5.26
Birds	3	10.34	1	5.26
Reptiles	0	0	1	5.26
Trimeresurus gracilis	0	0	0	0
Unknown reptiles	0	0	1	5.26
Arthropods	3	10.34	2	10.53
Insect exoskeleton	0	0	1	5.26
Larvae	3	10.34	1	5.26
Eggs	0	0	0	0
Fruits	1	3.45	1	5.26
No. of items per scat	1.3		1.1	
Levins index (*Lst*)		0.67		0.53
Pianka Index (*O*)				0.43

[a] Underlined food items were took as diet categories for further dietary comparison and calculations of Pianka index and Levins index.

Appendix 1

Identifying Scats of Yellow-throated Marten (*Marten flavigula chrysosphila*) and Siberian Weasel (*Mustela sibirica taivana*) by Logistic Regression Models

Introduction

Mammal scats can be broadly employed to study their presence/absence, relative/absolute abundance, habitat use, range and activity, and diet (Putman 1984). Scats containing parasite, hormone, and cells of animals can also provide information on health condition, physiological status and genetic materials for molecular analysis. However, for all possible applications to be valid, identifying the species from their scats correctly is a first step for further studies.

In Taiwan, several studies have reported the existences of yellow-throated marten (*Marten flavigula chrysosphila*) (Wu 2004) and Siberian weasel (*Mustela sibirica taivana*) (e.g., Lue *et al.* 1989, Ma 1990) by detecting their scats. However, marten scats are similar in shape and may overlap in size with large weasel scats (Murie 1954) and the difference of scats between these two species is rarely studied in Taiwan. This may cause census errors for both species.

Noninvasive genetic methods have been applied to identify mammal scats recently

(Waits and Paetkau 2005, Broquet *et al.* 2007) and are able to provide convincing evidence for identifying species or individual. Nevertheless, there are still some limitations to apply these techniques in field research. For example, fresh genetic materials are difficult to obtain for those wide ranging species or in areas difficult to access. Heavy field and laboratory works are required to obtain substantial and quality DNA data to minimize genotyping error. Some ecological studies, such as diet analysis, are often difficult to reach large sample size required by identifying the species with noninvasive genetic methods.

The traditional approaches for identifying marten and weasel scats are by morphological characters and odors of scats (see Birks *et al.* 2004). The odors might be ambiguous under highly variable weather and environment conditions, especially for the scats that existed in the field for a period of time. The scat morphology of similar animals may differ in size, structure or shape due to the differences of animal body size, digestive system, diet, and habit. Scat identification by morphological characters is helpful if the characters could be distinguished clearly.

Recent studies had compared the results of scat identification by direct observation and molecular analysis and concluded that experienced observers can identify scats as accurately as can molecular analysis (Zuercher 2003). In addition, scat identification through morphological approach can provide sufficient accuracy required by diet studies (Prugh and Ritland 2005). The objective of this study was to apply logistic regression models to identify scats of yellow-throated marten versus those of Siberian weasel by studying the morphological characters of scats from nine captive animals.

Materials and Methods

Sample collection

Scats of weasel were collected from eight individuals (six males and two females) from Taiwan Endemic Species Research Institute and those of marten were collected from one male individual from Pingtung Rescue Center, Taiwan in December, 2006. Adequate mice and chicken were fed to the animals one day prior to scat collection.

All of the scats collected from those nine captive animals were grouped into two types by their structures: simple and complex. Simple scats were formed by one self-twisted strand along (Figure A1-1a) and complex scats were constituted by two or more strands and were twisted into complicated form (Figure A1-1b). For those simple scats, the length and the width of the widest part of the scats (diameter) were measured. For those complex scats, the length, the diameter, and the width of the widest strand consisted in the scat (strand width) were measured.

Data analysis

Complex scats contained one more variable, the strand width, than the simple scats; therefore, logistic regression models were built separately for complex and simple scats. The interspecific comparisons of the scat characters were examined by Student's t-test. A correlation analysis was applied to detect whether the length, diameter and strand width of each group of weasel scats was influenced by body size, which was measured by body weight of animal.

Forward stepwise logistic regression analyses were used to establish the suitable models to classify the simple and complex scats into marten and weasel. Invalid variables were removed from the models based on Wald statistic (Harrell 2001). Hosmer-Lemeshow goodness-of-fit test was conducted to test the null hypothesis that the model adequately fitted the data.

Results

A total of 207 weasel scats and 45 marten scats were collected in December, 2006. Both marten and weasel produced simple and complex scats. The average diameter of marten scats was significantly larger than that of weasel scats both in simple and complex structures ($p < 0.05$ and 0.01 respectively, Table A1-1). The average strand width of complex marten scats was also significantly wider than that of complex weasel scats ($p < 0.01$). In the correlation analysis between the scat morphology and body weight of weasel, only the length ($r = 0.22$, $p < 0.05$) and the diameter ($r = 0.24$, $p < 0.05$) of the complex scats significantly correlated with body weight.

The logistic regression model equation of simple scats was:

$$\log\left(\frac{p}{1-p}\right) = 10.746 \times diameter\ (cm) - 9.638 \qquad \text{(Equation 1)}$$

where p is the probability of membership for marten and the scat would be classified as a marten scat while $p > 0.5$. The model was fit for the data (Hosmer-Lemeshow test, $\chi^2 = 8.544$, d. f. $= 8$, $p = 0.382$). The model of complex scats was:

$$\log\left(\frac{p}{1-p}\right) = 54.094 \times strand\ width\ (cm) - 22.701 \qquad \text{(Equation 2)}$$

where p is the probability of membership for marten and the scat would be classified as a marten scat while $p > 0.5$. This model also adequately fitted the data (Hosmer-Lemeshow test, $\chi^2 = 2.138$, d. f. =8, $p = 0.976$). The variables of the models are described in Table A1-2.

The overall percentages of correct classification of the simple model and the complex model were 92% and 95% respectively. Both the models had high percentage of correct classification but the percentage of correct classification for simple marten scats was low (25%) (Table A1-3). In the model of simple scats (Figure A1-2a), 75 % of marten scats are classified in error. On the contrary, for complex scats, most of the weasel (98.1 %) and marten (84.8 %) scats are correctly classified and concentrate at the extremes of the predicted probability (Figure A1-2b).

Discussion

Marten scats were wider in diameter and strand width than weasel scats. It could be attributed to the difference in their body size. The average weight of marten is 3 kg (Grassman *et al.* 2005) and that of weasel is 233.8 g (female) to 426.5 g (male) (Lee 1992). No strong correlation was found between the body size and the scat size (the diameter of simple scats and the strand width of complex scats) of weasel; therefore, intraspecific variation of scat size could be ignored. In other words, the variance in scat size could be explained by the interspecific, not intraspecific, difference of body size and characters of scat morphology were suitable variables to establish logistic regression models.

Due to its rarity in Taiwan, marten scats were only available from one individual in this study. The sample size of simple marten scat was small. More scats from different marten individuals will be needed to study the morphology of simple marten scat and the relationship between the body size and the scat size of marten in the future.

Both models for identifying simple and complex scats were robust with the Hosmer-Lemeshow test and accurate in classifying species except simple marten scats. Since high percentage of simple marten scats might be misclassified as weasel scats, I suggest that simple scats with low to median predicted probability (e.g., 0.1–0.5) should be excluded from the samples. Lower threshold value can provide more accurate results of classification. For complex scats, most scats obtained an extreme predicted probability and few obtained a predicted probability from 0.1 to 0.9, indicating that the complex scats could be classified into marten and weasel scats clearly.

Some alternative approaches of scat identification could be applied for different objectives and sample size requirement. In studies requiring high validity of scat identification, such as rare species detection (e.g., Kurose *et al.* 2005, Piggott and Taylor 2003, Davison *et al.* 2002), noninvasive genetics has found to be a reliable tool to provide accurate results. On the contrary, directly identifying scats with morphological characters is more efficient in some studies which need large sample sizes, such as diet analysis. Although noninvasive genetic methods could be used in these research (Waits and Paetkau 2005), the results from small sample size might be biased (e.g., Farrell *et al.* 2000, see also Trites and Joy 2005). The models developed in this study are able to identify the scats of yellow-throated marten and Siberian weasel effectively and quickly and could be applied to future field studies of these two animals.

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(a) Simple scat of yellow-throated marten

(b) Complex scats of Siberian weasel

Figure A1-1 Photos of one simple scat of yellow-throated marten and two complex scats of Siberian weasel. The scat of marten was collected from Pingtung Rescue Center, Taiwan in December, 2006. The scats of weasel were collected from Taiwan Endemic Species Research Institute in November, 2006.

(a) Simple scats
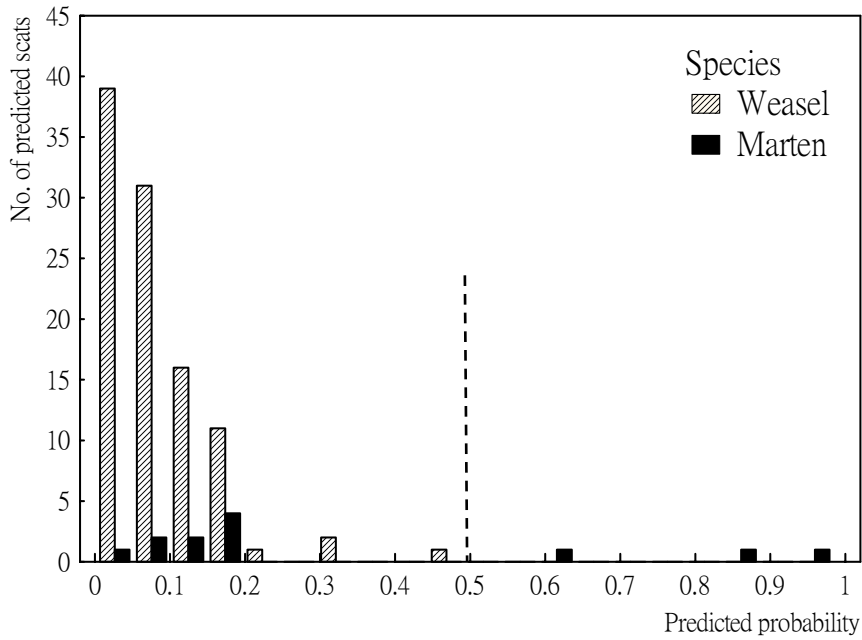
(b) Complex scats
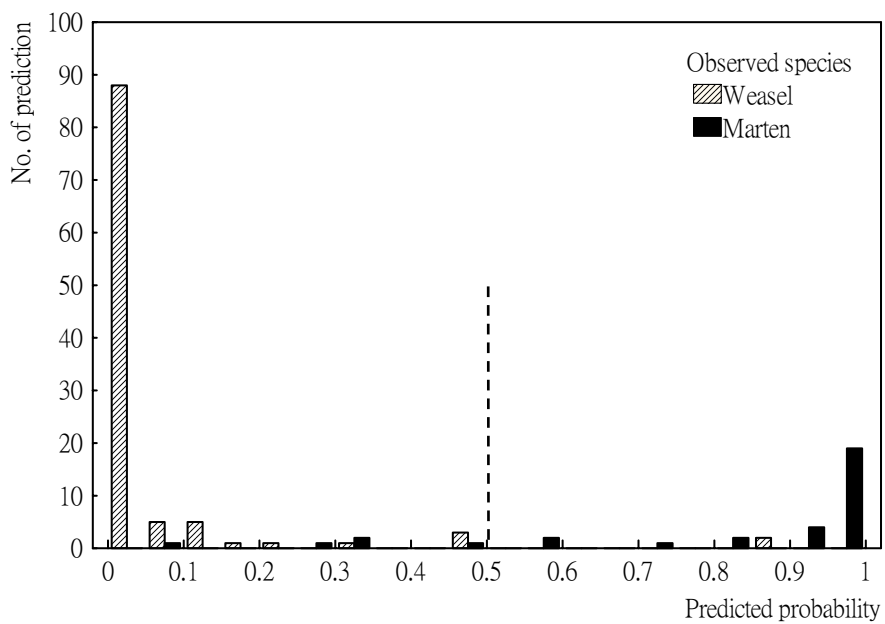
Figure A1-2 Distribution of the probability predicted by scat classification model for simple scats (a) and complex scats (b). Scats were classified as marten scats while the predicted probability is > 0.5. Different bars in the figures represented the initial observation of the scats.

Table A1-1 Interspecific comparisons of characters of two scat structure types.

Structure	Character	Species	N [a]	Mean ± SD (cm)	Min. (cm)	Max. (cm)
Simple Scats	Length	Weasel	101	6.80 ± 2.21	2.00	13.18
		Marten	12	7.01 ± 2.47	4.14	13.67
	Diameter*	weasel	101	0.61 ± 0.11	0.28	0.86
		marten	12	0.77 ± 0.20	0.58	1.26
Complex Scats	Length	weasel	106	7.70 ± 2.57	3.00	15.36
		marten	33	7.86 ± 2.27	4.05	12.53
	Diameter**	weasel	106	0.77 ± 0.11	0.52	1.04
		marten	33	0.98 ± 0.14	0.70	1.42
	Strand width**	weasel	106	0.31 ± 0.05	0.20	0.46
		marten	33	0.50 ± 0.07	0.37	0.66

[a] Number of scats
* Student's t-test is significant at the 0.05 level.
** Student's t-test is significant at the 0.01 level.

Table A1-2 Variables in the logistic regression models.

Model	Variable	coefficient	S.E.	Wald statistic	d.f.	p
Simple scats	Diameter (cm)	10.75	3.58	9.01	1	<0.001
	Constant	-9.37	2.52	13.88	1	<0.001
Complex scats	Strand width (cm)	54.10	12.20	19.68	1	<0.001
	Constant	-22.70	5.01	20.58	1	<0.001

Table A1-3 Classification table of the logistic regression models.

Predicted groups	Observed groups			
	Simple scats		Complex scats	
	Weasel	Marten	Weasel	Marten
Weasel	101	9	104	5
Marten	0	3	2	28
% Correct [a]	100	25	98.1	84.8

[a] Percentage of correct classification.

Appendix 2

A Reference for identifying guard hairs of mammals in high altitudinal mountain areas of Taiwan

Introduction

Mammal hair is an important tool for species identification, which could be widely applied to ecological research, game keeping and nature resource management (Twigg 1975). The guard hairs of mammal are more constant in identical characters and are more suitable for species identification than other hairs (e.g., fur hair and beard) (Wilkins *et al.* 1982, Teerink 1991). A single hair can be divided into four sections (base, shaft, shield and tip) and three components (scales, medulla, and the shape of the cross section through the shield) (Figure A2-1). Different patterns of these components at each section can be used to identify species.

There are about 24 mammal species distribute in high mountain areas of Taiwan (> 2500 m above sea level) (Lin and Lee 1982, Lu 1983, Lin 1991, Lee 1992, Wu 2004). This mammal fauna is very special that it includes seven endemic species and 14 endemic subspecies of Taiwan. Reference of guard hairs of these mammals would be a useful tool for conducting ecological researches. Lee (1994) had established a guard hair reference including ten rodent species and Ho (1996) had established one including 40 mammal species of Taiwan. However, these references do not contain detailed photo profile which would be helpful while examine the scale and medulla patterns.. The main

purposes of this study were to report a simplified procedure for preparing hair scale and medulla slides and to build a guard hair reference with a photo profile of mammal species in high altitudinal mountain areas of Taiwan.

Materials and Methods

Hair collection

Mammal hairs were collected from three sources: National Taiwan Museum, National Taiwan University Zoology Museum, and individuals previously captured by the author in Nan-Hu Mountain (24° 37´N, 121° 10´E). Mammal species potentially appeared in the high altitude areas of Taiwan were listed in Table A2-1, except Formosan high mountain least weasel (*Mustela formosana*), Formosan macaque (*Macaca cyclopis*), Formosan burrowing shrew (*Anourosorex squamipes yamashinai*) and *Soriculus sodalis*. For each species, 5-10 dorsal guard hairs were sampled from more than three individuals for microscopic slides preparation.

Preparation of microscopic slides

Scale slides

The scale pattern could not be observed directly under an optical microscope because lack of diaphaneity, and therefore should be impressed to a medium for observation (Williamson 1951 and Wildman 1954). The materials of the medium are usually gelatin, polyvinyl acetate and nail polish (Teerink 1991). In general, the gelatin requires 30 minutes for drying, and the nail polish is too viscous to tear the hair off.

Moreover, the gelatin needs to be dissolved with hot water that a heat plate is necessary and the preparation must be done in time to prevent the solution cooling down. The polyvinyl acetate is an extensively used adhesive material, such as wood glue (white glue), Carpenter's glue and water glue. I found that the water glue can be evenly smeared on the slide without producing bubbles and dry quickly; consequently, it is a suitable medium material to prepare the slides conveniently and reduce the operation time.

For each scale slide, I dripped 1 ml water glue (Simbalion HG50, Lion Pencil Co., Ltd., Taiwan) to a microslide and flatted the surface of the glue; then, hairs were laid above the surface of the glue. Several hairs could be laid alongside on single slide to save the slides and to observe faster. After 5-10 minutes of drying, the hairs were tore off from the slide with tweezers (Figure A2-2), and the mirror impression of the scale was left on the surface of the dry glue. Because the scale stripes are bilateral, this mirror impression can be directly viewed as the scale pattern. A cover glass was later placed on the slide and fixed with white glue to protect the impression.

Medulla slides

Following the procedures described in Teerink (1991), the hair was directly laid on a microscope slide, fixed with several drops of glues, and cut into several sections (Figure A2-3). Paraffin oil was dripped on the hair to infiltrate the chambers between cells. To increase the infiltration of paraffin oil, the slide was heated in 55 ˚C with a hot plate for 5 minutes. The shape and structure of the medulla would become clearly visible after the infiltration. Finally, a cover glass was placed on the slide and fixed with white glue.

Macro-characters of guard hairs

The length and width data of guard hairs were directly quoted from Ho (1996) and the colors of the hair were observed under a stereomicroscope. Other considerable characters for species identification were also recorded. The guard hairs of some species showed unapparent shield which looked almost as wide as other parts of the hair under a stereoscope. I defined the widest part of these hairs as their shield.

Species identification

The scale and medulla patterns used in this reference were referred to Wilkins *et al.* (1982) and Teerink (1991) and illustrated in Figure A2-4 and Figure A2-5. These patterns were sufficient to distinguish most of the species. The cross section slides were difficult to produce precisely without precision instruments (e.g., ultramicrotome and electron microscope) and were unnecessary for identifying target species of this study, thus were not used as clues for species identification.

Results

A hair reference for 20 mammal species was established. Detailed characters and photo profile of scale and medulla patterns of each species' guard hairs are listed in Table A2-1 and Table A2-2 respectively. Only characters governing the identification were used in the keys for species identification (Table A2-3). The species were divided into several groups by their macro-characters (i.e., length, width and color) in key 1 and

then explicitly identified with their micro-characters (i.e., scale and medulla pattern) in the following keys.

The scale pattern was more often used to distinguish the species than the medulla pattern. Five species showed two types of scale pattern, i.e., *Niviventer culturatus*, *Apodemus semotus*, *Microtus kikuchii*, *Callosciurus erythraeus* and *Dremomys pernyi*, but their medulla patterns between the two scale types were the same (Table A2-2).

The medulla patterns at the shield generally showed four groups of species. The "irregular ladder" was found in Soricomorpha, the "isolated cells" was found in Rodentia, the "filled" was found in most large species and the "cloisonné" was only found in Cervidae (Figure A2-5, Table A2-1, Table A2-2).

All of the 20 species could be distinguished clearly by the keys except of *Petaurista alborufus lena* and *Petaurista philippensis.* Their scale and medulla patterns were alike to each other. Moreover, the single hair color, length and width of them were also very similar.

Discussion

The procedures of preparing scale and medulla slides in this study were timesaving, easy to get the materials and convenient for operation. Both the scale and medulla slides can be completed and observed in ten minutes. Because the scale impression can be observed through the mirror image as well, one can omit the step of impressing the scale pattern on the cover glass and lay it reversely on the slide as Teerink (1991)

described and, as a sequence, reduced the time and material required in quick examination.

Although the water glue is a suitable material to make scale slides, its surface tension is lower than other materials. Some heavier hairs from large mammals (e.g., sambars, boars, and bears) may sink into the solution while laid on the slide. To avoid this problem, after dipping the glue on slide, one should wait 2-3 minutes before laying the hairs, thus the surface of the glue is half dry and the hairs will not sink into the glue easily.

Notably, the board petal, elongate petal and regular mosaic types of scale patterns were sometimes confused with each other, especially when these patterns occurred near the base where the number of scales was small. The irregular-waved mosaic and regular wave types of scale patterns were also similar and sometimes occurred in neighboring sections of a hair. Observers should pay attention and practice to identify these patterns well.

Hairs of two flying squirrels (*Petaurista philippensis* and *P. alborufus lena*) could not be distinguished in this reference. Although I did not make the cross section slides of their hair, the cross sections of these two species exhibited the same shape (ellipse) (Ho 1996). As a result, the cross section pattern was not a useful criterion to identify them. In this reference, the hair color of *P. alborufus lena* was reported black with 1/3 maroon band near shield and tip and seemed in conflict with the black color of the animal individual. However, the black color of the animal was not caused by their guard hairs but the fur hairs. Therefore, the hair color was also unable to distinguish the guard

hairs between the two flying squirrels.

Four species potentially existing in mountain area, e.g. Formosan high mountain least weasel, Formosan macaque, Formosan burrowing shrew and *Soriculus sodalis*, are not listed in this reference because their specimen are unavailable. These species should be added to this reference in the future.

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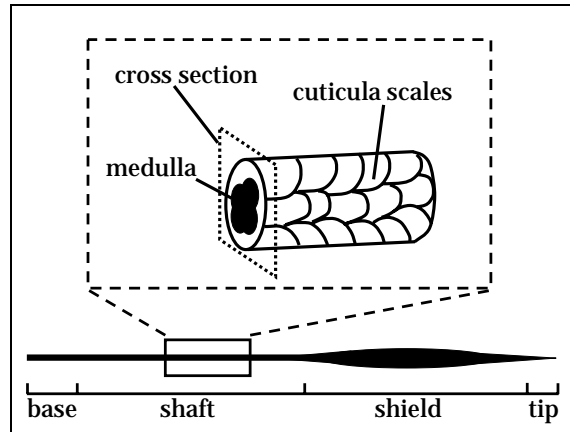
Figure A2-1 The structure of hair (derived from Teerink 1991).
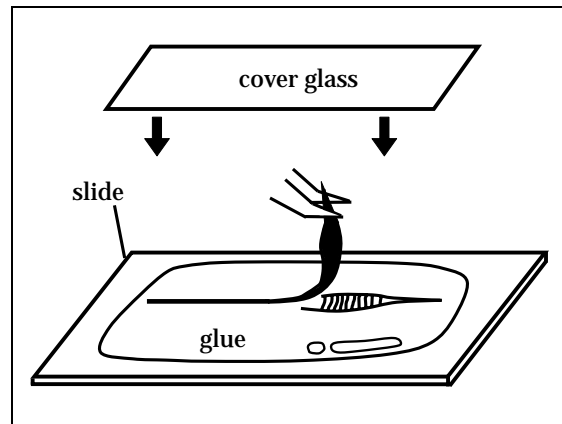
Figure A2-2 Preparation of scale slide (derived from Teerink 1991).
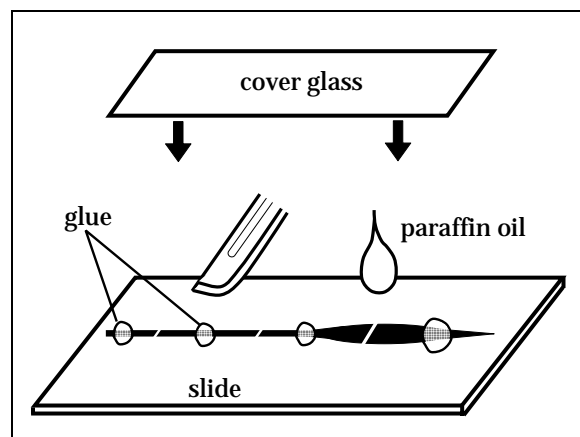
Figure A2-3 Preparation of medulla slide (derived from Teerink 1991).

a. board petal   b. diamond petal   c. elongate petal   d. irregular wave

e. irregular-waved mosaic   f. regular mosaic   g. regular wave   h. streaked

i. valley   j. valley + mosaic (V+M)
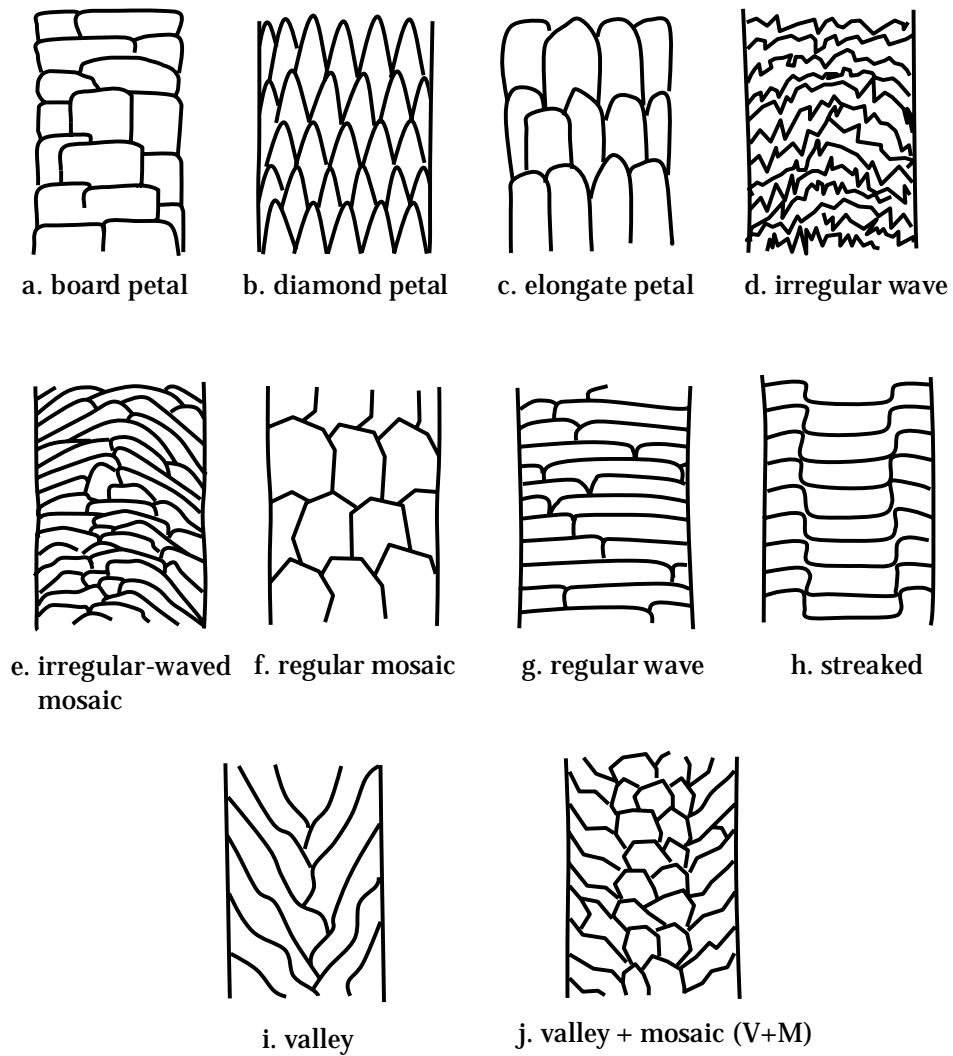
Figure A2-4 Scale patterns used in the mammal guard hair identification (derived from Wilkins *et al.* 1982, Teerink 1991).

a. cloisonné   b. filled   c. ladder   d. irregular ladder   e. isolated cells
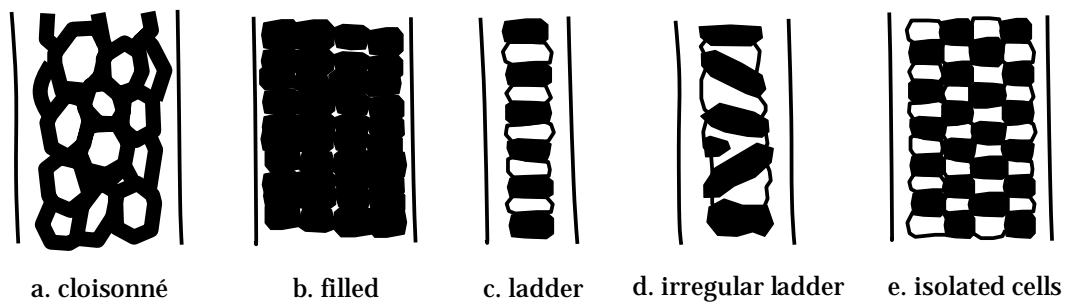
Figure A2-5 Medulla patterns used in the mammal guard hair identification (derived from Wilkins *et al.* 1982, Teerink 1991).

Table A2-1 Detailed characters of mammal guard hairs.

Order Family / subfamily Species	Scale pattern	Medulla pattern	Hair color[a]	Length[b] (mm)	Width[b] (μm)	Note
Soricomorpha						
Soricidae						
Episoriculus fumidus	sft[c]-EP[d], shd-ST	b-LA[e], shd-IL	dim gray with orange at tip	6-8	25-43	hair in lightning shape
Talpidae						
Mogera insularis	sft-EP, shd-IW	b-LA, shd-IL	dim gray with orange at tip	6-9	30-50	hair in wave shape
Rodentia						
Muridae						
Niviventer culturatus	type A b-BP, shd-IW type B b-RM, sft-RM, shd-V+M	b-IC(3), shd-IC(5)	dim gray	10-19	42-78	medulla cells form 'X' shape
Apodemus semotus	type A b-BP, sft-DP, shd-V+M type B b-DP, shd- V+M	b-LA, shd-IC(6-7)	dim gray	7-13	45-95	
Cricetidae						
Microtus kikuchii	type A b-V, shd-IWM type B b-RM, shd-RW	b-LA, shd-IC(3-4)	dim gray	9-17	40-57	
Eothenomys melanogaster	b-V, shd-RW	b-LA, shd-IC(4-5)	dim gray	7-10	40-80	
Sciurinae						
Callosciurus erythraeus	type A b-RM, sft-IWM, shd-IW type B b-EP, sft-RW, shd-IW	b-LA, shd-IC(5)	black with 1-2 yellow band near shield & tip	19-28	42-78	prominent edge at base
Dremomys pernyi	type A b-RM, sft-IWM, shd-IW type B b-IWM, shd-IW	b-IL, shd-IC(5-6)	black (rarely with 1 yellow band near shield & tip)	17-22	60-70	
Tamiops maritimus	b-IWM, sft-V, shd-RW	b-IC(2), shd-IC(3)	black with 1-2 yellow band near shield & tip	7-13	21-57	soft texture
Pteromyinae						
Petaurista alborufus lena	b-IWM, shd-IW	b-IC(2-3), shd-IC(4-5)	black with 1/3 maroon band near shield	20-39	35-75	shield is not apparent

[a] Color names were according to "X11 Web Color Names."

[b] Data from Ho 1996 except *Dremomys pernyi* and *Cervus unicolor swinhoei.*

[c] Codes for section of the hair: b-base sft-shaft shd-shield.

[d] Codes for scale patterns: BP-broad petal, DP-diamond petal, EP-elongate petal, IW-irregular wave, IWM-irregular-waved mosaic, RM-regular mosaic, RW-regular wave, ST-streaked, VA-valley, V+M-valley pattern plus regular mosaic pattern in the middle.

[e] Codes for medulla patterns: CL-cloisonné, LA-one cell ladder, IC-isolated cells (number of cells in a column), IL-irregular one cell ladder.

Table A2-1 Detailed characters of mammal guard hairs. (Continued)

Order Family / subfamily Species	Scale pattern	Medulla pattern	Hair color[a]	Length[b] (mm)	Width[b] (μm)	Note
Petaurista philippensis	b[c]-IWM[d], shd-IW	b-IC (2-3)[e], shd-IC(5-6)	black with 1/3 maroon band near shield	21-39	35-72	shield is not apparent
Belomys pearsonii	b-V, shd-RW	b-IL, shd-IC(3-4)	black with 1 orange band at shield	17-29	48-87	
Carnivora Mustelidae						
Martes flavigula chrysospila	b-RW, sft-RM, shd-IW	b-IL, shd-FI	maroon at base and orange at shield & tip	20-27	84-127	
Mustela sibirica taivana	b-DP, sft-IWM, shd-IW	b-IL, shd-FI	maroon	12-17	70-152	
Melogale moschata subaurantiac	b-IW, sft-RM, shd-IW	b-IL, shd-FI	orange with black at tip	26-33	100-145	
Ursidae						
Ursus thibetanus formosanus	b-RW, shd-IW	shd-FI	black	70-77	87-177	shield is not apparent
Artiodactyla Cervidae						
Cervus unicolor swinhoei	b-RW, shd-IW	shd-CL	dark goldenrod	57-68	160-250	rough texture, shield is not apparent
Muntiacus reevesi micrurus	b-RW, shd-RW	shd-CL	dark goldenrod with orange band near tip	17-27	76-130	shield is not apparent
Bovidae						
Naemoheadus swinhoei	b-IW, shd-IW	shd-FI	maroon	25-39	126-157	shield is not apparent
Suidae						
Sus scrofa taivanus	b-IW, shd-IW	shd-FI	black, orange near tip	78-132	226-364	fork at tip, shield is not apparent

[a] Color names were according to "X11 Web Color Names."

[b] Data from Ho 1996 except *Dremomys pernyi* and *Cervus unicolor swinhoei*.

[c] Codes for section of the hair: b-base, sft-shaft, shd-shield.

[d] Codes for scale patterns: BP-broad petal, DP-diamond petal, EP-elongate petal, IW-irregular wave, IWM-irregular-waved mosaic, RM-regular mosaic, RW-regular wave, ST-streaked, VA-valley, V+M-valley pattern plus regular mosaic pattern in the middle.

[e] Codes for medulla patterns: CL-cloisonné, FI-Filled, LA-one cell ladder, IC-isolated cells (number of cells in a column), IL-irregular one cell ladder.

Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs.
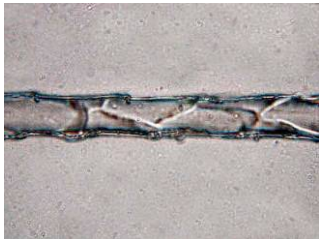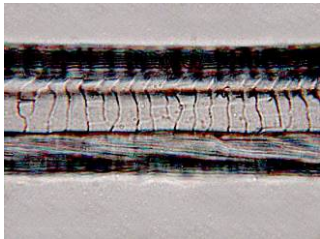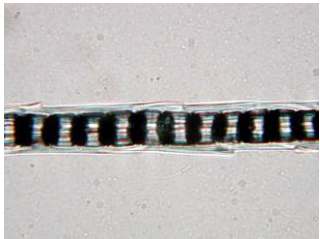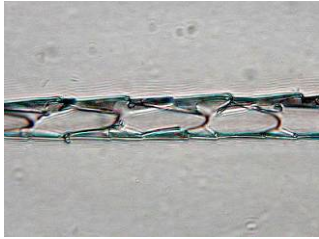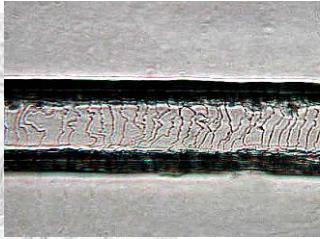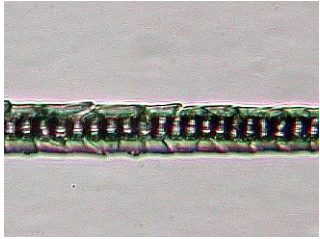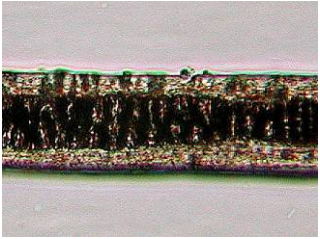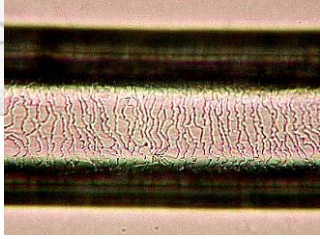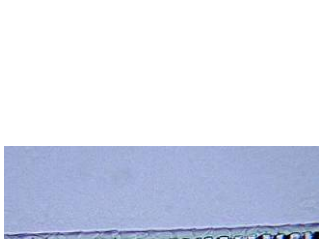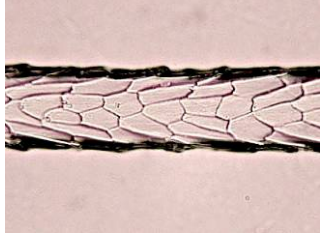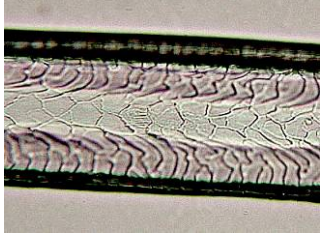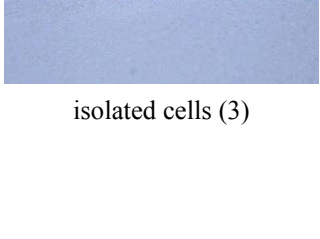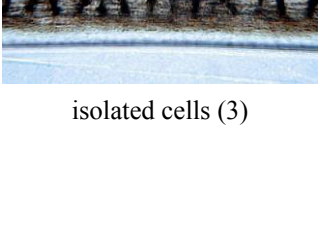
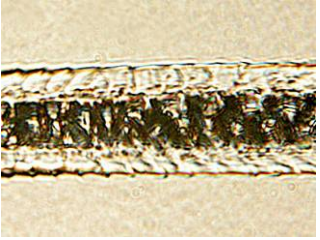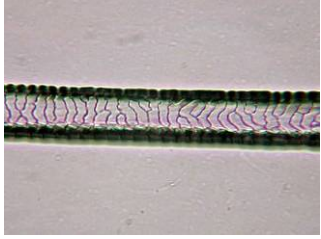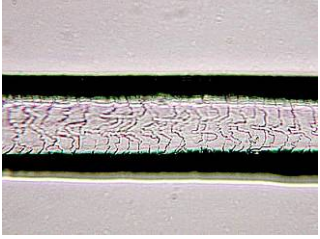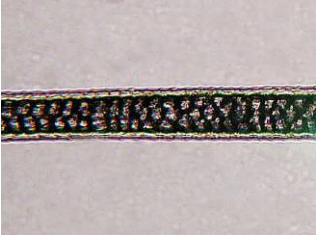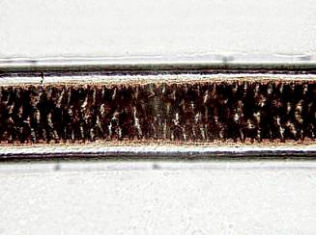| Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Episoriculus fumidus	elongate petal	NA	streaked	ladder	irregular ladder
Mogera insularis	elongate petal	NA	irregular wave	ladder	irregular ladder
Niviventer culturatus type A	board petal	NA	irregular wave	isolated cells (3)	isolated cells (3)
Niviventer culturatus type B	regular mosaic	regular mosaic	valley plus mosaic		

Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
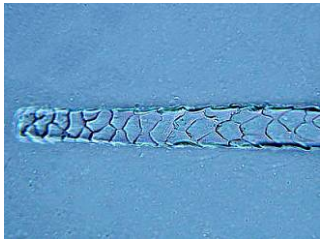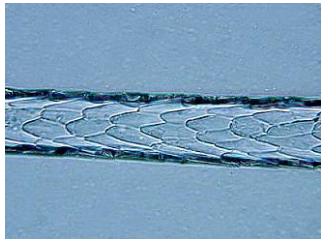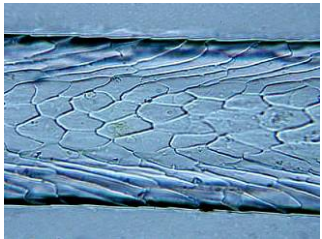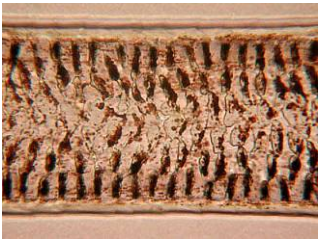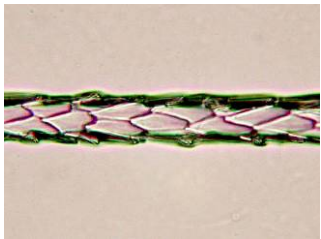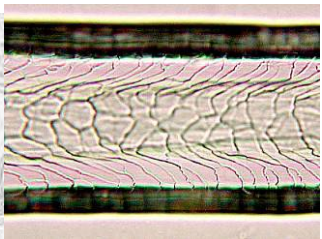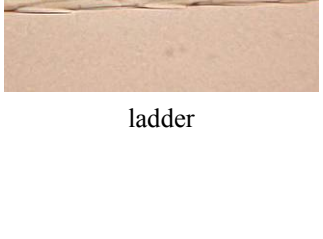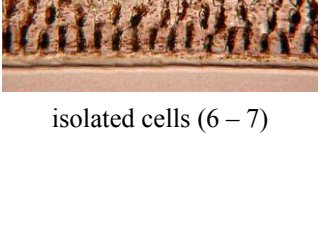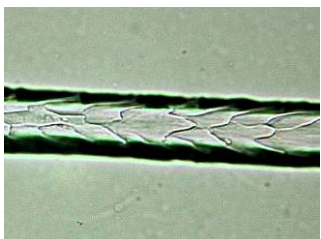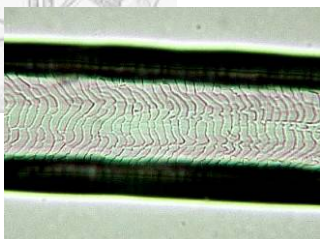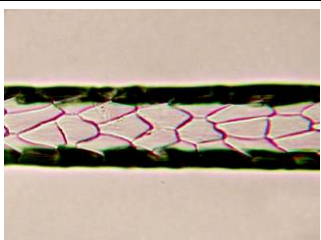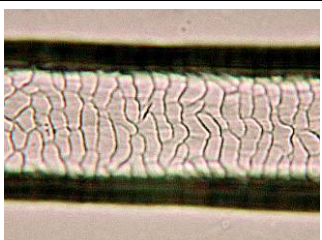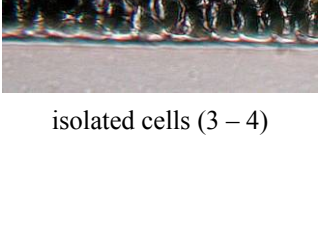
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Apodemus semotus type A	board petal	diamond petal	valley plus mosaic		
Apodemus semotus type B	diamond petal	NA	valley plus mosaic	ladder	isolated cells (6 – 7)
Microtus kikuchii type A	valley	NA	irregular-waved mosaic		
Microtus kikuchii type B	regular mosaic	NA	regular wave	ladder	isolated cells (3 – 4)

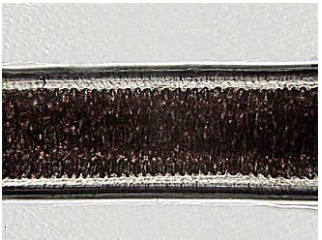Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
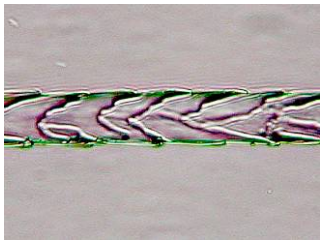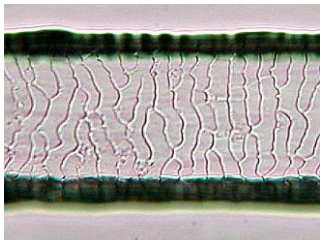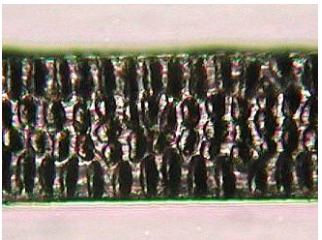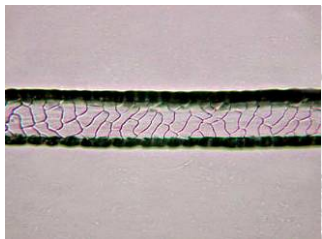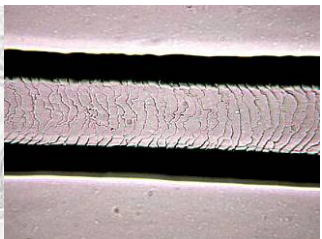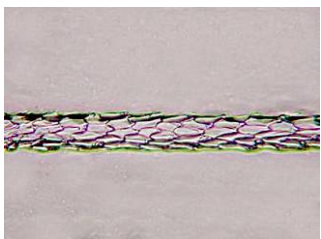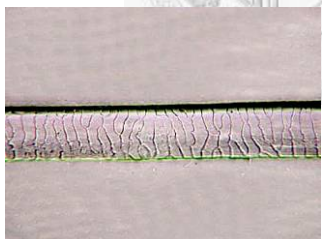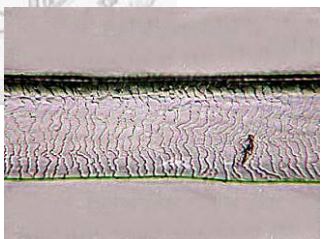
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Eothenomys melanogaster	valley	NA	regular wave	ladder	isolated cells (4 – 5)
Callosciurus erythraeus type A	regular mosaic	irregular-waved mosaic	irregular wave	ladder	isolated cells (5)
Callosciurus erythraeus type B	elongate petal	regular wave	irregular wave		

Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
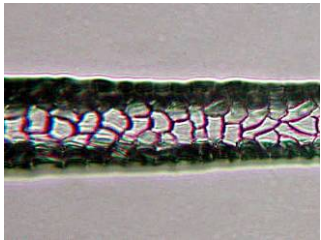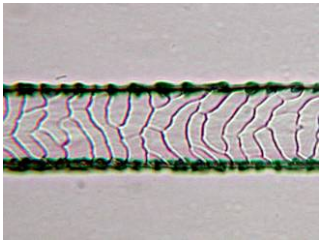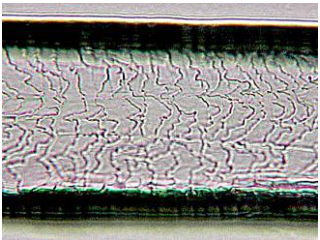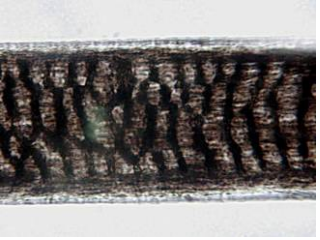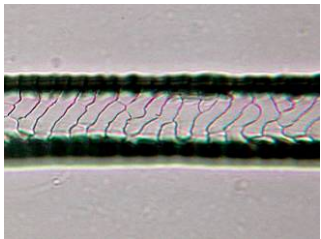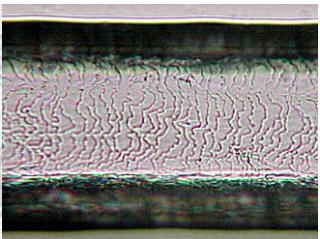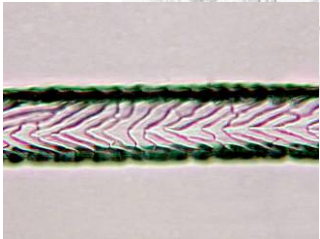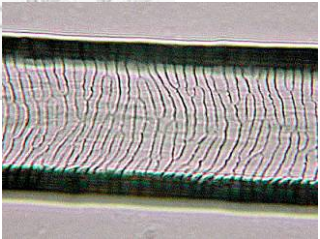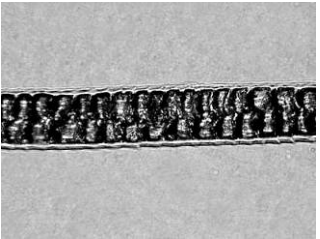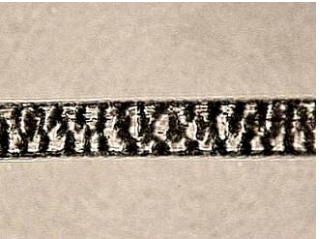
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Dremomys pernyi type A	regular mosaic	irregular-waved mosaic	irregular wave		
Dremomys pernyi type B	irregular-waved mosaic	NA	irregular wave	irregular ladder	isolated cells (5 – 6)
Tamiops maritimus	irregular-waved mosaic	valley	regular wave	isolated cells (2)	isolated cells (3)
Petaurista alborufus lena	irregular-waved mosaic	NA	irregular wave	isolated cells (2 – 3)	isolated cells (4 – 5)

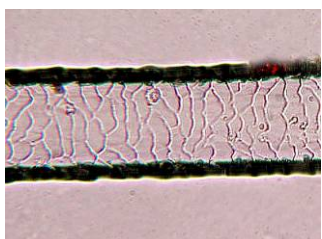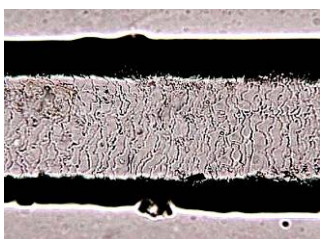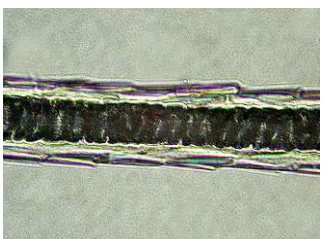Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
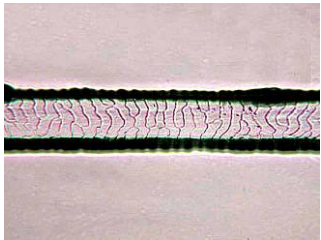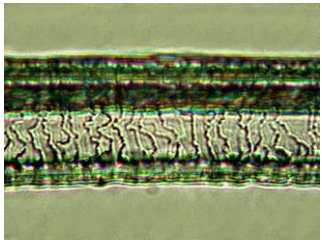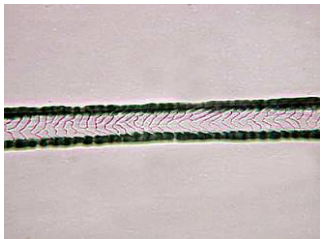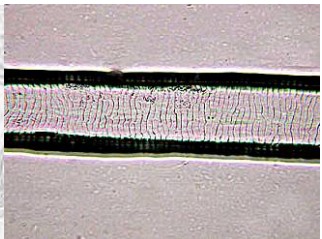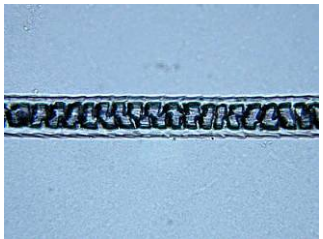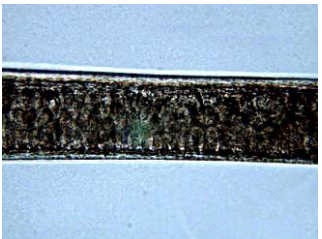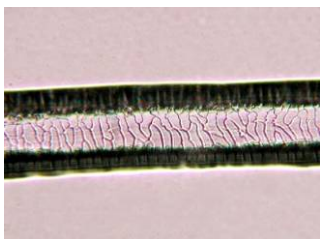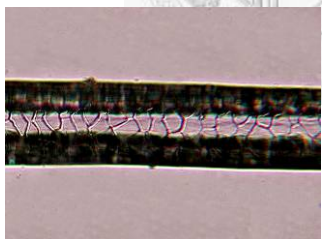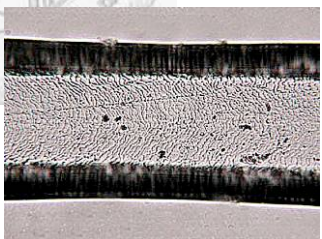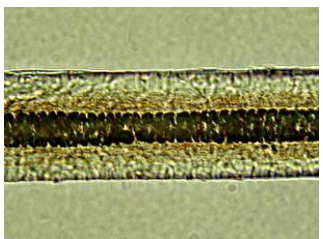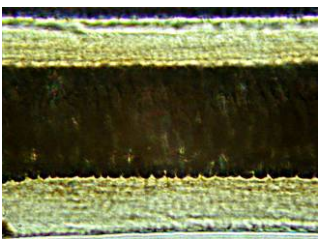
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Petaurista philippensis	irregular-waved mosaic	NA	irregular wave	isolated cells (2 – 3)	isolated cells (5 – 6)
Belomys pearsonii	valley	NA	regular wave	irregular ladder	isolated cells (3 – 4)
Martes flavigula chrysospila	regular wave	regular mosaic	irregular wave	irregular ladder	filled
Mustela sibirica taivana	diamond petal	irregular-waved mosaic	irregular wave	irregular ladder	filled

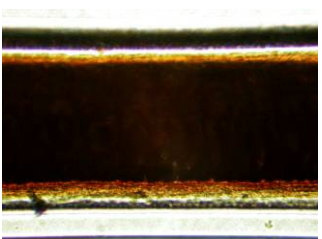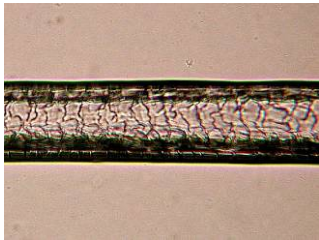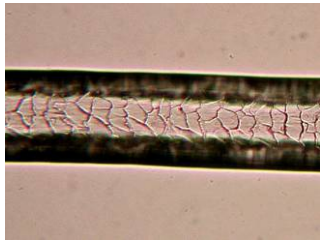Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
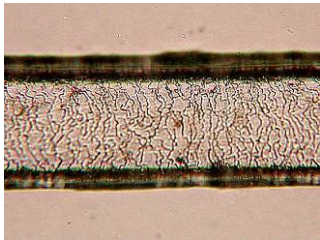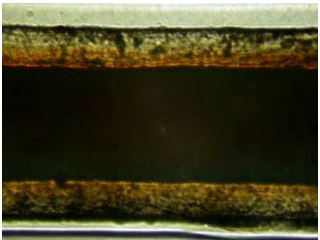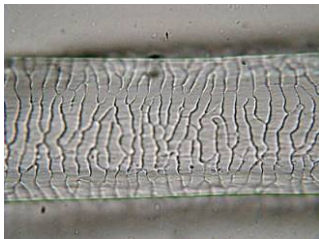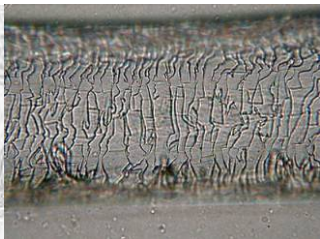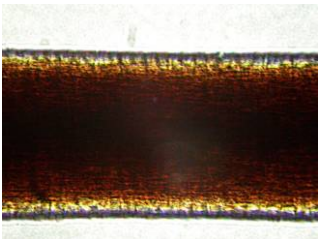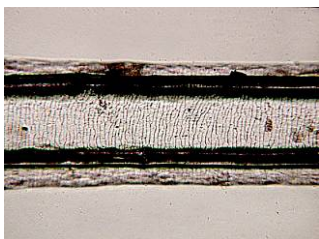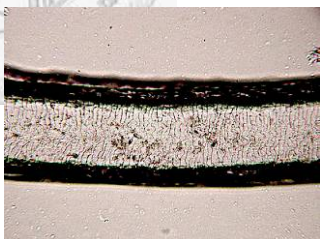
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Melogale moschata subaurantiac	irregular wave	regular mosaic	irregular wave	irregular ladder	filled
Ursus thibetanus formosanus	regular wave	NA	irregular wave	NA	filled
Cervus unicolor swinhoei	regular wave	NA	irregular wave	NA	cloisonné
Muntiacus reevesi micrurus	regular wave	NA	regular wave	NA	cloisonné

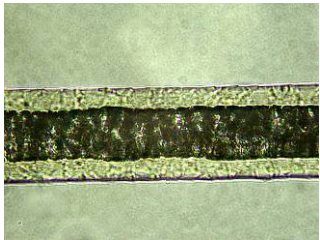Table A2-2 Photo atlas of scale and medulla patterns of mammal guard hairs (continued).
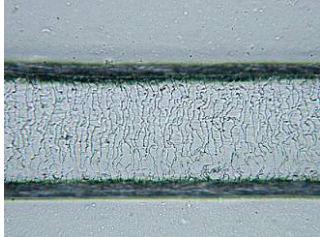
Species	scale pattern at base	scale pattern at shaft	scale pattern at shield	medulla pattern at base	medulla pattern at shield
Naemoheadus swinhoei	irregular wave	NA	irregular wave	NA	filled
Sus scrofa taivanus	irregular wave	NA	irregular wave	NA	filled

Table A2-3 Keys of mammal guard hair identification

Key 1

1. a. hair width > 100 μm 2
   b. hair width < 100 μm 3
2. a. medulla pattern at shield is cloisonné ....Key 2 (Cervidae & Bovidae)
   b. medulla pattern at shield is filled .... Key 3
3. a. hair shield is apparent 4
   b. hair shield is not apparent, hair is slender (length 17 ~ 39 mm), each section of hair are in similar width .... Key 4 (Pteromyinae)
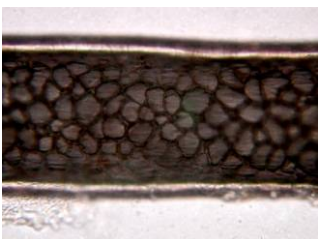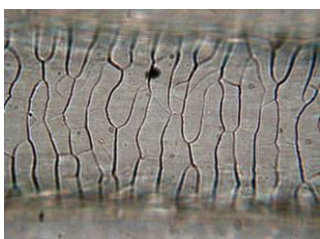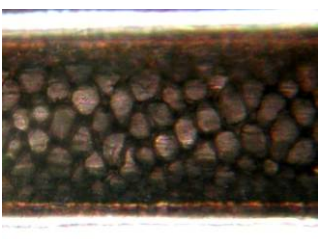4. a. hair length > 10 mm 5
   b. hair length < 10 mm, "lighting" or "wave" shape, hair color is dim grey with orange at tip .... Key 5 (Insectivora)
5. a. hair color is dim grey .... Key 6 (rodents)
   b. hair color is black, with or without yellow band near shield .... Key 7 (Sciuridae)

Key 2

1. a. scale pattern at shield is "regular wave" .... *Muntiacus reevesi micrurus*
   b. scale pattern at shield is "irregular wave" .... *Cervus unicolor swinhoei*

Key 3

1. a. hair color is black 2
   b. hair color is not black 3
2. a. scale pattern at base is "irregular wave", fork at tip .... *Sus scrofa taivanus*
   b. scale pattern at base is "regular wave" .... *Ursus thibetanus formosanus*
3. a. scale pattern at base is "irregular wave" 4
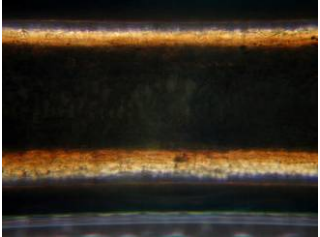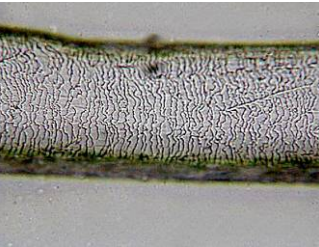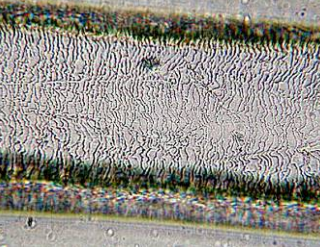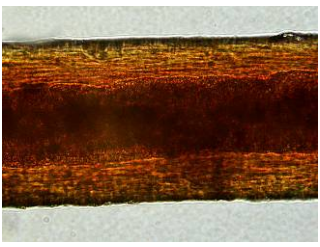   b. scale pattern at base is not "irregular wave" 5
4. a. scale pattern at shaft is regular mosaic, shield is apparent, hair color is orange with black at tip .... *Melogale moschata subaurantiaca*
   b. scale pattern from base to tip is all "irregular wave", shield is not apparent, hair color is maroon .... *Naemoheadus swinhoei*
5. a. scale pattern at base is "regular wave", and that at shaft is "regular mosaic" .... *Martes flavigula chrysospila*
   b. scale pattern at base is "diamond petal", and that at shaft is "irregular-waved mosaic" .... *Mustela sibirica taivana*

Key 4

1. a. scale pattern at base is "valley", hair color is black with 1 orange band at

    shield .... *Belomys pearsonii*

    b. scale pattern at base is "irregular-waved mosaic", and that at shield is "irregular wave",

    hair color is black with one maroon band near shield ....

    .... *Petaurista alborufus lena* or *Petaurista philippensis*

Key 5

1. a. scale pattern at shield is "streaked", hair in "lightening"

    shape .... *Soriculus fumidus*

    b. scale pattern at shield is "irregular wave", hair in "wave"

    shape .... *Mogera insularis*

Key 6

1. a. scale pattern at base is "valley"... 2

    b. scale pattern at base is "regular mosaic".. 3

    c. scale pattern at base is "board petal" 4

    d. scale pattern at base is "diamond petal" .... *Apodemus semotus* type B

2. a. scale pattern at shield is "irregular-waved mosaic"............................. *Microtus kikuchii* type A

    b. scale pattern at shield is "regular wave"............................... *Eothenomys melanogaster*

3. a. scale pattern at shield is "valley plus regular mosaic in the

    middle" .... *Niviventer culturatus* type B

    b. scale pattern at shield is "regular wave" .... *Microtus kikuchii* type B

4. a. scale pattern at shaft is "diamond petal", at shield is "valley plus regular mosaic in the

    middle"... *Apodemus semotus* type A

    b. scale pattern at shield is "irregular wave" .... *Niviventer culturatus* type A

Key 7

6. a. hair length > 17 mm.. 2

    b. hair length < 17 mm, scale pattern at base is "irregular-waved mosaic", and that at shield is

    "regular wave"... *Tamiops maritimus*

7. a. scale pattern at base is "regular mosaic"... 3

    b. scale pattern at base is not "regular mosaic"... 4

8. a. hair has prominent edge at base .... *Callosciurus erythraeus* type A

    b. hair does not have prominent edge at base.. *Dremomys pernyi* type A

9. a. scale pattern at base is "elongated petal", and that at shaft is "regular

    wave" .... *Callosciurus erythraeus* type B

    b. scale pattern at base is "irregular-waved mosaic".............................. *Dremomys pernyi* type B